Proceedings – Urban traffic control workshop, 14th ARRB Conference, Canberra, August 1988

Edited by

J.Y.K. Luk
THE PURPOSE OF THIS REPORT
To record: (a) the papers presented at the Urban Traffic Control (UTC) Workshop held on 29 August 1988 as part of the 14th ARRB Conference, Canberra;
(b) the discussion and replies compiled during the Workshop.

THIS REPORT SHOULD INTEREST
Engineers and researchers involved in traffic signal analysis and operation.

THE MAJOR CONCLUSIONS OF THE REPORT ARE
1. Australia can continue to make significant contributions in the area of traffic engineering by maintaining a rigorous, analytical approach and strong interaction between the research and practitioner communities.
2. UTC software and systems developed in Australia are advanced systems and are suitable for the export market.
3. The compliance rate of motorists to the dynamic speed advisory system in Melbourne needs to be ascertained.
4. Automatic vehicle monitoring and land navigation by dead reckoning are techniques that should be utilised to develop a new generation of traffic control systems.

AS A CONSEQUENCE OF THE WORK REPORTED, THE FOLLOWING ACTION IS RECOMMENDED
1. Enhance the cooperation between researchers and practitioners.
2. Promote the sale of software and hardware to overseas markets.
3. Develop on-line delay/queue length monitoring facilities in SCATS and TRACS.
4. Research into automatic vehicle 'non-identification' techniques based on the dead reckoning concept.

RELATED ARRB RESEARCH
P450 - Fundamentals of Traffic Signal Analysis
P451 - Time Series Analysis of Origin Destination Flows in a Small Area
P461 - Route Guidance and Vehicle Positioning
A857 - Urban Traffic Design Software Services
PROCEEDINGS — URBAN TRAFFIC CONTROL WORKSHOP
14th ARRB CONFERENCE, CANBERRA,
AUGUST 1988

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FOREWORD

The 1988 Urban Traffic Control Workshop was held in Canberra as part of the 14th ARRB Conference. It is the second ARRB Conference Workshop in the subject area of urban traffic control. The first one was held in Brisbane in 1978 when the traffic responsive control system, SCATS, of the Department of Main Roads, NSW was described in some detail and the name SCATS was first publicised to an international audience. Now SCATS is adopted to control more than 3300 signals in 20 cities around the world. It is interesting to note that the Main Roads Department (Queensland) has recently developed a new control system, TRACS, with PC based graphics and other user friendly features.

This report begins with the review papers by Rahmi Akcelik and James Luk of ARRB on the past, current and future research in traffic signal control models and systems in Australia. They give insight into the reasons for the successful development of models and systems such as SIDRA and SCATS.

Other papers in this report describe SCATS (and the associated computer-aided traffic engineering system, SCATES), TRACS and the dynamic speed advisory system, ADVISE. Two further papers are concerned with automatic vehicle monitoring and land navigation techniques. These techniques should enhance the operation of an urban traffic control system, and enable it to perform traffic management in real time. As new generations of dynamic traffic management systems come into operation they will, no doubt, be reported at UTC Workshops held in conjunction with future ARRB Conferences.

The Workshop proceedings were edited by James Luk. I am grateful to all Workshop participants for their help and cooperation. In particular, I wish to thank the authors, and also Bob Pretty and Roger Dunn for chairing the Workshop sessions.

P.W. LOWE
Executive Director
TRAFFIC SIGNAL RESEARCH IN AUSTRALIA: PAST, PRESENT AND FUTURE

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ABSTRACT

Australia has made significant research and practical contributions towards the development of techniques and tools for the design and operation of signalised intersections. Although strong interactions have existed between research and practice, not all the potential for such links have been used. An important problem facing the traffic engineering community in Australia and New Zealand is that various software used for different levels of signalised intersection analysis have little in common. The new Paired Intersection Modelling project at ARRB offers a great potential to establish the missing links amongst various software. The main areas of further traffic signal research and development are listed. The preparation of an Australian Capacity Analysis document, and the development of total intersection design tools are discussed in some detail. It is suggested that a coordinated research and development effort involving research organisations, universities, road and traffic authorities, consultants and other interested organisations would greatly benefit Australian traffic engineering and planning profession. Only if the tradition of a rigorous, analytical approach is continued and strengthened, Australia will continue to make significant contributions to the world in the area of traffic engineering.

ACKNOWLEDGMENT: This paper is presented with the permission of the Executive Director of ARRB, Dr M.G. Lay.
1. INTRODUCTION

The purpose of this paper is to generate discussion on research and development issues regarding traffic signals, from a single intersection to a network level. The state of the art is discussed briefly and areas of short-term to long-term research and development are indicated. The reader is also referred to the following recent articles as essential reading related to this paper:

(a) a Research in Progress report which describes the current traffic signal research at the Australian Road Research Board (Luk and Akcelik 1988a) – included in Appendix A of this report;

(b) a paper which presents a detailed review of the state of the art in traffic signal research and practice in Australia (Luk and Akcelik 1988b) – included in Appendix B of this report; and

(c) a paper by McLean (1988) which discusses traffic engineering research in Australia in a more general context (also see Lay 1988).

The discussion presented in this paper relates to New Zealand as much as to Australia, since the research and practice in that country has proceeded very much in parallel with Australia.

2. BACKGROUND

Australia has made significant research and practical contributions towards the development of techniques and tools for the design and operation of signalised intersections. These include:

• early research on vehicle-actuated signals (Grace, Morris and Pak-Poy 1964; Pak-Poy and Assoc. 1975);

• analytical techniques for capacity, performance and timing analysis1 (Miller 1964, 1968a,b; Akcelik 1981, 1984, 1988a,b,c);

• signalised intersection analysis software: SIMSET (Naim 1980), SIDRA (Akcelik 1984, 1986, 1987) and INSECT (Cotterill, Moore and Tudge 1984; Biggs and Bowyer 1986) for single intersections; MULTSIM (Gipps 1980) and CLOFFSET (Sims and Finlay 1984) for arterial roads; MULATM (Taylor 1983; Fisk 1987) for small networks including signalised intersections;

• traffic control systems for networks: SCATS (Sims and Dobinson 1979; Lowrie 1982; Luk, Sims and Lowrie 1982; Longfoot 1984; Luk 1984a; Negus and Moore 1984; Cornwell, Luk and Negus 1986; Giannicarro 1986; Luk and Cahill 1986) and TRACS (Blincow and Watten 1987); and


The above techniques, software and systems are discussed in some detail in Luk and Akcelik (1988b), and therefore will not be repeated here.

The following quote from McLean (1988) puts the Australian contributions listed above in a general context:

Research has played an important role in the development of traffic engineering. Australian traffic engineering research is characterised by a tradition of a rigorous, analytical approach to the investigation of traffic problems, input from a range of specialist disciplines, and strong interaction between the research and practitioner communities.

3. LINKS BETWEEN TRAFFIC SIGNAL RESEARCH AND PRACTICE

Both the analytical tools and practical systems listed in the previous Section show certain strengths, and are world leaders by any standards. Although strong interactions have existed between research...
and practice, not all the potential for such links has been used. Various weaknesses of the existing analytical tools, software and systems could be removed if better links were established between practice and research. This means that more research input into practical tools and systems would increase their fundamental qualities in traffic modelling and optimisation and more feedback from practice into research would lead to more advanced analytical methods as well as to more user friendly tools.

Experience with SIDRA during the last six or seven years of its development is an interesting example of the link between research and practice. Through its use in daily practice and through training courses and workshops, a strong research and development cycle has been established. This has resulted in continual advancement of traffic signal analysis techniques for single intersections through basic research in response to strong user feedback. As a result, Australia continues to be one of the world leaders in this area. This has also resulted in the development of more user friendly aspects for SIDRA as a practical tool (this aspect of SIDRA development can now be funded by the income it generates, i.e. the direct users pay for product development, but the related basic research is funded generally). There are great benefits in the continuation of this line of interaction between basic research and practical development. The potential areas of further research and development are extensive, as will be discussed later in this paper.

Another Australian development that can claim world leadership, SCATS, has been developed with input mainly from practising engineers. SCATS was developed as a dynamic system from the practical need to overcome the disadvantages of a fixed-time system then in operation in Sydney. This was carried out at a time when other leading countries believed that fixed-time area traffic control was the best that could be achieved. Various experimental dynamic systems that were designed with strong research input (in the UK and USA) had failed to show that dynamic systems could produce benefits above the fixed-time systems. It was significant that after the inspection of SCATS operation, the U.K. Transport and Road Research Laboratory staff stopped refuting the concept of dynamic control.

Successes have been achieved with dynamic/traffic-responsive systems since the early days. For example, SCATS have been shown to produce large benefits for arterial road cases. However, even today, in grid network situations, dynamic systems such as SCATS and SCOOT (Hunt, et al. 1981; Robertson 1982; Luk 1984a) have not produced very large benefits above fixed-time or linked V-A systems. In fact, in some cases negative benefits have been found. The benefits of the dynamic systems are often derived more as savings in the cost of manpower requirements for preparing and updating signal timing plans considering traffic variations over time.

A major component contributing to the success of SCATS has been its strengths in its general system design features that allow for flexibility to accommodate various traffic management strategies such as three-lane tidal flow control (Longfoot 1984) and tram priority (Cornwell, Luk and Negus 1986), and also due to its strengths in user links and in continuing development. SCATS has incremental feedback algorithms for on-line cycle length, green splits and offset computation developed from operational experience. These algorithms achieve a high standard of operation in practice even when the vehicle mix and saturation flows are variable. However, the lack of a detailed description, in the literature, of the analytical/theoretical background of cycle time, green split and offset algorithms used in SCATS does not help its image as a system which is strong in its traffic modelling and optimisation. The comparable UK system, SCOOT, had strong research input into its development. Perhaps as a result of this, SCOOT is perceived as a system with good traffic modelling and optimisation algorithms.

There is room for substantial research input towards the development of better control algorithms for dynamic control systems. SCATS has a level of sophistication in its system features that will easily allow the implementation of more elegant signal control algorithms. The Parramatta Experiment demonstrated the capability of SCATS to implement a variety of control methods including fixed-time, linked V-A, and its own algorithms. Long-term improvements in the traffic modelling and optimisation algorithms of SCATS would greatly enhance its chances in international competition. The traffic engineering community would gain a lot if the Australian tradition of a rigorous, analytical approach (McLean 1988) were adopted for its future development.
4. LINKS AMONG TRAFFIC SIGNAL ANALYSIS TOOLS

The discussion of links among the traffic analysis tools used in Australia, and their links to practice will concentrate on SIDRA, CLOFFSET and TRANSYT (Robertson 1982; Hunt and Kennedy 1980; Vincent, Mitchell and Robertson 1980) programs. These are analytically based programs appropriate for day-to-day design and analysis purposes. The use of SIMSET, which is a macro-simulation model, now appears to be limited to the Department of Main Roads, New South Wales where it was developed, and therefore it will not be considered further. INSECT and MULTSIM constitute another class of software since they are based on microscopic (vehicle by vehicle) simulation modelling unlike the macro-analysis approach coupled with signal timing computation techniques employed in SIDRA, CLOFFSET and TRANSYT programs. Although microscopic simulation modelling is very useful for research and educational purposes, its use is limited in day-to-day design due to the problems of computing efficiency and between-run variations (however, it is perhaps useful for design purposes until appropriate analytically based tools are developed).

SIDRA is now in use by all States in Australia, and is also used extensively in New Zealand practice. As a tool to prepare signal coordination plans for the SCAT system, CLOFFSET is available in all States in Australia, except Queensland which does not have the SCAT system, and in most New Zealand cities where the SCAT system is in use. TRANSYT-8 is used extensively in Queensland for the same purpose.

In fact, the lack of Australian development of practical design tools for signalised intersection networks is partly a result of the availability of the internationally successful TRANSYT program, and partly because SCATS control is oriented towards arterial coordination (hence CLOFFSET). It is interesting to note that the SATURN program for small area network analysis (Van Vliet 1982; Luk 1984b), which incorporates a TRANSYT-like model for signalised intersection networks, has been widely used in Australia and New Zealand for traffic management purposes, including those States and cities that use SCATS for traffic control. The Australian-developed MULATM program (Taylor 1983) has been used more for local traffic analysis, but its potential for general applications has been recognised (Fisk 1987).

An important problem facing the traffic engineering community in Australia and New Zealand is that the above programs used for various levels of signalised intersection analysis have little in common.

In its original development, SIDRA had some links with TRANSYT, but the subsequent development of a much more detailed capacity and performance model for SIDRA has not left much in common between the two programs (e.g. see Akcelik 1988b). However, SIDRA and TRANSYT (hence SATURN) do still have some common basic analytical concepts, and hence the potential for SIDRA-TRANSYT and SIDRA-SATURN links remains. However, external linking is not likely to be the best way of solving the inconsistencies amongst different programs.

CLOFFSET includes performance estimation formulae from ARR No. 123 (Sims and Finlay 1984), which is also the basis of SIDRA performance formulae. However, the subsequent SIDRA development of the formulae for two green periods per cycle as in the case of opposed and unopposed phases (yet unpublished) would not be in CLOFFSET. The ARR 123 formulae apply to isolated cases only, and hence are relevant to external links (side roads and entry links). Similarly, there seems to be a difference between CLOFFSET, with its arterial progression orientation (SCATS philosophy) and TRANSYT with its network optimisation orientation although both programs appear to use platoon dispersion modelling.

It would be a very interesting exercise to conduct comparisons of capacity and performance estimates from CLOFFSET (in the component validation sense) against established techniques such as SIDRA and TRANSYT. Such comparisons could be carried out by specifying the same timing plan to each program, and the modelling abilities of these programs could be tested at different levels of congestion. Such a comparison should be given high priority since the timing plans generated by CLOFFSET are used in day-to-day operation of SCAT systems.

5. A POTENTIAL FOR THE CONSISTENCY OF SIGNAL DESIGN TOOLS

A new project starting at ARRB (Paired Intersection Modelling), will extend SIDRA capacity and
performance modelling to the case of two or more closely-spaced intersections (coupled, or compound intersections), and will investigate the feasibility of extending this model to arterials and networks. The SIDRA level of detail at each intersection will be kept, and the analytical models of platoon dispersion and queue formation will be developed by drawing on from the earlier ARRB and overseas work (Luk 1987; Olszewski 1988; Raphouil 1988).

The project offers a great potential to establish the missing links amongst various programs used for different levels of signalised intersection design. It is hoped that the project can provide input into, and benefit from, the CLOFFSET program development. Similarly, SIDRA links to TRANSYT, SATURN or MULATM, and/or extension of the SIDRA paired (compound) intersection model to arterial and network levels would contribute to more detailed and accurate modelling of capacities and performance characteristics (delay, queue length and number of stops).

The feasibility of extending SIDRA to arterial and network levels would depend on the development of more efficient modelling of platoon delays than in TRANSYT (and this is possible!), and the practicability of this development would depend on the potential for its use in practice.

6. FURTHER RESEARCH AND DEVELOPMENT NEEDS

The following is a list of the main areas of further traffic signal research and development. For detailed discussions on points (b) to (f), see Appendices A and B. Points (b) and (e) have also been discussed in the previous sections of this paper. Points (g) to (j) are interrelated and will be discussed in detail.

(a) Calibration of traffic model parameters for capacity and performance estimates (saturation flows, etc.). Refer to Akcelik (1987, p. 39) for a detailed discussion on this although the subjects of platoon dispersion modelling, progression factors, acceleration and deceleration profiles and rates (relevant to geometric delays as well as fuel consumption, operating cost, etc) should be added to its list of recommended research.

(b) Paired (compound) intersection modelling (see Section 5).

(c) Vehicle-actuated signal research (isolated and linked).

(d) Database management systems that allow the preparation of an input data set that can be used in a range of traffic models (by extracting input data such as intersection description and traffic flow information from the same data base).

(e) Network monitoring and control (improved traffic modelling and optimisation algorithms for area traffic control systems).

(f) Automatic vehicle location and routing techniques for real-time traffic management.

(g) Phasing design for signalised intersections.

(h) Automatic design of intersection geometry (e.g. short lane design).

(i) Total intersection design (consistent analysis techniques for signalised and unsignalised intersections, including roundabouts) coupled with graphics and expert system applications.

(j) A Road Capacity Analysis document that brings together the analytical techniques developed in Australia, including the rural traffic analysis methods.

An Australian Capacity Analysis document

Although Australia has made significant contributions to the world literature and influenced the methodologies adopted elsewhere, it has not produced a single document that brings together analysis methods for different road facilities (different intersection types, urban arterials and networks, and rural roads) in a way similar to the U.S. Highway Capacity Manual. As explained by McLean (1988), the Australian Road Capacity Manual project was effectively terminated in 1974 partly because of the publication of the 1965 U.S. Highway Capacity Manual, and partly because the program proved to be too ambitious for the available sources.

Today, the situation is rather different. There is a body of very advanced and new knowledge which
has resulted from Australian research during the last decade or so. This body of knowledge encompasses the areas of signalised intersections, roundabouts, urban networks and rural roads. In all these areas, the Australian methodologies are as good, or better than any available around the world. They relate to the Australian conditions in their calibration details, and at the same time they are universal techniques because they are based on a rigorous analytical approach. The preparation of an Australian Capacity Analysis document (a technical guide) which incorporates the latest available techniques would be of great benefit to the Australian and world traffic engineering community. It would promote the use of consistent concepts and analytical techniques in different but related applications, and would offer good international competition to the US Highway Capacity Manual.

Total intersection design tools

Considering the developments in microcomputing, it is practicable to extend the existing traffic engineering analysis tools such as SIDRA to tools for the total design of intersections. This would involve automatic optimisation of intersection geometry for maximum capacity, and also the choice of optimum phasings for signalised intersections within the limitations set by the local conditions and design rules.

A personal computer package of this type would make use of computer assisted design (CAD), graphics and expert system techniques for user convenience and efficiency, and it would incorporate analytical tools such as SIDRA to be used repeatedly as an estimation module in the process of optimisation. Computing efficiency and between-run consistency of results are of utmost importance in this process, and therefore the use of an analytical tool such as SIDRA is feasible in contrast to the use of a simulation model such as INSECT.

This type of development is already occurring elsewhere in the world, and has great potential for use by the traffic engineering community in the 1990s (for example, see Montgomery 1987; Birkinshaw, Kirby and Montgomery 1988; Willumsen 1988). This line of development could go in parallel with the preparation of an Australian Capacity Analysis document so as to achieve consistency between design tools and the methodology behind them.

7. CONCLUSION

A coordinated research and development effort involving research organisations, universities, road and traffic authorities, consultants and other interested organisations would greatly benefit Australian traffic engineering and planning profession both in the short-term and the long-term. This is essential from an efficiency viewpoint (do not waste research resources, and develop more advanced techniques in a shorter period of time), also from an international credibility viewpoint (especially if we are serious about exporting our products).

Only if the tradition of rigorous, analytical approach to the investigation of traffic problems, input from a range of specialist disciplines, and strong interaction between the research and practitioner communities (McLean 1988) is continued and strengthened, Australia will continue to make significant contributions to the world in the area of traffic engineering.

NOTES

1. These techniques have been useful contributions to the world literature on the subject, and have had strong influences on the methods developed in other countries such as Sweden and USA. Although McLean (1988) suggests that ARRB Bulletin No. 4 (Miller 1968) was adopted as a basis for the signalised intersection chapter of the 1985 U.S. Highway Capacity Manual (Transportation Research Board 1985), it was more of an indirect effect through the influence of ARRB Report No. 123 (Akcelik 1981).

2. The current ARRB Report No. 123 (Akcelik 1981) has been in high demand, and its fourth reprint will be done soon. An ARRB project is in progress for the revision of this document to incorporate advanced analysis techniques that have been developed in conjunction with SIDRA software development (for example, see Akcelik (1988b,c) on advances in shared lane and opposed turn capacity modelling).

3. SIMSET is a macro-simulation model which was developed by the Department of Main Roads, New South Wales in the late 1970's when the analytical techniques available then were seen to be inadequate for dealing with
complicated intersection geometries and signal phasings. It dealt with problems such as short lanes through simulation, and as a result, its computer run times could be high. SIMSET did not make use of established analytical techniques for capacity estimation and signal timing computation.

4. The SIDRA program has been widely adopted for capacity, timing and performance analysis of signalised intersections. It has been under continuous development in response to user feedback. During 1987-88, four SIDRA training courses were held (Sweden, New Zealand, Queensland and Melbourne), and a training course will be held in November 1988 in Western Australia. At the end of July 1988, there were 94 organisations in 16 countries using SIDRA (this includes a total of 70 practising organisations in Australia and New Zealand).

5. INSECT was originally developed for roundabouts and unsignalised intersections. More recently, a signalised intersection module was added to the program under an ARRB project funded jointly by NERDDC, ARRB, DMR NSW and Road Traffic Authority, Victoria. ARRB interest in INSECT signalised intersection module is based on its potential as a useful research tool for vehicle-actuated signals. The signalised intersection module of INSECT remains to be subject to component validation against established analytical tools.

6. A new version of CLOFFSET, now called SCATES, is available.

7. For example, the SIDRA method can claim the following advantages over the 1985 U.S. Highway Capacity Manual method for signalised intersections (Transportation Research Board 1985) and the OSCADY method developed in the U.K. (Burrows 1987):

- Lane by lane analysis, allowing for varying lane flows and saturation flows, effective green times and lane utilization ratios without relying on lane grouping (movements can be described as lane groups or individual turns) — this results in improved capacity, delay and queue length prediction;
- Explicit consideration of short lanes (left and right turn bays, and lanes with parking close to the intersection) with excess flow modelling;
- Estimation of capacity and performance (delay, queue length and number of stops) by separate modelling of permitted and protected (filter and free) turn phases as two green periods with different saturation flows and lost times;
- A very general model of opposed (filter, or permitted) turns, with applications to slip lanes, turning on red, different priority rules, and allowing for differences in traffic flows and saturated green periods of opposing traffic lanes;
- A generalised and explicit model of shared lanes without need for the use of opposed turn adjustment factors;
- Lane blockage modelling for shared lanes allowing for a variable number of vehicles which can queue off the lane without blocking other traffic;
- Modelling of more complex intersection layouts and signal phasings, including signal timing computation features such as undetected movements, unequal degrees of saturation, and green split priority;
- More extensive output performance measures, including delay, queue length, number of stops, fuel consumption, and so on.

REFERENCES


CURRENT AND FUTURE DEVELOPMENT OF TRAFFIC CONTROL SYSTEMS

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ABSTRACT
This paper gives an outline of the development of SCATS, the Sydney Co-ordinated Adaptive Traffic System to meet the needs, initially, of the Department of Main Roads and how development has been affected by the increasing user bases. The possibilities for future development of traffic control systems in general are discussed together with an appraisal of the forces, i.e. technology advances and the market place, which will guide such development.
1. INTRODUCTION

The Sydney Co-Ordinated Adaptive Traffic Control System is an integrated computer based system for controlling traffic (by means of traffic signals) in typical urban traffic situations. Development of the system by the Department of Main Roads NSW (Department of Motor Transport prior to 1976) began in the early 1970's when the use of minicomputers became more attractive than the only previous technology of purpose-built hardware. Simultaneous development of the microprocessor based local controller for traffic signals by DMR and industry led to SCATS becoming a totally integrated system capitalising on the advantages of distributed computational power. The system is traffic responsive in two senses. At the local level the power of the microprocessor allows variation of the phase sequence and the duration of phases using traffic information from the inductive loop vehicle detectors installed on all approaches of the intersection. This local traffic responsiveness is referred to as 'tactical' operation. At the sub-system level (groups of one or more related intersections) changes to operational parameters in response to changing traffic demand are effected, again using traffic information from the detectors and passed to the 'regional' mini-computer. This level of traffic responsiveness is known as 'strategic' operation. Whilst a wide range of functions can be time-tabled to occur at specified times, the system operation is basically independent of time of day, relying essentially on traffic data to vary the operational parameters as a function of changing traffic demand. A more detailed description of the traffic related operation of SCATS is given in Lowrie (1982).

SCATS was originally developed for use in Sydney and the development was undertaken because of the unavailability of any proven traffic responsive system on the world market. Since 1980, SCATS has been adopted by most Australian cities, several cities in New Zealand and, more recently, SCATS systems have been installed in Shanghai and Singapore. At the time of writing SCATS is controlling more than 3300 signals in 20 cities. This widespread application of SCATS in cities ranging from small (about 20 intersections) to large (more than 1500 intersections) with widely varying traffic conditions and local requirements has resulted in accelerated development and improvement of the system aided by valuable input from the wide range of users. Development is undertaken by DMR on behalf of and in conjunction with these users and the two major Australian signal equipment manufacturers which are licenced to market SCATS overseas.

2. GENERAL

SCATS is more than a traffic control algorithm; it is a complete system in both hardware and software. The local controllers (especially the software) are unique to SCATS as are the associated communications protocol and message structure for transferring information to and from the regional mini-computer. The entire software package in the PDP-11 series regional computers (with the exception of the proprietary operating system) has been specifically developed to meet the requirements of a real-time on-line system. For example, the various input/output drivers are specifically designed for the application.

Each regional computer can control up to 128 intersections. Where more than one regional computer is required in a city, it is usual to upwardly expand the system by adding a central monitoring computer (PDP-11 series) to allow centralised monitoring of and data collection for all the regional computers. This software is included in the system and is also the subject of development. Several large SCATS applications include the top optional component, a VAX based system management and data storage/backup facility to provide users with a means of coping with the logistic problems of a large system. Again both the on-line and off-line software packages for the VAX are the subject of enhancement and expansion.

The rate of SCATS development is such that a new version of both the central monitoring and regional software is released to interstate and overseas users about once per year. Enhanced software is first tested in Sydney by simulation, then in one or two regional computers and finally in all Sydney regionals before release. About one in three or four releases contain large changes in the traffic operation of SCATS, other releases covering fault
rectification and numerous but more minor enhancements in traffic operation, user interface and computing technique. Many of the changes result from input from users outside DMR.

3. DEVELOPMENT NEEDS

An area traffic control system can vary only three basic operating parameters for the signals in one group: phase splits, offsets and cycle time. The algorithms controlling these are therefore the subject of great attention. Two other functions, often overlooked in discussion, are those of effective traffic data collection (for processing by the split, cycle and offset algorithms) and correct management by the regional computer of tactical freedom of individual local controllers. Furthermore, in the negative feedback control loops existing in the splits and cycle time algorithms, the degree of damping, hysteresis, gain and trend recognition must also be carefully executed. Unfortunately, memory constraints restrict the amount of data which can be stored for subsequent use in averaging or trend analysis techniques. These items are all periodically reviewed in the light of experience gained.

The correct application of the system to meet the needs of traffic depends greatly on the ease with which users can interpret information provided by the system on its operation and enter the parameters required to tailor the system to each application. This subject of 'user friendliness' is also the subject of development and enhancement.

Despite the great strides in computer technology in recent years, very real constraints are placed on the extent to which sophisticated algorithms can be implemented by the limits of computing speed and available memory. The balance between memory requirements for data or code and computing time must be carefully juggled to obtain the most within the constraints. Because of these limitations, SCATS uses the assembler language which gives the most efficient use of computer power. Refinement of the coding of the SCATS software is therefore also the subject of continuing development.

4. COMMERCIAL REALITY

The world market for traffic responsive control systems is currently dominated by two systems: SCATS and the British developed SCOOT. The two systems are fundamentally different. SCATS is essentially a feedback control system designed to allow the traffic engineer to implement the strategies and policies of his authority. SCOOT derives its signal settings from a traffic model coupled to an optimising routine and is designed to implement a minimum performance index with little opportunity for superimposition of the authority’s requirements. Both systems are functional to the extent that working systems have been installed in a number of cities.

In the case of SCATS it is fair to say that existing and future systems would continue to work very satisfactorily without further development. The author is not sufficiently familiar with SCOOT to comment with certainty on the degree of development required to reach the same standard although Robertson (1987) does recommend certain improvements.

Very little has been published in the public realm about SCOOT, except Hunt et al. (1981) which gives a description of the broad principles. The same can be said of SCATS except the fundamental algorithms described in Lowrie (1982).

Since that time, the two systems have entered an extremely competitive international market, in each case being marketed by the principal signal companies in the U.K. (SCOOT) and Australia (SCATS). It is therefore not commercially prudent for either party to publish details of proposed development, other than in broad terms which indicate a positive attitude to product improvement, for two reasons. In the case of recognised deficiencies in the system, no matter how minor, a statement by one party of a need for (or possibility of) improvement will be construed by the other party as a weakness. In the case of new features to be added to improve marketability, advance publication of details may give the competitor an early chance to develop a similar feature.

For these reasons, this paper, which ideally would be technically open to encourage discussion of matters of general interest, is, of necessity, published as a general commentary on the possibility for ongoing development.

5. TRAFFIC CONTROL

It is fairly evident that both SCATS and SCOOT will continue to be developed as knowledge and
experience increase. For example, both systems determine cycle time in quite similar ways yet no analytical method has been derived to calculate the optimum cycle time to be shared by a group of linked signals. Scope also exists in both systems for determining, by a computationally practical method, whether performance of a group of signals sharing a common cycle time would be improved if the group were divided into two or more uncoordinated groups operating under different cycle times.

The possibilities opened up by the development of image processing techniques, which would allow the direct measurement of speed, queues and hence average delay, will have a great impact on all traffic control systems and, incidently, overcome the reliability problem of the inductive loop detector.

Both systems will no doubt be developed further when influenced by extensions to their application. For example, improved detection and control of bicycles for the Asian market, non-English language input and output formats for currently untapped markets and increased emphasis on performance monitoring, route guidance or cordon control facilities. These developments will be largely market driven.

### 6. USER INTERFACE

It is true of both SCATS and SCOOT that the performance of the mini-computers is a limiting factor in providing a really elegant user interface. Means of interrogating data, entering system dependent parameters, presentation of data and operational functions can be greatly enhanced by the use of 'intelligent' terminals (personal computers) to greatly increase the available computing power. The use of a PC as the user interface offers mass storage, fast 'number crunching' and excellent graphics capabilities which together provide the possibility of powerful, informative graphics displays and storage of operational history for later analysis which will allow the user to manage large systems with a minimal manpower requirement.

### 7. THE FUTURE

Whilst the developers of both SCATS and SCOOT no doubt have a good understanding of the traffic related areas which are worthy of improvement, future development in these areas will be largely dependent on the degree of success achieved by current development and in the light of future experience and market forces.

It is likely that the power and availability of PC's at a reasonable price will lead to development of facilities which have not yet been considered. No doubt all users will look forward to development in this direction and, hopefully, will contribute to it.

In the longer term, inevitable changes in computer technology, both in hardware and software techniques as well as operating system improvements and advances in vehicle detection and data transmission will lead to re-structuring of traffic control systems and the use of very high level languages. The possibility of 'artificial intelligence' must not be overlooked. Given sufficient computing power, the possibilities for future development will be presented in ways which are very difficult to predict at this time. Maybe in the next 50 years traffic signals practitioners will look back on the literature and marvel at the crudity of co-ordination by means of signals sharing a common cycle time. If only our computers were powerful enough to implement 'asynchronous co-ordination'.

### REFERENCES


SCATS COMPUTER AIDED TRAFFIC ENGINEERING SYSTEM  
(SCATES)

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ABSTRACT

SCATES is a computer program for the calculation of phase splits, cycle lengths, offsets, delay, stops, fuel and operating costs for linear coordinated traffic signal systems. It provides all of the offset and split data for the Sydney Coordinated Adaptive Traffic Signal System (SCATS). It is an enhancement of an earlier program called CLOFFSET. Other uses for any linear traffic signal system are the determination of cycle lengths that provide the best two way progression, the determination of warrants for traffic signal coordination, and the analysis of road design projects involving multiple signal controlled intersections that interact to affect road performance. Hourly and annual delay, stops, fuel and total annual operating costs are output. The program can be used for simultaneous analysis for a.m., p.m. and business peaks of traffic signal phasing designs for isolated or coordinated intersections as an alternative to using manual methods. A fundamental knowledge of traffic engineering and traffic signal phasing design is required to use the program. Experience of SCATS is not needed but obviously is required if SCATES is used to produce SCATS data. The program is suitable for use in all countries. Data requirements are: intersection volume counts, saturation flows, phase designs, distance between intersections, turn bay lengths and link speeds. A file is made of the input data for subsequent recall or edit.

ACKNOWLEDGEMENT: The author wishes to thank the Commissioner of Roads and Traffic Authority NSW for permission to publish this paper.
1. INTRODUCTION

1.1 CLOFFSET (Cycle Length derived two-way OFFSETs)

SCATES is an enhancement of this earlier program reported in Sims and Finlay (1984).

1.2 SCATES OBJECTIVES

SCATES is a computer program for the calculation of phase splits, cycle lengths, offsets, delay, stops, fuel and operating costs for linear coordinated traffic signal systems.

The objectives are to provide:

(a) All of the offset and split data for SCATS,
(b) The determination of cycle lengths that provide the best two way progression,
(c) The determination of warrants for traffic signal coordination,
(d) The analysis of road design projects involving multiple traffic signal controlled intersections that interact to affect road performance with hourly and annual delay, stops, fuel and total annual operating costs being output,
(e) The analysis of a single intersection for hourly and annual delay, stops, fuel and total annual operating costs, and
(f) The simultaneous analysis for a.m., p.m. and business peaks of phasing designs for isolated or coordinated intersections as an alternative to using manual methods, SIMSET (Sims 1972) or SIDRA (see, e.g. Akcelik 1987).

1.3 POTENTIAL USERS

These include:

(a) All authorities that use the Sydney Coordinated Adaptive Traffic Signal System (SCATS),
(b) Authorities and consultants that design isolated or coordinated traffic signals,
(c) Authorities and consultants that evaluate proposed traffic management measures within a traffic signal system,
(d) Authorities and consultants that evaluate proposed road or intersection improvements at isolated signals or within a signal system, and
(e) Authorities and consultants that evaluate proposed changes to the traffic demand at isolated signals or within a signal system due to development proposals.

The program is suitable for use in all countries with all default data and left or right side driving flags contained in configuration files.

1.4 DATA REQUIREMENTS

These include:

(a) Intersection number for identification purposes,
(b) Intersection movement volumes,
(c) Intersection movement maximum saturation flows,
(d) Intersection movement phases,
(e) Distance between intersections,
(f) Turn bay lengths,
(g) Slip lane lengths,
(h) Mean free flow link speeds,
(i) Phase minima, and
(j) Pedestrian conflict times.

Data input flow to SCATES has been designed to generate a maximum of default data in order to minimise data input requirements. A.M. and p.m. peak volumes are required. Default business hours volumes are calculated from the peak flows as this data is frequently not available. All default data can be edited. A file is made of the input data for subsequent recall or edit.

1.5 USER SKILL REQUIREMENTS

A fundamental knowledge of traffic engineering and traffic signal phasing design is required. No experience of SCATS is required to use SCATES for evaluation purposes. Obviously SCATS training is essential if SCATES is used for the preparation of SCATS data. Notes on installing SCATES on an IBM-PC are given in Sims (1988).
2. REASONS FOR SCATES

2.1  CLOFFSET

The original program CLOFFSET determines those cycle lengths in the range 30 seconds to the maximum specified that give the best two-way progression for a linear traffic signal coordinated road. Having determined the appropriate cycle lengths the program then calculates all of the offset data and control parameters necessary for the correct operation of a SCATS regional computer. This data provides for both balanced and tidal flow demand characteristics.

It is not a maximum bandwidth type program and is an analytical model that initially calculates the best possible offsets for the direction of heaviest flow. The offsets take into account queues formed on the main road from side street entry demands and residual queuing caused by the effects of platoon dispersion and the funnel effect of green times becoming smaller at subsequent intersections. It then calculates alternative offsets for each intersection in turn with the objective of improving progression in the lighter flow direction. The performance index of the original and alternative offsets are compared and the best offsets used. Under equal directional demands, offsets favouring each direction are calculated and the offsets in the direction with the lowest performance index is used.

Accurate data is essential to SCATS and CLOFFSET eliminated the manual skills stigma earlier associated with SCATS. The CLOFFSET data and control parameters bias SCATS towards those cycle lengths that provide the best performance for two-way progression under the appropriate demand scenario's.

The program uses existing SCATS phase split data as input. The main road demands are calculated from a specified lane saturation flow and a specified number of lanes for the main road common to the length of the system. Link speeds and link distances are also required. Side street demands are calculated from the phase splits and assume a saturation flow common to all side streets.

A major design objective was to minimise the amount of input data needed. This has minimised user costs and ensured easy use and thus ready acceptance. CLOFFSET is used by all SCATS users in Australia, New Zealand, China and Singapore. The total number of intersections optimised is in excess of 3000.

2.2  ENHANCEMENTS IN SCATES

Phase Splits

Where a SCATS system is operational and has been optimised in its phase split performance then CLOFFSET was adequate for the calculation of SCATS offsets. For new systems where proven phase splits do not exist then complex cycle length and phase split calculations have to be performed to obtain the data. Each intersection has to be calculated for at least the a.m., p.m. and business peaks and then all data has to be recalculated when the system cycle lengths have been decided.

These calculations require a major skilled staff resource. If carried out manually using, say, ARR 123 (Akcelik 1981) then the resultant costs are of some magnitude due to the complexity. Also due to the complexity the probability of manual errors is high. The use of computer tools such as SIMSET or SIDRA reduce the cost and probability of errors but still require time consuming multiple calculations.

SCATES includes an analytical method to calculate all of the isolated and coordinated cycle length and phase split data needed, based on ARR 123. The method includes phase minima, pedestrian conflicts, overlaps, multiple greens per cycle, short lane affects and identify critical movements. Once the required intersection movement volume and associated data is input then the cycle length and phase split data is calculated for the a.m., p.m. and business peaks for all intersections. This eliminates the previous complex and tedious task and results in major savings in user resource costs. If the input data is edited then recalculation for the whole system is instantaneous. The ability for SCATS users to input proven SCATS phase split data is retained as an option.

Variation in the Number of Lanes in Main Road Links

CLOFFSET provided for a specified number of link lanes which was common to every link and for both directions of travel. The number of lanes was the same for the a.m. and p.m. peaks but could be varied for business hours.
The widespread introduction of ‘S’ lanes, directional ‘clearways’ and provision of more stop line lanes to improve capacities in some situations alters the criterion for offset optimisation. For example where the number of lanes increases the optimum offsets required may force a platoon to stop in order to maximise use of the capacity and hence reduce the degree of saturation or X value.

SCATES provides for variable link and stop line lanes up to a maximum of five on any approach.

**Provision of Annual Costs for Cost Benefit Evaluation**

CLOFFSET provides detailed data of delay, stops, fuel and speeds for eight traffic demand scenario’s. The scenarios are the two peaks and the business peak with shoulder periods for each plus two off peak periods. A cost file containing all of the necessary cost parameters and the hours per year for each demand scenario is utilised to calculate annual system operating costs from the eight scenario’s. The cost file can be edited with a SCATES option. This evaluation option of the program is now as frequently used as the SCATS options. With limited road improvement funds it provides the means to accurately identify and rank projects whether they be large or small in a quantitative manner.

Similarly the affects of altered traffic patterns and or increased demands on the road system due to development projects can be modelled and if necessary alternative designs for the road system can be explored. This evaluation option is run for each model to be compared. However if the differing models include road changes that alter the cycle lengths it is difficult for an unskilled user to ensure that the same demands apply to each model. SCATES enhances this option so that multiple models of the same road but with differing proposed road improvements or changes can be compared under exactly the same demands even though the peak hour cycle lengths may vary.

Input data files are created for specific demands. SCATES provides the means to alter any demand at run time so that the performance data includes vehicles stored outside the system if approaches are oversaturated. Demands may also be decreased if required for other reasons.

Generation of batch files that contain all of the data about the models to be compared and the demands to be used is automatic. This ensures repeatability and saves considerable time if further evaluations are required.

**Isolated Intersections**

The analysis of a single intersection is not possible with CLOFFSET, but SCATES allows the analysis of a single intersection for hourly and annual delay, stops, fuel and total annual operating costs with similar model comparison options as for systems. It also provides for the simultaneous analysis of a.m., p.m. and business peaks for phasing designs for isolated or coordinated intersections as an alternative to using manual methods, SIMSET or SIDRA.

### 3. SCATES OPTIONS MENU

#### 3.1 GENERAL INFORMATION

There are 22 options listed in the main menu. These can be selected by typing the option number followed by Enter or by moving the cursor with the up/down arrow keys to the required option and pressing Enter. Press key F1 for general help about SCATES and key F10 for detailed help on the subject at which the cursor is located. The above applies for Help on all data input screen pages.

#### 3.2 DESCRIPTION OF OPTIONS 0 to 21

0: Exit to MS/DOS.

Provides for a direct exit to MS/DOS from SCATES.

1: Make a SCATES Data File.

Prior to selecting any other menu options a data file must be made or must exist. This involves the selection of this menu option to make a file or the selection of menu option 2 to load an existing file for the system required.

2: Load a SCATES Data File.

An existing data file for the system to be modelled can be loaded with this menu option. When asked for the file name do not include the extension. Once a file is loaded all of the data is retained in memory until a new file is loaded. For example, any number of options can be selected without the need to reload the file.
3: Edit a SCATES Data File.

The file currently in memory will be available for edit of all data with this option.

4: Print a SCATES Data File.

The data in the file currently in memory will be printed with this option. The majority of data will be printed in the same screen format that is used for the creation or edit of the data.

5: Make a Reduced size SCATES File from a larger File.

A long system can be reduced in size if it is necessary to analyse the system as a number of smaller systems.

6: Delete a SCATES Data File.

Provides for the deletion of all SCATES files with the same name as the original data file.

7: Calculate a Performance Index (PI) Graph for Cycle Length Range.

Using business hours phase splits and the business hours specified demands and volumes a number of performance index (PI) graphs are plotted for cycle lengths from 30 seconds to a user specified maximum in 2 second increments.

The purpose of the graphs are:
(a) To determine the best cycle lengths that provide two way progression when the demand in both directions are approximately equal which normally occurs in business hours,
(b) To visually show the overall benefit of coordination compared to isolated operation as well as the disbenefit to the non-coordinated traffic, and
(c) To determine which of the 4 offset scenarios evaluated is the best.

The formula for the PI’s is: \[ \text{rate of delay + rate of stops} \times \text{stop penalty} \]. The stop penalty may be edited in the System Data Module (see Section 4.2).

The graphs available are:
(a) Side street isolated = Light Blue,
(b) Side street coordinated = Magenta,
(c) Target (theoretical perfect) two way progression = White,
(d) SCATS simultaneous optimum for direction a.m. (4) = Dark Blue,
(e) SCATS simultaneous optimum for direction p.m. (2) = Yellow,
(f) SCATS progressive optimum for direction a.m. (4) = Green,
(g) SCATS progressive optimum for direction p.m. (2) = Red,

8: Calculate SCATS Output Data and Statistics with No Time Distance diagrams.

All SCATS offset and split plan data is calculated and output to the printer. Optionally the data may also be stored on a floppy disc for subsequent loading to a regional computer. No time distance diagrams of the calculated split and offset plans are produced. The data file must contain SCATS slot numbers for this option. Prior to using this option a PI graph must be analysed in order to answer the required questions about the best two way progression cycle lengths and SCATS type offsets (directional number) for the three SCATS cycle length parameters (<%, S%1 and S%2).

9: Calculate SCATS Output Data and Statistics with Time Distance diagrams.

All SCATS offset and split plan data is calculated as for option 8 and time distance diagrams are drawn on a colour printer for the eight demand scenario’s.

10: Draw a Time Distance Diagram (Screen or Printer).

For any valid cycle length and split plan combination with either the data file entry demands or varied entry demands draw a time distance diagram. The diagram may be output to a colour printer or to a colour screen.
11: Calculate and Print Flexilink Data.

All offset and time of day schedule data for a suite of cableless link (Flexilink) plans can be calculated. The output data is printed in the exact format for direct loading to a SCATS regional computer. All required phase call pulses are provided but information on special release pulses etc. is not available to SCATES and must be entered to SCATS manually.


A drawing of the system is made on the screen. All intersections with all movement flows are shown for any valid cycle length and split plan combination with either the data file entry demands or entry demands specified. The demands specified by the user at input time is the maximum cycle length demands for the particular time-of-day period. At lower cycle lengths these are reduced by SCATES to achieve a degree of saturation appropriate to the cycle time. This option provides the means to view the actual movement volumes used by SCATES for any cycle length/phase split combination. The stop line degree of saturation is also shown for the main road through movements.

The drawing is not to scale and all intersections are shown at equal spacing. If the system cannot be shown on one screen page then press key ‘M’ to page to the next screen for the next group of intersections. You may page backwards to any intersection by pressing key ‘T’ followed by the intersection (or traffic control site TCS) number. Each page may be printed in black and white by pressing ‘P’ by a printer graphics routine internal to SCATES. If the user has a program such as PIZAZZ and a colour printer then [SHIFT PrtSc] will print the page in colour.

13: Check Coordinated Sequences for Optimum Coordination.

All coordinated turning phase sequences are tested to determine if they provide the most advantage for two way progression between each pair of intersections. Advisory messages are printed when the sequence is considered non-optimum. Sequence data is not changed as there may be a safety or local reason for the sequence. It is up to the user to heed the sequence messages by analysing the situation manually with the assistance of the time distance diagram option.

14: List Files.

The program allows all data files and all other files generated at run times to be listed.

15: Calculate System Performance for Road Design or Warrants.

This initially analyses six traffic demand scenarios representing the a.m., p.m. and business peaks with shoulder periods for each. Two additional scenarios representing low and medium off-peak demands are also analysed. The hourly delay, stops and fuel wasted above cruise travel time are printed. This data is then extended to annual figures by the use of a file called CLODST/CLO which contains the number of hours per year that each of the scenarios will operate. This file also contains all of the cost data such as vehicle operating cost per km and vehicle cost per hour, fuel cost, fuel rate, driver and passenger time costs, etc. This file can be edited by the user via option 17.

A detailed and summarised annual tabulation of delay, stops and fuel actually used together with annual system operating costs is output as a file and may also be printed. Main road and side street demands can be modified as required at run time. The annual tabulations give results for isolated operation, SCATS operation and for a pseudo freeway.

The freeway is intended as a bench-mark indication for comparison purposes. It is probably the ultimate that traffic management measures could achieve. The comparison between isolated control and SCATS provides the data necessary to determine the warrant or not for expenditure for SCATS.

For proposed road improvement projects or for development applications the original base case data file can quickly be edited to create new files with the proposed traffic and road changes. A run time question provides for the movement volumes in these files to be compared to ensure that the correct traffic patterns will be compared at run time. These files can be grouped into a single option 15 run by means of a batch file (.ALL) automatically generated by SCATES at run time. As well as the individual reports listed above a tabulation comparing the performance data of all files is produced.

The 'base case' model must be the file loaded to memory when option 15 is selected.
16: Evaluate Non-SCATES Offsets.

This option enables the comparison of offsets developed manually or by another offset optimisation program to be compared with the SCATES offsets using a common delay/stops calculation method. To date nobody has bettered the SCATES results over a range of cycle length operation.

17: Edit or Print Cost Data File (used with Option 15).

The file CLOCOST.CLO contains all of the costing data and hours/year needed by option 15 to produce the annual operating delay/stops and cost data. This option allows the file to be printed and edited as costs change or the systems peak hour and other periods per year vary from other systems.

18: Graph Performance Index on Screen from PI File.

This option allows the instant recall to the screen of the last performance index (PI) graph created by option 7.

19: Graph performance index on Printer from PI File.

This option allows the printing of the last performance index graph created by option 7. An Epson JX-80 compatible colour printer is required.


A simulation of the operation of the system is displayed on a colour screen. The simulation shows the road system with the specified intersection types together with the changing status of the signals and the movement of vehicles in two second time increments. The simulation can be for any valid cycle length/phase split combination and use the entry demands from the file or entry demands varied at run time. The simulation is not part of the SCATES model or optimiser but simply takes the SCATES calculated splits and offsets and then independently simulates. It is valuable for visually determining the affect of oversaturation and short turning bays.

Vehicles travelling from left to right are green and cyan in the other direction. Right-hand-turn (RHT) vehicles are yellow and left-hand-turn (LHT) are red. There are no signals shown for side streets but this can generally be deduced from the status of the main road signals. The through movement queues for side streets are shown in red when they have a red and are green when they have a green. The colour of LHT and RHT vehicles in side streets is the colour of the main road direction that they will take.

The simulation will automatically run for twice the number of cycles necessary for a vehicle to traverse the screen. More cycles can be run by pressing any number between 1 and 9. Simulation will be for that many extra cycles. Pressing 'I' will increment the simulation at the user-selected pace.

21: Alter Average Headway, Left/Right Driving, Intergreens

A file called CLOMODE.CLO retains this data and this option enables SCATES to be configured for the user's requirements. Use this option to set the SCATES defaults to the user's requirements. The saturation flow set here should be the most prevalent single through lane flow in the user's city. It is used to calculate the default saturation flows in the input data modules. Left/right driving only affects graphical input or output. The intergreen set is common to all phases of all intersections.

4. INPUT AND EDIT DATA MODULES

4.1 GENERAL INFORMATION

The data modules in the order of input sequence are:

(a) System,
(b) System Geometry,
(c) Volume,
(d) Phase splits, and
(e) Sub-systems.

The phase split and sub-system modules do not require input data and are for the viewing of the final calculations. Optional input of proven SCATS data is possible at this stage.

4.2 SYSTEM DATA MODULE

General Information

Volume Data required in this module is the actual traffic demand entering at either end of the system
and must be accurate and be in passenger-car-units (pcu’s). The demands requested are the total volumes on the entry approach including traffic that will turn left or right at the entry intersection.

The number of lanes and lane saturation flow data is used to calculate the default movement data for all intersections. The default data can be edited in subsequent modules. Locate the 'edit box' by using the Up and Down arrow keys. Type in the appropriate data and when complete the next arrow or function key pressed will terminate that entry. Press Home to move box to the first item and End to move to the last item. F10 will provide Help pertinent to the edit box position. The functions of keys F2 to F9 are indicated at the top of the screen and allow the user to move between the data entry modules.

Default Design Speed for peaks

The typical free flow speed attained in peak periods. Generally this is lower than the off peak speed. Note that it is the speed that should be attained if there were no queues or congestion or red signals.

Pedestrian Phase Skipping Cycle Length

The cycle length below which the pedestrian phase at mid-block pedestrian crossings will be skipped. Late start periods defined in seconds will also skip.

Stop Penalty

A stop penalty value of 0 optimises the system for minimum delay, a value of 40 optimises the system for minimum fuel, and a value of 20 optimises the system for minimum cost. A stop penalty value of > 40 optimises the system for minimum stops.

Demands for A.M./P.M./Business Peaks in Both Directions

The demand is given in pcu’s/h for the appropriate period and direction. The demands should be obtained from intersection counts or from reliable network model data. All Demand Volumes should be in pcu’s. If the system is oversaturated in any period then the user will subsequently be given warning or error messages. If there are no mistakes in intersection movement volumes, saturation flows or phases then the entry demands should be reduced until the time-of-day cycle length is in the range (140, 180) seconds. The demands can be increased to the true demand when the actual modelling option is ‘run’.

Because business hours volume data is frequently not available, default business hour data is calculated from the a.m. and p.m. data. If data is entered for business hours then no further default data will be calculated during the current data entry session. The default business volume = (a.m. volume + p.m. volume)/2 x K, where K = 0.85 if a.m. and p.m. volumes are balanced or K = 1 if tidal.

On a drawing of the system, the main road will be in the horizontal plane. Traffic travelling from left to right will be travelling in the p.m. or ‘2’ direction and from right to left in the a.m. or ‘4’ direction.

Prior to any modelling run, the user is asked if the user wishes to vary the entry demands. Any variations are for that run only. Variations allow for the testing of over- and under-saturation. If a decrease is specified then turning movement volumes for the direction of the demand are reduced by the ratio of the new to the original demand. Increases do not alter turning volumes.

System Default Lane Saturation Flow (Through Movement)

The lane saturation flow and the number of link lanes is used to calculate the default movement saturation flows. Turning movement saturation flows are suitably adjusted. The lane saturation flow entered should be for a typical straight through lane. The default lane saturation flow that SCATES enters to this box is obtained from the Saturation flow specified in Option 21 in the Main Menu. The value set in this module will be the one stored in the system file.

After saturation flows have been set for all intersections then changes to the system default lane saturation flow will alter all saturation flows by the ratio of the old to the new system default Lane Saturation Flow. This provides a means to quickly calibrate a system.

Total Number of Intersections

The maximum number of signalised intersections is 20. One intersection can be modelled for the purpose of obtaining cycle length, phase splits for the a.m., p.m. and business peaks simultaneously. To perform a single intersection analysis make a two intersection system with the first intersection being a mid-block pedestrian crossing. Make the Pedestrian control cycle length = 180 seconds to
cause the pedestrian phase to skip at all cycle lengths. The intersection to be modelled must be the second intersection and must have an intersection (TCS) number of 9999.

**Default Design Speed for Off-Peak**

Generally this is the speed limit. This speed is used for creating the default speeds for all links. These can be altered in a subsequent module.

**Maximum Number Of Link Lanes for Peaks/Off-Peaks**

This means the number of lanes across the whole road at the widest part, e.g. 6. It does not include turn bays or slip lanes.

### 4.3 SYSTEM GEOMETRIC DATA MODULE

**General Information**

This module provides for the entry and editing of intersection numbers, SCATS slot numbers, the type of intersection, link speeds, sub-system numbers and the distance between intersections in metres (see description of each item below). The compulsory entries are: intersection numbers, intersection types and distances. Slot numbers are essential to obtain SCATS data. When first entering data the sub-system numbers cannot be entered or altered as these will be calculated by SCATES. Use Pg Up and Pg Dn to move between pages of every 4 intersections. To add an intersection to the system, move the box to an intersection that will be adjacent to the new one. Press Key 'Ins' and the user will be asked appropriate questions to complete the addition. Data in subsequent modules must be updated. To delete an intersection, move the box to the intersection number and press key ‘Del’.

**TCS Number**

This is generally the traffic signal number and can be any number between 1 and 9999. Duplicate numbers cannot be used in the same file.

**Slot Number**

This is the SCATS regional computer interface (modem) reference number. Required to produce SCATS output data. May be any number between 1 and 128. Duplicate numbers not acceptable.

**Intersection Type**

This describes the type of the intersection to the model and is used to calculate as much default data as is feasible. It is also used in the model calculations to identify certain optimisation routines.

The maximum number of signalised approaches that can be modelled is 4. Intersections with a greater number of signalised approaches are rare and can usually be modelled as 4 approaches with modified phasing without unduly affecting the accuracy of the results.

The intersection types are:

(a) ‘M’ for Mid block pedestrian crossing,
(b) ‘D’ for a 4 way junction with diamond phasing on the coordinated road,
(c) ‘C’ for a 4 way junction with conventional phasing on the coordinated road,
(d) ‘T2’ for a T-junction with the stem of the T being approach 2; this will be on the bottom of the coordinated road,
(e) ‘T4’ for a T-junction with the stem of the T being approach 4 (top),
(f) ‘S2’ for a Seagull junction with same general geometry as a T2 type (max. of 3 phases), and
(g) ‘S4’ for a Seagull junction with same general geometry as a T4 type (a max. of 3 phases).

When intersection types are altered during an edit then all data in subsequent modules must be edited.

**Speed**

The expected or measured free flow mean speed in the link in the direction of travel in non-peak hour conditions. These are initially all set to the default off-peak design speed entered in the System Module.

**Sub-system Numbers**

After a file has been completed the numbers shown here indicate the sub-system number of each intersection. The numbers will initially be sequential numbers from 1 to the total number of sub-systems. These can be altered in the sub-system Module to SCATS sub-system. SCATS sub-system numbers cannot be altered in this module. In this module intersections can be moved from one sub-system to an adjacent sub-system provided the intersection is the only or first or last one in a sub-system.
Moving Intersections to another sub-system number will automatically put a protection lock on the file which inhibits the recalculation of all phase split and sub-system data. Recalculation can be forced by removing the lock in which case edited phase split and sub-system data will be lost. Note that a 'Seagull' type intersection that does not have a pedestrian movement cannot be the master intersection (SCATS PPO) in a sub-system and hence cannot be in a sub-system by itself.

Distance

This is the distance between intersections in metres from stop line to stop line. Where the directional distances are different then choose a mean compromise.

4.4 VOLUME DATA MODULE

General Information

This module provides for the entry and edit of: volumes, saturation flows, movement phases, turn bay lengths, slip lane lengths, walk times, late start times, Seagull walk times and walk phase and if needed the Seagull side street phase to be merged. F8 enables intersection pages to be selected by the intersection number. F9 enables the saturation flow data that SCATES has calculated from the user's input data to be viewed.

Each intersection has a screen page in this module. The page is in the form of a tabulation with a drawing of the intersection in the bottom left hand corner. Animated arrows on the drawing indicate which movement the user is entering data for. The tabulation is divided into three main areas for a.m., p.m. and business hours data. A further area is devoted to fixed data such as turn bay lengths.

A box type cursor indicates the data entry position. The current entry is completed when the cursor is moved to another location. Press F10 for Help at any cursor position. Tab moves the edit box directly to the bottom menu for bay lengths (Bay), slip lane lengths (Slip), late starts (L/S), minima (Min), and pedestrian conflict time (P/D) to be entered or edited.

Approaches are numbered 1 to 4 anti-clockwise and are identified on the left hand side of the screen under 'A'. Movements are identified as L, T and R for left, through, and right on the left side of the screen next to the approach number. The approach numbers are shown on the intersection drawing at the bottom of the screen and the approach/movement combination for the location of the edit box is shown by arrows and a highlighted number. Warning and Error messages for invalid data are generated.

For 2 phase T-intersections where the stem is one way away from the main road, code the stem as 'C' phase with zero volume. When creating a data file in any module pressing F7 causes a move to the next screen of the module to be entered or if all screens are complete to the next module. However an incomplete file can be saved from this module by pressing F4 which will save the data entered to a file. Data entry can be continued at a later time with the edit option.

Volume

Volumes are entered in pcu's per hour. The through volumes on the coordinated approaches cannot be entered as these are progressively calculated from the entry demands and the intersection movement volumes that the user inputs. During the creation of a new file, default volumes are placed in the correct cells for the type of intersection specified. These volumes have no significance except to indicate where volumes should be expected for a standard intersection of that type and to enable test files to be generated without entering any data in this module.

If a zero volume is entered, all approach/movement data in all plans is zeroed. All movements on a one-way street approach which exits traffic from the system must have zero volumes and saturation flows but a phase the same as the through movement of the opposite approach. If volumes exceed the probable capacity of the default saturation flows then a new default saturation flow is calculated. A warning message occurs if a negative volume occurs for through movements on the main road when entering a turn volume. Ignore this if the entry of other data eliminates the negation otherwise check the total volume data.

Saturation Flow

Saturation flows must be the maximum movement saturation flow and not a lane flow. They must not be modified for short lane or shared lane affects as this will be calculated by SCATES. Similar allowance for parking should not be made as SCATES
also calculates the modification required. The final calculated saturation flows can be viewed by pressing F9. This calculation does not occur in the Volume Module. If the user wishes to view changes then press in sequence F7, F4 and F9. The SCATES saturation flows cannot be altered except by variation of the original saturation flows or volumes or bay or slip lane lengths.

Saturation flow entries will be copied to the other plans during the creation of a new file unless these have already been entered.

Saturation flow rules for through movements are as follows:

(a) They must be the maximum saturation flow for the number of active approach lanes regardless of them being shared lanes.

(b) If parking is allowed in a lane in a peak or business hour period then it will not be active in that period. SCATES will compare the lower saturation flow in that period with the other periods and calculate a new saturation flow allowing for about 40 metres of no stopping prior to the stop line.

(c) RHT bays or LHT slip lanes or through lanes dedicated to turning traffic are not through lanes.

For right or left movements, the rules are:

(a) They must be the maximum saturation flow from the number of lanes from which the vehicle turn regardless of any short lane jamming affects or sharing considerations.

(b) All shared lane situations must have a a turn bay or slip lane specified of 20 metres. This information is used by SCATES to indicate shared lanes for saturation flow calculations and other purposes.

(c) For normal bays or slip lanes, always use a length longer than 20 metres.

(d) For through lanes dedicated as bays or slip lanes, always use a length longer than the link length of the approach.

Phases

The phases during which the movement is active are entered for all movements. If a movement has zero volume then a phase should be entered that is the same as the adjacent movement. Valid phases are 'A' thru 'G'. A maximum of three phases are allowed for overlaps. All overlaps must be entered in the correct operating sequence.

For left hand turns that may turn at any time enter 'S'. 'S' must not be used in combination with phases. For right hand turns that filter use 'S' and this cannot be used with phases. 'S' cannot be used for the main road RHT for Seagulls or for 'diamond' RHT's. Diamond overlaps are provided for on all approaches of type 'D' intersections and on approaches 2 and 4 of type 'C' intersections.

Gains

Enter the pcu's/h that enter the system from non-signalised sources. These could be parking stations or non-signalised junctions. Traffic is allowed to enter when there are no conflicts. Delay is calculated for this traffic.

Losses

Enter the pcu's/h that leave the system at non-signalised sources. These could be parking stations or non-signalised junctions. Traffic is allowed to leave as soon as it reaches the location which is assumed to be mid block.

Mid-Block Pedestrian Crossing Walk Time

Enter the (walk + clearance) time in seconds.

Seagull RHT Bay Length

Enter the length of the RHT bay in metres. It cannot exceed the link length minus 20 metres unless a through lane is in fact the RHT lane.

Seagull Pedestrian Crossing Walk Time

This is the walk across the normally non-signalised approach. Enter the (walk + clearance) time in seconds.

Seagull Pedestrian Crossing Walk phase

This is the walk across the normally non-signalised approach. Enter the phase preceding the introduction of the walk.

Seagull Merge Phase

If it is desirable for the side street of a Seagull to be merged with the normally non-signalised approach for safety or coordination reasons then enter the side street phase. This will ensure that the side street traffic enters the traffic stream during a gap in the platoons.
RHT Bay Length

Enter the length of the RHT Bay in metres. It cannot exceed the link length minus 20 metres unless a through lane is dedicated as the RHT lane. If a RHT is from a shared lane then a length of 20 metres must be entered. During creation of a new file a default Bay length of 20 is created when a RHT volume is entered for intersection types 'C' and 'T'. For types 'D' and 'S' the default bay length is 70. RHT bays from the stem of a T-intersection are not allowed.

Slip Lane Length

Enter the length of the slip lane in metres. It cannot exceed the link length minus 20 metres unless a through lane is dedicated as the LHT lane. If a LHT is from a shared lane then a length of 20 metres must be entered. During creation of a new file a default Bay length of 20 is created when a LHT volume is entered. Slip lanes from the stem of a T-intersection are not allowed.

Late Start Period

Late starts if specified operate at the start of the first phase in the coordinated phase sequence. They can be used to model conditional pedestrian features. If entered as a positive number the late start will be in seconds and will cease to operate when the cycle length is below the pedestrian phase skip cycle length. If entered as a negative number then thelate start will be a percentage of the cycle length modelled and will operate at all cycle lengths. The early start of a diamond phase in one direction is not specified by using the late start facility as the diamond early start is calculated from the volume and saturation flow data.

Minimum Phase Time

This is a minimum phase time specification for the through movement for any approach. In the calculation of phase splits a maximum cycle length of 140 seconds is assumed and the minimum time is calculated as a Y value (or flow/saturation flow ratio). The minimum phase time may be the (walk + clearance) time if pedestrian activity is more significant than vehicle activity. If this is greater than the vehicle Y value then it is used.

LHT Pedestrian Delay

This is a time period in seconds that a LHT will be prevented from turning due to conflict with pedestrians. The time is converted to a Y value at an assumed maximum cycle length of 140 seconds and added to the LHT movement Y value.

4.5 PHASE TIME AND SEQUENCE DATA MODULE

General Information

If data has been entered in any of the previous data modules and the data in this module has not been protected from change by a lock command then all cycle length, phase split and SCATS data is calculated and displayed in this and the next module. Editing in this module causes an automatic lock to be applied.

The calculation is performed for each of the three time-of-day periods and the methodology is:

(a) For each intersection and each of the three time-of-day periods calculate the full phase sequence.

(b) For each intersection calculate the true saturation flows for each movement taking into account shared and short lanes.

(c) For each intersection calculate the Y values for each movement taking into account phase minima, late starts and pedestrian conflict delay times.

(d) For each intersection identify the critical movements and calculate the isolated cycle length.

(e) Determine the longest intersection cycle length for each time period and make it the time-of-day period coordinated cycle length.

(f) Calculate the isolated phase splits.

(g) Calculate the coordinated phase splits and allocate the appropriate spare time to the phase with the highest X value where the isolated cycle length is less than the coordinated cycle length. Equalise phase times to the highest where they are within 5% of each other.

(h) For each intersection compare the differences in the phase splits for each time-of-day period and identify the type of SCATS split plan selection (real-time, mode = 1 or library, mode = 0) and if the intersection will be the master one of a sub-system. Identify the 'stretch phase' (<<) on which the controller shall rest in the absence of demands and which will also receive spare time from other phases due to vehicle actuation.
(i) Analyse the system for the creation of sub-systems containing only one master intersection and the most suitable grouping of other intersections into the sub-systems. Identify the master sub-system as being the closest sub-system to the centre of the system.

(j) Select the highest of the three time-of-day period cycle lengths as the preferred maximum cycle length for SCATS (X%) and calculate the maximum congestion cycle length (>%) as X%+20 if not greater than 180 seconds.

The phase time and sequence data module provides for the editing of: phase times, stretch phase, sequence and type of SCATS phase split operation. Phase times may be trimmed if necessary by entering a new value for any phase with the exception of the stretch phase. The sequence may be altered provided that new phases are not introduced. The stretch phase may be altered to any phase in the sequence.

Note that data editing carried out in this module will put a lock on the phase split and sub-system data. This means that in future edits this data will not be recalculated. At the completion of a create file or edit session the user also has the opportunity to lock the phase split and sub-system data so that it will not be recalculated during subsequent edits. Conversely the user may unlock this data and have it recalculated.

**Phase Time Percentage**

New percentage phase times are entered in this module. Stretch phase time cannot be altered but will be recalculated when another phase time is altered. The value shown for the mid block pedestrian minor phase is the time in seconds entered in the volume module. It may also be edited in this module. No stretch phase time is shown because the walk period is not a percentage.

**Sequence**

The sequence calculated by SCATES should be correct if the movement sequences were entered correctly. If the sequences displayed here are different to the expected then check the movement sequences in the Volume Module. The only exception is the sequence of split approach phases on approaches 2 and 4 where SCATES assumes an alphabetical sequence. The sequence can be altered here provided the phases remain the same.

**Stretch Phase (<>)**

The SCATES stretch (<> phase is calculated as the most important phase in the movement that has the highest X value. It may be altered to any phase in the sequence by skilled SCATS operators.

**Mode**

Mode = 0 is for split plan selection from the SCATS plan library. Mode = 1 is for Incremental Split Operation (ISS) in real time. Mode = 2 is the same as for Mode = 0 except side street delay is not calculated. This is necessary when analysing two systems that cross at a common intersection. Mode = 3 is the same as Mode = 1 except for no side street delay calculation.

### 4.6 SUB-SYSTEM DATA MODULE

**General Information**

This module lists the critical intersection number for each time-of-day period and provides for the editing of:

(a) Sub-system numbers in order to change them to SCATS sub-system numbers,

(b) Congestion cycle length for SCATS (>%),

(c) Normal maximum cycle length for SCATS (X%),

(d) Sub-system master intersection for SCATS,

(e) Master sub-system number for SCATS, and

(f) The calculated cycle lengths for the a.m., p.m. and business peaks.

If data has been entered in any of the previous data modules and the data in this module has not been protected from change by a lock command then all cycle lengths and SCATS sub-system data is calculated and displayed in this module. Editing in this module causes an automatic lock to be applied (see previous warning on the Phase Time and Sequence Data Module).

**Sub-System Number.**

Enter the correct SCATS sub-system (SS) Number. Sub-system numbers can be altered in this module. They cannot be altered in the Geometric Module. The Geometric module provides for intersections to be moved from one sub-system to another.
Note that a Seagull type intersection that does not have a pedestrian movement or a merge phase cannot be a master (PP0) intersection and hence cannot be in a sub-system by itself.

Normal Maximum Cycle length for SCATS (X\%)

This is the cycle length above which SCATS introduces stretch time. Below this cycle length SCATS operates in an 'equisat' mode and above it the degree of saturation is increased for the non-stretch phase movements.

Sub-system Master Reference Intersection (PP0)

This is the intersection in each sub-system which is the reference intersection for sub-system offsets. For example, it will have the offset reference of zero.

Master Sub-System Number

This is the number of the sub-system to which all other sub-systems eventually are married to. It has no offset reference to other sub-systems and its offset reference is 0 (LPO). To reduce the length of a chain of married sub-systems, the 'master' one is ideally located near the centre of the system.

Congestion Cycle Length for SCATS (>%) 

This is the maximum cycle length for the sub-system for SCATS. The value calculated by SCATES is the highest of the three peak periods analysed + 20 seconds. If greater than 180 seconds then it is 180 seconds. The difference between X\% and >% is the amount of stretch available.

Normal Maximum Cycle Length of the System for the A.M./P.M./Business Peak

This is the result of the calculations for the a.m./p.m./business peak and is the cycle length which will be used to calculate the a.m./p.m./business peak offsets. SCATS users who have not used accurate movement volumes should set this cycle length to the proven a.m./p.m./business peak cycle length.

5. EXAMPLES OF OUTPUT DATA

The outputs are as follows:

(a) SCATS offset data and control data to printer,
(b) SCATS Offset Data and control data to file for direct loading to a regional computer,
(c) SCATS phase split data to a printer or a file,
(d) Cableless (FLEXILINK) Data to a printer or a file,
(e) SCATES input data,
(f) All detailed performance data such as delay, stops, fuel, speeds and cost data for a single model run to a printer and to a file, and
(g) All detailed performance data such as delay, stops, fuel, speeds and cost data for all models in a comparative run plus a summary of the differences between the base case model and the other models to a printer and files.

Figure 1 illustrates the annual operational data of the Cleveland Street sub-system in Sydney and compares the outputs between isolated control and signal coordination using SCATS. Screen outputs showing the geometry of a system and the performance indices are shown in Figs 2 and 3 respectively (the original diagrams are in colour). Readers are referred to the SCATES user manual for the details of data input and output (Sims 1988).

6. CONCLUSIONS

SCATES is a useful computer program for optimising signal settings and predicting delay, stops, fuel, etc. for a linear coordinated traffic signal system and for a single intersection. Its other facilities for the calculation of system performance are particularly suitable for road designs and warrants. The program requires the user to have fundamental understanding of traffic engineering. Detailed knowledge of SCATS is, however, not necessary to use the program and SCATES should find many applications in Australia and overseas countries.
REFERENCES

SCATES Performance Summary (Annual)

Data File :- CLEVNOW.DAT  System :- CLEVELAND ST.
Stop Penalty = 20.  Pedestrian Control Cycle Length = 70.
Peak Hour Lanes = 4  Business Hour Lanes = 4

The following demands and capacities are calculated at the critical intersection in the indicated direction.
P.M. peak capacity for dir. 2 at 529 is 1319, demand is 964, difference 355
P.M. peak capacity for dir. 4 at 525 is 1582, demand is 1203, difference 379
A.M. peak capacity for dir. 4 at 534 is 1369, demand is 1065, difference 304
A.M. peak capacity for dir. 2 at 534 is 974, demand is 732, difference 242
Business capacity for dir. 2 at 534 is 899, demand is 633, difference 266
Business capacity for dir. 4 at 534 is 765, demand is 580, difference 185

Comparison Between Isolated and SCATS Control

<table>
<thead>
<tr>
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<th>Isolated</th>
<th>SCATS</th>
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<tbody>
<tr>
<td>Route length in km</td>
<td>1.50</td>
<td>1.50</td>
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<tr>
<td>Number of traffic or ramp signals</td>
<td>10.00</td>
<td>10.00</td>
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<tr>
<td>Average speed (includes side streets) (km/h)</td>
<td>8.14</td>
<td>19.09</td>
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<td>Annual vehicle hours at cruise (millions)</td>
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<td>0.35</td>
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<tr>
<td>Annual vehicle hours of delay (millions)</td>
<td>2.13</td>
<td>0.71</td>
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<tr>
<td>Total annual vehicle hours (millions)</td>
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<td>1.06</td>
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<tr>
<td>Annual vehicle km (millions)</td>
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<tr>
<td>Mean AADT</td>
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<tr>
<td>Annual number of stops (millions)</td>
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<tr>
<td>Annual fuel used in litres (millions)</td>
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<td>Annual fuel cost (millions)</td>
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<td>Annual vehicle operating cost (millions)</td>
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<td>Annual vehicle operating time cost (millions)</td>
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<td>Annual total operating cost (millions)</td>
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<td>Total operating cost / veh-km.</td>
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<td>0.71</td>
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<tr>
<td>Total operating cost per veh</td>
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<td>1.07</td>
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Fig.1 - SCATES annual operational data
Fig. 2 - System geometric data

Fig. 3 - Performance index graphs
THE TRAC SYSTEM

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ABSTRACT

The Traffic Responsive Area Control (TRAC) System has been developed by the Main Roads Department, Queensland to meet the area traffic control requirements of towns and cities. For large cities, a number of regional systems are linked in a network. The traffic control functions are distributed between a regional computer and microprocessor-based local traffic signal controllers. The regional computer performs the tasks that relate to the system as a whole, and the local controllers perform the tasks that relate to the intersections. Coordination plans are selected by the regional computer using average detector occupancy information. The plan selected is optimised by the local controller using the current detector data. If the communications between the regional computer and the local controller is lost, the controller ‘falls back’ to ‘cableless linked’ operation. The system provides a sophisticated user interface to ensure simple operation and a small training and support requirement. IBM PC’s or compatibles can be connected to the system as ‘workstations’ and they provide high resolution colour graphic displays of the system’s operation. The workstations can be connected to any system via dial-up or dedicated lines.

ACKNOWLEDGEMENTS: (1) To Main Roads for its commitment to the development of the TRAC system and permission to prepare this paper. (2) To the staff of the Traffic Systems Development section for their considerable contributions, talents and enthusiasm. (3) To the users of the system for their practical advice and assistance.
1. INTRODUCTION

TRAC is an acronym for Traffic Responsive Area Control, the area traffic control system developed by the Main Roads Department, Queensland. It is installed at four sites in Brisbane and these systems are connected in a network. It is also installed in the Queensland provincial cities Cairns, Townsville and Surfers Paradise. Further installations are planned for Ipswich, Toowoomba, Rockhampton and the Sunshine Coast.

Main Roads installed its first area traffic control system in Surfers Paradise in 1969 and this was followed by a system in Brisbane in 1973. These systems operated successfully until 1987. The techniques implemented in the TRAC system have evolved from the experience gained in the operation of these earlier systems.

The system will be described in this paper under the headings:

(a) System Overview,
(b) Introductory Concepts,
(c) Regional Control and Monitoring Software,
(d) Local Controller Software,
(e) Operator Service Software,
(f) Communications Software,
(g) System Hardware, and
(h) Proposed Developments.

2. SYSTEM OVERVIEW

The TRAC system has been designed to meet all area traffic control requirements - from a small number of intersections in a provincial town, to a large number of intersections in a major city. The requirements of large cities are met by linking a number of autonomous regional systems.

Where the systems are linked in a network, software is provided to ensure coordination can be achieved between intersections connected to different regional systems. The network facilities also provide for centralised data management, monitoring and reporting.

Each regional system is designed to control 96 intersections and the intersections can be grouped into 32 subsystems if required. The subsystems are usually groups of intersections in areas with similar traffic conditions. Sixteen vehicle detectors per intersection can be used to provide information for the regional computer.

There are no special requirements for the shape, or the location of the vehicle detectors. The intersection detectors are placed where they would normally be, in a fully traffic actuated environment. If the intersections have been operating fully traffic actuated before the coordination system was installed, detector changes are usually unnecessary.

The system uses microprocessor-based controllers, so the software design is based on the concept of distributed processing. Functions that relate to the system as a whole are performed by the regional computer. Functions that logically relate to the intersection are performed by the microprocessor in the local controller.

2.1 REGIONAL TRAFFIC CONTROL FUNCTIONS

The traffic control functions performed by the regional computer include:

(a) Synchronisation of the system clocks,
(b) Management of all data,
(c) Selection of appropriate coordination plans,
(d) Monitoring the operation of the local controllers and the vehicle detectors, and
(e) Provision of service to the operator.

The coordination plans are normally selected using information received from the vehicle detectors. They can also be selected from time-of-day schedules, or they can be nominated by the operator.
2.2 LOCAL TRAFFIC CONTROL FUNCTIONS

The local traffic control functions performed by the microprocessor in the controller include:

(a) Implementation of the coordination plan selected by the regional computer,
(b) Optimisation of this plan using information from the traffic detectors,
(c) Collection of volume and occupancy data from the vehicle detectors, and
(d) Implementation of a locally selected plan in the event of loss of communication with the regional computer.

2.3 OPERATOR FACILITIES

To achieve their full potential, area traffic control systems must be easy to use. For this reason, significant effort has been directed into the development of the user interface.

A comprehensive set of operator service functions is provided. These include programs for the display of current traffic operations, data management, message reporting, vehicle counting, and maintenance aids. The operations display programs include high resolution colour graphic displays of intersections, subsystems, regional systems and the network.

2.4 HARDWARE

The regional computer hardware consists of an HP1000 processor, a disc drive, a cartridge tape drive, a terminal for the system console, a printer for messages and reports, and a calendar-clock. Local or remote IBM and compatible PC's can be connected to the regional computer. These PC's function as traffic engineering workstations and are used for the colour graphic displays.

Communications between a remote operator and a regional system can be achieved using either a dial-up line or a dedicated line. The communications between regional computers connected in a network is performed using dedicated lines. In networked systems, asynchronous terminal channels and synchronous computer channels may be multiplexed over the same dedicated line.

The communication between the regional computer and the AWA or Philips microprocessor-based local controllers occurs via 300 bps serial links. Separate lines can be used to each controller, or multiplexed links can be used for groups of intersections. The data communications for 16 intersections can be multiplexed over a single leased line. The communications protocol is a variation of the one used by the SCATS system.

A schematic representation of a typical provincial city TRAC system is shown in Fig. 1.

2.5 DOCUMENTATION

The documentation which accompanies the TRAC system consists of two manuals - the User Manual and the System Administration Manual. The User Manual is a training aid, and is designed to introduce the system to the traffic engineers and operators. It contains descriptions of the programs required by these users, and details of the operating procedures. Because the system is simple to use, this manual is rarely required during normal operations.

The System Administration Manual is designed for those who install and manage the system. It describes the automated software installation procedures, configuration details for the hardware and software, disc management procedures, preventative maintenance, etc. Also included are listings of the customised operating system files which apply to the particular system.

2.6 PROPOSED DEVELOPMENTS

Proposed enhancements to the system include:

(a) The addition of performance measurement software,
(b) Enhancements to the operator service functions with the addition of more PC-based graphic displays, and PC-based forms management,
(c) Conversion of the system to the Unix operating system, to enable it to run on a wide range of hardware, and
(d) Inclusion of software for the generation of coordination plans.
3. INTRODUCTORY CONCEPTS

A number of basic concepts that are relevant to the TRAC system are considered in this section. These are:

(a) Operating Modes,
(b) Coordination,
(c) Plans, and
(d) Fallback

3.1 OPERATING MODES

The term Operating Mode is a summary term describing the type of control operating at an intersection. The operating modes that can be used are:

(a) Lamps Off,
(b) Flashing Yellow,
(c) Isolated - Fully traffic actuated,
(d) Coordinated - Traffic actuated, and
(e) Coordinated - Fixed.
In the Isolated mode, the controller operates independently and is usually fully traffic actuated. The green signals are introduced and extended to satisfy the demands received from the vehicle and pedestrian detectors. Maximum phase timers ensure all movements receive attention when the traffic is heavy.

In the Coordinated - Traffic Actuated mode, the controller references a coordination plan. The coordination plan defines the green signal introduction times required for uninterrupted travel through adjacent intersections. This plan is adjusted within limits to respond to the particular traffic at the intersection.

In the Coordinated - Fixed mode, the traffic actuation facilities are turned off. The controller then operates strictly according to the coordination plan. This mode is only used for testing purposes. It allows the coordination data to be checked by driving through the system.

### 3.2 COORDINATION

Coordination can be achieved when two or more intersections operate on a common cycle time and reference sets of phase timing data that relate to a single timing reference. The common cycle time is the Subsystem Cycle Time. The phase timing reference is called the Subsystem Cycle Clock, and it cycles from the value one, to the Subsystem Cycle Time.

In the TRAC system, a copy of the Subsystem Cycle Clock is held in each local controller. The Subsystem Cycle Clocks must be synchronised to achieve coordination.

### 3.3 PLANS

The traffic control technique used is based on the definition of subsystems with associated stored plans. These plans are the means used to specify the traffic control strategy to be used for the subsystem. The most significant parameter in the plan is the operating mode, and any of the available modes can be specified. The operating mode normally specified is coordination, and the plan becomes a coordination plan.

A total of 16 plans exists. The plans numbered one to eight have associated data elements which include operating mode, subsystem cycle time, phase introduction times, and phase variation information. Normally these plans are used for coordination data and, in most situations, all intersections in the subsystem have the same operating mode specified. However, as the mode is part of the plan data which is specified for each intersection, it is possible to have an intersection operating in a different mode from others in the subsystem.

Plans 9 to 12 are available, but are currently not used. These plans have the same associated data elements as plans one to eight. Plans 9 to 12 are not used, because eight plans meet the current requirements. This limit of eight plans has the advantage that the data will fit across an 80 column screen, and an A4 page. If additional plans are required in the future, plans 9 to 12 will be included.

Plan 13 is defined as the transition plan, and is used when a change occurs from one coordination plan to another. Plan 13 is not available for operator specified data. (Transition plans are described more fully in the section on controller software.)

For three plans, the operating mode is fixed and is implied by the plan number. These plans have no other associated data and therefore require no data storage in the local controller. The plans with fixed operating modes are:

(a) Plan 0 - Isolated,
(b) Plan 14 - Flashing Yellow, and
(c) Plan 15 - Lamps Off.

These plans can be used when the modes Isolated, Flashing Yellow, or Lamps Off, are required for all intersections in a subsystem. This saves plans one to eight for coordination mode, or for situations where the intersections in a subsystem require different modes for a particular plan.

### 3.4 Fallback

If communications between the regional computer and a local controller is lost, the local controller reverts, or falls back, to local control. In the fallback state, the local controller software clock is maintained solely by the 240 V mains frequency.

The controller can still select plans in this fallback state, if the following conditions exist:

(a) The local controller's linking software is enabled.
(b) The time-of-day plan introduction schedules are stored locally.
(c) The plan data is stored in the controller’s memory.

These conditions normally apply in the TRAC system, so the controllers remain linked, when they fallback. The selected plans will usually define the operating mode as coordinated, however all operating modes are possible. The fallback state when linking software is enabled is referred to as cableless linked.

If the above conditions are not met, the controller operates in the Isolated mode when it falls back to local control.

4. REGIONAL CONTROL AND MONITORING SOFTWARE

The control and monitoring functions performed by the regional computer include the following:

(a) Synchronisation of the System Clocks,  
(b) Management of the Plans and Schedules,  
(c) Plan Selection,  
(d) Monitoring of the Vehicle Detectors, and  
(e) Monitoring of the Local Controllers.

4.1 SYNCHRONISATION OF THE SYSTEM CLOCKS

To achieve coordination with the distributed approach used by the TRAC System, all local controller time-of-day clocks must be synchronised. The time reference chosen is standard time and in Brisbane, Eastern Standard Time applies. The regional computer maintains standard time in the local controllers by establishing a clock hierarchy and synchronising these clocks as follows:

Network Clock. If regional systems are connected in a network, one system is nominated to provide the timing reference. This system’s battery-backed hardware clock becomes the network clock, and it is set to standard time.

Regional System Clock. In a network, the regional system’s hardware clocks are set programmatically from the network clock each day. For stand-alone regional systems, the hardware clock is set directly from the standard time.

Operating System Clock. The regional computer’s operating system clock is set from the hardware clock each day.

Local Controller Clock. The regional computer sets the local controller’s time-of-day software clocks to standard time each minute, if the communications link is operational.

If communications with a local controller is lost, the regional computer is unable to maintain standard time in that local controller. This controller clock is then solely dependent on the 240 V mains frequency, and it will drift relative to standard time. To compensate for this, the regional computer does not set the other controller clocks in this subsystem to standard time while the communications link is down. All controller clocks in the subsystem will then remain synchronised by the mains frequency, and coordination in the subsystem will be maintained.

The local controller derives its cycle timing reference from the time-of-day software clock. This cycle timing reference is the Subsystem Cycle Clock. The derivation of the Subsystem Cycle Clock from the local controller’s time-of-day software clock is explained in the section on local controller software.

4.2 MANAGEMENT OF THE PLANS AND SCHEDULES

All traffic control plans, and the subsystem’s time-of-day plan introduction schedules, are stored in the regional computer. The regional computer converts this data into the form required and sends it to each local controller. This is done when the communications link with the controller is established, and whenever relevant data changes are made.

The plans and schedules are processed as follows:

(a) Plans. The coordination plan data entered by the operator includes the subsystem cycle time, coordination offset, phase introduction times, and additional phase control data. The phase timing and special control information is specified relative to the start of the cycle. The local controller requires the timing information as introduction times which reference the Subsystem Cycle Clock, so the regional
computer converts this data into the required form. The plan data with the required adjustments is then sent to the local controller.

(b) Time-of-day Plan Introduction Schedules. The operator specifies the time-of-day plan introduction schedules for each subsystem for normal operations. In addition, a special event calendar can be defined for public holidays or other unusual conditions. Four additional schedules can be defined for these special events.

The regional computer re-examines these schedules each day and produces a time-of-day plan introduction schedule for the next week. This derived schedule is used by the regional computer if plan selection by time of day is required. It is also sent to the local controller to be the fallback schedule if communications failures occur.

While the data in the controller is being updated, the regional computer sets the controller's fallback mode to isolated. This ensures that the controller does not attempt to run coordinated on incomplete data. This situation could occur if the communications link failed during the data loading process.

4.3 PLAN SELECTION

The plans for each subsystem are selected by the regional computer. The selected plan numbers are sent to the local controllers, where they are implemented by the local controller software. The plans can be selected using one of the following methods:

(a) Average vehicle detector occupancy,
(b) Time-of-day schedule, and
(c) Operator override.

4.3.1 Plan Selection Using Average Detector Occupancy

Detector occupancy information is obtained for up to 16 vehicle detectors per intersection. Detector occupancy is a measure of the time the vehicle detector loop is actually occupied by a vehicle. The occupancy information for each detector is accumulated for one-minute periods and it is held by the regional computer as a percentage.

For plan selection purposes, the vehicle detectors in each subsystem are assigned to occupancy groups. All occupancy detectors in each subsystem automatically belong to the all detectors group. They may also be associated with one of the other four groups available. Each minute, an average detector occupancy value is determined for each detector group in each subsystem. This is done as follows.

A linear regression analysis is performed using the average detector occupancies for each detector group for the current sampling period. The sampling period is specified by the traffic engineer and must be in the range 5 to 15 minutes. The value of average detector occupancy to be used for plan selection is then determined by projecting from the mid-point of the current sampling period along the regression line. This projection interval is also specified by the traffic engineer, and must be in the range 0 to 15 minutes. This procedure is summarised in Fig. 2.

The values of average detector occupancy determined for each detector group are then compared with the subsystem's detector occupancy plan selection table. This table defines the average detector occupancy range limits for each plan. The average detector occupancy range limits are specified for all detectors in the subsystem, and for the four other detector groups if required. The plan selected is the one which satisfies all the specified conditions. If more than one set of conditions are satisfied, the set containing the highest detector group number determines the plan.

The form of the detector occupancy plan selection table is shown in Table I. This table shows the data entry screen and the associated help information used by the traffic engineer when specifying this data.

4.3.2 Plan Selection by Time of day

Time of day is used to select the required plan for the subsystem in the following situations:

(a) The detector occupancy selection data has not been specified.
(b) The number of operating detectors is less than 75% of the total number defined in the subsystem for use in the occupancy calculations.
(c) The specified time-of-day plan introduction schedule includes an override indicator for the current time. The override indicates that selection of the associated plan is mandatory at this time.
(d) One or more controllers in the subsystem have lost communications and have fallen back to cableless link operation.
4.3.3 Plan Selection by the Operator

Facilities are provided to allow the operator to override the other plan selection methods, and nominate a particular plan for a subsystem. This is normally used for checking the coordination data, but it can also be used for special events or emergency situations. When a plan override is invoked, the time at which the override will be automatically released, is also set by the operator. The default period is one hour.

4.4 MONITORING OF THE VEHICLE DETECTORS

The performance of a traffic responsive area control system is critically dependent on the accuracy of the data from the detectors. For this reason, the monitoring of the vehicle detectors by the regional computer is comprehensive. The local controller software does not make any detector monitoring decisions.

It is known that vehicle detectors may fail in the following ways:

(a) Continuously occupied. The detector appears to be continuously occupied by a vehicle even when the loop is unoccupied.
(b) Continuously Unoccupied. The detector fails to register the presence of a vehicle when the loop is occupied by a vehicle.
(c) Overcounting. The detector counts more vehicles than actually pass over the loop. A particular case of this fault occurs when the detector pulses and records an impossibly high number of vehicles.
(d) Undercounting. The detector misses some vehicles that pass over the loop.

For monitoring purposes, the regional computer data classifies the vehicle detectors into the following categories:

(a) Very high volume detector,
(b) High volume detector,
(c) Normal detector,
(d) Low volume detector,
(e) Very low volume detector, and
(f) Off peak parking-bay detector.

The regional computer uses the one-minute volume and occupancy information returned from the local controllers to determine if the detectors are operating correctly. The tests used are:

(a) Continuously Unoccupied test. An unoccupied timer is maintained for all detectors and it is reset whenever the one-minute volume for the detector is non-zero. The detector is deemed to have failed if the unoccupied timer reaches the fail time. The fail time is recalculated each minute using formulae which increase the fail time in periods of low traffic activity, and for low volume detectors.
### TABLE I

**DETECTOR OCCUPANCY LIMITS FOR PLAN SELECTION**

<table>
<thead>
<tr>
<th>Subsystem Data Summary</th>
<th>PLAN SELECTION FROM DETECTOR OCCUPANCY</th>
<th>Form 3 of 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUBSYSTEM 1</td>
<td>Ipswich Rd. O’keefe St. to Juliette St.</td>
<td></td>
</tr>
</tbody>
</table>

**Occupancy Sample Period 10 min**

**Occupancy Projection 2 min**

<table>
<thead>
<tr>
<th>Occupancy Limits % for</th>
<th>Plan</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Detectors</td>
<td>- Low</td>
<td>0.0</td>
<td>3.0</td>
<td>15.0</td>
<td>30.0</td>
<td>30.0</td>
<td>30.0</td>
<td>25.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>- High</td>
<td>5.0</td>
<td>18.0</td>
<td>35.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Group 1 Detectors</td>
<td>- Low</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>35.0</td>
<td>.</td>
<td>.</td>
<td>0.0</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td>- High</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>100.0</td>
<td>.</td>
<td>.</td>
<td>20.0</td>
<td>.</td>
</tr>
<tr>
<td>Group 2 Detectors</td>
<td>- Low</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>0.0</td>
<td>36.0</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td>- High</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>10.0</td>
<td>100.0</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Group 3 Detectors</td>
<td>- Low</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>20.0</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td>- High</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>100.0</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Group 4 Detectors</td>
<td>- Low</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>25.0</td>
<td>.</td>
</tr>
<tr>
<td></td>
<td>- High</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>100.0</td>
<td>.</td>
</tr>
</tbody>
</table>

**SUBSYSTEM DATA SUMMARY FORM 3 HELP**

**OCCUPANCY SAMPLE PERIOD**: Period over which the one-minute average detector occupancies will be sampled to determine the value of occupancy to be used for plan selection. The range is 5 to 15 minutes. The sampling process is repeated each minute.

**OCCUPANCY PROJECTION**: The time used to project the estimated value of the average detector occupancy forward from the mid-point of the current sample period. The range is 0 to 15 min.

**DETECTOR OCCUPANCY LIMITS**: In the All Detectors category, the range 0 - 100% must be specified. For the other groups any range is valid. Low limits must be less than high limits.

**PLAN SELECTION CRITERIA**: A plan is selected if ALL conditions of occupancy are satisfied. If all conditions are satisfied for more than one plan, the plan associated with the conditions containing the highest detector group number is selected.

**GENERAL**: All vehicle detectors in the subsystem are included in the general group. The detectors can also be included in one of the other four detector groups if required.
Continuously Occupied Test. An occupied timer is maintained for all detectors and it is reset whenever the one-minute occupancy for the detector is not 100%. The detector is deemed to have failed if the occupied timer reaches the fail time. The fail time is recalculated each minute using formulae which cause the fail time to increase with increasing traffic activity. The calculated fail time is also dependent on detector category, and is increased for the higher volume detectors.

Overcounting Test. In this test, the volumes recorded are compared with the value specified as the maximum for the associated category. If the specified value is exceeded, the detector is considered to have failed.

Undercounting Test. Undercounting is a difficult fault to detect, and can only be done using volume comparisons. This is not included in the current version of the software. It will be added in a future revision.

Whenever a detector failure is found, the data from that detector is ignored. The detector is still monitored however and when it is found to be operating correctly, the failure condition is cleared. There is no requirement for operator intervention.

4.5 MONITORING OF THE CONTROLLER OPERATIONS

The regional computer requests the following information from the controller every two seconds.

(a) Operating Mode. The possible modes are lamps off, flashing yellow, isolated, coordinated - actuated, and coordinated - fixed.

(b) Controller Linking Software State. The controller reports this as linked or unlinked.

(c) Other Controller Hardware and Software Indicators. Status information is returned for the RAM, master relay, lamp active monitor relay, flashing yellow relay, watchdog timer, startup, alarm cancel (or retry) button, and the defined fallback mode.

From this information, and the communications link status, the regional computer maintains a summary controller status indicator. This is called the Intersection's Operational Status Indicator. It has the values - OK, Fault and Failed.

If the operational status is OK, all the controller status indicators are normal. If the Operational Status is set to Fault, some abnormal condition exists and the regional computer undertakes remedial action in an attempt to restore normal operations. If normal operations cannot be restored after a number of attempts, the Operational Status Indicator is set to Failed.

When the intersection's operational state is reported as Failed, it usually means hardware service is required. However, periodic retries are attempted by the regional computer in case the failure has been caused by an intermittent condition. If the communications link is operational, the failed controller is monitored continuously. When the failure is repaired, normal operations are restored without operator intervention.

Other controller information is requested when the operation of the intersection is being monitored. This information includes the current plan, subsystem cycle clock value, current phase, phase demands, basic sequence timer, signal group greens, and the vehicle detector actuations.

5. LOCAL CONTROLLER SOFTWARE

The local controller software used in the TRAC system is a variation of the NSW DMR's standard controller software. Main Roads Queensland are grateful to the NSW DMR for their assistance in the creation of versions of their software for the TRAC system.

Software currently exists for the AWA Delta 3 and Delta 2, and the Philips PTF3, PTF and PSF controllers. A version of the DMR's 'C' software for the TRAC system is planned for the near future.

The modifications to the controller software do not affect the preparation of the intersection descriptions or personalities, and the standard CGEN program is used. The operation of the controller in the Isolated operating mode is also unchanged.

The controller software used in the TRAC system will be described under the following headings:

(a) Controller Plan and Schedule Data,
(b) Intersection Control, and
(c) Detector Data Collection.
5.1 CONTROLLER PLAN AND SCHEDULE DATA

The plan and schedule data used by the local controller consists of the following:

(a) Plan required by the regional computer,
(b) Fallback plan introduction schedule, and
(c) Plan data.

5.1.1 Plan Required by the Regional Computer

The regional computer stores the number of the plan required to operate at the intersection, in the memory of the local controller. This information is sent when the communications link is established and whenever plan changes are required.

5.1.2 Fallback Plan Introduction Schedule

This is the time-of-day plan introduction schedule used by the local plan selection software for fallback operation. The table is not coded. It contains a separate schedule for each day of the week. Each day's schedule contains 12 plan introduction entries. Each entry consists of a plan introduction time and the plan number.

5.1.3 Plan Data

The plan data table provides space for up to 12 coordination plans. The TRAC system is currently using only eight. The plan data consists of the required operating mode, subsystem cycle time, seven phase introduction times, and seven special facilities for phase sequence control and timing. The operating mode data element provides the capability of implementing all available modes directly. There are no other data elements required to define the operating mode.

5.2 INTERSECTION CONTROL

The operation of the controller software when it is linked will be considered under the following headings:

(a) Plan Selection,
(b) The Running Plan,
(c) The Transition Plans,
(d) Optimising of the Current Cycle, and
(e) Setting the Subsystem Cycle Clock.

5.2.1 Plan Selection

The local controller's linking software is enabled by the regional computer when it has successfully loaded the plan data, the plan number required by the regional computer, and the fallback plan introduction schedule. The controller's plan selection software reads the plan required by the regional computer and implements this plan.

If communications with the regional computer fails and the controller's watchdog timer times out, the controller software deletes the plan number stored by the regional computer. If the local plan selection software is enabled in the fallback state, the time-of-day plan introduction schedule is searched to determine the required plan.

The communications watchdog timer is set to five minutes to ensure that a definite communications failure has occurred before the controller falls back to local plan selection.

5.2.2 The Running Plan

If a coordination plan is to be implemented, the controller software derives a running plan from the specified plan data. This running plan is the one the controller actually uses to control and time the phases. The running plan is recalculated before the start of each cycle with the intention of correcting any existing offset variation during the next cycle. The derived data for this running plan is stored separately from the plan data specified by the traffic engineer.

The advantage of this system is that controller operation is not disrupted by plan changes, changes to the stored plan data, or changes to the local controller clock's time. The effects of all such changes are implemented in the next running plan which is determined immediately before the next cycle. Disruptive cycles with abnormal phase times or unusual phase sequences do not occur.

5.2.3 The Transition Plan

If a plan change occurs, the running plan calculated before the start of the next cycle, will be a transition plan. In most cases the transition to the new coordination plan is made in one cycle. In a few cases however, an unacceptably long cycle would be required if the transition was to be done in one cycle. In these situations, two shorter transition
cycles are used. In all cases however, there are no
abnormal phase times, or unusual phase sequences.

The transition plan is defined as plan 13, and the
local controller informs the regional computer that
plan 13 is operating while the transition is under­
way. This allows the regional computer to distin­
guish between the normal plans and the transitions.

5.2.4 Optimising the Current Cycle

The plan data specified by the traffic engineer
includes allowable phase variation information.
The variations that can be specified include, alternate
phase sequences, early phase terminations, and
the skipping of phases altogether if there is no
demand. The local controller uses the current detec­
tor information to optimise the running cycle within
the limits specified in the coordination plan.

If the regional computer informs the local control­
er that a detector has failed, an artificial demand is
substituted for that detector. The associated phase
then runs the time defined in the coordination plan.

5.2.5 Setting the Subsystem Cycle Clock

The Subsystem Cycle Clock is maintained by the
local controller software and provides the timing
reference for the coordination data. It is derived
from the local controller's time-of-day clock and
cycles from the value one, to the current Subsystem
Cycle Time. It is derived in such a way that it is
always synchronised for all intersections in the
network that are operating on the same cycle time.

If the coordination plan changes and a new subsys­
tem cycle time results, the Subsystem Cycle Clock
is reset. It is reset to the remainder of the division:
Time of day in seconds divided by the new Subsys­
tem Cycle Time. Because the local controller’s
time-of-day clocks are synchronised, this has the
effect of synchronising all Subsystem Cycle Clocks
which are operating on the same cycle time.

This synchronisation of the Subsystem Cycle Clocks
occurs regardless of when this cycle time was
actually introduced at the intersection. It is also
independent of the subsystem or system to which
the intersection is connected. This is because the
local controller time-of-day clocks are synchro­
nised throughout the system or network. Coordi­
nation can be achieved between intersections
connected to different subsystems, or different
regional systems, whenever they are using the same
cycle time.

5.3 DETECTOR DATA COLLECTION

The local controller collects one-minute detector
volume and occupancy information, and detector
actuation data, for the regional computer.

Two sets of detector volume and occupancy accumu­
lators are maintained by the local controller.
This allows the regional computer to retrieve
the information in the minute following its accumu­
lation.

When vehicle detector actuation information has
been requested by the regional computer, the local
controller provides the following information every
two seconds:

(a) A new vehicle has been detected, or no new
vehicle has been detected, in the previous two
seconds.
(b) The detector has been fully occupied, or has
not been fully occupied, for the previous two
seconds.

The distinctions between a new vehicle and an
existing vehicle, and between fully occupied and
not fully occupied detectors, are necessary for the
measurement of the performance parameters: stops,
delay, and queue length.

6. OPERATOR SERVICE SOFTWARE

The subjects covered in this section include:

(a) The User Interface,
(b) The Operator Service Programs, and
(c) Graphic Displays.

6.1 THE USER INTERFACE

The development of the user interface for the TRAC
system was done with consideration for the prin­
ciples of software ergonomics. This is the study of
the efficient communication between the operator
and the computer system. It consists essentially of
two components: ease of operation, and presenta­
tion of information.
6.1.1 Ease of Operation

To achieve the desired ease of operation, all traffic operations programs can be completely menu driven, and comprehensive help is provided for every screen. All screen displays are accompanied by a function key menu which lists all the options available to the operator. This menu is displayed on labels at the bottom of the screen, which relate to eight programmable function keys on the keyboard. Particular functions are always associated with the same key, e.g. Help is always Function Key 1.

Screen menus are used in addition to the function key menus where appropriate. These menus display a list of options on the screen, together with all previously selected choices from higher level menus. The interface presented to the user is consistent across all programs and can be introduced by describing the functions performed by some of the standard function keys.

(a) Help Function Key: This key is available with all traffic operations screen displays. It provides the operator with assistance which is relevant to the current screen display.

(b) Data Entry or ENTER Function Key: Data entry is only available to nominated users. If the Data Entry key is selected, the fields on the screen into which data can be entered, are displayed in inverse video. Data can only be entered into the highlighted fields. After the data values have been entered into the screen fields, the ENTER function key is used to store the values. Any invalid values are flashed and the problem is explained by a message in the window line of the display. The help screen associated with the display provides details of valid data values for all data elements displayed on the screen.

(c) Previous Menu Function Key: This key is used with all screen menus below level one. It allows the operator to return to previous menus in the event of an error, or desired change in the option selection process.

(d) Print Function Key: This key is displayed whenever a printed report of the information displayed on the screen is appropriate. Pressing this key generates a screen menu which lists the printers available to the operator. In a stand-alone system, the printer can be any local or remote printer connected to the system. In a network, the operator can select any printer connected to any system in the network.

(e) Exit Program Function Key: This key is available on all screen displays and allows the operator to terminate the program at any point during its operation. In the event of an operator forgetting to terminate a program before leaving the terminal, the terminal time-out feature ensures the programs do not run indefinitely.

The operator service programs have been designed so they don't crash, even in the event of serious operational errors. For serious errors, the program reports a message in the display window line and presents the operator with a function key menu with the options Help, Restart Program and Exit Program. If the operator chooses Help, a detailed explanation of the error message is displayed.

6.1.2 Presentation of Information

All screen displays, printed reports, messages, and documentation have been developed with consideration for three principal factors - legibility, layout and language.

The simplest method of improving legibility is with the use of lower case characters. Experiments have shown that the characteristic word shape provided by the ascenders and descenders of lower case characters significantly improves legibility. All displays and reports developed for the system use lower case characters except for headings or where special emphasis is required.

The layout of all displays and reports has been done using the principle that layout is almost as important as content. This involves using space generously and wisely, and avoiding the use of lines of asterisks or similar characters that often clutter computer-generated output.

The language used in communication with the operator has been given considerable attention. Arbitrary and meaningless names are usually difficult to remember, even for experienced operators. To avoid this situation, the data element names used have familiar traffic engineering terms. Where reference is made to data elements in the controller software, provision is made to allow the operator to
replace the name with a more meaningful term. For example, the plan data element name Y+, is replaced by Alternate Phase Sequence or its abbreviation Alt Ph Seq, in data summaries.

When entering data for the regional computer software, the operators are not required to remember any data element acronyms or numeric codes. However for screen displays, space on the screen is a constraint, so abbreviations are sometimes necessary. For example, the intersection data entry screen uses coord for coordination mode, and flash for flashing yellow.

6.1.3 Training and Support Requirements

The effort invested in the user interface has been rewarded by a small training requirement, and a low level of requests for support. The provincial city experience in Queensland demonstrates this.

Each system installation occupied two people from the Development section, and two people from the Operations group for one week. This involved commissioning the hardware, installation of the software and the previously prepared data, and the training of the local operators (usually traffic signal electricians).

The users of these systems made two or three support calls a week for the first few weeks. This reduced to about one every three months after the first year. All systems have dial-up terminal communications, so requests for assistance can be attended to quickly.

6.2 THE OPERATOR SERVICE PROGRAMS

When the traffic operators log on to the TRAC system, they are presented with a set of menus which list all the traffic operations programs available. From these menus the operators can perform all traffic operations functions without being aware of, or requiring any knowledge of, the operating system controlling the machine.

The traffic operations programs available to the operator are arranged in functional categories, and these categories are listed in the primary menu. The categories are:

(a) Operations Display,
(b) Data Management,
(c) Message Reporting,
(d) Vehicle Counting, and
(e) Operations Maintenance.

6.2.1 Operations Display Programs

This category contains all the programs which display current system conditions. Both character-based, and graphical programs are available. The graphic programs only run on an IBM PC or equivalent with EGA, VGA or 8514 graphics facilities. The programs available are:

(a) Intersections Operations Summary,
(b) Subsystem Operations Summary,
(c) Subsystem Occupancy Plots,
(d) Intersection Operations Graphics Display,
(e) Subsystem Operations Graphics Display,
(f) System Operations Graphics Display, and
(g) Network Operations Graphics Display (if applicable).

A monochrome representation of the intersection display is shown in Fig. 3.

6.2.2 Data Management Programs

The Data Management category includes the programs used by the operator to manage the traffic system data. The list below describes the programs presented to those operators who are authorised to perform data entry. The menu presented to other users does not reference data entry.

(a) Subsystem Data Summary and Entry,
(b) Intersection Data Summary and Entry,
(c) Detector Data Summary and Entry,
(d) Special Events Data Summary and Entry,
(e) Counting Site Data Summary and Entry,
(f) Approach Data Summary and Entry,
(g) System Description Listings,
(h) Traffic Data and File System Backup, and
(i) Traffic Data Output File Creation.

6.2.3 Message Reporting Programs

All messages produced by the traffic system programs are logged in disc files. The following list identifies the programs involved in the production of reports from these message log files. Also included is the program used by the operator to select
and direct the messages which are required to be output to a logging printer when they are generated.

(a) Message File Report,
(b) Intersection Fault Report,
(c) Detector Failure Report, and
(d) System Messages Selection and Direction.

6.2.4 Vehicle Counting Programs

Any of the vehicle detectors can be assigned to counting sites. The one-minute volumes for each site are accumulated and stored in disc files. These files are held for the current day and previous seven days. Information required for historical purposes is transferred either to magnetic tape, or to a designated computer system, each week.

The vehicle counting programs available to the operator are:

(a) Vehicle Volumes Daily Report (Current Week - Disc),
(b) Vehicle Volumes Weekly Report (Current Week - Disc),
(c) Vehicle Volumes Daily Report (Permanent Sites - Tape),
(d) Vehicle Volumes Weekly Report (Permanent Sites - Tape),
(e) Permanent Vehicle Counting Master File Update,
(f) Permanent Vehicle Counting Master File Creation, and
(g) Transfer Permanent Counts to Planning System.

6.2.5 Operations Maintenance Programs

The Operations Maintenance category contains programs which are available to assist the operator in the maintenance of normal traffic operations. These programs are used during testing, and in the diagnosis and repair of faults. The programs available are:

(a) Controller Communications Exerciser,
(b) Controller Communications Monitor,
(c) Retry Failed Intersections, and
(d) Subsystem Plan Override.
6.3 GRAPHIC DISPLAYS

All graphic displays presented by the TRAC system are produced on an IBM or compatible PC. The PC requires either EGA, VGA or 8514 graphics capability. The regional computer switches the PC from terminal emulation mode to PC mode, for these displays.

All graphics programs have been developed using Microsoft Windows. Windows is an extension of the PC operating system, and it provides the required multi-tasking capability. When the programs which display current traffic operations are running, separate tasks run in the PC. These are the graphics display task, the task which communicates with the regional computer, and the task that communicates with the operator.

The static components of the intersection, subsystem, system and network graphic displays are prepared initially using AutoCAD. The resulting AutoCAD drawing files are converted into Windows drawing files. These Windows drawing files are then stored on all PC's which are to be used as traffic engineering workstations.

The AutoCAD drawing preparation process is facilitated with a set of customised AutoCAD functions. These functions speed up the drawing preparation process, and identify all the variable information which is to be updated at run time.

7. COMMUNICATIONS SOFTWARE

The communications software can be subdivided into controller communications software and network communications software. Controller communications software relates to the communication between the regional computer and the local controller. Network communications software is concerned with the communication between regional computer systems in a network.

7.1 CONTROLLER COMMUNICATIONS SOFTWARE

The regional computer communicates with the local controllers using a serial data communications system. The communications software used in the local controller is a modified version of the SCATS communications software. These modifications were performed by the NSW DMR. The regional computer communications software was developed by Main Roads. Communication between the regional computer and the local controller occurs every two seconds.

The modifications to the normal SCATS communications software include:

(a) Modifications to some of the existing messages, and
(b) The inclusion of new messages.

The ability to return multiple controller and detector status replies, from a single status request. This reduces the number of requests required by the regional computer.

The extension of the communications watchdog timeout period to five minutes. This ensures that temporary communications problems don't cause the controller to fall back to local control.

In the event of a communications fault or failure, the regional computer tries continually to re-establish the data link. When the fault is repaired, communication resumes without the need for operator intervention.

7.2 NETWORK COMMUNICATIONS SOFTWARE

Network communications software involves the communications between regional computer systems in a network. This communication is required for the following:

(a) Synchronisation of the clocks in a network,
(b) Management of a centralised message logging system,
(c) Management of a centralised vehicle counting system, and
(d) Management of a network printing facility. This enables the generation of a report on a particular system, and the printing of this report on any printer in the network.

The communications software to support these facilities is provided by HP's Distributed System software. This package includes the network services: program-to-program communication, remote program scheduling, remote file access and file transfer.

In a network, the PC's and terminals used by the engineers and operators, are usually connected to a
The TRAC system provides a virtual terminal program called Connect to meet this requirement. It enables a PC or terminal directly connected to one regional system, appear to be connected to another system in the network.

8. SYSTEM HARDWARE

The hardware used in the TRAC system will be described under the following headings:

(a) Regional computer hardware,
(b) Traffic engineering workstation hardware,
(c) Network communications hardware, and
(d) Controller communications hardware.

8.1 REGIONAL COMPUTER HARDWARE

The recommended hardware for the regional computer system consists of the following:

(a) An HP 1000 model A400 processor with 2.5 MBytes of memory.
(b) An HP 7957A, 80 MByte disc drive.
(c) An HP 9144A cartridge tape drive.
(d) An HP 700/92 terminal as the system console.
(e) A printer. Epson and compatible printers are supported.
(f) A calendar-clock. Main Roads have developed a battery-backed clock which connects via an RS232 interface for this purpose.
(g) HP 12040D eight channel asynchronous communications multiplexers. One multiplexer is required for the peripherals. An additional multiplexer is required for each group of eight local controllers.
(h) Two 1800mm high steel cabinets, with rack mounting facilities for the regional computer and all associated communications equipment.

The current cost of the above equipment, excluding the controller communications multiplexers, is approximately $48000. The multiplexers cost $3800, and one is required for each group of eight intersections.

8.2 TRAFFIC ENGINEERING WORKSTATION HARDWARE

Any IBM PC or compatible can be used as a workstation. A typical configuration consists of an IBM PS/2 model 50 with an 8514 monitor and adapter. This provides colour graphics at the resolution 1024 x 768.

Attached printers and plotters are used at some sites. Most PC printers and the HP 7475 and HP 7550 plotters are supported. Where both printing and plotting facilities are required in one device, the HP Paintjet can be used. It prints and plots in colour.

8.3 NETWORK COMMUNICATIONS HARDWARE

The network communications hardware includes equipment for both asynchronous and synchronous communications.

Synchronous communications links are used for computer-to-computer communications in network situations. Dedicated lines are used for all synchronous communications channels. In a network, both synchronous channels and asynchronous channels are required. They can be multiplexed over the same dedicated communications line.

The network communications equipment currently used in the TRAC systems is as follows:

(a) Dial-up modems - Netcomm 2400A, V.22bis (2400 bps),
(b) Dedicated line modems - Datacraft 5098 and 5298 V.29 (9600bps),
(c) Statistical multiplexers - Micom models LG1, MB2 and MB3, and
(d) Port selector - Micom 6000.

8.4 CONTROLLER COMMUNICATIONS HARDWARE

The controller communications hardware refers to equipment in the serial communications link.
between the regional computer multiplexers and the local controllers. The associated hardware housed in the communications cabinet in the computer room includes, 300 bps modems, line protection units and line termination blocks with surge arrestors.

In some situations it is economical to multiplex the controller communications links. The factors that affect this decision are the number of intersections in a particular Telecom exchange area, and the distance between this exchange and the regional computer’s local Telecom exchange.

Where economical, a Telecom Permitted Attachment Private Line (PAPL) is leased between the regional computer and a point in the Telecom exchange area containing the intersections. This line can carry the communications for 16 intersections. In the existing TRAC systems, Datacraft V.29 modems and Micom MB2 statistical multiplexers are used for this purpose. Telecom local loops, or private cables are used from the remote multiplexer to the individual intersections. The normal 300 bps modems are used on these lines.

9. PROPOSED DEVELOPMENTS

Proposed developments for the TRAC system include the following:

(a) Performance measurement,
(b) Extensions to the PC-based software,
(c) Conversion to the Unix operating system, and
(d) Plan generation.

9.1 PERFORMANCE MEASUREMENT

Performance measurement software has been planned and development is scheduled to commence this year. The basic parameters to be determined are: vehicle throughput, degree of saturation, vehicle stops, delay, and queue length. From these basic parameters, a number of derived measures of performance will be produced. This information will enable objective assessment of system performance.

In addition to these measures, it is planned to analyse the controller’s actual operation, and compare this with the data stored for each plan. This data, together with the performance measurement information, will assist the operator in refining the stored plan data.

9.2 EXTENSIONS TO THE PC-BASED SOFTWARE

The future developments planned for the PC-based operator service software include:

Enhancements to the existing graphic operations displays. It is proposed to display alternate sets of information in the information windows on the graphic displays. The choices will include diagnostic information, vehicle volume data, and performance measurement information.

Transfer of the forms management software from the regional computer to the PC. The generation of screen forms is currently performed by the regional computer and the PC emulates a HP terminal when these forms are displayed. It is proposed to move the forms management to PC-based programs. This will reduce the amount of information transferred over the communications link, and improve the response time. Only data will be sent between the PC and the regional machine.

9.3 CONVERSION TO UNIX

There are many benefits to be gained by adopting a standard operating system. These include the ability to buy hardware from more than one supplier, and the wider range of software available from third party sources.

Until recently there were no standard operating systems that were suitable for real-time applications. Unix has become a de facto standard operating system, and real-time versions are now available. For these reasons, it is planned to convert the TRAC system to run under Unix.

9.4 PLAN GENERATION

The existing system is based on the concept of the regional computer selecting an appropriate plan, from a set of stored plans. The software design also allows for the calculation of appropriate plans if required.

The regional computer could calculate the plan required using the current detector data. This calculated plan would then be stored in a reserved space in the local controller’s plan data table. The regional computer would then direct the local controller to run this plan. This could be repeated each cycle if required.

Main Roads Department has no immediate plans to implement this system, but it is an option if it is required in the future.
THE ADVISE DEMONSTRATION-EXPERIMENT ON CANTERBURY ROAD MELBOURNE

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ABSTRACT

Road experiments over five years have culminated in a demonstration of the advisory speed information system, ADVISE, in Melbourne. Using a 10-kilometre stretch of arterial road, the system takes data from the traffic signal operation, forecasts its future status and computes the advisory speeds, which are displayed on roadside light-emitting diode signs. Computer hardware and software development and the design of the display is described. Early results show that driving at excessive above speed-limit speeds is curbed and that, with increased traffic flow, fuel savings are available with comparable travel times. Subsequent improvements are detailed and a survey of drivers is underway.

ACKNOWLEDGMENT: The funding of the project under the National Energy Research Development and Demonstration Program is gratefully acknowledged. The project was a joint one with the Road Traffic Authority of Victoria whose willing cooperation is appreciated.
1. INTRODUCTION

Over the past five years, the CSIRO Division of Energy Technology (now incorporated in the new Division of Building, Construction and Engineering) has conducted a series of graduated experiments in conjunction with the Road Traffic Authority of Victoria (RTA) to demonstrate the fuel saving capabilities of dynamic advisory speed signs. Earlier results reporting savings of 10 - 15 per cent are given or referenced in Trayford et al. (1984, 1985, 1987). After these experiments confirmed the ability to calculate advisory speeds from the dynamic traffic signals, it was decided to evaluate the advisory sign system by means of a public demonstration experiment on Canterbury Road, Melbourne.

2. THE ARTERIAL ROAD

A 10-km section of Canterbury Road, from Surrey Hills to Mitcham, was used in the demonstration. Canterbury Road is a straight radial commuter road, with occasional undulations, running through the middle to outer-eastern Melbourne suburbs and with some strip shopping development along the course of the road. The section used for experiment lies between 10 and 20 km from the city centre with a two or three lane divided highway for the outer 6 km, and two lanes in each direction for the remainder. A speed limit of 60 km/h applies to the inner 6 km, with the outer 4 km at 75 km/h.

There are ten signalised intersections, one a triplet, including three pedestrian crossings. The advisory signs were located 120 m downstream from each previous intersection (only one for the triplet) and from each pedestrian crossing, with one extra sign in a particularly long link. This made a total of 12 signs in each direction.

3. THE ADVISE INFORMATION SYSTEM

The ADVISE (Advisory Display of Variable Information for Speed and Economy) system takes its incoming data from the adaptive signal control system SCATS (the Sydney Co-ordinated Adaptive Traffic System), implemented locally in Melbourne, and described by Lowrie (1982). SCATS uses information from under-road loops located near the stopline to change adaptively the phase splits, cycle times and offsets of the traffic signals for grouped intersections. This information is processed at a regional site and monitored from central control.

The ADVISE computer was located at the regional traffic signal control site and received a stream of data each second containing the above information on each intersection served by a sign. Because the SCATS computer used only data in the present (i.e. only transient or current data), the ADVISE system was required to predict the future status of the signal system first. The accuracy of prediction has been reported by Doughty et al. (1986).

To make efficient use of the incoming SCATS data and to provide a rapid update of sign information, these successive operations of the ADVISE computer had to be handled simultaneously. This was achieved by using a locally made Pulsar Turbodos 16 bit 80186 computer equipped with a master and five slaves. The slaves handled data unpacking, signal prediction, advisory speed and message calculation, sign data out, radio signal data out and data recording. Intermediate transfer of data between the slaves, each with its own process, was accomplished by first-in-first-out buffers (FIFOS) resident on the hard disk.

The digital speed to be displayed on the sign was subject to many constraints, including the need to merge smoothly the advised vehicle with any predicted queue downstream, the calculation of a path through more than one intersection if possible and the need to avoid advising speeds that might reduce the capacity of the following portion of the platoon. Constraints such as the recognition of minimum acceptable speeds, speed limits and rounding to the 5 km/h increments shown on the display were accommodated. An update from this intensive processing for all 24 signs was available every 1.3 seconds and was transferred via a 1200 Baud modem and multi-drop leased lines to the individual signs. Each sign was interrogated every 30 seconds for errors. Fail-safe provisions in the sign hardware
caused the whole sign to blank independently if unsafe or misleading messages were sent or formed within it.

4. THE DYNAMIC SIGNS

The choice of display medium for the signs was based on the following criteria:

- ability to show the required messages;
- visibility under different lighting conditions;
- reliability of components; and
- cost of the signs.

The technologies investigated included magnetic flips (both seven segment and dot matrix), light emitting diodes (LEDs), fibre optics, large-sheet liquid-crystal and incandescent-bulb matrix. Samples were evaluated by a group of observers under a variety of lighting conditions and sun direction, using photography to provide an objective record.

From this evaluation it was concluded that LEDs performed better than any other technology except when facing the sun, when magnetic flips were marginally better. In low light levels LEDs have the great advantage of being self-illuminating and also use very low power levels. It was decided to use super-bright yellow LEDs with a black background. These colours did not conflict with conventional traffic sign use.

The signs were erected on mast arms overhanging the first and second lanes at a height of 5.5 m. The displays were mounted in a one square metre polycarbonate-faced box and consisted of elements made up from 300 milli-candella LEDs. Some 3000 LEDs were used in each sign, dissipating a total of 150 w. LEDs also had the advantage of a narrow emitting angle, full matrix definition, very high reliability and good conspicuity. The narrow emitting angle allowed the precise targeting of the display message to a reading zone some 50 to 100 m in front of the sign, such that the dynamic information was received accurately at a particular viewing point and time.

5. THE DISPLAY

Two sets of investigations were made to help decide the content of the message to be displayed on the signs. Firstly, a group of 8 drivers was given different in-car displays, including speed, speed range, distance of valid advice and traffic intensity level while travelling along the test route described in the previous set of experiments (Trayford et al. 1984, 1987). Their driving performance, including fuel consumption, was evaluated while driving to a number of these display configurations and a ranking of the displays was obtained. The drivers were also required to rank the signs preferentially after completing the tests. It was found that displays containing up to four items of information gave the best results, provided they were textual and not graphical in nature. In particular an indication of the general level of traffic density was valued highly.

In addition psychologists from Monash University evaluated the various possible displays in terms of comprehension. In these studies, groups of respondents were asked to rate different displays, with the comprehension measured by an open-ended questionnaire. Similarly to the road tests, the displays with three or four information elements, particularly those containing distance and traffic information, performed better than those with one or two. On the basis of these two investigations it was decided to include speed, speed range, distance and traffic intensity on the signs. Figure 1 shows the layout of the sign including the small bars which give a tolerance (in units of 5 km/h) to the displayed speed for passage through the next intersection on the green phase. Bars to the left extend the tolerance to lower speeds and to the right to higher speeds (but limited to the speed limit). The traffic intensity levels shown initially (at the top of the sign) were LIGHT, MEDIUM and HEAVY corresponding to saturation levels of less than 20 per cent, 20-55 per cent and above 55 per cent respectively. Provision was made to show DELAYS at higher levels after gaining experience with the operation of the system.
6. DESIGNED EXPERIMENT

Two associated experiments were run concurrently to evaluate changes resulting from turning on the ADVISE system. As well as using two instrumented test cars on Canterbury Road, both before and after switch-on, two cars with fuel meters were used on Canterbury Road and a control circuit of similar length on surrounding roads. Test runs were made in six time periods, am peak, am off-peak, pm peak, evening off-peak, Saturday morning and early Sunday morning (12-2 am). Runs were made on all seven days of the four-week before-period and the four-week after-period. A total of 16 sessions were completed each week, each comprising 20 single direction trips over the four cars, thus giving a grand total of 2560 trips. The total distance travelled was 32 256 km.

Three techniques were used in gathering the data. The test cars either followed the ADVISE information (Advise runs), or floated with surrounding traffic, nulling out any passing manoeuvres (Float runs) or followed similar vehicles (Chase runs). Overall in the two experiments 58 per cent of the runs were made to test the response of the public, 25 per cent were control loop runs and 17 per cent tested the system potential. This enabled a series of comparisons to be made between the before and after situations (and taking account of the control circuit) with each of the measured variables such as travel time, fuel consumption, stop rate and lane changes, etc. Supplementary data on vehicle counts were also obtained from automatic classifiers, hand collected numberplate surveys and selected intersection queue lengths. Further to the above, traffic signal system data, which could be synchronised to the one-second data collected in the instrumented cars, were recorded thereby allowing a graphics reconstruction of a trip with a computer-generated time-distance plot.

7. RESULTS

Early analyses of the results concentrated on driver compliance, travel time and fuel consumption in the morning peak and off-peak period. Later analysis will look at acceleration spectra and delays using measurements taken along the length of the road.

On the non-linear compliance scale defined for these experiments (Trayford et al. 1987), vehicles assessed using the Chase technique showed a mean compliance of 30 per cent in the off-peak periods, whereas the test cars following the ADVISE signs recorded compliances of up to 60 per cent. The test cars following the ADVISE sign showed a fuel consumption reduction of 7 per cent overall periods after the signs were switched on. For Chase and Float runs overall fuel consumption decreased slightly across all vehicles in the off-peak only. However, a rise in traffic volumes was found on the test route, which would otherwise tend to increase fuel consumption, and this rise was larger than the increase experienced on the surrounding roads. Speeds measured each second for complete trips plotted as a frequency distribution (Fig. 2) indicated a lowering of speeds above the speed limit into the 40-60 km/h region (for the 60 km/h zone). In particular, instances of high speed, above 90 km/h, appear to have been eliminated.

The reduction in over-speed-limit speeds reported above may have led to small increases in trip travel times, in general around 2 per cent, but these were not significant considering the rise in traffic volumes on the test route and surrounding roads. The change in traffic volumes, set out in Table I, shows that the presence of the dynamic signs on the test route certainly did not deter traffic from using the road but attracted twice the increase in traffic experienced on parallel routes.

A record of calls of tow trucks to incidents on the relevant section of road has been examined. While the first four months of operation has shown less calls (96 compared to 120) based on the prior year’s data, this is not yet sufficient to signify a change. Further data are being accumulated.

8. SUBSEQUENT IMPROVEMENTS

The collection of detailed delay data led to the immediate finding that obtaining progression through two of the major intersections was difficult. The distributions of delays at both of these intersections showed that re-timing of the offsets was necessary before the ADVISE system could meet the raised expectations of motorists engendered by the publicity produced at switch-on. Subsequent re-timing combined with a procedural change in the method of applying the offsets for each signal plan has produced a significant improvement in the ability to identify long constant-speed trajectories for translation to the sign display.

In the first months of operation the extensive software code, some 6000 lines of Pascal, was found to
TABLE I

MEAN TRAFFIC VOLUME, MORNING OFF-PEAK, BOTH DIRECTIONS, FOR EACH FOUR-WEEK BEFORE AND AFTER PERIOD

<table>
<thead>
<tr>
<th>Test route</th>
<th>Before (veh/h)</th>
<th>After (veh/h)</th>
<th>Change (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1702</td>
<td>1790</td>
<td>5.1</td>
</tr>
<tr>
<td>Test route</td>
<td>1097</td>
<td>1207</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Predictions for pedestrian crossings were not included in the initial software code. This feature is now included for the three pedestrian crossings in the test route, although to give the necessary advance warning a sufficient prediction of the intermittent running of a pedestrian crossing is difficult. At certain times within the signal cycle a pedestrian crossing can be demanded and serviced within a few seconds. The absence of this feature was, however, a point of public criticism of the system.

Traffic level prediction, especially at saturation, was also found to be quite difficult. SCATS data contains the degree of saturation and the signal green length, which can be used as an aid to determining queue length and oversaturated conditions. However this limited information, based on the passage of vehicles over the road loops at the stopline, is only partly helpful in the non-linear region near saturation. Nevertheless display predictions in this region are now given, where necessary dropping the speed indications and only displaying DELAYS, as a measure to increase system credibility. Therefore with speed information present, the message DELAYS refers to conditions for some distance beyond the next intersection, giving a chance for drivers to make a route change. With the speed information deleted, DELAYS indicates congestion immediately ahead and improves the credibility of the system to drivers who find themselves in a near-stationary queue. The only information which can provide this last indication is the phase splits and degree of saturation from the next intersection, transformed into a queue estimate.

Recently a better appreciation of the situation at intersections with high degree of saturation, but short red phases (and consequently small queues), has led to improved queue predictions.

The minimum displayed speeds were another point of criticism. At first the minimum display was 25 km/h but after objections these calculated speeds were replaced by PREPARE TO STOP up to new minima of 30 km/h in the 60 zone and 40 km/h in the 75 zone.

The visibility of display suffered from poor louvre alignment and some glare problems in sunny
conditions. Both of these are being rectified but again only after the initial experiments.

Together with fault monitoring, a hazard alert system operated from central control will shortly be incorporated into the sign. This will enable any one of a set of 16 words to be displayed on the upper 8 character alpha-numeric board.

9. ERGONOMIC CONSIDERATIONS

ADVISE is an engineering system interfacing with humans through the medium of the sign display. In common with other road traffic systems, provision of a technically sound system does not imply that overall goals are met. Recognition, comprehension and motivation by the driver, and subsequent action, are all required before objective measures can show the desired effects. Driver attitudes, knowledge of the existence of coordination, the compliance with speed limits and the value of fuel saving all impact on the degree of acceptance of ADVISE.

These questions are being studied by means of presurvey panels and a subsequent householder survey in the region served by Canterbury Road. Other groups such as taxi and truck drivers will also have to be considered. The impact of education about ADVISE will have to be explored. First-time drivers seem prone to misconceptions about the information given by the system (which can only reflect the dynamics of the signal control system). Figure 3 shows the window of opportunity for reasonable speeds on a typical approach to an intersection. Only a third of the typical signal cycle off two minutes can generate comfortable approach speeds. The certainty of a stop for drivers not in the coordinated platoon (if available) is not appreciated by many drivers. Commuters waiting at the stopline have the chance, by observing the cycling of the sign ahead, to gauge the speed window possibilities available and therefore to drive accordingly. Frequent users spotted the idiosyncrasies of ADVISE, pointing out prediction error bugs and the early lack of pedestrian signal anticipation (since incorporated).

10. CURRENT STATUS

The system has proved reliable in use. Since switch-on, availability has quickly risen from 95 per cent in the first two weeks to better than 99 per cent. The results show that excessive above-speed-limit speeds have been reduced and that a sizeable fuel reduction is available for vehicles that both comply with the signs and with the road speed limits. Improvements have been made which give better matching to the constraints imposed upon the ADVISE system. Together with some ADVISE algorithm changes, these modifications, being tested on-road, have the ability to markedly increase driver satisfaction and compliance, and hence better realise the benefits of the ADVISE system. To test drivers' satisfaction of the system, a driver survey is being made at some 500 homes. Resulting from this, further educational and ergonomic work may be initiated.

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**Fig 3 – Typical approach speed window**
REFERENCES


MEASUREMENT OF TRAFFIC PERFORMANCE USING AVM

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ABSTRACT

This paper describes the evaluation and selection of an automatic vehicle monitoring system for integration into the SCRAM area traffic control system. The prime objective of the project is to provide an effective measure of system performance. Brief discussions on various automatic vehicle monitoring (AVM) systems are provided along with the implementation strategy in accordance with the stated objectives. Based on the work done so far an experimental study will be conducted using an active transponder system. This experimental project will involve 40 vehicles and up to 10 outstations initially.

ACKNOWLEDGEMENT: We thank the Chairman and Managing Director of RTA for permission to publish this paper.
1. INTRODUCTION

The SCATS area traffic coordination system was selected for implementation in Melbourne in 1979. During the initial stage of this implementation, several studies were conducted to evaluate the benefits of SCATS in Melbourne. These studies included before and after surveys of travel times, stops and delays along and around the selected routes. These studies were very costly due to the amount of resources required to provide statistically acceptable data. Some of the problems associated with these studies are cost, validity of data following changes in control strategy and changes in traffic demands. It was found that with an area traffic control system which provides easy access to all control parameters, traffic engineers can and will experiment with different options. The results of these experiments are judged by observations and measurements done at the local intersections. However these observations and measurements do not reflect accurately the effects of these changes in the macro sense. The only way to see if any improvement has been made is to re-collect travel time data and other associated information. The introduction of a large scale automatic vehicle monitoring system (AVMS) would not only reduce the overall cost of collecting travel time statistics but also provide a more regular and up to date source of information on the performance of the network. Furthermore, it is considered that 'travel time' is one of the better measures which can be related directly to the level of service provided by a traffic authority.

In 1986 the Road Traffic Authority started investigating automatic vehicle monitoring systems. The purpose was to find a system that could easily be integrated into the SCRAM (Signal Coordination of Regional Areas in Melbourne) network to provide travel time information along specific routes. The project is now at the stage of implementing a small experimental system in the metropolitan area of Melbourne. The purpose of this paper is to give a brief insight into the technologies available for automatic vehicle monitoring, the problems encountered in adapting off the shelf equipment to suit the Authority's requirements and finally the implementation of this experimental system.

2. PROJECT OBJECTIVES

The main objective of this project is to collect travel time data by using an AVMS. At present the SCRAM network collects data that indicates the volume of traffic passing through an intersection but not the time it takes for an individual vehicle to get from one point to another. The travel time information gathered from the AVMS could be used to improve the linking of intersections within the SCRAM network. As the traffic signal coordination system already comprises a large communication network it is logical to use it as the communications medium to channel the information collected from the AVMS back to a central processing point. Also as the data will be collected at the actual intersection, accurate data pertaining to the travel time from one point to another can be obtained.

A secondary objective of the project is to design a system which can be used to provide priority passage through intersections for public transport vehicles with the possible extension of this to emergency service vehicles. The means by which the AVMS information could be used to action this is still under development.

In order to implement an AVMS, standards regarding coding format and communications protocols need to be defined. The definition of the coding format initially requires that it only be capable of uniquely identifying a vehicle. As the objectives and the possible long term uses become more evident the definition of a coding format becomes broader.

The coding format for the automatic vehicle identification system is currently based on a 32 bit binary code. This allows for unique identification of every vehicle in Australia as well as allowing for groups of bits being allocated for special purposes. These special purposes include vehicle priority systems for public transport, emergency service vehicles and permit status of heavy vehicles. These other areas of usage, especially in the area of heavy vehicle monitoring are currently being looked into by another working party within the RTA. From a cost perspective it is fairly important that the experimental system be easily integrated into the existing equipment system.
3. SYSTEM TYPES

3.1 GENERAL

The types of equipment available for an AVMS system are all similar in that all require some sort of electronic tag or transponder to be placed on the vehicle to be identified. The stage is then read by a reader or interrogator unit. The following is a brief summary of the basic technology available for readers is being tested on buses in Shanghai. However, this system has not been evaluated in detail due to the difficulties in mounting the reader and the maintenance of the barcode.

3.2 INFRA-RED/RF

This system comprises an electronic reader and transponder. When triggered, the reader emits an encoded pulse of infra-red aiming at the desired capture area. If a transponder is visible within this capture area then it emits a radio frequency signal which is received by the electronic reader. The radio signal is modulated, allowing identification information stored in the transponder to be encoded onto the transmitted signal.

3.3 RF (SHORT RANGE)

This system comprises an electronic reader and a passive tag which is attached to the vehicle or object to be identified. The reader emits a low level unmodulated RF signal via an antenna that shapes the beam to cover the desired area of capture. A tag entering the beam modulates the signal with the message encoded within the tags circuitry. The reader detects the modulated reflected signal and decodes the identification. The tag is not a transmitter and does not contain any components that generate RF signals. The tag acts as a field disturbance device modifying slightly the signal transmitted by the reader.

3.4 LOOP (PASSIVE)

This system comprises an electronic reader and a passive transponder which is attached to the underside of the vehicle. A relatively large current circulates through the loop in the road. As the transponder passes over the loop this current is sufficient to couple enough power into the transponder to allow it to transmit its identification code back to the loop which acts also as a receiving antenna.

3.5 LOOP (ACTIVE)

This system comprises an electronic reader and an active transponder which is attached to the underside of the vehicle. The transponder in this case is powered by the vehicles or internal battery. As the transponder passes over the pickup loop it transmits its identification to the reader via the loop. In some systems the transponder will only transmit when it is triggered by the presence of a loop signal.

3.6 TRIANGULATION SYSTEMS

This system comprises at least 3 strategically placed transmitter sites and radio transponders mounted in vehicles. The locations of these transmitters determines the area covered by this system. The transponder is polled by the transmitters and the response from the transponder is monitored by the remote transmission and reception sites and by means of computer analysis the position and identity of the vehicle ascertained.

4. SELECTION CRITERIA

The selection criteria used are based on the objectives outlined in Section 2. The equipment selected must be suitably sized so that it will fit into a standard traffic signal controller. The equipment has to be fairly robust to withstand the extremes of temperature and humidity that is experienced within a controller housing. In order to simplify the interface between the signal controller and the monitoring system it was decided to use RS-422 for communication. The main benefits being that the electrical characteristics of RS-422 allow for long cable runs if it is required that the AVMS be located externally from the controller. Also only one hardware interface is required to talk to multiple channels of the AVMS with the traffic signal controller being the master and each channel of the identification (ID) system being slaves. The traffic signal controller polls each of the channels of the AVMS system sequentially and then passes any relevant information within the SCATS protocol to the regional traffic coordination computer.

As one of the objectives is to be able to incorporate some form of vehicle priority system it is important to be able to indicate from which direction a vehicle approaches an intersection so that the correct phasing can be set up. As some vehicles only require priority access under certain conditions it is
necessary to be able to change the code being sent from the vehicle to indicate whether or not priority is required, i.e. part of the transmitted code needs to be variable and the rest fixed. The code is modified by means of a simple switch arrangement within the cabin of the vehicle.

The system chosen by the RTA for its experimental study ended up being based on an active transponder and loop system. The transponder being capable of transmitting a 32 bit code to a loop buried in the road. The infra-red or radio frequency (RF) based system and the RF only based system were unable to necessarily discriminate from which direction the vehicle was approaching the intersection.

5. IMPLEMENTATION

In December 1986 the RTA released a draft specification for AVM field equipment. This specification described in broad terms the basic operational requirements of the mobile transmission unit and the fixed receiver unit that was required for the experimental system. The physical and electrical characteristics of the receiver station unit is fairly rigid so that the unit can be accommodated in existing controller housings. The type of interface supplied must be capable of handling either single or multi-channel AVM units. This therefore meant that some form of multiplexing technique needed to be employed. In order to simplify this it was decided to adopt the RS-422 interface and the use of a polled protocol as discussed earlier.

The RTA has carried out tests with various manufacturers equipment to determine its suitability for any experimental system. The selected system of an active transponder and loop system has so far only been tested under controlled conditions in the laboratory and on a closed racing circuit. The results of the tests indicate that the detection of codes can be done reliably at speeds up to and exceeding 120 km/h. The shape of the loop used is not critical as the system self tunes itself to the loop on power up, thus allowing or simple installation at a variety of sites.

Discussions were held with the various controller manufacturers and the Department of Main Roads in Sydney regarding the development of suitable controller firmware to capture data from an AVM system and passing the data in the SCRAM network. As the Department of Main Roads, N.S.W. was about to implement a similar experimental system within Sydney it was decided to use the firmware that had been developed for that system as the equipment being purchased by the RTA would be compatible to this firmware. The protocol used is fairly simple and does not allow for multi-channel systems at this point in time. The controller would monitor the spare RS-232 channel on a standard controller and when it received 4 bytes of information and a carriage return it would send a 5 byte SCATS message to the regional computer. The higher level polled protocol will be implemented later in the year and will be developed by the DMR. The higher level protocol will allow for the inclusion of multi-channel operation on a single port and also support the reporting of status conditions within the AVMS itself. Software for collection of data at the regional computers is currently under test by the DMR and will be released as part of SCATS Version 4.5.

Initially up to 40 vehicles will be fitted with a transponder and up to 10 intersections will have interrogation equipment installed. The experimental intersections will be selected in such a way that they are connected to at least two different regional computers. This is to ensure that the information collected at the central computer will handle more than one source of data in real time. Each regional computer will date, time stamp and attach a location label to the incoming data. Once the data has been collected it will be stored and later analysed. This vehicle ID code, time and origin data will be analysed and presented following some further discussions with users. Due to the number of user groups interested in this data, the presentation will need to be considered in some detail.

6. LONG TERM REQUIREMENTS

Since this project began several aspects have changed. The original objectives of the project although not changed are now tending to become part of a possibly larger and more sophisticated Automatic Vehicle Monitoring and Information System. This is because other interested groups within the community see other useful tasks in which the implementation of a vehicle monitoring system would be useful. One of these groups is the users of heavy vehicles. At a recent workshop held in Melbourne with representatives from government, industry and unions it was generally agreed
that an Automatic Vehicle Identification system would be of benefit to all parties represented.

The technology available for Automatic Vehicle Monitoring systems is still at an evolving stage with various manufacturers both local and overseas working on new and better products. In view of the fact that the technology is still at a growth stage it is imperative that in a large scale implementation that the standards which are eventually decided upon be flexible enough to allow for envisaged improvements and future applications.

As an AVMS grows so does the load on the communications network. At present only some general study has been carried out to ascertain the possible loads that a full scale AVM network would impose. It is apparent though that the existing SCRAM network would require upgrading and or modification in its structure to handle a large scale AVM system. The experimental system should provide useful data on which to base future loading estimates on the SCRAM network.

7. CONCLUSION

The immediate task at present is the successful implementation of the experimental system so that data can be collected and analysed. Using this data and by consultation with other interested groups it is intended that a long term strategy can be developed for automatic vehicle monitoring systems.

An AVMS will greatly benefit the travelling public regardless of the type of system adopted. The questions being raised now and those that come out of the experimental system will greatly assist in development of a large scale system.
LAND NAVIGATION SYSTEMS AND TRAFFIC MANAGEMENT

Geoff Lowe
NAVTEK
and
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Australian Road Research Board

ABSTRACT

This paper briefly describes the technologies suitable for the navigation of motorists in a road network. The factors that have contributed to the slow adoption of these technologies are identified. These include: appropriateness, usefulness, cost and accuracy. This paper proposes a vehicle location system that employs low cost dead reckoning (DR) units, together with satellite global positioning. The development of low cost DR units will also enable the production at ARRB of a new generation of Road Geometry Data Acquisition System, suitable for road geometry measurement and traffic management.
1. INTRODUCTION

A land navigation system for vehicles, both conventional and off-road, can be defined as a system which provides via a suitable display, the present vehicle location and perhaps the vehicle heading, the current track and the described destination or route. Navigation systems with these features are commonly available and utilised in aircraft navigation. Navigation in the skies requires these features because of the relatively high speed with which an aircraft changes location, the sparsity of navigation, beacons (sign-posts) and the lack of 'roadside' reference points. The same navigation problems also have to be overcome at sea; however, the slower rate of travel has not demanded the same need for electronic computation assistance. There have been nearly 50 modern land vehicle navigation and guidance systems developed. Some of these have passed through research and development stages but have not been implemented. Others have been tested on road networks, a few have yet to be tested on actual roads and only a couple are commercially available to motorists. Despite the maturity and widespread application of navigation systems in aircraft and ships, navigation aids have had little application in land vehicles.

Three important factors have contributed to the slow adoption of navigation and guidance aids for motorists:

(a) appropriateness and usefulness,
(b) cost of navigation systems, and
(c) accuracy of location demanded for the road network.

Navigators of aircraft and ships are trained in the skills of navigation and have it as their primary function to perform. The average motorists is not familiar with the concepts of headings, coordinates and only has a modest appreciation of map usage. Typically the land navigation developments to date have been unable to adequately communicate navigation and guidance information with the motorist. The accuracy of location and the large amount of road network data needed to make a navigation system useful to the motorist has contributed to the complexity and cost of such systems (Stephens 1986; Lowe 1988).

2. NAVIGATION TECHNIQUES

Navigation systems can be broadly classified as either dead reckoning (DR) or fixing systems. Dead reckoning involves the calculation of the change of position from a known starting point using information about the heading direction and distance travelled. It is an integration process with an accumulating error in the estimated present position. Dead reckoning may use a range of heading and distance determination devices such as:

Heading: Needle compass
          Electronic compass
          Radio direction finder
          Gyro compass

Distance: Knotted rope (ancient sailors)
          Marine log
          Odometer
          Doplar Radar
          Accelerometer
          DME, Radio distance measurement

Determination of the present position by fixing involves the computation of an absolute position from measured distances and/or bearings to several points of known location. This method does not use mathematical integration and has a bounded error in the estimated location. The fixing technique may use a variety of systems and devices both on land and in the skies and heavens.

Terrestrial: Bearing compass
            Gyro compass
            VOR, Radio direction measurement
            DME, Radio distance measurement
            Omega, Long range distance measurement
            Microwave ILS

Extra Terrestrial: Theodolite and Chronometer,
                  sun and stars
                  Navstar GPS, Satellite general
                  Transit, Satellite marine

Both dead reckoning and fixing systems are available at sea, in the air and on land. The accuracy and
reliability of each type of system and device depends on its application environment and the extent to which it is self contained in the moving platform or relevant on external references. The land application places significant limitations on many systems. All fixing methods rely on references external to the navigator platform and rely on continuous undistorted propagation of electromagnetic radiation. This can be generally achieved in homogenous space around an aircraft in the sky or a ship in the sea. Land application of fixing techniques have generally been limited by terrain irregularity, line of sight, interference and limited range. These limitations result in reduced accuracy, short range of coverage or unreliability. Likewise, dead reckoning techniques which rely on external references for measurement of heading or distance suffer limitations when used on land.

3. TECHNIQUES SUITABLE FOR LAND NAVIGATION

The only navigation system which does not suffer limitations due to application on land is the inertial navigation system which uses internal gyroscopes and accelerometers. In fact the prototype of the inertial navigation system used in new Boeing aircraft was developed and tested in land vehicles. The USA Department of Defence is constructing a new 18 satellite fixing system called Navstar Global Positioning System which should be complete in the mid 1990's. Navstar will provide global coverage and provide commercial receivers with absolute position with an error of less than 30 metres. This performance can be expected in open country on land also and represents the highest accuracy land navigation system. However, Navstar uses microwave frequency transmissions which are expected to be interrupted by trees and buildings in the urban environment. It is generally accepted that the most appropriate navigation system for accuracy and reliability will be an integrated inertial navigation system with Navstar global positioning. With commonality and global usage of Navstar by defence and commercial aircraft, ships and defence land vehicles and infantry, the cost of Navstar receivers is forecast to be affordable for motor vehicle applications. Comparatively low cost dead reckoning systems will need to be developed to integrate with Navstar to provide satisfactory operation in the urban environment. The performance of the dead reckoning sub-system can be improved with adaptive Kalman filtering to reduce the effect of sensor errors being integrated (Lowe 1988).

4. NAVIGATION DEVELOPMENTS FOR THE MOTORIST

Navigation and guidance systems to aid motorists negotiate the road network are being developed in two general areas:

(a) autonomous in-vehicle navigation using DR/Navstar with map data, and

(b) network to vehicle guidance and road information.

Automotive manufacturers and navigation equipment suppliers are pursuing the navigation equipment aspect, primarily as it offers future product sales. However, the practicality and usefulness of such systems for motorists remains an unanswered question. Driver communication methods are under development and assessment with work being done on visual displays and maps of the road network, indication of current vehicle location, destination command, suggested route, coordinate system and oratory instruction. These sophisticated systems are likely to remain high cost items and not affordable by the general motorist (Honey and Zavoli 1987).

Vehicle guidance and road network management has been the domain of governments and major projects are underway in the UK (Jeffery, Russam and Robertson 1987) and West Germany (Von Tomkewitsch 1986). These projects use an infrastructure of roadside communication devices to provide in-vehicle route guidance and road network information. The cost and complexity of the infrastructure is high however the in-vehicle equipment is potentially low cost and acceptable to the motorist. The appropriateness of route guidance for the Australian road network and its acceptance by the Australian motorist remain unanswered questions to date.

It is conceivable that a practical and affordable system could evolve from a merging of these parallel developments. Evidence of such cooperation has been shown in the European program named PROMETHEUS which involves government, private companies and universities from 19 countries.
with a projected budget of $500 million. PROMETHEUS is the program for European traffic with highest efficiency and unprecedent safety.

5. LAND NAVIGATION APPLIED TO TRAFFIC MANAGEMENT

Land navigation systems when used in the urban road network can provide useful data for traffic and fleet managers about the origin, route, destination, time and progress of vehicles. These data are computed by all dead reckoning navigation systems as a matter of course. Various navigation systems have evolved into vehicle location systems when the market was found ready to accept the product. The location systems have provided, via communication links, the vehicle location, destination, route, progress and status to a central data gathering or coordinate organisation. The Melbourne Transit Authority has one such system in operation which tracks the vehicles' location and provides them with navigation data. Sydney University has developed a system which can track a number of beacons attached to vehicles and this system may be installed for Perth's taxi and police fleet. Other fleet operators such as the Melbourne Ambulance and the Fox Transport Group are presently evaluating in-vehicle monitoring systems which will provide these data to a central fleet management centre (Lowe 1988).

The opportunity exists for organisations involved in traffic management, planning and control to tap into the vast amount of traffic data which are becoming available as a consequence of navigation systems being adapted to fleet management. The data are real-time and could be used for dynamic feedback to traffic control systems as well as data logging for subsequent analysis.

6. CONCLUDING REMARKS

The work done by ARRB in developing the Road Geometry Data Acquisition System (RGDAS) for the measurement of road geometry (Rawlinson 1986) has a traffic management application which is yet to be explored. The RGDAS system is in essence the sensor heart of a medium cost inertial navigation system. Data collected by RGDAS has been subsequently processed to prove route information of the test vehicle. Recent investigations have shown that a very low cost re-engineered version of RGDAS, using new low cost accelerometers and heading sensors could provide similar accuracies and navigation data for use in traffic management.

The opportunity exists for ARRB to apply a new generation RGDAS based vehicle monitoring system to traffic management. Such work could also put ARRB at the forefront of low cost road geometry measurement.

REFERENCES


1. INTRODUCTION

The Workshop was attended by more than 150 delegates. ARRB records suggested that the delegates were from road and traffic authorities (28 per cent), research and educational institutes (14 per cent), local government (31 per cent), industry and motorist organisations (7 per cent), and consultants (20 per cent). The report below was compiled by the Editor from the discussion held after the formal presentation of papers at the Workshop. The theme of the discussion centred around the possible future direction of research and development in UTC systems from an Australian perspective. The discussion, however, was of interest to delegates from overseas countries including Sweden, Denmark, the U.S., the U.K., Malaysia, Singapore, Hong Kong and China.

2. TRAFFIC RESPONSIVE URBAN TRAFFIC CONTROL

The subject of comparing the performance of fixed-time and traffic responsive control systems was raised. It must be recognised that comparison studies are, of necessity, carried out under equal traffic conditions in the Method 1 and Method 2 cases, otherwise the two sets of measurements cannot be compared. As it is difficult to arrange the same 'abnormal' traffic conditions or 'incidents' for the Method 1 and Method 2 measurement periods, the comparison studies omit the effects of abnormal traffic conditions and usually such effects are carefully sifted out of the data.

Traffic control systems of any significance are continuously subjected to the effects of 'incidents' and it is intuitively likely that even the crudest of traffic responsive systems will recognise and try to avoid oversaturated conditions which might result from, for example, the termination of a peak plan before the peak has actually finished. The traditional studies overlook what is, at least potentially, the greatest improvement in operation which a responsive system can offer when compared to a fixed-time system.

If a responsive system can equal the performance of a well optimised fixed-time system under equal conditions, it is highly likely to give vastly superior results in the real world of incidents. Secondary benefits of responsive systems, also not measured by the traditional comparison methods, are the less onerous task of producing the data required by the system and the insulation given against the gradual degradation in performance ('ageing') which occurs with fixed-time systems as traffic conditions change over time.

3. DYNAMIC SPEED ADVISORY SYSTEM

The ADVISE system again raised interesting comments related in particular to motorists' compliance. It was suggested that the compliance rate could be higher if the signs were spaced at closer spacing with two or even three per road section rather than only one. However, cost and visual pollution have precluded spacing closer than about 650 m. One long road section of over 1 km does have two signs in the Canterbury Road experimental site.

It was also pointed out that the signs comply with the legal requirements of 'advisory' signs and the onus remains with the driver. Dynamic speed signs could possibly lead to dynamic speed limits with attendant legal problems. This issue is a matter for further research and debate but a future sophisticated highway system may well require this level of control.

4. SCATES AND SIDRA

There was some discussion on the similarities and differences between the arterial road model, SCATES and the single intersection model, SIDRA. Consideration should be given to the integration of the two models and other ARRB or DMR-NSW products with a common database approach and common input-output links.
5. FUTURE RESEARCH

The on-line measurement of system performance in terms of delay, queue length, or travel time remains a fundamental issue in urban traffic control. This could be achieved by the modelling of queue formation and dissipation, by vehicle location technologies using in-vehicle transponders and roadside signposts. An UTC system, if equipped with vehicle location or even route guidance facilities, could improve its operation irrespective of whether it is a fixed-time or traffic responsive system.

The use of digital analysis of video pictures for queue and delay estimation was raised. If such a technique becomes feasible it will be of great benefit to UTC because it would allow accurate knowledge of queue dynamics and also allow very good estimates of delay for use in an optimisation process.

Future research on adaptive UTC systems could concentrate on the relationship between the cycle length and the network capacity in real time. The feasibility of signal coordination without a common cycle length should also be investigated.

Although Australia pioneered the use of microprocessors in traffic signal controllers, the flexibility made available has not yet been fully utilised by the traffic engineering profession. Research is therefore needed to achieve optimal vehicle-actuated controller settings for intersections installed with stop line detectors. Perhaps an extra detector in advance of the stop line could improve the estimation of traffic demand on that approach and hence the operation of the controller.

It was suggested that future traffic management could take the form of vehicle navigation in a multidimensional information space. Traffic responsive travel paths could be optimised in real time in this information space of the 21st century!
APPENDIX A

TRAFFIC SIGNAL RESEARCH AT ARRB

Rahmi Akcelik and James Luk

(Reprint from Aust. Rd Res. 18(1))

1. INTRODUCTION

The research strategy described below is within the framework of the current ARRB Three Year Plan. It provides a more detailed description of various future research activities, and outlines interactions among various projects within the Road Users Work Area. This note has been prepared as a discussion paper and comments from State Road Authorities, other government agencies and consultants, and researchers involved in this area are most welcome.

2. SINGLE INTERSECTION MODELLING

The SIDRA program has been widely adopted for capacity, timing and performance analysis of signalised intersections (Akcelik 1981, 1984, 1986, 1987a and 1987b). It will be developed in response to user feedback. An input data management system (SIDMAN) and a graphical input-output package (SIDGRA) are currently being developed. To enhance the use of SIDRA in practice, training courses and workshops will continue to be organised. SIDRA documentation and review of ARR No. 123 will be undertaken under P450.

Future research and development on SIDRA include the following:

(a) incorporation of roundabouts and unsignalised intersections; a Feasibility Study will be prepared,
(b) paired intersection modelling and linkage to areawide models - the future development of SIDRA into a paired intersection and ultimately into a network model will be described in Section 3.
(c) calibration of saturation flows and other parameters in SIDRA (as described in ARR No. 148),
(d) optimisation of phase sequences; a practical approach rather than a theoretical one is likely to be adopted, and
(e) optimum signal timings (in relation to practical timings).

Current research is undertaken at the University of Melbourne to update the basic saturation flow values in ARR No. 123 and SIDRA (ARRB Project No. 87/12E). These values will also be correlated with the corresponding values obtained on-line from the SCATS control system.

It is anticipated that research into vehicle-actuated (VA) operation will be initiated in the near future. While Australia pioneered the use of microprocessor signal controllers, there has been little research on VA control strategies during the last decade. Most VA controllers in Australia adopt the method of ‘waste time’ and ‘headway’ settings in addition to the normal ‘gap’ setting. With this method, when the time between successive vehicle actuations exceeds the headway setting, the excess or waste time is accumulated. The green period is terminated when the accumulated value of waste increments equals the waste time setting, in addition to the normal gap change. Huddart (1980) suggests that this method can provide a longer green when there is more traffic, but may be slow in identifying the end of a dense traffic platoon. Guidelines for the setting of such parameters in existing VA controllers need to be developed. New strategies for VA control need also be investigated.

An intersection model called INSECT has been developed to emulate the DMR-NSW specified signal controller logic (Biggs and Bowyer 1986). It is a microscopic, event-scanning simulation model, and still needs calibration and validation. An upgraded INSECT model could be useful for investigating the optimal use of VA controllers and for
developing new control algorithms. This line of research would also help the calibration of SIDRA for VA conditions.

3. AREAWIDE SYSTEM MONITORING AND CONTROL

Current research at ARRB has also concentrated on the on-line monitoring of the performance of area traffic control (ATC) systems. A scheme has been developed for the estimation of delay, queue length and no. of stops in a system such as SCATS (Luk and Cahill 1986; Luk and Besley 1987). The scheme utilises the stop line departure flows for link flow estimation, and employs platoon dispersion in the modelling of queue formation and dissipation. Liaison will be maintained with SRA’s and traffic authorities for its implementation in SCATS and other ATC systems. The research has also successfully demonstrated the technique of retrieving traffic flow information directly from a signal controller using the ARRB data logger VDDAS (Fraser 1981). This technique will be further utilised for estimating the traffic volume of a turning or through movement from approach counts at any signalised intersection.

The queue estimation software developed will be linked with the SIDRA program to form a paired intersection model. This model will be particularly useful in analysing two intersections separated by a small distance of, say, 200 m or less. Computer software will also be developed to speed up the modelling of platoon dispersion and hence the modelling of queue formation. The research into such a model will have interaction with the current development of the CLOFFSET program for the preparation of cycle length and offset data in SCATS (Sims and Finlay 1984). Progression factors that account for the level of platooning in delay calculations will also be developed from the paired intersection model (Transportation Research Board 1985).

Consideration will also be given to the linkage of SIDRA to areawide models such as TRANSYT/8 (Vincent, Mitchell and Robertson 1980), SATURN (van Vliet 1982) or LATM (Taylor 1983). The detailed modelling embedded in SIDRA would contribute to more accurate simulation of queue length, delay and stops than currently possible. Alternatively, a SIDRA-based paired intersection model could be extended to a network model. The development of such a network model will also draw on the results of a concurrent ARRB project (87/22) on traffic flow in arterial roads. This project will analyse algorithms currently adopted in network models for the simulation of car-following, lane-changing and other driver behaviour.

ARRB is sponsoring the development of a low cost dead reckoning unit for vehicle positioning. This unit could be interfaced directly into a taxi radio communication network. At the start of a trip with a customer, the taxi driver provides the initial coordinates for the central depot. As the vehicle moves away from its initial location, its real-time coordinates are calculated by the dead reckoning unit and inserted into the existing message protocol. This message is radioed to the central depot in the usual manner. This activity would be linked to the development of future land navigation and SCATS-based vehicle monitoring systems. With a dead reckoning unit, the monitoring of journey times could be achieved without identifying individual drivers.

4. DATA BASE MANAGEMENT SYSTEM FOR TRAFFIC MODELS

It is desirable to prepare an input data set that can be used in a range of traffic models. This is particularly useful for comparing the accuracy of these models and for the linking of, say, two models to perform a broad range of analysis. The difficulty of preparing a single set of data as input to more than one traffic model was discussed in Luk (1984). A solution would be to develop a data base management system (DBMS) that facilitates and standardises the input data. The development of the input software module, SIDMAN, for SIDRA can be seen as an initial effort in this direction.

SIDMAN can be readily adapted for use in the area network model TRANSYT/8. It will be developed further for other network models. A workshop to standardise input data formats and requirements may be organised for researchers and practitioners involved in traffic modelling.

5. LIST OF ACTIVE RELATED PROJECTS AT ARRB

P393 - Roundabout capacity and performance
P422 - Urban transport performance measurement
REFERENCES


APPENDIX B

TRAFFIC SIGNAL RESEARCH IN AUSTRALIA - A REVIEW
James Luk and Rahmi Akcelik
(Paper presented to the 67th Annual Meeting of the Transportation Research Board, Washington, D.C., January 11-14, 1988)

1. INTRODUCTION

There are about 5500 traffic signals in Australia, most of which are installed in capital cities each with a population of 1 million or more people. Australia also has a high vehicle ownership rate - 16 million people driving 9.1 million vehicles. In parallel with the extensive use of traffic signal systems to facilitate efficient movement of people and vehicles in a road network, research and development on signal systems have always received high priority at the Australian Road Research Board (ARRB) and various Australian traffic engineering institutions.

This paper reports on the current state-of-the-art of traffic signal systems, and the software used for the design of signal systems in Australia. Current and future activities are also outlined.

2. TRAFFIC SIGNALLING IN AUSTRALIA

2.1 SIGNAL SYSTEMS

The urban traffic control (UTC) systems in Australia can be broadly classified into:

(a) fixed-time control in which signal timing plans are switched into operation by time-of-day and is still used in some parts of the Melbourne central business district (CBD),

(b) adaptive fixed-time signal plan selection according to information from strategically located detectors and is adopted in some arterial roads in Brisbane,

(c) linked vehicle-actuated (VA) control in which VA intersection controllers are used in a fixed-time area control system, e.g. in parts of the Melbourne, Adelaide and Brisbane CBD’s, and

(d) traffic responsive control using the Sydney Coordinated Adaptive Traffic System, or SCATS (14, 20, 32, 33).

A variety of hardware and software is employed for the implementation of the first three categories. For example, the Melbourne CBD network is under the control of the ‘first generation’ UTCS software (13). A detailed review of Australian traffic signalling in the pre-1978 period was given by Huddart (15). Most of the systems described in that report are still in operation.

SCATS

In the last ten years, the Department of Main Roads, New South Wales (DMR-NSW) has developed one of the most advanced dynamic traffic control systems in the world - SCATS. All Australian States except Queensland now use SCATS. Systems have also been installed in New Zealand, Singapore and China. Over 3000 signalised intersections are now operating under the adaptive control of SCATS as seen in Table I. This number has been increasing at a rate of about 500 a year. In Melbourne alone, some 2000 sets of signals are to be linked by the year 2000.

A major advantage of SCATS is its flexible system structure. The range of possible system configurations is shown in Fig. 1. A minimum system configuration consists of a regional computer with up to 120 local controllers. A maximum system configuration consists of many regional computers (each with up to 120 sites) connected to a central monitoring system with high resolution colour graphic display of real-time system operation. SCATS can be implemented by stages to suit local needs.
TABLE I
IMPLEMENTATION OF SCATS*

<table>
<thead>
<tr>
<th>City</th>
<th>No. of signals connected to SCATS</th>
<th>No. of regional computers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sydney &amp; other NSW cities</td>
<td>1350</td>
<td>17</td>
</tr>
<tr>
<td>Melbourne</td>
<td>984</td>
<td>14</td>
</tr>
<tr>
<td>Adelaide</td>
<td>300</td>
<td>6</td>
</tr>
<tr>
<td>Perth</td>
<td>124</td>
<td>2</td>
</tr>
<tr>
<td>Canberra</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>Hobart</td>
<td>60</td>
<td>2</td>
</tr>
<tr>
<td>Darwin</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>New Zealand cities</td>
<td>270</td>
<td>8</td>
</tr>
<tr>
<td>Shanghai</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>Tianjin</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Singapore</td>
<td>24</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3234</strong></td>
<td><strong>54</strong></td>
</tr>
</tbody>
</table>

* as of September 1987

Australia developed and employed microprocessor-based traffic controllers since 1974. This made it possible to realise the dynamic traffic control philosophy, and was instrumental in accelerating the further development of SCATS. Currently, SCATS-compatible controllers are manufactured by Amalgamated Wireless Australasia (AWA) and Philips Communications Systems. AWA has been appointed as the sole licensed agent for SCATS.

The traffic performance of SCATS was evaluated in a floating-car survey in 1981 in the suburb of Parramatta, Sydney. SCATS was compared with fine-tuned fixed-time control (21, 25). The fixed-time plans were optimised using Version 7 of the program TRANSYT (16). The Parramatta network consisted of both the grid and arterial road types. The survey results indicated that there was no significant difference between SCATS and fixed-time control in journey time. SCATS was, however, 9 per cent better than fixed-time control in minimising stops.

SCATS was found to be particularly successful in reducing stops in the arterial road segment of the survey area. It was 25 per cent better than fixed-time control in reducing stops. Further evaluation of SCATS was carried out in the Maroondah Highway, an arterial road in Melbourne (28) and the results agreed with those obtained in Parramatta. Since majority of the urban traffic in Australia cities are carried by arterial roads, the benefit of SCATS in reducing journey time, stops and fuel consumption is substantial. The benefit/cost ratio for signal coordination using SCATS is estimated to be 10 for the Maroondah Highway.

In Australia, SCATS has been used to implement a range of traffic control measures that include three-lane tidal flow control, tram priority, and speed advisory signs.

**Three-lane Tidal Flow Control**

Sydney has a number of three-lane bridges on major arterial roads where they cross the Sydney Harbour and adjacent rivers. Until recently, the tidal flow directions on these bridges was controlled manually. Long delays were caused on occasions when the tidal directions were not changed at the right times or when the demand in both directions exceeded the capacity of a single lane, e.g. during weekends due to recreational traffic.

A microprocessor signal controller was modified to control the median at both ends of the bridge, and a bridge subroutine was added to the SCATS software (19). When the traffic flow or demand in each
direction is less than the capacity of one lane (designated as $s$ veh/h), one lane in each direction can satisfy the demand with no significant delay. When the demand in one direction is more than $s$ but less than $2s$ and the demand in the other direction is less than $s$, then two lanes in one direction and one lane in the other will also satisfy the demand. This is the common mode of operation. However, when the demand in each direction exceeds $s$, the centre lane will have to be cycled like a two phase signalised intersection. The total lost time per cycle is equal to twice the time taken to change the direction of the centre lane (about two minutes).

To ensure a stable operation, hysteresis is built into the control system to restrict the frequency of changing bridge direction. For example, if one lane in each direction is adequate to handle the flows, the bridge lane directions can stay as they are in the ratio $2:1$. If the demand in both directions are less than $s/3$, flows will be restricted to one lane in each direction. The lane configuration for a typical weekend is illustrated in Fig. 2.

The system has been in operation since 1983. No serious accidents have occurred on the bridges or their immediate approaches. Public response to the dynamic system has also been favourable.

**Tram Priority**

SCATS has been used effectively to give trams priority within mixed traffic environment (9). This is achieved by using transmitters mounted under the front of each tram. The transmitter automatically activates detector loops in the road. The loops are connected to the local SCATS controllers which implements the required strategy. SCATS is able to achieve time transfer between phases so that priority is achieved at the time when a tram needs it. Two options are available for time transfer in SCATS:

(a) time gain (TG) - absorb time in the current cycle not used by previous phases, and

(b) false green (FG) - use time allocated to a subsequent phase if not called.

The basic concept of window stretching by time transfer is illustrated in Figs 3 and 4. The standard sequence in the absence of trams are A phase (the coordinated phase) followed by C phase. Phases B and D are 'optional' phases to increase the green time allocated to the tram movement. As shown in Fig. 3, if the tactic required is an extension of the coordinated phase only (i.e. A+B), C phase will use the time allocated to D phase. The average green time available to both the main and crossing movements remains unaffected and the amount of unnecessary priority is minimised.

The priority scheme is introduced into tram routes together with signal coordination. The overall effect has been evaluated in two routes of 11 km long in Preston, Melbourne. The journey times of the trams and cars along the coordinated routes, and those of the cross-streets, were measured. Up to 10 per cent reduction in tram journey times in the peak direction in peak hours was obtained with no significant increase in car journey times. The cross movements had mixed results, but most of them did not suffer from significant increase in delay. As SCATS generally favour the direction of heavy flow, it is expected that signal coordination would have contributed to the majority of the savings in journey times along tram routes.

**Advisory Speed Signs**

A pilot scheme to advise motorists of appropriate speeds to achieve fuel efficient driving has been installed in Melbourne. The speed advisory system retrieves from SCATS the prevailing traffic flow data, calculates and displays the advised speed. The system is described in more detail in Section 3.3.

**TRACS**

It should also be noted that, in Queensland, the Main Roads Department (7) has recently completed the development an UTC system called the Traffic Responsive Area Control System (TRACS). The system can adopt either the adaptive fixed-plan selection control or the linked VA control method. It is installed in Brisbane and in three other provincial cities. These four systems are linked as a network using a Hewlett Packard HP1000. The TRAC System has an emphasis on user-friendly features and is particularly easy to prepare input data and to interpret system output information. For example, six categories are used to describe the status of each detector in the control system. These are determined from one minute volume and occupancy information accumulated by the local controllers. The six categories are:

(a) very high volume detector, and
(b) high volume detector.
(c) normal detector,
(d) low volume detector,
(e) very low volume detector, and
(f) off-peak parking bay detector.

When a detector fails, the data from that detector are eliminated from all calculations. The detector is still monitored. If it is found to be operating correctly, the failure condition is cleared. A message is reported and the data are again used.

2.2 TRAFFIC SIGNAL MODELLING

The preparation of signal timing plans for the operation of UTC systems often require the aid of off-line computer models. The most commonly used software in Australia are SIMSET of DMR-NSW (27) and the ARRB program SIDRA by Akcelik (1-5) for single intersection designs, and the TRRL program TRANSYT/8 for areawide networks (36). The preparation of SCATS offset plans and cycle lengths for signal coordination has also been made easy with the release of the program CLOFFSET by Sims and Finlay (33).

SIMSET

The first version of SIMSET was developed in 1973 as a research tool by the DMR-NSW. It is a macroscopic simulation model which does not involve the simulation of individual vehicles. It builds approach queues using second-by-second uniform arrival flows and terminates green phases as soon as queues on all critical lanes have been discharged, or when the phase times have reached their maximum values. This is the basis of estimating delays and computing signal timings in SIMSET.

Version 2 of SIMSET provides options for the simulation of random arrivals and pays special attention to the treatment of short lanes. SIMSET is widely used for single intersection designs and for preparing phase and cycle length data in SCATS for signal coordination. SIMSET-2 adopts the operation of phase logic controllers. It does not explicitly model the individual movements of a group control philosophy.

SIDRA

SIDRA is an analytical model in the sense that it consists of a set of equations and mathematical algorithms. The capacity and timing analysis methods used in SIDRA have evolved from the simple but sound base of the ARRB Bulletin No. 4 (26), and then the more comprehensive method of ARR No. 123 (1). SIDRA methods are now substantially more advanced, and an ARRB project for the revision of ARR No. 123 to incorporate the new methods of SIDRA is in progress.

Since the first release of SIDRA-2 in 1984, its use in practice, research and teaching has increased steadily. There are currently over 70 organisations in Australia, New Zealand and twelve other countries that use SIDRA. SIDRA-3 was released in July 1987. This version has been developed to take advantage of the user-friendly features of personal computers. It is much improved in terms of its program structure, data input, various options available, traffic models and timing computation techniques. Both the main-frame and micro-computer versions are available. The reader is referred to the latest available SIDRA newsletter (SIDNEWS) available from ARRB for the conditions of SIDRA licence agreements.

SIDRA is particularly useful for the analysis of complicated cases of signalised intersections with permissive (opposed) and protected (unopposed) turns, short lanes (turning lanes, or lanes with upstream parking), and the interaction of different movements in shared lanes. The lane-by-lane method of analysis used in SIDRA improves the accuracy of capacity and performance estimation.

The capacity estimation method allows for the blocking of two movements in a shared lane by each other, e.g. permissive turns and through traffic (5). This new method uses the intervals of lane blockage as effective red time (lost time). This is unlike the traditional methods such as the 1985 U.S. Highway Capacity Manual (USHCM) in which the green times are kept unaffected but saturation flows are adjusted down in order to allow for capacity losses (34). The method of SIDRA improves the estimation of queue lengths, and therefore better estimates of delay, short lane capacity, etc. are achieved.

SIDRA can predict not only the delay and queue length, but also such measures of effectiveness (MOE’s) as number of stops, fuel consumption, pollutant emissions and operating costs. A recent U.S. paper by Powell (29) has discussed the inadequacy of the USHCM in this respect and used the
ARR No. 123 models. SIDRA models for predicting delays, number of stops and queue length are more improved than the ARR No. 123 models, particularly in the case of two green periods such as the case of permissive and protected turns. SIDRA models for fuel consumption, emissions and cost are based on ARR work that won an ITE award (8).

SIDRA can determine signal timings (cycle time and green splits) for complex phasing systems with almost any combination of overlap movements, minimum and maximum green time constraints, and two separate green periods for two movement. It can be used to determine green splits for a specified cycle time. It can also be used for capacity and performance evaluation purposes where both cycle time and green splits are specified.

In contrast to modelling by simulation, SIDRA uses an analytical modelling approach coupled with an iterative approximation method of computation. As a result SIDRA runs very quickly. This allows for the analysis of many design alternatives efficiently so as to achieve an optimum signalised intersection design.

An option to implement the USHCM method for signalised intersections using the SIDRA traffic models and timing computation methods is being developed. This option is partly available in SIDRA 3.0 in the form of a default values file 'calibrated' according to the USHCM method, which is supplied with the SIDRA package. The USHCM option is expected to be fully operational in the next release version of SIDRA. The details of an application of SIDRA to an example from the 1985 USHCM (Fig. 5) can be found in Akcelik (4). This example highlights the differences between SIDRA and the USHCM methods for opposed (permissive) turn modelling.

TRANSYT

The TRANSYT program was developed by the U.K. Transport and Road Research Laboratory (TRRL) (30) for the modelling of traffic progression in signal-controlled urban networks. It searches for a set of signal settings that minimise vehicle delay or a combination of delays and number of stops. The program has been distributed to many countries and Version 7 was modified as TRANSYT/7F to suit right-hand drive countries (38).

TRANSYT is often used as a standard against which adaptive control methodologies have been tested (17, 25). ARRB has been the agent for Version 8 of the program in Australia since 1981. Both the main-frame and micro-computer versions are available. The program was calibrated and validated in Luk and Akcelik (23) with the floating-car survey data collected in Parramatta. At the network aggregate level, TRANSYT/8 was found to overestimate journey time by about 10 per cent and stops by about 20 per cent. The program was particularly accurate in predicting the benefit of signal coordination. TRANSYT/8 is widely used for optimising signal timing plans, especially in Queensland, where SCATS has not been installed. In other States, it is common to use SIMSET and SIDRA for phase and cycle length optimisation, and CLOFFSET for offset plan preparation in SCATS.

CLOFFSET

The CLOFFSET program was developed by Sims and Finlay (33) to calculate the optimum cycle lengths and offsets for two-way progressive flows in linear traffic signal systems. It also provides the optimum offsets for tidal flow conditions. To aid the preparation of SCATS data, its input and output are in exact SCATS formats. Particular effort has been made to ensure that the program is easy to use and that input data requirements are minimal, within the constraints of accurate results. For example, CLOFFSET does not require the user to supply the link flow information, but calculates the traffic demand from green phase times (as stored in a SCATS data base), assumed degrees of saturation, and observed traffic volume gains and losses in each link. The cycle time is varied in steps of 2 s or 4 s to identify from delay and stop calculations the optimal combinations of cycle lengths and offsets in the range from 30 s to the maximum value specified. Delays and stops are calculated at each cycle length, taking into account:

(a) platoon dispersion,
(b) flow through the yellow phase,
(c) starting delay,
(d) the back of residual queue,
(e) overlap phase advantages, and
(f) speed variation due to signal status ahead.
Colour graphics have also been added to the program, which is now an essential component in the training of SCATS personnel.

3. CURRENT AND FUTURE RESEARCH ACTIVITIES

3.1 SINGLE INTERSECTION OPERATION

Research at ARRB will continue to develop accurate, reliable and easy-to-use design guides and software for traffic signal design and operation. The SIDRA program will be developed in response to user feedback. An input data management system (known as SIDMAN) is being developed to facilitate the preparation of input data. To enhance the use of SIDRA in practice, training courses and workshops will continue to be organised. Future research will include:

(a) incorporation of options for the analysis of roundabouts and unsignalised intersections,
(b) optimisation of the phase sequences in the model,
(c) calibration of parameters used in the opposed turn and overflow queue sub-models, and
(d) extension of SIDRA to the modelling of paired intersections, and the linking of the program to an areawide model such as TRANSYT or others.

Current research is undertaken at the University of Melbourne to update the basic saturation flow values in ARR No. 123 and SIDRA, and to correlate them with the corresponding values obtained on-line from SCATS.

It is anticipated that research in vehicle-actuated (VA) operation will be initiated in the near future. While Australia pioneered the use of microprocessor signal controllers, there has been little research on VA control strategies during the last ten years. Most VA controllers in Australia adopt the method of 'waste time' and 'headway' settings in addition to the normal 'gap' setting. With this method, when the time between successive vehicle actuations exceeds the headway setting, the excess or waste time is accumulated. The green period is terminated when the accumulated value of waste increments equals the waste time setting, in addition to the normal gap change. Huddart (15) suggests that this method can provide a longer green when there is more traffic, but may be slow in identifying the end of a dense traffic platoon.

An intersection model called INSECT has been developed to emulate the DMR-NSW specified signal controller logic (6, 10). It is a microscopic, event-scanning simulation model, and still needs calibration and validation. It could be useful for investigating the optimal use of VA controllers and for developing new control algorithms.

3.1 AREAWIDE SYSTEM MONITORING AND CONTROL

Current research at ARRB has also concentrated on the monitoring of the performance of SCATS on-line. A scheme is proposed whereby the data collected from stop line detectors is utilised for the modelling of queue formation and dissipation, and hence vehicle delay in a network (23, 24). With detectors located at the stop line, SCATS cannot determine the fraction of traffic entering the link from upstream approaches (i.e. the in-flows). Vehicle detectors in most other UTC systems are located at mid-block or close to the upstream end of a road link; these systems can measure traffic flow or demand on the road link more accurately. On the other hand, stop line detectors provide an accurate picture of how vehicles depart from an intersection (18). The proposed scheme therefore consists of two parts:

(a) estimation of the turning fractions and hence the link flow with a recursive least squares algorithm, and
(b) modelling of queue formation and dissipation at the stop line in a manner similar to the TRANSYT program.

The link flow estimation procedure is as formulated by Cremer and Keller (11) and is illustrated in Fig. 6. Assuming the conservation of flows, the link flow $y_4$ is given by:

$$y_4(k) = q_4(k)$$

$$q_4(k) = a_{44}(k)q_1(k) + b_{41}(k)q_2(k) + b_{42}(k)q_3(k)$$

where $k$ is a time series index representing an interval of several signal cycles,
\( q_i(k) \) is the upstream flows at entry \( i, i = 1, 2, 3 \) at time \( k \) (veh).

\( \dot{q}_i(k) \) is the estimated flow at the upstream end of the link at time \( k \) (veh),

\( b_{ij} \) is the turning fraction of flow from \( i \) to \( j \), and

\( y_4(k) \) is the output link flow (veh) allowing for the offset between the intersections.

The flows \( q_1, q_2, q_3 \) and \( y_4 \) are directly measurable quantities from SCATS detectors. The turning fractions \( b_{ij} \)'s are unknown quantities to be estimated from the input-output flows \( q_1, q_2, q_3 \) and \( y_4 \). Note that \( q_4 \) is not available in SCATS and is determined from the equation:

\[
q_4(k+1) = b_{14}(k)q_1(k+1) + b_{24}(k)q_2(k+1) + b_{34}(k)q_3(k+1)
\]

Platoon dispersion modelling is then applied to \( q_4 \) to predict the arrival profile at the downstream stop line. Queue dissipation and formation are modelled as in TRANSYT but using on-line, measured stop line departure profiles. The proposed scheme does not require the assumption of vehicles departing at pre-determined, constant saturation flows.

In a study carried out in Box Hill, Melbourne, both the queue length at the start of a green period and the maximum back of queue were measured at the downstream stop line. These were compared with the corresponding predicted queue lengths using the proposed scheme. The upstream and downstream flow profiles were retrieved directly from the signal controllers. Due to telemetry limitations, SCATS currently does not provide flow profiles of sufficient accuracy for queue prediction. The field data were analysed with the time interval \( k = 4 \) cycles for link flow estimation, and with a profile step size of 4 s for modelling queue formation.

Some results of the Box Hill Study are illustrated in Figs 7 and 8. These are the time variation of the maximum back of queue in the a.m. (peak) and p.m. (off-peak) periods. Each period consisted of 88 cycles and was of about three hours duration. The availability of measured departure profiles at the stop line was particularly useful in incident detection. This is illustrated at cycle 12 in Fig. 7. The proposed scheme was successful in tracking the time variation of the measured queue lengths except during cycles 30 to 35 in the a.m. peak period.

Further research is needed in refining the incident detection algorithm for oversaturated conditions.

The correlation coefficients (\( R^2 \)) and root mean square errors between the measured and predicted queue lengths are given below:

| Queue at green start (a.m. peak) | 0.71 | 8  |
| Queue at green start (p.m. off-peak) | 0.77 | 4  |
| Max. back of queue (a.m. peak) | 0.64 | 12 |
| Max. back of queue (p.m. off-peak) | 0.52 | 7  |

The accuracy for predicting the maximum back of queue is not as high as the accuracy for predicting the queue at green start. This is due to vehicles changing lane as they join the back of queue. At this macroscopic level of simulation, the results are regarded as satisfactory. Because detectors in SCATS are installed in each lane, it was also possible to compare the predicted and measured queues at the lane-by-lane level. The lane-by-lane results show a similar level of accuracy as the single movement analysis.

Further research will be undertaken to improve the accuracy of modelling the system performance in real time. This will enable SCATS to provide an accurate picture of prevailing traffic conditions based on network delay. Offset optimisation by reducing network delay or queue length (31) could also be considered as an alternative to the current objective of bandwidth maximisation in SCATS.

The DMR-NSW will continue to take a leading role in the development and maintenance of SCATS. It provides the Secretariat of the SCATS Management and Users Group for information exchange and users' feedback. With extensive operational experience now available from Australia and overseas installations, SCATS should only need fine-tuning to meet local requirements. Long term development may include the re-programming of the software in a high level language such as C or PASCAL, and improvements in telemetry for traffic data gathering such as those from an automatic vehicle monitoring system described in Section 3.4.

### 3.3 DYNAMIC ADVISORY SPEED SIGNS

The Road Traffic Authority of Victoria (RTA) and the Commonwealth Scientific and Industrial
Research Organisation (CSIRO) are jointly conducting research into the benefits of providing drivers with speed advice (35, 39). The concept is that drivers would be advised a speed which would allow them to arrive at the following set of traffic signals during green. This concept is not new and was reported by von Stein in 1961 (37). Based on in-vehicle display of the advised speeds, field tests by CSIRO have shown that the concept could reduce vehicle stops by 50 per cent and fuel consumption by 15 per cent.

Determining the appropriate speed to advise in a dynamic system such as SCATS is more complicated than in a fixed-time control system. The green times in SCATS change in response to prevailing traffic conditions. Software has been developed by CSIRO to predict downstream green times and queue lengths to calculate appropriate link speeds (12).

The advisory speed system, known as ADVISE (Advisory Display of Variable Information for Speed and Economy), was switched into operation for trial in a SCATS-controlled arterial road in Melbourne in November 1987. Apart from the advised speed, messages on the roadside display sign include:

- ‘light’, ‘medium’ and ‘heavy’ for the traffic conditions ahead,
- dots to indicate the bandwidth available (i.e., whether a vehicle can drive at a higher or lower speed and can still pass through the intersection in a green phase), and
- the distance that the driver is expected to travel at the advised speed before he may have to stop.

The performance of ADVISE will be monitored for the following twelve months. On-going development is still needed in its integration with SCATS and in queue length predictions (Section 3.2).

3.4 AUTOMATIC VEHICLE MONITORING (AVM)

There are also interests in monitoring the performance of SCATS by means of automatic vehicle identification (AVI). The intention is to equip government vehicles and taxis with coded transmitters. These vehicle identification (VI) codes are sent to roadside receivers utilising the existing network of SCATS detector loops as the receiving antennae. The receivers could also be installed inside the traffic controllers. The central control computer could provide the processing of the VI codes to obtain the point-to-point journey times in various parts of the signalised network. These journey time samples could then be used for fine-tuning of the SCATS algorithms, for offset optimisation based on journey time minimisation, for incident detection, for traffic diversion, and for system monitoring in general. The concept is an attractive one but the following issues need to be addressed:

(a) VI code structure - the number of bits in the code for identifying each vehicle, class of vehicle, level of priority and error checking.

(b) Type of transmitter and receiver - this will depend on the costs involved and on the ability of the system to transmit/receive VI codes to/from in-ground loops at speeds up to 110 km/h.

(c) Telemetry changes - SCATS messages are transmitted at 300 baud over dedicated telephone cables. This transmission speed is limited by the receiver/transmitter units at both the traffic signal controller and regional computer ends. High speed communication units are required to cater for the additional VI codes. SCATS protocol and message formats need to be re-examined.

(d) Central processing software - this has yet to be developed and should be integrated with the current system monitoring facilities.

The microprocessor controller is a key component in a future SCATS-based AVM system, serving the role of a roadside data interchange unit. As microprocessor and memory become more powerful and cheaper, a controller can accommodate more sophisticated traffic control and communication requests. It becomes a unit not just for signal timing control, but also for other traffic aids. These include vehicle tracking mentioned above, road pricing, and driver information by roadside display or radio broadcasting.

The impetus for developing a SCATS-based AVM system will probably come from the taxi industry. For security reasons, a taxi driver is keen to keep the central depot (or control centre) informed of his current locality in real time while on duty. ARRB
is sponsoring the development of a low cost dead reckoning unit for vehicle positioning. This unit is to be interfaced directly into a taxi radio communication network. At the start of a trip with a customer, the taxi driver provides the initial coordinates for the central depot. As the vehicle moves away from its initial location, its real-time coordinates are calculated by the dead reckoning unit and inserted into the existing message protocol. This message is radioed to the central depot in the usual manner.

4. CONCLUSIONS

Australian signal research in the last ten years has produced useful urban traffic control systems and signal design techniques for practice. In particular, the SCAT system and the SIDRA model have been widely accepted in Australia and in overseas countries. Continuing user feedback will further enhance their applications.

Current and future activities will centre around developing SCATS into a dynamic traffic management system. These will utilise the current extensive network of loop sensors and include the online monitoring of its system performance, automatic vehicle monitoring, and the integration of advisory speed system into its operation. The refinement of SCATS tools such as CLOFFSET will continue.

Options for analysing the roundabout and unsignalised intersection are to be incorporated into SIDRA. The extension of the program into a paired intersection model, and the linkage to areawide models will be investigated. Research into the optimal operation of microprocessor controllers manufactured in Australia will be initiated.

REFERENCES


DESIGN A
This system structure as used in CANBERRA, HOBART, AUCKLAND and WELLMINGTON, gives:
* Full SCATS operation for a region of up to 120 sites;
* Traffic and SCATS data collection and analysis and;
* Fault reporting.

DESIGN B
This combination, as used in PERTH, gives:
* ALL OF THE ABOVE, plus
* Centralised system management for a multi-region system;
* Central monitoring remote from Regional Computer installations.

DESIGN C
This arrangement can be used, as in ADELAIDE, for staged implementation of design "D" (Below). It gives:
* ALL OF THE ABOVE, plus
* Sophisticated traffic and SCATS data collection, analysis and system management.

DESIGN D
This structure, in SYDNEY, SHANGHAI and MELBOURNE, gives:
* ALL OF THE ABOVE, plus
* Dedicated system management facility;
* High resolution colour Graphic display of real-time system operation and performance; and,
* Rapid visual assessment of every level.

Fig. 1 - System configurations using SCATS
Fig. 2 – Lane configuration for a typical weekend in three-lane tidal flow control.
Fig. 3 - Extension and early-start options in tram priority

Fig. 4 - Flexible window stretching
**SIDRA INPUT DATA PREPARATION FORM**

Prepared by: Rahmi Akcelik

Date: July 1986

Intersection Title: U.S.H.C.M. 85, Example 3 (page 9-50)

Computer File Name: S 97

Reference No.: Conf. Workshop

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Include lane disciplines, short lane lengths, grades, etc.

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**SIGNAL PHASING** (Description: Option to match U.S.H.C.M. timings)

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Use symbols

- Lane interaction
- Short lane

**OTHER FEATURES**

- Flow scale:
  - E-W: 118% (PHF = 0.85)
  - N-S: 111% (PHF = 0.90)
- Heavy vehicles:
  - E-W: 5%, N-S: 2%
- All grades = 0
- Number of parking lanes = 5 (E-W)
- Lane util. ratio = 0.90
- All intergreens = 3
- All lost times = 2
- c = 119, f1 = 0.8, 13, 87
- gmin = 22 (pedestrians)

Specify environment class, restricted turns, special movement types, etc.

Fig. 5 - Example from U.S. Highway Capacity Manual 1985
Fig. 6 – Link flow estimation in SCATS
Fig. 7 – Maximum back of queue as a function of time (a.m.)

Fig. 8 – Maximum back of queue as a function of time (p.m.)
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