FEDERAL OFFICE OF ROAD SAFETY
REPORT DOCUMENTATION PAGE

Report N°	Report Date	ISBN	Pages
	June 1994		46

Title and sub-title: Adaptive Speed Limit Signs for Road Safety

Author: Donald, G S

Performing Organisation: CERTS International Pty Ltd
Level 1, 51 Rawson Street (PO Box 716)
Epping NSW 2121

Sponsor [Report available from]: Federal Office of Road Safety
PO Box 594
Canberra ACT 2601

Abstract:

A state-of-the-art report was prepared on adaptive speed limit signs; that is, intelligent signs displaying variable speed limits based on weather or traffic conditions. A review of the international literature was undertaken, and an international conference was attended in Europe, where first hand knowledge was gained on this application of IVHS (intelligent vehicle highway systems) technology. It was found that adaptive speed limit signs are in use on freeways in several countries, notably the USA, Germany, and Taiwan, on a pilot basis at this stage. Several other countries may also have pilot installations, or are considering that option for sites where fog or ice are prevalent, or where traffic congestion is likely to arise from incidents. A sample specification was prepared for an Australian pilot project, to trial and demonstate the technology. For this purpose, the Roads and Traffic Authority of NSW was consulted through a project team involving staff from road safety and technical policy areas, and from three regions. In one of these regions, a field trial of similar technology was current on the F6 Sydney- Wollongong freeway, for fog warning/ advisory speed signs rather than speed limits. In the other two regions, the use of adaptive speed limit signs was under consideration for the Hawkesbury Valley section of the F3 Sydney-Newcastle freeway. It was concluded that there is no technical or legal impediment to trialling adaptive speed limit signs on a freeway in NSW, although specific legislation would be required to introduce adaptive speed limits on a fully operational basis.

Key Words: Adaptive speed limit, Variable speed limit, Variable message sign, Weather sensor, Fog detector, Traffic incident detector.

Notes:

(1) This report is produced by FORS and is disseminated in the interest of information exchange.

(2) The views expressed are those of the author and are not necessarily those of FORS.

(3) The Federal Office of Road Safety publishes four series of reports:
- (a) reports generated as a result of research done within FORS are published in the OR series;
- (b) reports of research conducted by other organisations on behalf of FORS are published in the CR series;
- (c) reports based on analysis of FORS statistical data bases are published in the SR series;
- (d) minor reports of research conducted by other organisations on behalf of FORS are published in the MR series.

CONTENTS

EXECUTIVE SUMMARY

This is a state-of-the-art report on intelligent signs used for displaying variable speed limits on freeways. The intelligent sign, in this case, is one which can automatically sense weather and/or traffic conditions, and display a speed limit appropriate to the conditions. Because these devices can dynamically adjust the speed limit without human intervention, they are called adaptive speed limit signs.

The adaptive speed limit sign is an application of IVHS (intelligent vehicle highway systems) technology, in which great interest has developed in recent years, particularly in Europe, Japan and the USA. The technology for intelligent signs has been developing for over twenty years, and is now sophisticated and reliable. Adaptive speed limit signs are in use in several countries, notably the USA, Germany, and Taiwan. Some countries have opted for adaptive advisory signs, rather than speed limits, but there seems to be growing interest in adaptive speed limits for specific locations.

In the USA, variable speed limits have been used in some locations for many years, and adaptive speed limit signs have recently been installed in at least two projects in different States. The available evidence for the use of adaptive speed limit signs in Germany is comprised mainly of magazine advertisements for the technology. However, the use of adaptive speed limit signs in Taiwan has been documented in a journal article. No performance evaluations were available, but the general impression gained from the literature was that the technology works well enough.

The components of an adaptive speed limit sign are:

- a variable message sign, displaying the speed limit (and perhaps the reason for it);
- one or more weather sensors, for detecting conditions such as fog, rain, wind, temperature, and ice or water on the road;
- possibly traffic sensors, for detecting traffic incidents and queues;
- a control computer; *eg* the ubiquitous PC.

Recently, an intelligent fog warning sign displaying advisory speeds was installed on the F6 Sydney-Wollongong freeway by the Roads and Traffic Authority (RTA) of NSW. The experience gained with this pilot installation will be very useful in extending the advisory system to a regulatory regime. In conjunction with the adaptive speed limits research project, an RTA working group has developed a proposal for introducing adaptive speed limit signs on the Hawkesbury Valley section of the F3 Sydney-Newcastle freeway.

A sample specification for a pilot project on the F3 was prepared for the above working group, and is included in this report. Because mains electricity supply is generally not available on the F3, the type of variable message sign was selected to minimise power requirements. On one carriageway, two signs were proposed to be adaptive to fog, rain or wet road surface, while on the other carriageway a comparison of loop-based and video traffic sensors was proposed.

The legal implications of adaptive speed limits were considered. Current legislation in NSW requires speed limits to be posted by human intervention. Therefore, new legislation would be required to make computer controlled, adaptive speed limits enforceable. However, for the purpose of a field trial or demonstration project, there should be no problem in displaying adaptive speed limits in an area identified to the public as a trial section.

It was concluded that there is no technical or legal impediment to trialling adaptive speed limit signs on a freeway in NSW, although specific legislation would be required to introduce adaptive speed limits on a fully operational basis.

oooOOOooo

ACKNOWLEDGEMENTS

The assistance of the following people is gratefully acknowledged in the preparation of this report: Peter Croft, Douglas Quail, Graham Brisbane, Terry Keating and Keith Rigby of the NSW Roads and Traffic Authority, Phil Reid of Telecom Australia, and John Longfoot of JEL Consulting.

1 INTRODUCTION

This project and report were commissioned by the Federal Office of Road Safety, to investigate the use of "intelligent" speed limit signs on freeways. These regulatory signs, involving advanced technology, would be adaptive to hazardous conditions such as fog and rain, slippery road surface, roadworks and traffic incidents. The objectives of the project were to improve the management of vehicle speed in these situations, and thus contribute to improving road safety. The project had the following specific goals:

- Report on the world's best practice for the use of advanced technology in regulating the speed of road traffic.
- Facilitate the introduction of dynamic, adaptive speed limit signs to Australia.
- Develop a technical specification for a pilot project on adaptive speed limit signs in NSW.

The immediate benefit expected of the project would be the opportunity for road authorities to readily introduce the technology. Ultimately, when the proposed signs are implemented, a reduction in traffic crashes, injuries and fatalities can be expected on freeways. Along with improved road safety, there will be benefits in reduced community costs associated with traffic crashes.

The project was essentially concerned with technology transfer, and did not involve scientific experimentation or equipment purchase. This state-of-the-art review involved a literature survey and participation in the international technical community of IVHS (*intelligent vehicle highway systems*).

2 INTELLIGENT VEHICLE HIGHWAY SYSTEMS

The purpose of IVHS is to improve road transport with respect to safety, efficiency, comfort and the environment. The emerging IVHS technologies are also known as road transport informatics, advanced transport telematics, smart roads and smart cars, integrated road transport environment, and so on.

This group of new technologies covers several functional areas, such as traffic management, traveller information, vehicle control, fleet management and public transport. The area of advanced traffic management includes, for example, coordinated adaptive traffic signals and the use of automatic variable message signs for traffic control (*McQueen and Taylor 1993*), including adaptive speed limits.

Rapid progress is being made in developing IVHS applications, particularly in Europe, Japan and the USA. In Australia a national association, IVHS Australia, was established in 1992 to provide a focus for technology development. In 1993, international activity was focused with a planned series of IVHS World Congresses, and with the International Standards Organisation (ISO) establishing an IVHS Technical Committee. This committee has, in turn, set up about fifteen working groups, of which one is chaired by an Australian; *ie* WG9 - "Integrated Transport Information, Management and Control". The work area of this group is large and complex, as shown in Appendix 1, and includes the use of variable message signs for traffic control (*eg* adaptive speed limits).

Some Australian technology for traffic control, called SCATS, is part of the IVHS Guidestar project being implemented in the USA (*Michalopoulos et al 1993*). Recent IVHS applications in Australia, relating to speed management, have been the radar speed camera (*Hitchens 1994*) and Safe-T-Cam (*Murdoch and Reid 1993*), which can automatically recognise number plates for processing traffic infringements.

3 SPEED MANAGEMENT TECHNOLOGY

The recent advances in technology offer significant opportunities for improving road safety through speed management. These opportunities can only be realised with a broad based, concerted effort by government and the community. The following arrangements in NSW for developing the use of such technology, may be typical within Australia.

To tackle the overall issue of speeding, a Community Advisory Group on Speeding was established, with wide representation. This group oversees a Speed Management Taskforce involving the Roads and Traffic Authority (RTA), Police and Health Departments, Local Government and the motorists association (NRMA). The taskforce has a role in:

- exploring the potential for the use of current technology to better understand the characteristics of the speeding problem;
- identifying opportunities for the use of current technology to improve speed management.

In this context, RTA is actively involved in developing applications of advanced technology for speed management. One such initiative is a fog warning system currently being trialled at one site on the F6 freeway between Sydney and Wollongong (*Brisbane 1993, Leverenz and Brisbane 1993*). New technology is intended to replace an existing sytem (*Morris 1975*), which is not sufficiently adaptive to local conditions. The new technology system will operate automatically, using sensors for fog and rain to activate a warning sign, with an advisory speed message related to the visibility. That is, the advisory speed sign is to be an "intelligent" device, displaying information adaptive to the local environment.

Experience with the single pilot, fog warning sign indicated that the effectiveness of the advisory speed sign was only marginal. Drivers tended to "play games" with the technology, increasing speed before reaching the sign to test its response. Speeds did decrease after the sign, but only for a short distance. While the advisory sign might become more effective as the novelty wears off, or with the addition of more advisory signs, a significant improvement is by no means assured, at this stage. On the other hand, the effectiveness of a regulatory sign (variable speed limit) could be addressed by enforcement.

The concept of variable speed limits was endorsed by a recent Australian study, "The Speed Review" (*Fildes and Lee 1993*), sponsored jointly by RTA and the Federal Office of Road Safety (FORS):

> "The advantages of variable speed limits taking account of poor visibility, bad driving conditions or special needs such as school zones warrants further consideration (ibid, p 36). ...The refining and testing of such technology must be undertaken prior to its implementation (ibid, p 96)."

Accordingly, the current project is directed towards trialling the technology for adaptive speed limit signs. In addition to sensing weather conditions, the sensing of traffic conditions (*eg* congestion) is also of interest. A proposal for such a field trial is discussed in Section 6.

4 LITERATURE SEARCH

A literature search was conducted through the RTA Library, using the following sources:

- Australian Road Research Board's ROAD database;
- Department of Transport and Communications' LASORS database;
- European Space Agency Information Retrieval Service (ESRIN);
- DIALOG Information Services, USA.

Initially, the key words used were *variable message signs* (VMS); with *changeable* or *adaptive* instead of *variable,* and with *road, road safety* or *traffic.* The output of this search was 324 references, of which about 30 were followed up. Some of the documents sought were not obtainable, or were in foreign languages, but abstracts were available in most cases and several abstracts have been used as minor sources.

Subsequently, a further search was conducted through ESRIN and DIALOG using the key words *variable, speed limit* and *sign,* generating 68 items with abstracts. In this second phase of the search, the abstracts were generally relied on, rather than full references.

Other references were obtained from professional contacts and by attending an IVHS conference in Germany (26th International Symposium on Automotive Technology and Automation - Dedicated Conference on ATT/ IVHS). In fact, this conference attendance resulted in the principal reference sources; the conference proceedings and later acquisition of *Traffic Technology International '94.*

The references given in Section 8 of this report were reviewed in full, except for those marked with asterisks, for which only abstracts were obtained.

5 LITERATURE REVIEW

5.1 Variable Speed Limits

A large number of references were found on variable (or changeable) message signs and their use; relatively few of these referred to variable speed limits. However, the second phase of the literature search, specifically for variable speed limit signs, generated a significant number of references.

In USA, variable speed limit signs have been in use on the New Jersey Turnpike since the early 1960's (*NCHRP 1979*), with speed limits being changed when adverse weather, pavement or traffic conditions exist. A similar approach was adopted in a mountainous region of Wyoming (*Bell 1975*). More recently, the cost benefit has been analysed of a variable speed limit system displaying both maximum and minimum speed limits (*FHWA 1989*). Variable speed limit systems with automated sensing of weather and traffic conditions have been installed in:

- Albuquerque, New Mexico (*Harwick 1989*);
- Washington State - system called "TravelAid" (*Judycki 1992*).

In Germany, variable speed limit signs were trialled in 1972 (Zackor in *Smulders 1990*), and theoretical control concepts have been developed (*Cremer and Fleischmann 1987*). Such signs are currently in use, with automatic sensing of traffic and weather conditions (*Zackor and Schwenzer 1988, Stiegler 1991, Kuehne 1993, Boschung 1994, ANT Bosch Telecom 1994, Siemens 1994*). Early use in Switzerland is also likely (*Gottardi 1972*).

In the Netherlands, trials with automated sensing (*Klijnhout 1984*) led to the use of variable speed limits where high traffic concentrations were common (*Remeijn 1992, Smulders 1992*). However, the Dutch have opted for advisory speed signs generally on their motorways (*Smulders 1990*). Within Europe, variable speed limits have also been:

- at least trialled in France and Italy (*Lemaitre and Laurand 1974*, *Filippi et al 1989*);
- studied in Spain (*de la Rosa 1988*);
- planned in the UK, for sectons of the M25 Motorway (*Hodgson et al 1992, Winney 1993*); and
- proposed in Sweden, for different seasons of the year (*Nilsson 1990*).

In Taiwan, variable speed limit signs are in use on the National Freeway in fog-prone areas and at tunnels (*Chen and Lien 1986, Ju 1990*).

Commonly, variable speed limits have been adopted at roadworks (*VicRoads 1990*) and at schools (*O'Grady 1975, Hawkins 1993*). While these applications do not require the use of "intelligent" or adaptive signs, that is, signs operated automatically using advanced sensing technology, the use of variable message signs may be advantageous. This would apply especially to roadworks on freeways (*Hanscom 1982*).

The general impression gained from the literature was that the technology works well enough, but specific comment was not found on either the operational reliability of the signs, or on the effectiveness of the adaptive speed limits.

5.2 Variable Message Signs

Early references on Variable Message Signs (VMS) show the development of technology in sign types, from manually operated to electro-mechanical to wholly electrical (*HRB 1971, NCHRP 1979, Hodge and Rutley 1978, Rutley et al 1983, Goldby 1984, Derrick 1988*). Electro-mechanical signs typically include several types: roller "blind", rotating drum or prism, and disc-matrix (or flip-disc).

Later references tend to focus more on wholly electrical signs, specifically fibre optic and super LED (light emitting diodes), although flip-disc signs and shutters on fibre optic signs are also prevalent (*Garner and Vingrys 1988, Kerr et al 1988, Shamskhou 1991, Jenkins 1991, Dudek 1992, SYLVIA 1993, TEC 1993, Stainforth 1994, Lewis and Roe 1994*). The last of these references describes the use of LCD (liquid crystal display) shutters for fibre optic signs.

Attention has been given to the design and benefits of VMS (*Brown and Schofield 1992*), optical and photometric standards (*Jenkins 1991*), as well as human factors and behaviour (*Upchurch 1992, Durand-Raucher et al 1993*). Comprehensive guidelines are now available on the use of VMS (*Dudek 1992*), as well as an extensive local register of commercial suppliers (*TEC 1993*).

An important design factor for light emitting signs is their visibility in strong sunlight, and several levels of light intensity are desirable. While these signs are proving to be popular, they do require a mains power supply. On the other hand, rotating prism signs could be powered by solar energy, and may have a fail-safe advantage for variable speed limits, in that some message is always displayed.

5.3 Weather sensing

Early references are available on fog detection (Spear in *HRB 1971*), but as for VMS, the technology has developed and proliferated in recent years (*Leverenz and Brisbane 1993, ANT Bosch Telecom 1994, Boschung 1994, Paulsen 1994, Rittich 1994*).

Apart from fog, ice seems to be the weather condition most commonly detected or predicted (*McDonald 1994, Boschung 1994*). Ice prediction involves comprehensive data collection at road sites, including wind speed and direction, temperature and humidity, precipitation of rain or snow, road surface moisture, salt concentration and depth of snow (*Paulsen 1994, Rittich 1994*). Ice sensors also detect wet road surfaces (*McDonald 1994*).

5.4 Incident detection and image processing

Detection of traffic incidents or congestion on freeways has traditionally been achieved with the use of inductive loops installed in the pavement (*Chen and Lien 1986, Baxter 1989, Kurfees 1990, REIR 1991, bin Mohamed 1992, Sin and Snell 1992, van der Vlist and Brocken 1992, Hall et al 1993, Lam and Tritter 1994, Wall et al 1994*). These loop detector applications are usually linked with VMS and video surveillance cameras for the management of incidents and congestion on freeways.

In recent years, video vehicle detectors have been introduced, such as the Australian *CAMDAS*, US *AUTOSCOPE* and Belgian *CCATS* systems (*Diaz 1992, Michalopoulos et al 1993, Traficon 1993, Cypers et al 1993, de Henau 1993*). In their simplest form, these video detectors merely replace pavement loops, sensing vehicles for traffic counts; speed and headway measurements. However, the video detector can also be used to manually monitor turning movements, driver behaviour, traffic incidents and congestion.

Automatic video image processing is available, capable of automatically detecting traffic incidents and queues. Applications were found, for example, in the UK (*Daneshfar 1994*), France (*Blosseville et al 1993*), Belgium (*Renard 1993*), Spain (*Guillen and Martinez 1993*), Japan (Sakai et al 1993) and USA (*Michalopoulos et al 1993a and 1993b*). The last reference describes the Guidestar project, mentioned earlier, in which video incident detection using Autoscope is being trialled on the Minneapolis-St Paul freeway.

Different analysis techniques are used (*Hoose 1992 and 1994*):

- loop emulation - products called AUTOSCOPE, CCATS, and TULIP;
- vehicle tracking - products called TITAN, TRISTAR, Traffic Tracker;
- scene analysis - product called IMPACTS (*Dalgleish 1994a and 1994b, Sullivan and Baker 1993*).

Sophisticated software is also available for number plate recognition (*Murdoch and Reid 1993, Fahmy 1993, Ali et al 1993*).

Other technologies used for vehicle detection are:

- radar, or microwave radiation (*Kuhne 1991, Lion 1993, Smith 1993, Manor 1994*);
- infrared radiation (*Steinbach 1994*).

However, as with the simplest form of video vehicle detectors, these devices tend to function like pavement loops, without the image capture or processing potential of video detectors.

5.5 Speed detection, warning and enforcement

The Sydney-Wollongong freeway (F6) fog project, mentioned earlier, incorporated a speed detection and warning system which probably did not perform to its full potential at one pilot site, without the use of enforcement (Brisbane 1994). Vehicles were not identified on the F6, but on the M20 Motorway in the UK, a different approach is being trialled (Jasper 1993, Hill and Adaway 1994). Automatic number plate recognition has been incorporated, so that the VMS warning displays a speeding vehicle's registration number as well as its speed. The objective of this field trial is to induce a behavioural change in the motoring public, without resorting to enforcement measures. However, if enforcement proves to be necessary, the system could possibly be adapted to that purpose.

Similarly, in an Australian application of adaptive speed limit signs, enforcement of the speed limit could be achieved automatically using Australian technology (*Murdoch and Reid 1993, Hitchens 1994*).

In Portugal, an innovative approach to improving road safety at accident "black spots" is the use of intelligent warning lights on guide posts (*Lichter 1994*).

6 AUSTRALIAN PILOT PROJECT

To facilitate the implemention of adaptive speed limits, a site specific technical specification was developed. By focusing on a particular site, considerable meaning could be added to the concept of adaptive speed limits. To develop a pilot project for trialling the technology, the NSW Roads and Traffic Authority (RTA) was consulted through a project team on which the following sections of RTA were represented:

- Road Safety Bureau;
- Transport and Network Development Branch;
- Legal Services Branch;
- Wollongong Zone;
- Newcastle Zone;
- Sydney Region.

A site on the F3 Sydney-Newcastle freeway was selected for a pilot project on adaptive speed limit signs. On the Hawkesbury Valley section of this road, a number of serious accidents has occurred in recent years, particularly on the northern side. As a result, a study of aquaplaning potential was initiated by the RTA's Newcastle Zone, finding that high rainfall intensity was of particular concern in that area. To address this concern, the investigation of adaptive speed limits is appropriate. The concept of the proposed pilot project on F3 is to:

- adopt the fog and rain detection system, recently installed on the F6 Sydney-Wollongong freeway;
- add automatic video sensing of traffic conditions, as the freeway can become congested;
- arrange for a field trial of variable speed limits, using variable message signs.

For this purpose, the sample specification in Appendix 2 was prepared, focusing on a site convenient for a trial rather than the most critical area. Because of the perceived benefits of adopting a variable speed limit system, a comprehensive system may be proposed over a length of about thirty kilometres.

The implementation of such a scheme will require specific legislation, as current legislation in NSW requires speed limits to be posted by human intervention. Therefore, new legislation will be required to make computer controlled, adaptive speed limits enforceable. However, for the purpose of a field trial or demonstration project, there should be no problem in displaying adaptive speed limits in an area identified to the public as a trial section. In this case, enforcement of the adaptive speed limits would not be possible for the pilot project.

The pilot project would also have limitations for demonstrating the effectiveness of the incident detection system. Traffic incidents will begin at a point and the effect (a queue, stationary or slow moving) will progress upstream as more vehicles arrive. The purpose of reducing the speed limit because of an incident is to slow down the traffic to a speed where drivers will be able to safely join the back of the queue without risk of a further accident. To achieve this, the point of detection must be sufficiently downstream so that when the latency time of the incident detector and the safe time to reduce speed under the conditions are considered, a vehicle will have reduced speed by the time it arrives at the queue. Of course if an incident endures, the queue back-up will inevitably reach the sign and the warning will be insufficient. For this reason a small pilot project can never be wholly effective.

The incident detection should occur well downstream of the signs, but for practicality and economy, the proposed pilot project only allows for incidents to be detected close to the signs.

7 CONCLUSION

From the literature review, it is evident that variable speed limit signs have been used successfully on some US freeways for many years. Also, with new technology, the feasibility of intelligent speed limit signs has been proven, with pilot applications in the USA, Europe and Taiwan.

Further, it appears that all the equipment needed for adaptive speed limit signs has reached a relatively mature stage of development, and is available commercially from several sources. Considerable local experience has accrued with the sensors required for weather conditions and traffic conditions, and with variable message signs using advanced technology.

Therefore, it can be concluded that no technical or legal impediment exists to conducting an Australian pilot project for adaptive speed limit signs. A potential site for a pilot project has been nominated, and a technical specification drafted.

Subject to a satisfactory pilot or demonstration project, new legislation could be proposed with confidence to enable the adaptive speed limits to be enforced, and permit the introduction of adaptive speed limits on a fully operational basis.

8 REFERENCES

Ali A T, Bulas-Cruz J, and Dagless E L, (1993) "Vision-based Road Traffic Data Collection", Proceedings 26th ISATA Dedicated Conference on ATT/IVHS, Germany, September, pp 609-616.

ANT Bosch Telecom (1994) "Stop and Go? Make the Traffic Flow with Information Technology and Control Systems", *Traffic Technology International '94, p 111.*

Baxter, D H (1989) "Changeable Message Signs for Freeway Operations - Preliminary Results of Sign Usage in the Long Island Freeway Corridor", ITE Compendium of Technical Papers, pp 287-292.

*Bell, G H (1975) "New Aids in Winter Traffic Control", *Public Works, Vol 106 N^{o} 8, pp 58-60.*

Blosseville J-M, Morin J-M, and Lochegnies P, (1993) "Video Image Processing Application: Automatic Incident Detection on Freeways", Pacific Rim TransTech Conference, Seattle, July, Proceedings Vol 1 - Advanced Technologies, pp 77-83.

Boschung, M (1994) "Danger - Black Ice!", *Traffic Technology International '94, pp 168-171.*

Brisbane, G J B (1993) "Driver Response to Fog Conditions - An Intelligent Approach", Pacific Rim TransTech Conference, Seattle, July, Proceedings Vol 1 - Advanced Technologies, pp 347-353.

Brisbane, G J B (1994) "Speed Modification - Intelligent Signs for the Future?", 17th ARRB Conference, Queensland, August, Proceedings (in print).

Brown R J, and Schofield M J, (1992) "The Design and Benefits of VMS Information Systems", 20th PTRC Summer Annual Meeting, University of Manchester, Proceedings, pp 13-24.

Chen G S Y, and Lien S C, (1986) "Discussion of Effectiveness of Taiwan National Freeway Traffic Control System", 13th ARRB/ 5th REAAA Conference Proceedings 13(7), pp 46-57.

*Cremer M, and Fleischmann S, (1987) "Development of a Control Concept for Flow-dependent Use of Variable Message Signs and Entrance Regulation in Urban Motorway Networks", Technical University of Hamburg, Germany, Report, 47 pp.

Cypers L, Tegenbos R, and Lemaire F, (1993) "Evaluation of Image Processing Techniques for Traffic Surveillance on the Antwerp Ring Motorway (Belgium)", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 595-602.

Dalgleish, M J (1994a) "Vehicle Detection for Advanced Transport Telematics", Golden River Traffic Ltd, UK.

______________(1994b) "Applications for Video Vehicle Detection", Golden River Traffic Ltd, UK.

Daneshfar, M (1994) "MoniVision - Queue Detection and Integrated Traffic Management System", *Traffic Technology International '94, pp 152-5.*

Derrick, A J (1988) "Variable Message Traffic Signs, Bristol", *Highways and Transportation, Vol 35 Nº 11, November, p 62.*

Diaz, E L (1992) "An efficient PC Based Video Vehicle Detector", Proceedings 16th ARRB Conference, Perth, Part 7, pp 217-226.

Dudek, C L (1992) "Guidelines on the Use and Operation of Changeable Message Signs", Texas Transportation Institute, Research Report 1232-9.

Durand-Raucher Y, Yim Y, and Ygnace J-L, (1993) "Traffic Information and Driver Behviour in Paris Region", Pacific Rim TransTech Conference, Seattle, July, Proceedings Vol 1 - Advanced Technologies, pp 166-169.

Fahmy, M M M (1993) "Computer Vision Application to Automatic Number-plate Recognition", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 625-638.

*FHWA (1989) "Variable Speed Limit System Cost Benefit Analysis", US Federal Highway Administration Report FWHA-RD89-004, Office of Safety and Traffic Operations R&D, May, 43 pp.

Fildes B N, and Lee S J, (1993) "The Speed Review: Road Environment, Behaviour, Speed Limits, Enforcement and Crashes", Monash University Accident Research Centre, September.

*Filippi F, Guerriero G, Cecconi C, and Mantovani G, (1989) "Traffic Monitoring and Information Technology: The Case of the Perugia Urban Freeway", 2nd International Conference on Road Traffic Monitoring, London, Institution of Electrical Engineers Proceedings, pp 108-112.

Garner L F, and Vingrys A J, (1988) "Photometric properties of the Type 400 Fibre Optic Motorway Sign", *Australian Road Research 18(3), September, pp 173-181.*

Goldby, F J M (1984) "Variable Message Traffic Signs", *Highways and Transportation, July, pp 8-16.*

*Gottardi, G (1972) "Surveillance and Control System on the N1, Limmattal, Zurich", *Strasse & Verkehr, Vol 58 N^O^ 5, pp 220-224.*

Guillen S, and Martinez J J, (1993) "Evaluation of the INVAID AID System in a Ring Motorway Section in Madrid", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 603-608.

Hall F L, Shi Y, Aultman-Hall L, and Masters P H, (1993) "Before-After Evaluation of FTMS Effectiveness", Pacific Rim TransTech Conference, Seattle, July, Proceedings Vol 1 - Advanced Technologies, pp 15-21.

Hanscom, F R (1982) "Effectiveness of Changeable Message Signing at Freeway Construction Site Lane Closures", Transportation Research Record 844, pp 35-41.

*Harwick, N K (1989) "Albuquerque Variable Speed Limit System", 26th Paving and Transportation Conference, University of New Mexico, Proceedings, pp 133-141.

Hawkins, N R (1993) "Modified Signs, Flashing Beacons and School Zone Speeds", *ITE Journal, June, pp 41-44.*

de Henau, A (1993) "The Use of Inductive Loops and CCATS Cameras for Urban Traffic Analysis at Five-way Junctions", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 647-654.

Hill G, and Adaway B, (1994) "Machine Vision Applied to a Speed Violation Detection-Deterrent System", *Traffic Technology International '94, pp 100-3.*

Hitchens, D (1994) "The Traffic Camera Initiative", *Traffic Technology International '94, pp 68-71.*

Hodge A R, and Rutley K S, (1978) "A Comparison of Changeable Message Signals for Motorways", TRRL Supplementary Report 380.

*Hodgson W S, Stannett A B, and Harbord B J, (1992) "Advances in Motorway Signal and Control Systems", 6th International Conference on Road Traffic Monitoring and Control, London, April, Institution of Electrical Engineers Conference Publication 355, pp 94-98.

Hoose, N (1992) "Using the IMPACTS Image Analysis System for Incident Detection", 20th PTRC Summer Annual Meeting, University of Manchester, UK.

_________(1994) "Incident Detection and Traffic Surveillance using the IMPACTS Video Analysis System", *Traffic Technology International '94, pp 94-9.*

HRB (1971) "The Changeable-message Concept of Traffic Control", Highway Research Board Special Report 129.

Jasper, K (1993) "Reduce Speed Now!", *Surveyor, 22 April, pp 19-20.*

Jenkins, S E (1991) "Optical and Photometric Standards for Variable Message Signs", ARRB Research Report ARR 216.

Ju, R-S (1990) "Freeway Surveillance and Control System in Taiwan", *Institute of Transportation Engineers Journal, Vol 60 N^{O} 9, September, pp 43-46.*

Judycki, D C (1992) "Innovative Safety and Operations Highway Projects in the United States", *ITE Journal, Vol 62 N^{O} 12, December, pp 25-29.*

Kerr J S, Snelgar S, Jordan T R, Emmerson P G, and Linfield P B, (1988) "Optimum Display Factors for Light Emitting Variable Message Road Signs", Vision in Vehicles II, Elsevier Science Publishers, North-Holland, pp 277-288.

Klijnhout, J J (1984) "Motorway Control and Signalling: the test of time", *Traffic Engineering + Control, April, pp 193-195.*

*Kuehne, R D (1993) "Line control on Urban Freeways Using Knowledge-based Optimisation Techniques", PRTC 21st Annual Meeting, September, Proceedings Seminar C, pp153-164.

Kuhne, R D (1991) "Freeway Control Using a Dynamic Traffic Flow Model and Reidentification Techniques", Transportation Research Record 1320, pp 251-259.

Kurfees W, and Cline J C, (1990) "Determining Variable Message Sign Locations in a Freeway Management System", ITE Compendium of Technical Papers, pp 43-46.

Lam J K, and Tritter D B, (1994) "Innovative Technologies in the COMPASS Advanced Traffic Management System", *Traffic Technology International '94, pp 44-9.*

*Lemaitre G, and Laurand P, (1974) "Operational and Safety Signalling on Urban Motorways", Conference on Traffic Control and Transportation Systems, Amsterdam, Proceedings, pp 259-272.

Leverenz A J, and Brisbane G, (1993) "Proposed Fog Detection and Speed Advisory System: An Australian Initiative in Safer Motoring", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 719-723.

Lewis M, and Roe I, (1994) "Advances in Variable Message Signs", *Traffic Technology International '94, pp 212-215.*

Lichter, I A (1994) "Automatic Incident Detection and early Driver Warning System for Black Spot Areas", *Traffic Technology International '94, pp 156-9.*

Lion, D (1993) "Automatic Incident Detection and Traffic Analysis Using Radar", Thomson-CSF, Paris.

Manor, D (1994) "RTMS Multiple Zone Radar Detector and its Applications", *Traffic Technology International '94, pp 178-181.*

McDonald, A (1994) "Cost Effective Ice Prediction", *Traffic Technology International '94, pp 172-6.*

McQueen R, and Taylor P, (1993) "Signs to the Rescue", *Highways, April, p 21.*

Michalopoulos P G, Jacobson R D, and Anderson C A, (1993a) "Field Implementation and Testing of a Machine Vision Based Incident Detection System", Pacific Rim TransTech Conference, Seattle, July, Proceedings Vol 1 - Advanced Technologies, pp 69-76.

Michalopoulos P G, Jacobson R D, Anderson C A, and DeBruycker T B, (1993b) "Automatic Incident Detection Through Video Image Processing", *Traffic Engineering and Control, Feb, Vol 34 N^O 2, pp 66-75.*

bin Mohamed, D (1992) "A Fully-computerized System for Efficient Traffic Management of the Closed-toll Expressway System", 7th REAAA Conference Proceedings (1), pp 48-56.

Morris, R F (1975) "Electronic Driver Aid Systems for Freeways", Institution of Engineers, Australia, Engineering Conference, Hobart, Proceedings, pp 292-296.

Murdoch C, and Reid P, (1993) "Safe-T-Cam: An Innovative Imaging System", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 725-729.

NCHRP (1979) "Changeable Message Signs", Transportation Research Board, National Cooperative Highway Research Program, Synthesis of Highway Practice 61.

*Nilsson, G (1990) "Proposal for Investigation of Time Differentiated Speed Limits", VTI Report N^{O} 607, Linkoeping, Sweden, 24 pp.

*O'Grady, J (1975) "Safe Routes for City Pupils are Guarded by Variable Message Signs", *Rural Urban Roads, Vol 13 N^{O} 11, November, pp 28 -29.*

Paulsen, T A (1994) "SCAN-MATIC Road Monitoring System", *Traffic Technology International '94, pp 164-7.*

REIR (1991) "Innovative M25 Information System", *Road Engineering Intelligence & Research, March/April, p 7.*

*Remeijn, H (1992) "The Dutch Fog Detection and Warning Project", 6th International Conf on Road Traffic Monitoring and Control, London, April, Institution of Electrical Engineers Conference Publication 355, pp 89-93.

Renard, M (1993) "Performance Improvement of Existing Traffic Control CCTV Installations by Use of Image Processing Techniques", Proceedings 26th International Symposium on Automotive Technology and Automation, Dedicated Conference on ATT/ IVHS, Germany, September, pp 617-623.

Rittich, D (1994) "Prospects for Traffic Control Systems", *Traffic Technology International '94, pp 32-7.*

*de la Rosa, J C (1988) "Study of Safety Systems and Prevention of Traffic Accidents Caused by Wind Action", Thesis, Polytechnic University of Valencia, Higher Technical School of Industrial Engineering, Spain.

Rutley K S, Hodge A R, and Lines C J, (1983) "A New Motorway Signal", TRRL Laboratory Report LR 1075, Departments of the Environment and Transport, UK.

Sakai K, Ishige M, Itoh T, and Uemura T, (1993) "In-tunnel Traffic Flow Measuring and Monitoring System Using ITV Cameras", Proceedings 26th International Symposium on Automotive Technology and Automation, Dedicated Conference on ATT/ IVHS, Germany, September, pp 639-646.

Shamskhou, H (1991) "Technology Evaluation of Variable Message Signs: A Comparative Analysis of LED vs Fibre Optic Technology", ITE Compendium of Technical Papers, pp 509-512.

Siemens (1994) "At the Forefront of Motorway Traffic Control", *World Highways/ Route du Monde, March, p 55.*

Sin F Y C, and Snell A, (1992) "Implementation of Automatic Incident Detection Systems on the Inner Metropolitan Freeways in Melbourne", 7th REAAA Conference Proceedings (1), pp 337-346.

Smith, R (1993) "Traffic Management Utilising Advanced Traffic Detection System", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 679-687.

Smulders, S (1990) "Control of Freeway Traffic Flow by Variable Speed Signs", *Transportation Research - Part B: Methodological, UK, Vol 24B N^o 2, April, pp 111-132.*

*________(1992) "Control by Variable Speedsigns - The Dutch Experiment", 6th International Conference on Road Traffic Monitoring and Control, London, April, Institution of Electrical Engineers Conference Publication 355, pp 99-103.

Stainforth, R (1994) "Display Technologies for Variable Message Signs in Traffic Applications", *Traffic Technology International '94, pp 216-220.*

Steinbach, B G (1994) "Passive Infrared Detection for Traffic Control", *Traffic Technology International '94, pp 190-3.*

*Stiegler, E-M (1991) "Flexible Management of Traffic Flow", *Schott Information, N^o 55, pp 3-5.*

Sullivan G D, and Baker K D, (1993) "Model-based Vision for Road Traffic Understanding", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 559-566.

SYLVIA (1993) "Signs of the Times", *World Highways/ Routes du Monde, Sep/Oct, pp 39-41.*

TEC (1993) "Changeable Message Signs - Review of Company Information", Transportation Environment Consultants, Report to Roads and Traffic Authority, NSW.

Traficon (1993) "CCATS (Camera and Computer Aided Traffic Sensor) - Video Image Processor", Trafficon, Belgium.

Upchurch, J (1992) "A Human Factors Analysis of Three Variable Message Sign Technologies", 20th PTRC Summer Annual Meeting, University of Manchester, Proceedings, pp 37-48.

VicRoads (1990) "Influencing Road User Behaviour through Roadworks", Roads Corporation of Victoria, Australia.

van der Vlist M J M, and Brocken M G M, (1991) "DARTS and Variable Message Signs", Proceedings 24th ISATA Dedicated Conference on RTI/ IVHS, Italy, pp 159-166.

Wall H B, Marsden B G, and Agah M M, (1994) "An Advanced Traffic Management System for the Arizona Department of Transportation", *Traffic Technology International '94, pp 50-4.*

Winney, M (1993) "Multiway Momentum", *New Civil Engineer, N^O 1052, 29 July, p 8.*

*Zackor H, and Schwenzer G, (1988) "Assessment of a Situation-related Speed Management System on Freeways", *Forschung Strassenbau und Strassenverkehrstechnik 532, 94 pp.*

* These references were not reviewed in full; abstracts only were obtained.

9 ABBREVIATIONS AND ACRONYMS

AID	Automatic incident detection
ARRB	Australian Road Research Board
ATT	Advanced transport telematics
CAMDAS	Camera data acquisition system
CCATS	Camera and computer aided traffic sensor
CCTV	Closed circuit television
DARTS	Development of advanced road transport strategies
FORS	Federal Office of Road Safety
FTMS	Freeway traffic management system
HRB	Highway Research Board
IMPACTS	Image processing for automatic computer traffic surveillance
INVAID	Investigation of automatic incident detection

ITE	Institute of Transportation Engineers
ITV	Internal television
IVHS	Intelligent Vehicle Highway Systems
ISATA	International Symposium on Automotive Technology & Automation
LCD	Liquid crystal display
LED	Light emitting diode
NCHRP	National Cooperative Highway Research Program
NSW	New South Wales
PC	Personal computer
PTRC	Planning and Transportation Research and Computation
REIR	Road Engineering Intelligence & Research
RTA	Roads and Traffic Authority
RTMS	Remote traffic microwave sensor
SCATS	Sydney Coordinated Adaptive Traffic Signals
TEC	Transportation Environment Consultants
TRRL	Transport and Road Research Laboratory
UK	United Kingdom
USA	United States of America
VMS	Variable message signs

APPENDIX 1

IVHS Applications Area

APPENDIX 2

Sample Pilot Specification

SAMPLE TECHNICAL SPECIFICATION

FOR PILOT INSTALLATION OF

ADAPTIVE SPEED LIMIT SIGNS

1 INTRODUCTION

1.1 Purpose

The Hawkesbury Valley section of the F3 Freeway has a history of serious accidents related to excessive speed in wet weather. This section of road is characterised by steep grades and winding alignment, compared to the rest of the route between Sydney and Newcastle. The climatic conditions in the Hawkesbury area are also relatively severe in respect of rainfall intensity, wind and fog.

A recent study of aquaplaning potential in the area found that the high rainfall intensity, combined with the winding road geometry, increased both the risk and consequences of vehicle aquaplaning (or hydroplaning). This phenomenon is extremely hazardous as braking and steering are impossible. It is most likely to occur when vehicles are travelling at high speed and water is flowing or ponding on the road surface. Regulation of vehicle speed would be an effective control to reduce the risk of aquaplaning.

In the same area, incidents often occur for other reasons related to the terrain. As an added safety measure it is appropriate to warn drivers of incidents ahead. An appropriate way to do this would be to promptly apply a reduced speed limit, at a sufficient distance before the incident.

As a result of the concern about potential aquaplaning and incidents on the F3 Hawkesbury section, a proposal was developed for a variable speed limit, adaptive to the environmental and traffic conditions. This proposal is to be investigated by means of a pilot project for adaptive speed limit signs; that is, "intelligent" signs that can display speed limits appropriate to the prevailing conditions.

1.2 Project description

The pilot project for adaptive speed limit signs on F3 will be a development of the fog warning/driver advisory system currently being trialled on the F6 Sydney-Wollongong freeway. This F6 field trial involves the use of variable speed signs of an advisory nature, rather than regulatory signs as proposed for F3. Proponents should acquaint themselves with the site of the F6 field trial.

- variable speed limits (as distinct from advisory speeds) are to be implemented;
- the variable speed signs are to be adaptive to traffic conditions (particularly congestion), as well as weather conditions (fog, rain and wet road surface).

Automatic detection equipment for traffic incidents is to use proven loop technology and video based equipment for comparative evaluation.

As mains power is generally not available on the F3, the variable message signs for displaying adaptive speed limits are to be of the electromechanical, rotating prism type.

1.3 Site description

The site of the pilot project is just south of the Hawkesbury River on both carriageways of the F3 Sydney-Newcastle Freeway. Two adaptive speed limit signs are to be installed on each carriageway, on structures to be provided by others.

Fog-rain and surface water detectors are to be placed in the vicinity of each variable message sign, and incident detectors are to be located downstream (traffic flow) of each sign. One video and one loop-based incident detector are to be located on each carriageway. The control computers are to be securely housed in weatherproof enclosures.

The location of all devices and equipment is to be generally as shown in Figure 1 (not included in draft).

2 SCOPE OF THE WORK

The work will consist of the management and implementation of the:

- system, equipment, software design and communications;
- data specification, including collection, format and management;
- manufacture if not a stock product;
- factory acceptance test;
- supply of hardware, software and documentation;
- installation;
- commissioning;
- final on-site system test;
- user training.

Proponents are required to submit details of the above items in their proposals.

The system shall comprise:

- Four rotating prism, variable speed limit signs, with all required mounting hardware and electrical circuits and connectors ready for all-weather installation.

- Four fog and rain detectors, with all the required mounting hardware and electrical circuits and connections ready for all weather installation.
- Four surface water detectors, with all the required mounting hardware and electrical circuits and connections ready for all weather installation.
- Two loop based incident detection systems to cover three traffic lanes, with all mounting hardware, brackets, electronic circuits and parallel or serial data communications and power connections, suitable for all weather outside operation.
- Two video based incident detecting systems to cover three traffic lanes, with all mounting hardware including poles, gantries or brackets, complete with all required CCD cameras, electronic circuits and parallel or serial data communications and power connections, suitable for all weather outside operation.
- Computer hardware and software to take inputs from all the above detection devices or systems, calculate the appropriate speed limit for each of the signs and provide outputs and inputs to drive and monitor the signs. Outputs shall also be provided for future video enforcement equipment. The system shall include:
  - video image processing and alarm outputs capability for traffic incidents;
  - communications to monitor status and alarm conditions at the sites.
- All power and signal cables, conduits and connection boxes for cables between the central computer and all field devices.
- Solar and battery power supplies for all equipment.

The supply or integration of video enforcement equipment is NOT required

3 QUALITY ASSURANCE

Proponents are to submit a brief description of their quality assurance program as it relates to this contract. The Proponent's quality system shall conform to Australian Standard AS 3901 (or the equivalent international standard ISO 9001). Within two weeks of the award of a contract, the Proponent shall produce a Project Quality Plan, detailing the following items:

Project Management Personnel
Documentation
Procurement
Manufacturing
Quality Assurance
Quality Control
Work Instructions
Inspection and Test Plans
Inspection and Test Schedules.

4 FUNCTIONAL REQUIREMENTS

4.1 Variable Message Signs

Variable message signs (VMS) shall be electromechanical, rotating prism signs. The VMS must be supplied with all required mounting hardware and electrical circuits and connectors ready for all-weather installation. VMS shall comply with the relevant Australian Standards for optical and photometric qualities. The design of the speed limit signs shall be in accordance with the relevant legislation, and generally as shown in Figure 2 (not included in draft).

The VMS shall display a variable speed limit with a variable explanatory legend on the right hand side. The speed limit options shall be 80, 100 and 110 km/h, and the legend options shall be "weather", "congestion", "hazard" or no legend.

The signs shall be illuminated with shielded 40 watt fluorescent lamps.

The signs shall have the facility to hold status information locally. On reception of a display signal from the control computer, the sign shall promptly display that speed and send a check signal back to the control computer indicating the actual displayed signal taken from a point as close to the final display as possible.

Continued display of speed at each sign shall depend on the continuous successful reception of a separate, correct watch-dog signal from the control computer. If there is no watch-dog signal, there must be no sign display.

4.2 Fog-rain and water sensors

The fog-rain sensor shall be capable of detecting and discriminating between fog and rain. It shall be at least equal in performance and reliability to the sensor used on the RTA's F6 field trial.

The surface water detector shall be mounted in the centre of the slow lane at each northbound location. It shall be capable of discriminating between wet and dry road conditions.

4.3 Traffic sensors

The loop based incident detection system shall be capable of operating over a 500 metre length of the southbound carriageway, to the south of the Cowan site.

Video based incident detection shall be capable of operating from a CCTV camera with at least 500 X 500 pixel resolution. The camera location shall allow a footprint of 400 to 500 metres along the southbound carriageway, to the south of the Berowra site.

Both systems shall be capable of monitoring the traffic in at least three lanes, and automatically detecting a traffic queue or traffic incident, such as a stopped vehicle on the shoulder.

Video incident detectors will be preferred as self-contained intelligent detectors which include the incident detection and queue length image processing algorithms. However, it is acceptable for the algorithms to be included in the control computer.

4.4 System integration and reporting

Each VMS shall be integrated with its sensors and communications using an appropriate control computer and software. Each integrated system shall operate automatically as an intelligent sign. The northbound signs shall display:

- 110 km/h for clear, dry conditions;
- 100 km/h for light fog, light rain or wet road surface;
- 80 km/h for heavy fog or heavy rain (intensity greater than 20 mm/h).

The southbound signs shall display:

- 110 km/h for uncongested traffic conditions;
- 100 km/h for moderate traffic congestion ahead;
- 80 km/h for heavy traffic congestion ahead.

Each ASLS system shall be capable of printing a record of the sign status, by date and time at which the status of the sign changed. The video data relating to traffic incidents shall be capable of transmission to the client's traffic control centre via modem.

Each ASLS system computer hardware and software shall take inputs from the above weather sensors and/or traffic sensors and, from this information, shall continuously calculate on line an appropriate speed for the overall conditions, and shall transmit this speed to the variable speed limit sign.

The inputs from the weather sensors shall be condensed by an algorithm to a "degree of severity" scale (say from 0 to 10) to indicate linearly the hazard to traffic. Similarly outputs from traffic sensors should be used to calculate two factors; (a) a degree of severity and (b) an expected distance to incident or queue. Software shall be provided to cross check detector information for a sensible correlation between sensors and detectors and for sensible values and a sensible transition between values. Any violation of these checks should cause the system to ignore inputs until sense is restored. Software shall monitor that the detectors are operating at all and report an alarm if not.

An algorithm shall be designed to take this information and calculate a speed limit which should increase safe operations under the conditions. The speeds shall be calculated in 5 km/h increments up to 110 km/h, and a minimum value for the displayed speed limit shall be operator settable. Even if the calculated value fell below this minimum value, the minimum value would continue to be displayed. The speed display shall not be changed more often than an operator set-time of 60 seconds. The speed displayed should be based on the detection values received since the last change, plus a predictive element based on the rate of change of the inputs. As it is likely that no software for this is currently available, it is essential that the software can be altered in the light of experience by the client. At least, all relevant parameters and factors used in the calculation should be available for viewing and alteration by an authorised operator, at the system terminal. The system operator should also be able to view on the terminal, all inputs, critical intermediate calculated values, the final calculated speeds and the actual sign displays.

The VMS shall provide feedback of the speed and the legend actually displayed, and the operational condition of the sign. If the display does not match the sent speed/ legend, then a re-try should occur immediately. If the wrong information is still displayed, a table in the control computer should indicate whether, from a safety viewpoint, the speed could be left displayed or another alternative could be tried. In the latter case a signal should be sent which tries to display the chosen alternative, and an alarm should be registered. For this purpose, a separate connection might be needed. When the control computer receives an indication that a sign has failed, the condition should be registered and reported as an alarm.

An external hardware/software watch-dog facility shall be provided which is only "held on" while the computer hardware and software are both operating correctly, the output of this shall be extended to the signs. The proponent shall detail how this is to be done.

Each ASLS system shall have a dial-in, dial-out modem facility. It shall be possible for a remote operator to dial in and have all the facilities for system and alarm monitoring and control that a local operator would have. In the event of an urgent alarm, such as critical detector or sign failure, the computer shall have the facility to dial out to another computer and send alarm signals. The alarm protocol shall be included in the documentation.

All sign changes, with the speed displayed and time of day and date should be logged to disk with a summary of sensor output conditions at the time. All alarms shall be logged to disk and printer. Log files shall be circular, if the storage allocated is exceeded, then the most recent logged data should overwrite the oldest data. The areas allocated to system operation logging and alarm logging must be separate so that alarm data will not be overwritten by system operation data. Software should be available to allow an operator to view or print all saved log data in summary or in full, selected by item or range of items over a selected range of times.

There shall be separate file areas for new unacknowledged alarms and acknowledged alarms. When an alarm first occurs, it is placed in the unacknowledged file area. When a system operator acknowledges an alarm, it shall be transferred to the acknowledged area and tagged with the operator ID. If the alarm is still present it must then stay in both areas, if the alarm has ceased, this should be tagged onto the alarm for operator attention and, when acknowledged, it should be cleared from the unacknowledged area.

The software itself should be very clearly documented to facilitate later alteration if this should prove necessary. It is a condition of the contract that the client has full rights to use and alter the software for its own use for the once off purchase price paid on this contract. The supplier would have full rights and ownership of the originally delivered software in respect of third parties. However the client would have full rights to any alterations and improvements it made.

Proponents must submit in the fullest detail possible, details of the algorithms proposed to calculate sign speeds. Emphasis will be placed on the perceived ability to produce an acceptable and workable algorithm.

5 HARDWARE REQUIREMENTS

5.1 General

The equipment to be supplied under the proposed contract shall be broadly in compliance with the following hardware specifications:

- Australian Standard AS 3000 General Wiring Rules
- The client specification ECA/2 - "Requirements for Electronic Systems in Outdoor Applications".

The equipment offered shall be the latest models of the type of equipment manufactured at the time of submission of the Proposal. The Proposal shall state the locations where this equipment has been successfully installed in the past. Any available documents, reports or papers detailing the performance of the system or parts of the system should be submitted.

The hardware design shall incorporate generous and comprehensive diagnostic system indication to enable technical staff to prove the operation of each section and component of the system.

Details of the Indicator and Diagnostic functions available in the proposed system shall be provided with the Proposal.

The hardware shall be rigorously designed for the harsh environment. Specific requirements for enclosure ratings and printed circuit board construction are in client specification ECA/2. Cabling to all externally located equipment shall be terminated in approved connectors and durable coatings shall protect the cabling from weather and pollutants. External cabling and connector arrangements shall be submitted to the client for approval.

5.2 Control computer and printer

The control computer(s) should be able to operate in a non air-conditioned environment. It should be chosen from industry standard equipment which is fully supported in Australia. If a personal computer is chosen, it should be of the industrial variety. The microcomputer system shall be selected from sixteen bit or larger, operating at greater than or equal to 16Mhz. Sufficient RAM shall be provided for all operating executable programs and data to reside in RAM without recourse to overlays or page swapping. Sufficient disk storage shall be provided to hold a copy of all operating systems, programs and data plus logged alarm and system operation data for an estimated period of at least six months. An operator terminal shall be provided to enter parameters and monitor system operation and alarms.

An output report printer shall be provided selected for reliability of operation and legibility of the text. A dial-in dial-out modem facility shall be provided to enable a remote terminal to duplicate the facilities of the local terminal and enable sending of alarms to a central location.

Full details of the proposed computer and printer shall be submitted.

5.3 Non interruptable power supply

A non interruptable power supply for each ASLS system shall be provided, based on solar collectors with backup batteries, filters and regulators, with sufficient capacity to run the computer equipment, signs, fog-rain and incident detectors. The voltage stability and harmonic content of the output shall be within the requirements of all the connected equipment.

5.4 Power and signal cabling

All power and signal cables, conduits and connection boxes for cables between the control computer and all field devices shall be supplied. All power cabling and related work to comply with Australian Standard wiring rules for cable conductor size and insulation. Signal cables shall be appropriate for the mode and distance of transmission yielding transmission levels and error rates to guarantee there is no noticeable malfunction due to loss of signal level or noise (appropriate error detection and correction must be incorporated in the equipment provided). All terminations shall be appropriate for the current and voltages employed and properly sealed from weather and/or housed in weather-proof enclosures.

5.5 Spare parts

Spare parts for the various equipment components shall be supplied under this Contract.

Within two weeks of the awarding of a contract, the Proponent shall submit to the client the priced list of spare parts recommended to be held in stock, showing the part (by number and description), the item of which it is a component, the number of spares and the unit cost, the total amounting to the tendered value submitted with the Proposal. The recommendation for spare parts shall take into account the availability within Australia of components and the anticipated frequency of in-service failure of the components.

The prices of listed spare parts shall be quoted in the currency of the supplier's country of origin with conversion to Australian dollars at the exchange rate applicable (to be stated) at the date of submission of the spare parts list. Prices quoted shall be exclusive of sales tax but shall include freight and delivery, packing and import duty.

Prices as above for parts as listed shall be firm to the end of the contract warranty period. Parts may be purchased by the client at the listed prices, if ordered at any time up to the end of the warranty period.

The Proponent shall supply to the client by the date of hand-over of the ASLS system, all spare parts ordered by the client.

Parts used as maintenance replacements during the contract warranty period from the spare parts stock held by the client shall be replaced by the Proponent on a regular basis so that, at the end of the contract warranty period, the client holds a full inventory of parts ordered as spares.

6 FACTORY TESTING AND INSPECTION

Factory testing of the system shall be carried out as far as is reasonably practicable at the manufacturer's works and shall be witnessed by the client. The witness testing and inspection shall be timed such that all equipment shall be available at the same time.

The items which may practically be incorporated shall be connected into a system as proposed for the ASLS system and as far as is practicable, all functions of each item shall be exercised to demonstrate the correct operation of the system. Where it is not practical to incorporate an item into the factory testing set-up, but that item is necessary to prove the correct performance of the system (for example, vehicle presence detector loops), the item shall be simulated.

The proponent shall have available in his premises an area designated for factory testing where the equipment to be tested will be set up in a logically arranged manner to allow ready communications between and visual observation of personnel engaged in the factory testing. The environment shall be compatible with the types and functions of the equipment to be tested. All items of factory equipment, measuring instruments, etc. required for factory testing shall be supplied by the Proponent and shall be available in the testing area for the period of testing.

Not less than one month prior to the scheduled commencement of factory testing, the Proponent shall submit to the client, for approval, a schedule of tests to be carried out and a statement of the intended procedure. The anticipated duration of factory testing as proposed shall also be advised. The client may request additional testing if deemed necessary.

The Proponent shall allocate appropriate senior personnel to carry out the factory testing, supported by necessary technical staff.

After each component item, group of items, function, etc. is satisfactorily tested and witnessed, the Proponent and the client or its representative shall sign the factory testing report for that item and, as appropriate, affix to the component a sticker indicating satisfactory factory testing. On completion of factory testing, the signed testing report, together with a brief narrative report by the Proponent detailing variations from the approved testing schedule and procedure and the reasons therefor, shall be submitted to the client for its records.

Notwithstanding the execution of satisfactory factory testing and the witnessing thereof by the client or its representative, the Proponent shall accept full responsibility for the satisfactory performance of the system and all of its components after installation.

7 INSTALLATION AND COMMISSIONING

7.1 Installation

Installation of the ASLS system shall be conducted without undue interference to the flow of traffic on the F3.

The Proponent shall submit an installation program to the client for approval four weeks prior to intended commencement of installation. Installation shall not proceed without the client's written acceptance of the installation program.

All material, equipment, tools, plant, hire etc. required for the installation work, shall be supplied by the Proponent.

Installation shall be carried out in a workmanlike manner to the satisfaction of the client.

7.2 Commissioning

After installation by the Proponent of all components of the ASLS system, commissioning will be undertaken immediately by the Proponent.

During commissioning all equipment functions and operations shall be checked and the Control Computer thoroughly proved. Commissioning shall be witnessed by the client. This shall constitute the final acceptance test.

7.3 Acceptance

A Certificate of Practical Completion shall be issued by the client after one week's satisfactory operation of the ASLS system, from which time the Warranty Period shall commence.

8 DOCUMENTATION

8.1 General

Documentation is a vital part of the contract and, accordingly, 10% of the contract sum shall be held by the client against the supply of acceptable documentation.

The following documentation shall be supplied to cover the ASLS system. Three complete sets of all documentation shall be supplied within two weeks of issue of the Certificate of Practical Completion.

At least interim documentation shall be delivered as part of the commissioning, before final acceptance.

8.2 User Manuals

The user manuals shall fully describe the operation of the ASLS system and its components, covering all the operator controls and functions encountered in using the system, and routine external (non-technical) service requirements.

8.3 Technical Manuals

Technical manuals shall be supplied for each item of equipment. Each manual as a minimum shall contain:

- (i) Equipment specification.
- (ii) Detailed description of operation.
- (iii) Installation and Set-Up Instructions.
- (iv) Trouble-shooting guide.
- (v) Parts Lists.

8.4 Technical Drawings

Drawings may be incorporated into the technical manual volumes, but shall include at least the following detail:

(i) General arrangement drawings.

(ii) Electronic system block diagram(s).

(iii) Power supply system schematics (within ASLS system).

(iv) Electronic circuit schematics.

(v) Printed circuit board layouts.

(vi) Terminal block layouts.

(vii) Exploded views of mechanical components and assemblies.

(viii) Site plans showing position of all ducts, cables, housings, poles, gantries terminal boxes and equipment.

(ix) Communication and control cable schematics.

(x) Detail drawings of special brackets, mounting hardware etc.

8.5 Software Listings

Computer software shall be documented in a separate manual and presented on magnetic media (floppy disk or cartridge) in the word processor format of Word for Windows version 2a, or later. Software listings shall be fully documented and arranged in logical sequence. Software documentation shall include not less than the following components:

(i) Flow diagrams.

(ii) Original Source code, fully commented to accepted standards in sufficient detail to enable a full understanding of the purpose and method of operation of each part of the software, how it links with other parts of the software to perform the whole job, and clear specifications of the boundary conditions.

(iii) Variable lists and addresses.

(iv) Cross reference tables for variable addresses and labels and data file structures.

(v) The appropriate compilers, cross assemblers, etc. applicable to the source code.

The cost of licences for the compilers and cross assemblers shall be included in the price for this item.

Where an item of equipment is a standard stock item and comes with inbuilt computer and software *eg* a self contained incident detector, the client may wave the disclosure of source code.

The client may enter into a confidentiality agreement with the software supplier, regarding software listings.

8.6 Presentation

Manuals shall be of the loose leaf type in hard cover binders. Text shall be printed on high quality A4 size bond paper. Drawings and diagrams shall be of the "as constructed" equipment, plastic covered, drawn on A3 size sheets or photo-reduced to A3 size for binding. Covers shall be suitably embossed. Pages shall be numbered.

Manuals and drawings shall be written in the English language.

9 WARRANTY

All equipment offered shall be subject to a twelve months warranty period. The warranty for the ASLS system shall be provided by the Proponent and shall cover, but not be limited to:

- all parts and labour for on-site equipment;
- failure to comply with the specification;
- design faults;
- workmanship;
- manufacturing defects;
- transportation damage;
- premature and normal failure of components.

10 TRAINING

The Proponent shall recommend an appropriate training program in the use, routine maintenance and servicing of the ASLS system, covering both on-site and off-site training, as appropriate.

During the training period instruction shall be given to technical personnel who will ultimately assume responsibility for the equipment maintenance. All forms of failure modes shall be treated in the instruction period.

oooOOOooo

SCHEDULE OF INFORMATION TO BE RETURNED WITH THE PROPOSAL

Reference	Description
Clause 2	Details of: - system, equipment, software design and communications; - data specification, including collection, format and management; - manufacture if not a stock product; - factory acceptance test; - supply of hardware, software and documentation; - installation; - commissioning; - final on-site system test; - user training.
Clause 3	Brief description of the Quality System proposals.
Clause 4.4	Details of the algorithms proposed to calculate sign speeds.
Clause 5.1	Locations where the offered system has been installed, and any available documents, reports or papers detailing the performance of the system, or parts of it. Details of the indicator and diagnostic functions available in the proposed system.
Clause 5.2	Full details of the proposed computer(s) and printer(s).
Whole Specification	Tender for project requirements.

APPENDIX 3

References - Subject Grouping

1 VARIABLE SPEED LIMITS

Bell, G H (1975) "New Aids in Winter Traffic Control", *Public Works, Vol 106 Nº 8, pp 58-60.*

Chen G S Y, and Lien S C, (1986) "Discussion of Effectiveness of Taiwan National Freeway Traffic Control System", 13th ARRB/ 5th REAAA Conference Proceedings 13(7), pp 46-57.

Cremer M, and Fleischmann S, (1987) "Development of a Control Concept for Flow-dependent Use of Variable Message Signs and Entrance Regulation in Urban Motorway Networks", Technical University of Hamburg, Germany, Report, 47 pp.

FHWA (1989) "Variable Speed Limit System Cost Benefit Analysis", US Federal Highway Administration Report FWHA-RD89-004, Office of Safety and Traffic Operations R&D, May, 43 pp.

Fildes B N, and Lee S J, (1993) "The Speed Review: Road Environment, Behaviour, Speed Limits, Enforcement and Crashes", Monash University Accident Research Centre, September.

Filippi F, Guerriero G, Cecconi C, and Mantovani G, (1989) "Traffic Monitoring and Information Technology: The Case of the Perugia Urban Freeway", 2nd International Conference on Road Traffic Monitoring, London, Institution of Electrical Engineers Proceedings, pp 108-112.

Gottardi, G (1972) "Surveillance and Control System on the N1, Limmattal, Zurich", *Strasse & Verkehr, Vol 58 Nº 5, pp 220-224.*

Hanscom, F R (1982) "Effectiveness of Changeable Message Signing at Freeway Construction Site Lane Closures", Transportation Research Record 844, pp 35-41.

Harwick, N K (1989) "Albuquerque Variable Speed Limit System", 26th Paving and Transportation Conference, University of New Mexico, Proceedings, pp 133-141.

Hawkins, N R (1993) "Modified Signs, Flashing Beacons and School Zone Speeds", ITE Journal, June, pp 41-44.

Hodgson W S, Stannett A B, and Harbord B J, (1992) "Advances in Motorway Signal and Control Systems", 6th International Conference on Road Traffic Monitoring and Control, London, April, Institution of Electrical Engineers Conference Publication 355, pp 94-98.

Ju, R-S (1990) "Freeway Surveillance and Control System in Taiwan", *Institute of Transportation Engineers Journal, Vol 60 Nº 9, September, pp 43-46.*

Judycki, D C (1992) "Innovative Safety and Operations Highway Projects in the United States", ITE Journal, Vol 62 N° 12, December, pp 25-29.

Klijnhout, J J (1984) "Motorway Control and Signalling: the test of time", Traffic Engineering + Control, April, pp 193-195.

Kuehne, R D (1993) "Line control on Urban Freeways Using Knowledge-based Optimisation Techniques", PRTC 21st Annual Meeting, September, Proceedings Seminar C, pp153-164.

Lemaitre G, and Laurand P, (1974) "Operational and Safety Signalling on Urban Motorways", Conference on Traffic Control and Transportation Systems, Amsterdam, Proceedings, pp 259-272.

NCHRP (1979) "Changeable Message Signs", Transportation Research Board, National Cooperative Highway Research Program, Synthesis of Highway Practice 61.

Nilsson, G (1990) "Proposal for Investigation of Time Differentiated Speed Limits", VTI Report N° 607, Linkoeping, Sweden, 24 pp.

O'Grady, J (1975) "Safe Routes for City Pupils are Guarded by Variable Message Signs", *Rural Urban Roads, Vol 13 N° 11, November, pp 28 -29.*

Remeijn, H (1992) "The Dutch Fog Detection and Warning Project", 6th International Conf on Road Traffic Monitoring and Control, London, April, Institution of Electrical Engineers Conference Publication 355, pp 89-93.

de la Rosa, J C (1988) "Study of Safety Systems and Prevention of Traffic Accidents Caused by Wind Action", Thesis, Polytechnic University of Valencia, Higher Technical School of Industrial Engineering, Spain.

Smulders, S (1990) "Control of Freeway Traffic Flow by Variable Speed Signs", Transportation Research - Part B: Methodological, UK, Vol 24B N° 2, April, pp 111-132.

_________(1992) "Control by Variable Speedsigns - The Dutch Experiment", 6th International Conference on Road Traffic Monitoring and Control, London, April, Institution of Electrical Engineers Conference Publication 355 pp 99-103

Stiegler, E-M (1991) "Flexible Management of Traffic Flow", *Schott Information, N° 55, pp 3-5.*

VicRoads (1990) "Influencing Road User Behaviour through Roadworks", Roads Corporation of Victoria, Australia.

Winney, M (1993) "Multiway Momentum", *New Civil Engineer N° 1052, 29 July p 8*

Zackor H, and Schwenzer G, (1988) "Assessment of a Situation-related Speed Management System on Freeways", Forschung Strassenbau und Strassenverkehrstechnik 532, 94 pp.

2 VARIABLE MESSAGE SIGNS

Brown R J, and Schofield M J, (1992) "The Design and Benefits of VMS Information Systems", 20th PTRC Summer Annual Meeting, University of Manchester, Proceedings, pp 13-24.

Derrick, A J (1988) "Variable Message Traffic Signs, Bristol", *Highways and Transportation, Vol 35 N^{O} 11, November, p 62.*

Dudek, C L (1992) "Guidelines on the Use and Operation of Changeable Message Signs", Texas Transportation Institute, Research Report 1232-9.

Durand-Raucher Y, Yim Y, and Ygnace J-L, (1993) "Traffic Information and Driver Behviour in Paris Region", Pacific Rim TransTech Conference, Seattle, July, Proceedings Vol 1 - Advanced Technologies, pp 166-169.

Garner L F, and Vingrys A J, (1988) "Photometric properties of the Type 400 Fibre Optic Motorway Sign", Australian Road Research 18(3), September, pp 173-181.

Goldby, F J M (1984) "Variable Message Traffic Signs", Highways and Transportation, July, pp 8-16.

Hodge A R, and Rutley K S, (1978) "A Comparison of Changeable Message Signals for Motorways", TRRL Supplementary Report 380.

HRB (1971) "The Changeable-message Concept of Traffic Control", Highway Research Board Special Report 129.

Jasper, K (1993) "Reduce Speed Now!", *Surveyor, 22 April, pp 19-20.*

Jenkins, S E (1991) "Optical and Photometric Standards for Variable Message Signs", ARRB Research Report ARR 216.

Kerr J S, Snelgar S, Jordan T R, Emmerson P G, and Linfield P B, (1988) "Optimum Display Factors for Light Emitting Variable Message Road Signs", Vision in Vehicles II, Elsevier Science Publishers, North-Holland, pp 277-288.

Lewis M, and Roe I, (1994) "Advances in Variable Message Signs", *Traffic Technology International '94, pp 212-215.*

McQueen R, and Taylor P, (1993) "Signs to the Rescue", Highways, April, p 21.

Morris, R F (1975) "Electronic Driver Aid Systems for Freeways", Institution of Engineers, Australia, Engineering Conference, Hobart, Proceedings, pp 292-296.

Rutley K S, Hodge A R, and Lines C J, (1983) "A New Motorway Signal", TRRL Laboratory Report LR 1075, Departments of the Environment and Transport, UK.

Shamskhou, H (1991) "Technology Evaluation of Variable Message Signs: A Comparative Analysis of LED vs Fibre Optic Technology", ITE Compendium of Technical Papers, pp 509-512.

Siemens (1994) "At the Forefront of Motorway Traffic Control", *World Highways/ Route du Monde, March, p 55.*

Stainforth, R (1994) "Display Technologies for Variable Message Signs in Traffic Applications", *Traffic Technology International '94, pp 216-220.*

SYLVIA (1993) "Signs of the Times", *World Highways/ Routes du Monde, Sep/Oct, pp 39-41.*

TEC (1993) "Changeable Message Signs - Review of Company Information", Transportation Environment Consultants, Report to Roads and Traffic Authority, NSW.

Upchurch, J (1992) "A Human Factors Analysis of Three Variable Message Sign Technologies", 20th PTRC Summer Annual Meeting, University of Manchester, Proceedings, pp 37-48.

3 WEATHER SENSING

ANT Bosch Telecom (1994) "Stop and Go? Make the Traffic Flow with Information Technology and Control Systems", *Traffic Technology International '94, p 111.*

Boschung, M (1994) "Danger - Black Ice!", *Traffic Technology International '94, pp 168-171.*

Brisbane, G J B (1993) "Driver Response to Fog Conditions - An Intelligent Approach", Pacific Rim TransTech Conference, Seattle, July, Proceedings Vol 1 - Advanced Technologies, pp 347-353.

____________(1994) "Speed Modification - Intelligent Signs for the Future?", 17th ARRB Conference, Queensland, August, Proceedings (in print).

Leverenz A J, and Brisbane G, (1993) "Proposed Fog Detection and Speed Advisory System: An Australian Initiative in Safer Motoring", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 719-723.

McDonald, A (1994) "Cost Effective Ice Prediction", *Traffic Technology International '94, pp 172-6.*

Paulsen, T A (1994) "SCAN-MATIC Road Monitoring System", *Traffic Technology International '94, pp 164-7.*

Rittich, D (1994) "Prospects for Traffic Control Systems", *Traffic Technology International '94, pp 32-7.*

4 INCIDENT DETECTION/ MAGE PROCESSING

Ali A T, Bulas-Cruz J, and Dagless E L, (1993) "Vision-based Road Traffic Data Collection", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 609-616.

Baxter, D H (1989) "Changeable Message Signs for Freeway Operations - Preliminary Results of Sign Usage in the Long Island Freeway Corridor", ITE Compendium of Technical Papers, pp 287-292.

Blosseville J-M, Morin J-M, and Lochegnies P, (1993) "Video Image Processing Application: Automatic Incident Detection on Freeways", Pacific Rim TransTech Conference, Seattle, July, Proceedings Vol 1 - Advanced Technologies, pp 77-83.

Cypers L, Tegenbos R, and Lemaire F, (1993) "Evaluation of Image Processing Techniques for Traffic Surveillance on the Antwerp Ring Motorway (Belgium)", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 595-602.

Dalgleish, M J (1994a) "Vehicle Detection for Advanced Transport Telematics", Golden River Traffic Ltd, UK.

________________(1994b) "Applications for Video Vehicle Detection", Golden River Traffic Ltd, UK.

Daneshfar, M (1994) "MoniVision - Queue Detection and Integrated Traffic Management System", *Traffic Technology International '94, pp 152-5.*

Diaz, E L (1992) "An efficient PC Based Video Vehicle Detector", Proceedings 16th ARRB Conference, Perth, Part 7, pp 217-226.

Fahmy, M M M (1993) "Computer Vision Application to Automatic Number-plate Recognition", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 625-638.

Guillen S, and Martinez J J, (1993) "Evaluation of the INVAID AID System in a Ring Motorway Section in Madrid", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 603-608.

Hall F L, Shi Y, Aultman-Hall L, and Masters P H, (1993) "Before-After Evaluation of FTMS Effectiveness", Pacific Rim TransTech Conference, Seattle, July, Proceedings Vol 1 - Advanced Technologies, pp 15-21.

de Henau, A (1993) "The Use of Inductive Loops and CCATS Cameras for Urban Traffic Analysis at Five-way Junctions", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 647-654.

Hill G, and Adaway B, (1994) "Machine Vision Applied to a Speed Violation Detection-Deterrent System", *Traffic Technology International '94, pp 100-3.*

Hitchens, D (1994) "The Traffic Camera Initiative", *Traffic Technology International '94, pp 68-71.*

Hoose, N (1992) "Using the IMPACTS Image Analysis System for Incident Detection", 20th PTRC Summer Annual Meeting, University of Manchester, UK.

__________(1994) "Incident Detection and Traffic Surveillance using the IMPACTS Video Analysis System", *Traffic Technology International '94, pp 94-9.*

Kuhne, R D (1991) "Freeway Control Using a Dynamic Traffic Flow Model and Reidentification Techniques", Transportation Research Record 1320, pp 251-259.

Kurfees W, and Cline J C, (1990) "Determining Variable Message Sign Locations in a Freeway Management System", ITE Compendium of Technical Papers, pp 43-46.

Lam J K, and Tritter D B, (1994) "Innovative Technologies in the COMPASS Advanced Traffic Management System", *Traffic Technology International '94, pp 44-9.*

Lichter, I A (1994) "Automatic Incident Detection and early Driver Warning System for Black Spot Areas", *Traffic Technology International '94, pp 156-9.*

Lion, D (1993) "Automatic Incident Detection and Traffic Analysis Using Radar", Thomson-CSF. Paris.

Manor, D (1994) "RTMS Multiple Zone Radar Detector and its Applications", *Traffic Technology International '94, pp 178-181.*

Michalopoulos P G, Jacobson R D, and Anderson C A, (1993a) "Field Implementation and Testing of a Machine Vision Based Incident Detection System", Pacific Rim TransTech Conference, Seattle, July, Proceedings Vol 1 - Advanced Technologies, pp 69-76.

Michalopoulos P G, Jacobson R D, Anderson C A, and DeBruycker T B, (1993b) "Automatic Incident Detection Through Video Image Processing", *Traffic Engineering and Control, Feb, Vol 34 N^{O} 2, pp 66-75.*

bin Mohamed, D (1992) "A Fully-computerized System for Efficient Traffic Management of the Closed-toll Expressway System", 7th REAAA Conference Proceedings (1), pp 48-56.

Murdoch C, and Reid P, (1993) "Safe-T-Cam: An Innovative Imaging System", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 725-729.

REIR (1991) "Innovative M25 Information System", Road Engineering Intelligence & Research, March/April, p 7.

Renard, M (1993) "Performance Improvement of Existing Traffic Control CCTV Installations by Use of Image Processing Techniques", Proceedings 26th International Symposium on Automotive Technology and Automation, Dedicated Conference on ATT/ IVHS, Germany, September, pp 617-623.

Sakai K, Ishige M, Itoh T, and Uemura T, (1993) "In-tunnel Traffic Flow Measuring and Monitoring System Using ITV Cameras", Proceedings 26th International Symposium on Automotive Technology and Automation, Dedicated Conference on ATT/ IVHS, Germany, September, pp 639-646.

Sin F Y C, and Snell A, (1992) "Implementation of Automatic Incident Detection Systems on the Inner Metropolitan Freeways in Melbourne", 7th REAAA Conference Proceedings (1), pp 337-346.

Smith, R (1993) "Traffic Management Utilising Advanced Traffic Detection System", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 679-687.

Steinbach, B G (1994) "Passive Infrared Detection for Traffic Control", *Traffic Technology International '94, pp 190-3.*

Sullivan G D, and Baker K D, (1993) "Model-based Vision for Road Traffic Understanding", Proceedings 26th ISATA Dedicated Conference on ATT/ IVHS, Germany, September, pp 559-566.

Traficon (1993) "CCATS (Camera and Computer Aided Traffic Sensor) - Video Image Processor", Trafficon, Belgium.

van der Vlist M J M, and Brocken M G M, (1991) "DARTS and Variable Message Signs", Proceedings 24th ISATA Dedicated Conference on RTI/ IVHS, Italy, pp 159-166.

Wall H B, Marsden B G, and Agah M M, (1994) "An Advanced Traffic Management System for the Arizona Department of Transportation", *Traffic Technology International '94, pp 50-4.*