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

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CHAPTER 3

ANALYSIS ARRANGEMENTS

3.1 Experimental Proposal

3.1.1 Stage 1 Proposal

Before investigation could be made as to whether driver characteristics could be changed in restricted visibility conditions, it was first necessary to know what the 'normal' characteristics are, this being the purpose of the first part of this research project.

To achieve this a site needed to be chosen where a comparison could be made of the speeds drivers adopt in various restricted visibility conditions. In view of the long term aim of assessing any changes in vehicle characteristics it was also necessary for speed readings to be made at points before and after any features designed to change these.

A site was therefore required which provided speed measurements over a reasonable length of road before and after a point where visibility was being measured. This would also need to be suitable for allowing a sign to be erected and similar readings to again be taken.
be monitored over a 20 second period when travelling at speeds selected by the driver as appropriate to the conditions. It would also allow future trials which attempted to modify such characteristics through a sign display at Site C to give an indication at Sites C, D and E as to whether drivers had responded to any prompting for change. Site A would be used as a control.

### FIG 3.01: TRIAL SITE

<table>
<thead>
<tr>
<th>Site</th>
<th>E</th>
<th>D</th>
<th>C</th>
<th>B</th>
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<td>Slow Lane</td>
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</table>

- Overhead Sign (Disconnected)
- Traffic Signal Loops (Spacing 150 m)
- Fog Detector

3.1.2 Variables

Having established the base arrangements for the test, the next requirement was to establish the variables which would need to be evaluated.

Overseas analysis concentrated on driver characteristics for varying visibilities by time of day (night Vs day) and travel lane. However the method being followed and the anticipated frequency of fog meant other variables could be looked at to assess any particular affect they might have on such characteristics.
Variables selected to be looked at were:

i) Visibility

Visibility is the key variable for the trial against which other variables are to be assessed. As indicated earlier the value to be used for visibility is based upon the extinction coefficient of the atmosphere. The starting point for analysis was originally intended to be 250 m based on UK research which indicated: "the traffic remains substantially unaffected until the MVR drops to around 200 m" (White and Jeffery, 1980).

However, in the event of a different pattern occurring the equipment was initially set to record all vehicle speeds where visibility was below 1000 m.

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**FIG 3.02 VISIBILITY - 0800-1900, 26 MARCH 1992**
The fog detection equipment purchased allowed for visibility to be measured in 15 sec intervals. Early trials showed considerable variations of visibility in very short time periods. Fig 3.02 shows the variation which occurs during the course of a typical foggy day. As can be seen from the graph, on March 26th 1992 visibilities of less than 250 m occurs many times during the 13 hours from 08:00 to 19:00 with no consistent periods of uniform visibilities during the time fog occurs.

Examination of another day using a shorter period of one hour as shown in Fig 3.03 shows the considerable variation in visibilities with changes from 500 m+ (considered unrestricted for drivers) to less than 100 m in a period of under 2 minutes.

FIG 3.03 VISIBILITY - 1230-1330, 13 SEPTEMBER 1993

This rapid variation in visibility is considerably different from that occurring in the types of fog used to examine vehicle performance in overseas tests. Such fogs usually
were of a more consistent nature and longer periods (15 minute minimum) were
adopted (White and Jeffery, 1980; Hawkins, 1988)).

On the basis that a motorist reacts to conditions in the immediate environment, it is
critical that any assessment of driving characteristics is based on the most relevant and
recent information available to the motorist. Even using the minimum 15 sec
assessment period available in the equipment, a motorist travelling at 100 km/h will
have traversed a distance of 450 m during the period an assessment of visibility is being
made.

During the time such a distance is traversed a motorist would not expect to continually
brake and accelerate. Rather a motorist would allow a vehicle to travel at a speed based
on an assessment of the conditions in the approach to a particular point. Given the
extreme volatility of visibility in the Bulli Tops area, the conditions in the approach to
measuring point would not be the same as that at the point itself.

Depending on whether the approach visibility was better or worse than that at the actual
measuring point, speeds would vary accordingly. As a consequence an increase in the
speed variations would be expected when relating the speeds to a specific visibility at
the measuring point.

The degree of such variations cannot be determined utilising the resources available.
However changes to the variation (as measured by the Standard Deviation or the
Coefficient of Variation) would still be relevant to determining whether changes in
driving characteristics during reduced visibility occurs.
What remains critical is to assess the visibility most appropriate to the driver's perception. This has meant using the minimum time period of 15 seconds available and ensuring the measurement is made as closely as possible to the travel path of the vehicle.

It is worth noting that the rapid variation in visibilities must greatly affect the credibility of a warning system that is based on the assumption that visibility remains uniform over a substantial period of time, as occurs in most parts of the UK. Since the existing Driver Aid system on the F6 was developed on the same basis, with displayed safe driving speeds being based on the subjective assessment of the breakdown crews when they are in the area (approximately 30-60 minute periods with longer intervals if they are to attend a vehicle breakdown or accident), the consequent advice to drivers must be severely lacking in credibility.

Improvement in credibility would be substantial if the advice to drivers was directly linked to the most recent visibility measurement. This will be provided in the subsequent measures developed to change driver characteristics where they do not drive in accordance with the conditions.

ii) Speeds

Speed is one of the dependant variables for which changes are to be assessed in accordance with changes to the environment. As outlined previously, both the speeds and headways of vehicles can be a critical factor to safe driving in fog. A major purpose of this thesis is to assess what speeds are being travelled as visibility declines.
Further assessment can then be made of any changes to these speeds that can be induced in a driver and to what extent such changes can improve driving safety.

Speed measurements are usually determined as either desired speed, free speed (the speed a vehicle would travel with no other vehicles present) or actual speed. In this instance however information is sought on the speed performance of motorists as visibility changes regardless of which of these speed types they are travelling under. For such an analysis it is only necessary to know the changes in speed which occur as visibility changes, applicable to all vehicles. (In a later analysis in Chapter 4 an assessment of the differences between all vehicles and lead vehicles shows the differences to be uniform and less than 1 km/h different.)

iii) Headways

Headway is the other dependant variable being considered. Much overseas research placed emphasis on the changes in headway characteristics which occurs in fog conditions as outlined in Section 2.6.2. However, as indicated earlier, actual research on such characteristics appears limited.

The purpose of analysing headway is to assess whether the practice of tailgating is occurring. Tailgating is where vehicles use the preceding vehicle as an object to follow through the hazardous area. Where this hazard is fog, then as the fog increases it is theorised that vehicles will close up on the preceding one in order to keep it within the available visibility. The resulting headway may become incompatible with the available sight distance.
Kocmond & Perconok (1970) chose a two second time for analysis, ‘Because the “California rule” for following (i.e., one car length for every 10 mph) reduces to a recommended headway of approximately 2 seconds’.

White and Jeffery (1980) focus their results on headways of under two seconds although they provide information on headways of up to nine seconds.

Hawkins (1984) indicates a choice of a five second gap for trailing vehicle analysis, although then goes on to provide analysis for vehicles trailing by up to six seconds.

Australian practice has been to consider that vehicles are bunched (or modifying their behaviour to that of the vehicle in front) when a minimum free headway is being observed (Taylor & Young, 1988). Adoption of a value for the appropriate minimum free headway has varied with five seconds being commonly used. Hoban (1984) recommends a figure of four seconds for Australian rural highways.

Taylor (Taylor & Young 1988) suggests this is amended by not considering vehicles with speed differentials of -5 km/h to +10 km/h to allow for the elimination of vehicles which are involved in overtaking manoeuvres. However, when considering the effect of fog on headways, such speed differentials present one of the major problems. Even if an overtaking manoeuvre is being performed, there remains an element of danger if the sight distance is affected by fog restricting visibilities to less than 150 m. This danger is increased if the driver reduces the headway distance to the preceding vehicle regardless of the reason for such a reduction.
Analysis is therefore done on the distribution of headways where vehicles are bunched with no allowance being made as to the reason of the headway measurement. In this study a headway value of four seconds or less has been adopted as the value for which a vehicle is considered to be following the preceding vehicle.

It should be noted that if the practice of changing headways occurs, it would be expected to show itself in an analysis of slow lane vehicles. For vehicles within the fast lane it is not just a matter of trailing the previous vehicle but may also involve moving up to overtake a vehicle which is returning to the slow lane. Accordingly any pattern showing in the fast lane could not be considered as representative of a following pattern.

FIG 3.04 TRAFFIC SPLIT IN EACH LANE BY SITE AND TIME OF DAY
Information on cross lane headways was not obtained as traffic is free flowing and slow lane behaviour (keeping left unless overtaking) is good. This can be seen from the data sets where over 75% of all vehicles can be seen to travel in the slow lane (Fig 3.04).

iv) Vehicle Lengths

This trial is aimed at assessing changes to driver characteristics as visibility changes. In order to evaluate changes which are affected by driver choice as opposed to restrictions in behaviour controlled to some extent by the vehicle itself, analysis of speeds is to be mainly based on the speed and headway of cars through the site. However some analysis will be made on heavy vehicles. For definition purposes cars have been taken as vehicles of length 7 m or less. This allows easier analysis from the output data.

v) Travel Lane

Obvious differences exist between vehicles in the fast and slow lanes and this parameter needed to be included as a variable. Unlike most overseas research sites where vehicle volumes often forced flows from out of the slowest lane, lower volumes at the chosen site have resulted in a large proportion of fast lane traffic using the facility purely for overtaking manoeuvres.

This is emphasised by the traffic split throughout the chosen site where the effects of the 5% ascent before the first measurement location (see Appendix H) can be seen in the traffic split throughout the site (Fig 3.04) where the overall volume of traffic using the fast lane drops from 27% to 16% over the 600 m between sites A and C.
vi) Time of Day

The basic theories on visibility referred to in Chapter 2 point out the significant difference which occur between day and night when considering visibility. There is also some question as to what occurs during the twilight period between these times. As indicated in Section 2.1.2 the study of accidents gives some indication that there may also be differences in characteristics between dusk and dawn.

The data was therefore set up to allow assessment of day, night and the twilight periods of dusk and dawn (twilight being defined as the half hour period either side of sunrise and sunset in Sydney (Manly Hydraulics Laboratory, 1992-94)).

vii) Day of Week

The nature of the motorists using the road through the trial site is mainly commuters during the week whilst recreational drivers are more prevalent at weekends, particularly Sundays.

For analysis purposes the weekday period was taken to be from Mondays to Fridays with analysis made of Sunday characteristics to allow a comparison and assess any difference in characteristics at that time. Some analysis was also made on Saturday characteristics, this period also offering the potential of a different pattern as the drivers would be a mixture of commuters, recreational drivers who are either 'just out for a drive' or travelling to a tourist destination.
viii) Wet and Dry Conditions

Although the visibility available during fog conditions is considered to be well below that which occurs due to rain (Allen et al, 1977) as discussed in Section 2.3.2, it may be that there is some further change to driving characteristics if there is actual precipitation during fog conditions (i.e. the effect of a combination of conditions).

As the fog detection equipment eventually purchased possessed the capability of measuring precipitation, use is made of this facility to include precipitation as a parameter for analysis.

3.2 Site selection.

3.2.1 Assessment Criteria.

In order to evaluate the characteristics of Australian drivers in a restricted visibility environment, a site was required where parameters such as vehicle speed, headways, volumes, lane distribution and platooning could be measured against a range of visibilities.

Specific criteria considered in adopting a site were:

- power which is only available at the existing display sites,
- freedom from contamination of driver performance due to influences other than that caused by the natural environment. To this extent a site was
preferred where the driver was not affected by the displays of the existing
driver aid system, such displays being of a variable and subjective nature as
discussed in the Section 2,

- frequency of periods of restricted visibility - this was needed both to ensure
  sufficient quantity of results could be obtained (especially at the lower end
  of the visibility scale) and to have a site where fog was a consistent enough
  occurrence that a uniform behaviour pattern would have been developed by
  motorists using the road on a regular basis (if fog was a rarity, driving
  characteristics would be more variable and detection of a pattern would
  become more difficult),

- free flow of traffic - in order to ensure that the true characteristics of
  motorists was being evaluated and not a characteristic enforced by
  surrounding traffic, a section of road with Level of Service C or better (as
defined by Guide to Traffic Engineering Practice - Part 2 (NAASRA, 1988)),
  this being the level at which an adequate volume of free flowing traffic
  could be anticipated,

- good lane discipline - measurement techniques used for speed convert the
  time taken for a vehicle to travel a fixed known distance to speed. If lane
  discipline (the restriction of vehicles to travel within their own lane at the
  measuring loops) was not high, the results could be distorted as vehicles cut
  across loops,
• accessibility for equipment installation and monitoring - regular access to the site would be required to download results and change aspects of the trial. It was essential that this should be obtainable in an easy and safe manner,

• a site where further analysis could be carried out on changes to driving characteristics,

• a straight horizontal alignment (a driver's desired speed is restricted by horizontal curvature, the tighter the curve the greater the effect on a choice of relative speed (McLean, 1978)).

Once the characteristics are known in periods of specific visibilities, it is possible to identify benefits which would be obtainable if we knew whether such characteristics had been changed. Such benefits could either be in reducing speeds, reducing speed variation or reducing headways.

The benefits in reducing speeds are obvious in that if a vehicle is travelling in excess of the available sight distance it will be unable to stop for a stationary object (such as another vehicle having already had an accident in the travel path). Slowing down a vehicle will both reduce the probability of such an event occurring and reduce the seriousness of the accident if it does occur.

Safe stopping distances for particular speeds vary according to a number of factors such as the coefficient of friction of the surface (including any effect for rain or a wet surface), vehicle speed, grade and reaction time (see Appendix C). How this is
calculated varies between countries as can be seen in Fig 3.05. This project has used the DMR Design Guide (DMR 1988) amended to use a reduced reaction time of 1.8 seconds, a compromise time between the 2.5 seconds normally used on such roads and the figure of 1.4 seconds considered appropriate in fog conditions (Heiss, 1976).

Given that in daylight fog conditions a vehicle may only be visible at one third of the sight distance as indicated by the MOR (see Section 2.3.1) it is easy to see from Fig 3.05 that overdriving (driving at a speed which will not allow safe breaking within the lane when another vehicle comes into view) can easily occur.

For example in daylight and more particularly dusk conditions when an accident occurs and the MOR is below 200 m, such an obstruction may only be visible from a distance
of 70 m. This means any vehicle travelling in excess of 70 km/h will be overdriving greatly increasing the risk of turning the initial accident into a multiple vehicle one.

In the case of relative speeds differentials, considered by some to be a predominant accident cause (Brisbane, 1994), the benefits are that reducing these relative speeds will also reduce the probability of an initial accident. In any particular visibility condition there is a maximum speed reduction which can be undertaken without colliding with the preceding vehicle. If the speed differentials are in excess of this maximum a collision within the same lane becomes unavoidable.

As an example when the visibility as measured by the MOR is restricted to 100 m, a vehicle travelling at 100 km/h can only slow down to about 62 km/h within this range plus any additional reductions for specific site parameters such as grade (see Fig 3.06). If the speed differential between vehicles exceeds this a collision will occur unless the second vehicle can change its travel path (see Appendix C).

![FIG 3.06 DECELERATION SIGHT DISTANCE - DAYTIME](image-url)
In Stage 3 of the project modification of speeds was attempted and in particular those of drivers whose relative speeds to preceding vehicles are excessive.

To select such a site would require all the conditions identified above to apply throughout a length of road, such a length to allow measurement of an initial speed, characteristic modifying action to be taken and subsequent performance to be measured including the distance travelled whilst performance is being modified.

3.2.2 Site Analysis

i) Fog Frequency

An overall summary of the analysis of the records for the usage of the current F6 Driver Aid system for 1985 - 1990 is shown in Appendix A.

As indicated earlier, these figures are based on subjective evaluations and if objective figures were to be available, they would be likely to show a variation from the analysis in Appendix A. Nevertheless analysis of the records do show information which is able to be used for general investigation of the problem in the area and to assist with site selection.

In Fig 3.07, which provides a summary of the distribution of the usage of Northbound sites, sites South of station 56 are shown to have fog occurrences in excess of 100 hours per year, with sites around Bulli Tops (60 - 65) indicating over 200 hours per year of occasions when it was considered warning advice to motorists was required.
Individual analysis of the records for site 64N (the site showing the greatest fog frequency) was carried out to examine the occurrence of fog in terms of frequency by month in terms of days per month and hours per month, as well as hourly distribution over the year.

As can be seen in Fig 3.08 and Fig 3.09, over a six year period there is a clear predominance for fog occurrences during the early months of the year (from January to April) of around 30 hours/month occurring on 6-8 days/month reducing to an average of only 2 hours per month in July. In terms of the yearly total, the number of days when there is an occurrence of fog averages at 50 days per year. This greatly exceeds the occurrence rate of 35 days per year upon which design was based (Morris, 1975).
FIG 3.08 MONTHLY FOG OCCURRENCES (DAYS) AT SITE 64N: 1985-1990

FIG 3.09 HOURS OF FOG OCCURRENCES PER MONTH AT SITE 64N 1985 - 1990
When examining overseas data, it is clear that the fog in the Bulli Tops area occurs at an extremely high frequency in comparison to other sites where the rate of occurrence is considered a problem.

In the UK, which has a reputation for frequent fog occurrences, analysis of 36 locations in the vicinity of various motorways between 1958 and 1967 where visibility fell below 200 m (the range considered of greatest importance to the road user) at 0900 hrs shows a highest occurrence rate of 17 days per year with an average of 6.3 days per year (Moore & Cooper, 1972).

The use of 0900 hrs would again indicate the differing nature of the fog experienced in the UK, this being the time a ground fog would be experienced following the cooling of the atmosphere below the saturation point during the night period. As shown in Fig 2.02, the fog at Bulli Tops is evenly spread throughout the 24 hour period.

In the USA a 1972 study (National (US) Transportation Safety Board, 1972) showed only 3 States having small localised areas covered by fog on a recurring basis in excess of 50 days per year.

From these figures it can be seen the area at the Southern end of the freeway has a very high number of fog occurrences and would be appropriate in terms of any criteria for high frequencies of restricted visibility periods.
ii) Level of Service (NAASRA, 1988)

Level of Service (LOS) provides an indication of how a section of road performs ranging from LOS A where traffic is in free flow and drivers are virtually unaffected by the presence of others in the traffic stream to LOS E where volumes are close to capacity and driver performance is mostly controlled by other vehicles in the traffic stream. (LOS F is used to describe failed flow conditions where demand exceeds capacity).

Any evaluation of driving characteristics which attempts to assess the speed at which a driver chooses to travel is obviously best done where the driver is unaffected by the behaviour of others, i.e. LOS A. As indicated in Sect 3.2.1 an LOS of at least C is considered necessary to provide the conditions required for the trial purposes. An analysis of the selected site is provided in Appendix E. This shows a LOS A is obtained at the chosen site, meeting this requirement.

iii) Lane Discipline.

Good lane discipline is due to there being minimal reason for lane changes. This is achieved when Level of Service is good (see above) and entry and exit opportunities are minimised. This second requirement removes the option of using sites in the vicinity of sites 61S, 64N, 65N, 00S-04S, and 02N-04N where there are significant areas of merging and diverging. Locations North and South of these sites are not affected by weaving traffic manoeuvres and provide the sort of lane discipline required.
iv) **Accessibility.**

Accessibility to equipment is not a major problem at any site in the area although locations where features were built into the original Driver Aid system offer easier access, this having already been provided when original construction took place.

v) **Freedom From Outside Influence.**

The presence of the existing system means that traffic in both directions may be affected by the existing display system. Only sites 46S, 67N and 01S have traffic passing which has not been affected by displays on the existing system.

vi) **Future Options.**

The restrictions in this regard do not greatly differ from the requirements of the initial trial stage. However in order to use the first site as a control, the first loop would ideally be located at a point where drivers would not have had an opportunity to change their speeds due to the effect of any display. 67N is the only site to meet this criteria.

vii) **Maximised Traffic Volumes**

As the occasions of fog occurrences remain a low probability event, the greater the traffic volume at a site the quicker meaningful data sets will be obtained from those occasions when fog does occur.
3.2.3 Selection.

A number of sites were considered as potential test sites, these being:

56S - A typical site on the main part of the F6 Tollway located in the middle of the existing system,

01S - A site removed from the effects of the Tollway with no contamination from previous signs,

64N - The site with the greatest recorded fog occurrences,

67N - A site on the main northbound route with no previous display sites affecting driving performance.

<table>
<thead>
<tr>
<th>TABLE 3.01 KEPNER-TREGOE ANALYSIS FOR SITE SELECTION</th>
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<tr>
<td>FREQUENCY OF FOG OCCURRENCES</td>
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<td>LANE DISCIPLINE</td>
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<td>OPTIONS FOR FUTURE RESEARCH</td>
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<td>WEIGHTED VALUES</td>
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</table>
Based on the above criteria a Kepner-Tregoe analysis (Kepner-Tregoe, 1987) was carried out to select the most appropriate site. Details of this analysis are shown in Table 3.01.

From this analysis the northbound lanes of site 67N were selected as being the most appropriate location to carry out the testing work.

In order not to have driving performance affected by existing fog warning devices, arrangements were made to have the advisory sign on display at the site disconnected from the existing Driver Aid System whilst the normal driving performance evaluation was to be determined. Selection of this site however provided an option for the existing system to be evaluated before alternative proposals were trialled.

3.3 Equipment.

3.3.1 Visibility Measurement Devices.

As discussed in Section 2.7 the two main devices for measurement of visibility are transmissometers and scatter devices.

Consideration was given as to which device would be the most appropriate for this particular work. Transmissometers offer a greater degree of accuracy (± 10%) than scatter devices (± 20%). However transmissometers make an evaluation of visibility based on the attenuation of light over a variable baseline. Accuracy increases as the length of the baseline increases with several hundred metres being required for the best
results. Scatter devices use a 1 m baseline allowing measurement of visibility at a point to be made.

FIG 3.10 PHYSICAL LAYOUT OF FD12

In considering the characteristics of motorists, decisions are made on a motorist's immediate environment. As such the visibility in the immediate vicinity of a driver will have the greatest effect on the driving performance adopted. With some delayed effect due to reaction time, which for speeds of 100 km/h means a 30 m distance will be
covered, vehicle movement will reflect driver assessment of the environment. In terms of measuring a driver's response to the conditions, it is therefore desirable for the visibility to be known in the area where the driver makes a decision.

This information is more readily supplied with the use of a scatter device which can make an assessment of visibility at a point within 10 m of the driver's vision. On this basis a scatter device was selected for measurement of visibility.

In this instance a Vaisala FD 12 Fog Detection device (Haavasoja, 1990) was selected (Fig 3.10). This device is a forward scattering measuring device with the receptor set at an angle of 33° from the transmitter direction.

Selection was based on price and the availability of the instrument with technical support within Australia. Following purchase and installation Vaisala company representatives visited the site to calibrate the equipment. Calibration was checked at six monthly intervals by RTA personnel and annually by Vaisala. At no time during the trial was recalibration found to be needed.

The equipment was installed at a location 10 m from the edge of carriageway with the transmitter and receptor at approximately the eye height of a motorist in a car (Fig 3.11).
FIG 3.11 FD 12 RELATIVE TO ROADWAY
A position was selected where vegetation did not interfere with the passage of fog so that any difference in visibility within the roadway and at the instrument was minimised. (Fig 3.12)

3.3.2 Speed Measurement Devices.

i) Options

Options for the equipment to measure vehicle speeds at the site consisted of radar units, tube counters, loops installed in the pavement and piezoelectric cable. In evaluating each of these for suitability of use, their performance in the areas of vehicle speeds, ability to identify differences between cars and other vehicles, reliability, detection of vehicle lane travel and headway measurement were considered.
Some of the factors taken into consideration were as follows:

Radar

Outputs from available radars only provides speed detection although it was considered that methods could have been incorporated into the site to provide headway information. Vehicle type information could not be provided.

Difficulty exists in obtaining information from individual lanes as radar measures across a line. This would also lead to a high probability of false results where vehicles travel in both lanes within a short time period.

Units are expensive and not readily available for the number of locations for which they would be required in a replacement system.

Tubes:

Existing RTA Trafficorder units already exist to allow a thorough vehicle analysis to be carried out using loops with information readily available on speeds, headways and classifications. To utilise this data would however require modifications to the Trafficorder units in order to allow the information to be used in association with the output from the Fog Detector. Such modifications would have been possible but at a cost estimated at $20,000.

The tubes placed on the road surface frequently suffer damage due to traffic, particularly in high speed areas. In view of the infrequency of fog occurrences, it was important that conditions be monitored at all times. With tubes, continued
maintenance could not be guaranteed, making it likely that opportunities would be missed, thereby considerably lengthening the data acquisition process. This would be of even more significance in future evaluation stages as there would be a significant likelihood that all ten sites would be not be operational at the same time.

There would also be a considerable cost and safety risk factor with continued replacement of tubes being required in high speed traffic conditions.

Lane differentiation would be a problem if, as in the case of site 67N at the start of the project, a central median was not available. (A New Jersey kerb was installed in June 1993.)

Loops

There was no readily available system to utilise loops for the purpose required. However it was considered possible that they could be adapted to provide the information required.

Previous experiences with loops in traffic signal situations had shown difficulties with tuning of the loops (i.e. the time taken for a signal to reach the analysis point must be uniform which would not occur if the loops were not tuned properly or varied during operation). This problem has cast some doubts on some earlier UK research carried out prior to the 1980s where Hawkins indicated:
"The research commenced in the mid 1970s with the objective of studying traffic characteristics related to the high incidence of multiple accidents occurring on motorways in thick fog. Extensive trials showed the results could not be regarded as being reliable due to loop tuning difficulties" (Hawkins, 1988)

Technology has now provided equipment to eliminate these tuning difficulties. However a comparison was carried out to ensure speed results obtained from the loops did not vary and correlated to results which would have been provided by radar which provided a correlation factor of 0.99 (Appendix D).

Piezoelectric Cable (sometimes known as piezo strips)

As with loops it would be possible to have these strips placed in individual lanes to provide all the information provided, although as with loops no readily available system exists to access the data required.

The cost would be significantly higher than for traffic signal loops

The technology for this method remains relatively undeveloped (Taylor and Young 1988) and early experiences from results of trials carried out by the RTA's Rhodes Workshop show a variability which suggests the data cannot be relied upon for accuracy.
ii) Selection

Following an assessment of each type of device, a Kepner-Tregoe analysis was again carried out to select the best option, details of which are provided in Table 3.02.

<table>
<thead>
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</table>

Based on this analysis Traffic Signal Loops were selected as the best method to assess vehicle speeds.

Following selection of pavement loops, a configuration as shown in Fig 3.01 was adopted to provide the information required. This provided 5 speed measurement locations in each lane at 150 m intervals over a length of 600 m. In addition to installation of the loops, cable ducting was needed to connect the loops to the central processing facilities.
The loops were set out as shown in Fig 3.13 and provided a signal when traversed by a vehicle. Interpretation of these signals was required to provide:

i) details of speed (calculated from the time the vehicle took to travel a fixed distance between inductance points 1 and 2)

ii) vehicle length (calculated from the time a presence on inductance point 2 was detected until it departed from 3; by knowing its speed from i) above the length can be calculated)

iii) headway (calculated from the time between a presence departing inductance point 3 and the departure of the next presence).

![Loop Layout Diagram](image)

**FIG 3.13 LOOP LAYOUT**

The fog detector was installed at the central site at a distance of 10 m from the slow travel lane as shown in Fig 3.12.

A computer program was written in C programming language by the RTA’s Mr Andrew Vasiliou to record the information from the loops and fog detector (Appendix I). The results were stored on a Toshiba 3200 laptop computer located on site.
The computer and equipment associated with tracking the passage of vehicles across the signal loops were installed in a Traffic Signal Control Box (Fig 3.14).
3.4 Stage 2 Proposal

The second stage of the project involved the utilisation of the existing (1974) sign at the test site to evaluate any effect it may have on traffic. The purpose of this was to confirm or disprove the belief that the signs had no effect on traffic and to test the effectiveness of the system being developed prior to the construction and installation of the new larger sign.

The criteria to be followed when using variable message signs is set down by the CIE in its technical publication on Roadworks (CIE 1988). These criteria are basically the same as for any road sign but may only be required on an intermittent basis. When not in use, it remains important that a false message is not left in place. The following requirements are set out by the CIE:

- * Conspicuity: Signs need to attract attention so 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.

The proposal was to have the sign attached to the fog detector in the same way as the new sign would be in Stage 3 and have the sign display "FOG" together with use of the attached flashing lights.
Using the sign in this manner did not fully replicate the way in which the sign was previously used. As the system operated before the trial commenced, the existing system could only be said to meet one of the four criteria set out by the CIE for the appropriate use of variable message signs, that of Comprehensibility. Stage 2 would add credibility to the display (although given the number of years the system was lacking in this, whether such credibility would be established within the trial time frame could be questioned.).

The requirements of legibility and conspicuity (particularly in fog) would still not be provided.

3.5 Stage 3 Proposal

The final part of this project involved the replacement of the existing fibre-optic sign with a new intelligent sign. Prior to the development of such a sign, investigations were carried out on the current types of signs available and other characteristics which would be applicable.

In selecting an appropriate sign display, the requirements of the CIE as detailed above were followed.
3.5.1 Type of Sign

Three are many types of sign currently on the market which can advise motorists of matters relevant to the driving tasks. These include:

<table>
<thead>
<tr>
<th>Sign Type</th>
<th>Static</th>
<th>Changeable Message</th>
<th>Variable Message</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static displays using reflective</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotating prism (illuminated)</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Flip discs (illuminated)</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Neon*</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fibre-optic*</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>LED (Light Emitting Diode)*</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

* Self illuminated sources

The problem of course in fog is that a sign that relies on reflected light has the same visibility in the daytime as another vehicle (or even less if it is of insufficient size). With MOR ranges of below 100 m, this can result in the sign only being visible for about 1 second of travel time, insufficient time for a message to be conveyed to a motorist.

It therefore became essential that a sign should take advantage of the additional sight distance offered by a self-illuminated light source. Of the three remaining options a fibre-optic medium was considered to have the best performance. In a comparison of a wide range of sign types prepared for the Arizona Department of Transportation it was
concluded that fibre-optic signs are the most legible in all conditions throughout the day and night (Upchurch, 1991).

Whilst the use of neon signs have been considered successful in Oregon, there is no record of their use in other locations and their use is not favoured. Neon has a tendency to bloom in fog conditions (US Dept of Transportation, 1979) and maintenance in a gantry situation over the road was considered a problem.

At the time of this study, LED technology was still in a state of change and doubts still exists on the long term degradation of these type of lights and the long term operating costs (Wyman, 1995).

A fibre-optic sign was therefore selected for use in this project.

3.5.2 Letter Size and Colouring

The visibility of a sign is based on the intensity of the lamps and the sign, the size of the lettering and the colour of the light. A 50W 12V tungsten halogen lamp produces a luminous intensity of up to 4000 candela. From Fig 2.10 it can be seen that this will produce a sign which is visible in a thick fog at around 60m. For a motorist travelling at 80 km/h, this provides around two seconds for a two word message to be observed before the motorist passes under the sign. For a two word message as is proposed, this conforms to the requirement for a display at one word/second for optimum recognition (Jenkins, 1993).
For a fibre-optic variable message sign with an approach speed of 90 km/h UK and French requirements are set out in Table 3.03 (CIE, 1993).

<table>
<thead>
<tr>
<th></th>
<th>Minimum Character Height</th>
<th>Recommended Character Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>300*</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>200</td>
<td>400</td>
</tr>
</tbody>
</table>

* Upper Case

Based on the above, a sign with letter size of 400 mm was selected for the project.

In terms of light colour, selection appeared to be a choice between white and yellow/orange based on observation of current practice and lighting.

Jenkins reports that there is anecdotal evidence that yellow is a more effective colour in reduced visibility although this had not been documented in any papers reviewed in the preparation of his report for the ARRB (Jenkins, 1993). However research into neon lighting claims the maximum visibility to the eye occurs in the yellow-green region of the spectrum (500 millicrons) whilst the maximum transmission of light in poor weather occurs in the orange region (635 millicrons) (Miller, 1977). Transmission of light to incorporate both of these properties obviously relies on light with a predominance in the yellow-orange region of the spectrum.

Accordingly a sign using such a yellow-orange colour was chosen for use.
3.5.3 Variable vs Fixed Message

Whilst the benefits of a full variable message sign were attractive in that it provided for a much wider ranges of messages which could be displayed, such signs presented problems in that they would require a large number of movable shutters and would cost at least twice that of a sign with a limited number of fixed messages for the same letter height.

(The newer signs now on the market have addressed the shutter problem by putting an opaque LED lens in front of the fibre optic cell display. By passing a charge through the LED, it can be made transparent allowing the fibre optic display to be seen. However this was not an option at the time, nor when the final decision came to replace the existing system. The new system now installed has utilised variable message signs using shutter technology and within the first year experienced the problem of shutters sticking.)

For the purpose of the trial it was considered possible to develop a sign which used up to five fixed displays in each of three panels of up to six characters. These could be used for the purposes of determining the effectiveness of a small number of fixed messages. Besides the advantage of cost and the ability to have a larger than minimum lettering, such a sign could be built at the RTA’s Granville workshops allowing greater flexibility in implementing any changes which might be required as the project progressed (and as were eventually needed).
3.6 Final Sign Development

The final solution chosen was for a sign which is divided into three panels with several fixed messages available on each segment (Fig 3.15). Character displays used a fibre-optic matrix with letter heights of 400 mm. On either side of panel 3 is a green arrow which is intended to advise the motorist to which lane (and hence which vehicle) the message is applying if relevant. For contrast a black background was provided. Whilst the sign relies on the use of up to four fixed messages in each panel, these can be combined using a different message from each panel to provide differing advice to motorists. (See Chapter 5)

Please see print copy for image

FIG 3.15 - SCHEMATIC LAYOUT SHOWING DISPLAY OPTIONS FOR EACH PANEL (BRISBANE 1994)

The sign was to be erected on a cantilever support which places the arrows over each lane. The erection of the sign directly over the travel lane of a motorist greatly improves the visibility of the sign by reducing the distance to the sign before it becomes unreadable (when the angle of vision to the sign exceeds the design angle). In the case of a 6° half angle lens, as was used, a sign placed at 6 m over the roadway requires a minimum distance of about 24 m to be clearly visible. This compares with a similar
sign placed clear of the shoulder (10 m from the fast lane as for the old system), which ceases to be clearly visible from about 43 m. In the case of dense fog where the sign may not become visible until about 70 m away, this can almost double the available viewing time.

3.7 Costing

Site costs for the project were as follows:

Stage 1  ‘Vehicle characteristics in fog with no signs’

- Installation of Signal Loops $10000
- Provision of Ducting $30000
- Fog Detector (inc. installation) $20000
- Site Installation $15000
- Laptop Toshiba $3000

Stage 2  ‘Vehicle characteristics in fog with existing (1974) sign’

- Adjustment to equipment $5000

Stage 3  ‘Vehicle characteristics in fog with new sign’

- Sign $80000
- Gantry $50000
- Installation $30000
- Guardrail $12000
- New Computer* $5000

* Original computer failed due to site conditions and was replaced by a heavy duty machine.

Total Costs $280000
These funds were provided for from the RTA’s Research and Development budget.

Analysis of the results were carried out as part of this thesis and not costed to the capital costs.

It should be noted that all of these costs provided for resources which would be required throughout the process of assessing both existing characteristics and the provision of further equipment to modify such characteristics.