‘MOVA’: TRAFFIC RESPONSIVE, SELF-OPTIMISING SIGNAL CONTROL FOR ISOLATED INTERSECTIONS

by R A Vincent and J R Peirce

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Traffic Group
Transport and Road Research Laboratory
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MOVA: TRAFFIC RESPONSIVE, SELF-OPTIMISING SIGNAL CONTROL FOR ISOLATED INTERSECTIONS

ABSTRACT

More than half of the UK's 9000-plus signalised junctions are controlled by independently-operated (uncoordinated) signals with green times varying in response to local traffic flows. MOVA (Microprocessor Optimised Vehicle Actuation) is the new signal control strategy researched and developed by TRRL for such isolated intersections. Data from vehicle detectors on the junction approaches are analysed by an on-line microprocessor implementing the MOVA program; the durations of the green signals are controlled by a delay-and-stops minimising logic, or, if any approaches become oversaturated (congested), by a capacity-maximising process.

Subject to a final large-scale trial, MOVA is intended as a general replacement for the gap-seeking, D-system vehicle-actuated (VA) control currently in use. This report describes the MOVA system, its main principles, the development trials which have taken place, and the assessments of benefits due to MOVA. It is concluded that MOVA reduces vehicle delay by an average of about 13 per cent throughout the working day, compared with up-to-date D-system VA; further benefits are likely where, as is often the case, critical VA controller settings (maximum green times) are based on out-of-date traffic data.

1 INTRODUCTION

MOVA (Microprocessor Optimised Vehicle Actuation) is the new signal control strategy researched and developed by TRRL for isolated intersections. Some 60 per cent of the estimated 9250 signalised junctions in the UK have independently operated (uncoordinated) signals with green times varying in response to local traffic flows: MOVA is designed to be suitable for controlling the majority of these isolated signals. This report describes the MOVA system, the development trials which have taken place, and the assessments of benefits due to the improved control.

Since the 1930's, most UK isolated traffic signals have operated with 'vehicle-actuated' (VA) control of the green times; vehicles crossing detectors on the junction approaches are able to extend an existing green signal between minimum and maximum time limits, or to recall a green if the lights are currently red. Although the detectors and control equipment have improved substantially over the 50 years, the key principles of VA control have remained essentially unchanged. MOVA is the result of a major TRRL research programme to develop an improved control strategy: this takes advantage of microprocessor technology to implement logic which is beyond the capabilities of earlier equipment.

1.1 THE SCOPE FOR IMPROVED CONTROL

During the course of the research it became clear that, although conventional D-system VA control was often very effective, it does have two limitations:

(a) a tendency to extend green times inefficiently when traffic is flowing at considerably less than full saturation rate, especially on multi-lane approaches

(b) inappropriately set maximum-green times can adversely affect delays: it is particularly difficult for the traffic engineer to choose compromise maximum-greens to cover the wide range of traffic conditions which occur at different times of day, days of the week, or seasons of the year; it is also time-consuming to update these maximum greens regularly.

The self-optimising features in MOVA are designed to overcome both of these difficulties.

Publications concerned with the improvement of isolated signal control suggest that developments fall broadly into two categories. The first category may be considered as stage-based control, in which the microprocessor is used mainly to optimise the duration of the green time given to each signal stage (Miller 1963, Steierwald 1970, Robertson and Bretherton 1974, Bang 1976, De La Breteque 1979). The second category, in contrast, is more phase (or signal-group) orientated control in which the microprocessor is used mainly to provide flexible sequences and combinations of signal groups (Bouman 1980, Hallworth 1980, Hawke 1984, Reid 1984, Barnes 1984). Thus, strategies in category 1 are generally more restricted in the number of stages and the stage order, while strategies in category 2 are limited more by the way the green durations are determined - usually by a simple gap-seeking algorithm.

At present, from experience at TRRL, it would seem unlikely that the commonly-available microprocessors are powerful enough to combine fully the desirable features of both the above categories of strategy. TRRL research has concentrated on category 1 (stage-based) self-optimising control in the belief that this addresses itself more directly to the optimal timing of...
green for critical traffic movements; the phase-based flexibility of category 2 control is often of benefit to non-critical rather than critical traffic movements. Consequently, MOVA is structured to make decisions about stage-to-stage changes. Nevertheless, many of the underlying calculations are phase or signal-group related, and it is therefore possible to provide some of the phase-to-phase flexibility apparent in category 2 strategies. This is achieved by user-selected conditions applied to various stage demands such that some stages can be omitted from an otherwise fixed sequence of stages, depending on traffic conditions at the time.

2 EQUIPPING A SITE FOR MOVA CONTROL

This section describes the equipment necessary to implement MOVA and gives examples of the site-specification data defining its use at a junction.

In some cases, it may be desirable to enhance other features of the junction prior to MOVA installation. For example, it is often useful to improve lane-line and directional-arrow road-markings to encourage good lane discipline and hence more accurate counting from detectors. For the same reasons, a review of parking, waiting, and loading regulations may be beneficial. It may also be worth considering a revised stage sequence, taking into account the possibilities for conditional omission of stages with MOVA.

2.1 DETECTORS

MOVA has been implemented using detectors solely of the buried inductive-loop variety; these are the only detectors in common use in the UK which give reliable lane-by-lane counting and also a ‘presence’ output.

The most obvious difference between MOVA and the current UK standard D-system method of VA signal control is in the layout of loop detectors. Figure 1 illustrates the detector locations actually used at one

![Fig. 1 Detector locations at a MOVA controlled junction](image-url)
of the experimental MOVA sites. Separate detectors are installed in each lane, and their size and shape are designed to provide a good compromise between possible overcounting and undercounting. Reasonably accurate counts of arrivals are needed to allow flows, delays, stops, queues, etc to be estimated.

Normally, two detectors per lane should be located so as to give vehicle cruise-times between loops and stop-line of about 3.5 and 8.0 seconds; these values are by no means critical, however, and considerable flexibility in location is possible. In urban areas, these cruise-time criteria will commonly result in detectors being located at about 40 m and 100 m before the stop line. Where approaches widen out to give extra lanes near to the junction, it is usual to omit the distant detector in a short lane and to use just one detector at about 40 m as in Figure 1. The normal size and location of the diamond-shaped loops used by MOVA are shown in Figure 2, but some dimensions can be varied to cater for width limitations or particular irregularities in the road surface. The distant detector is named the 'IN-detector' and (by analogy with the labelling used in the D-system) the detector at about 40 m is called the 'X-detector'.

In certain lanes, it may be necessary to install an additional detector immediately prior to the stop-line; this will usually be for control of right-turn early-cut-off situations (as described later in 6.1), but can be needed (rarely) as an extra demand detector. Generally, with MOVA, in contrast to D-System VA, most approaches do not have detectors nearer than about 40 m from the stop-line: this slightly increases the possibility that vehicles may remain undetected if they stop, or stall, or otherwise fail to clear during the green after they arrive at the stop-line. Use of an extra demand detector has been found to be necessary on only a few of the approaches so far controlled with MOVA.

2.2 THE MOVA MICROPROCESSOR
Following research trials of MOVA, using a minicomputer in a mobile laboratory (see Section 6), the MOVA system has been developed for wider application as a powerful, self-contained, microprocessor-based module, which can be added to any modern UK traffic signal controller. Later developments may integrate MOVA more fully into the controllers, but the following describes the add-on MOVA equipment.

The MOVA detectors are connected directly into the MOVA computer system; none of them are connected to the standard controller. The local signal controller is fitted with a standard Urban Traffic Control (UTC) interface, to allow the MOVA computer to force the traffic signals to change stage. The controller sends signal status confirmations to MOVA which, in turn, sends back stage-change commands, all via the UTC-interface. This is a reliable and proven method, and is likely to be used in most initial applications.

Thought is being given to an alternative method which could have wider application: MOVA would trigger a stage change by sending the controller a single pseudo-detector signal which would be fed into the normal detector inputs of the controller instead of the usual D-system detections. In the absence of other, genuine, detector signals, and provided that the controller has no constraints on particular stage-to-stage changes, this would force the required stage to appear.

2.3 SITE CONFIGURATION DATA
In addition to the necessary detector and signal connections, the MOVA program must be provided with data to define the characteristics of the particular junction and features of its control. Much of this data will be familiar to the practising traffic engineer who is used to conventional control; other data will be novel. To aid the configuration process, TRRL has produced an off-line Data Set-up Program for use in the office, to create the required data-set; this can then be transferred into the MOVA computer.

At a few sites, it may be useful to change some MOVA parameters by time-of-day or day-of-week: for example, it may be required to change the sequence of stages, or to exclude certain stages, at particular times. Provision has therefore been made to include three different data-sets (or 'plans') in MOVA and to
switch between these according to a user-defined timetable.

The Data Set-up Program assists the user by describing each data item required, and suggesting suitable default values whenever possible. Many other data values are derived automatically from previously entered data, and need be altered by the user only in exceptional cases. MOVA is currently set-up to cater for a maximum of 8 stages, 12 links, 16 lanes, and 32 detectors. Examples of some of the key data are as follows.

(a) The user must define the grouping of lanes into ‘links’. MOVA makes some decisions on a lane basis and others for links, where a link represents 1, 2, or 3 adjacent traffic lanes on the same signal phase, or may represent a pedestrian demand-dependent phase. This usage is similar to that in the well-known TRANSYT program (Vincent et al 1980). A link consists of a single lane unless a multi-lane queueing situation exists as follows: several lanes are judged to provide queueing space for a single common link queue if traffic from each of the 2 or 3 lanes discharges in a similar way during the same greens, and lane directional-arrow markings do not inhibit the formation of roughly equal-length queues. On multi-lane links, MOVA will judge saturation flow to have ended as soon as any of the constituent lanes is discharging at less than normal saturation rate.

(b) For each lane, the user specifies data including: distances from each detector to the stop-line, saturation flow information, and the typical cruise speed of traffic. To allow the traffic authority to give higher priority to clearing queues on particular lanes during oversaturated conditions, a lane weighting-factor is available.

(c) For each link, the user lists, amongst other parameters: the signal stage(s) during which the link receives green, a minimum green time, whether it is a traffic or pedestrian link, and certain codes to define the conditions under which a demand on the link will produce a demand for any of the stages; this latter code allows some use of conditional demands and stage-skipping options. A stop-penalty value can be set to give more or less importance to stops on individual links when MOVA considers the merits of extending a green signal; the optimiser computes a performance index (delay + stops, similar to that in TRANSYT) and is more likely to hold green for links given a high stop-penalty due, for example, to a high proportion of heavy or fast vehicles.

3 THE PRINCIPLES OF MOVA CONTROL

To decide how long the green signal should be displayed to any particular stage, MOVA makes a number of sequential decisions during the green period, based upon traffic flow and queue information derived from the vehicle detectors. In this way, the stage green may be thought of as having the following component periods, some of which may be of zero duration on occasions.

(a) The absolute minimum green period for the current stage followed by a further variable minimum green period for each link to cater for those vehicles which have already crossed the X-detector(s) and for which the absolute minimum green is insufficient.

(b) After the full minimum green period, there follows a period when the queue on at least one relevant link is judged to be still discharging at saturation flow.

(c) After the end of saturation flow has been observed for all relevant links, there is a period when MOVA estimates the benefits and disbenefits of continuing the current stage green. This optimisation process makes use of a performance index — a weighted combination of vehicle delay and vehicle stops. Unless benefits exceed disbenefits, the green is terminated for the current stage.

The following subsections describe more fully the decision process listed above.

3.1 MINIMUM GREEN CALCULATIONS

The absolute minimum green for a stage is user-specified: it is the shortest green to which drivers and pedestrians can be expected to react safely. The normal absolute minimum green time in the UK is 7-seconds. At the end of the stage minimum, MOVA checks how many vehicles have been counted over the X-detector since the lights previously went red for each lane which has just commenced green. From these lane counts, MOVA estimates the minimum time needed to clear the queue between the X-detector and the stop-line, for each lane. The link minimum is then taken as the largest of the lane minima for lanes forming the link. This process is akin to the variable-minimum facility once common on UK traffic signal controllers operated by pneumatic detectors.

3.2 DETERMINING END OF SATURATION FLOW FOR A LINK

Once the minimum green for a link has expired, traffic should generally be moving freely over the X-detector in each lane on the link. By examining the size of the time ‘gap’ between successive vehicles as measured at the X-detector, MOVA decides whether or not the traffic is discharging at measurably below full saturation rate. As soon as any one lane of a link is judged to be discharging traffic at less than full rate, then the link also is judged to have reached the ‘end-of-saturation’ condition.
The gap-checking method used to determine the end of saturation flow involves the comparison of the current gap, or sometimes the sum of the current and previous gaps, against pre-specified critical-gap values. Figure 3(a) shows an example distribution of gaps (i.e. the detector 'off' times) as measured for vehicles discharging at saturation flow: the mean gap is about 1.3 seconds. In a long stream of discharging vehicles,
it is quite likely that a gap of (say) twice the mean gap size will occur among the many gaps being checked, even though the probability of such a large gap is less than .05 as seen in Figure 3(b). Consequently, to reduce the probability of a spurious 'end-of-saturation' decision, MOVA uses critical gaps of around 3.5 seconds, varying slightly with the lane saturation flow.

3.3 DETERMINING END-OF-SATURATION FOR THE CURRENT STAGE

MOVA checks whether each link currently receiving green has reached end-saturation or not, and also decides which of these links are 'relevant links' which must reach end-saturation before a change to the next stage is considered. Some links currently green will continue to receive green in the next stage also; such links are not relevant when deciding whether to end the current stage green. When all relevant links have, individually, reached end-saturation, then the current stage is also at end of saturation. Until this decision is made, MOVA simply extends the current green stage, subject only to the (usually long) maximum greens. MOVA is so designed for the following reasons:

(a) Evidence from simulation studies suggests that minimum delay is usually achieved if traffic discharging at saturation rate receives enough green to clear the queue completely. (MOVA has special features to cater for exceptional situations which occur with approaches which widen near to the junction—see section 5.3)

(b) The model of traffic behaviour and the predictive algorithms used in the delay and stops optimisation process may not be realistic until queues on relevant links have cleared.

3.4 OPTIMISATION OF DELAY AND STOPS WITH MOVA

Once the current stage has reached end-saturation, queues should have cleared and traffic should be flowing freely on all relevant links. MOVA then uses a model representing traffic on each separate lane receiving a green signal. This model is updated from IN and X-detectors every half-second and represents both the predicted position and movement of vehicles, assuming free-flow conditions; queueing is not represented.

Figure 4 illustrates the MOVA lane model. Vehicles occupying a loop are represented by a '1' in the box corresponding to the detector location. When a detector changes from 'on' to 'off', the departing vehicle is counted and a '1' is placed in the box immediately downstream of the detector box; during each subsequent pass through the program, these vehicles are moved one box nearer to the stop-line on the assumption that vehicles travel at the lane-specific cruise speed which is arranged to correspond to one box per half-second.

MOVA uses these models of lane behaviour to calculate which vehicles will benefit if the current green is extended by varying amounts into the future. The maximum number of vehicles potentially benefiting per 1-second of green extension is thereby estimated.

MOVA also maintains a count of vehicles currently queueing at red signals around the junction. From these counts and the measured average arrival flows expected to join these queues in future, MOVA estimates disbenefits which an extension of the current green would cause. In making these calculations, MOVA estimates how long traffic on the currently-

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Fig. 4 The MOVA model of traffic flowing down an approach lane
green lanes would have to wait for the signals to become green again next cycle, if the current green were not extended.

Figure 5 shows the key components of the delay changes attributable to extending rather than ending the green, for a simple 2-link 2-stage junction. The example shows the build-up and decay of queues on the two conflicting links for two cases: either, stage 1 green ends 'now', or stage 1 green is extended by time 'dt' to allow a bunch of arriving vehicles to depart before the green ends.

(i) Change now sequence

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(ii) Change after extension dt sequence

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<tr>
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<th>STAGE 1</th>
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Fig. 5 Example delay changes as used by MOVA optimiser
The net change in delay due to the extension is obtained by summing the following:

- Delay saved by Link 1 traffic using the green extension, as depicted by area 1A in Figure 5.
- Delay suffered by Link 2 traffic waiting extra time (dt), as shown by area 2 in Figure 5.
- Delay incurred by Link 1 traffic waiting for the (later) next green, as shown by area 1B in Figure 5.

Finally, to correct for the estimated increase in cycle time (dc) due to the extension (dt), the net delay change is corrected to a net change in the rate of delay at the junction.

In principle, the consequences of such an extension will not end after just one cycle. However, simulation studies have indicated that the improvement in optimisation achieved by predicting further into the future is negligible for the normal (under-saturated) conditions during which MOVA uses this procedure.

The above calculations provide an estimate of the net delay saving (positive or negative) due to extending the green. Vehicles which would be able to pass through an extended green without stopping produce a further benefit; each vehicle-stop saved is valued as equivalent to a pre-specified number of vehicle-seconds of delay. MOVA then calculates a 'performance index' (PI) equal to the sum of the net delay and the weighted stops for all relevant links. These calculations are repeated at 0.5-second intervals. If the PI falls to zero or below, MOVA changes the signals to the next stage; a positive PI causes the current green to be extended.

3.5 CYCLE-TIME CONTROL

Generally, MOVA is set up to operate within maximum-green times which are considerably larger (+50 per cent) than used conventionally; this is usually acceptable because MOVA will not extend the green inefficiently and will rarely reach the maximum limits. At some busy sites, however, long-term heavy flows might result in a consistently longer cycle than is desirable. Some reasons why it may be best to limit the cycle are: because pedestrians may otherwise cease to wait for a safe time to cross, because very long saturated greens may cause exit-blocking problems, or because right-turn (RT)-traffic which is not given a free-RT stage receives insufficient opportunities to turn.

Current systems achieve a constraint on cycle time by limiting stage or phase maximum green times; this severely reduces flexibility. MOVA handles the constraint differently and allows the stage maximum greens to continue to be set generously long; the user merely specifies a desired upper limit to the cycle time. MOVA will then limit individual stage green times automatically to achieve the desired cycle time; the user does not need to specify the durations of the stage greens making up the limited cycle time. The constraint imposed by MOVA on each stage varies continuously, depending on traffic conditions at the junction as a whole. The procedure checks the merit of allocating additional green time to the current stage compared with the others, and thereby allows the green times to drift in response to changing levels of congestion. This feature is likely to be particularly useful where peak traffic flows are highly variable and conventional maximum greens are difficult to set well.

The cycle-limit, if adopted, applies during both normal (unsaturated) conditions and congested (oversaturated) conditions; it also applies with an automatically revised lower cycle limit during short-cycle control (see Section 5).

4 CONTROL DURING OVERSATURATED CONDITIONS

MOVA has special features to cater for situations when one or more approaches to a junction are left with a significant queue at the end of green and are judged to be 'oversaturated'. In such circumstances, traffic flow and queue information from the vehicle detectors is unlikely to be fully representative of the true conditions. MOVA automatically recognises oversaturation and switches from the normal delay-and-stops minimisation to a capacity-maximising process to clear the congested approach(es) as quickly as possible. Once a junction is oversaturated, there is likely to be a strong correlation between signal timings which maximise capacity and those which minimise delay. This assumption is the basis for MOVA control during periods of oversaturation.

4.1 CONTROL TO MAXIMISE CAPACITY FOR OVERSATURATED LINKS

If one or more lanes on a link are oversaturated, then the link as a whole is judged oversaturated and MOVA adopts the alternative capacity-maximising control when deciding the green time for the link (sub-section 4.2 gives more detail and explains what happens if several links are simultaneously oversaturated). The link will first receive the appropriate minimum green as usual (see 3.1). After the minimum green, MOVA no longer checks for the end of saturation flow in the normal way; instead, it assesses the efficiency of use of the green and decides whether capacity is likely to be maximised by continuation of this green or not.

The capacity-maximising process (described in 4.2 below) will, when appropriate, allow the green on an oversaturated link to continue even though the traffic may be discharging at a rate which is measurably less than the normal saturation flow. Thus, there is a built-in adjustment for links where the discharge rate tends to decrease as the green continues. This feature will
also provide some corrective action when the discharge on a link is reduced due to casual obstructions such as parked vehicles, or if the discharge is erratic due to drivers leaving occasional excessive gaps between vehicles for any reason.

4.2 THE CAPACITY-MAXIMISING LOGIC
Details of the logic are complex, and only the broad principles are given here.

If the link saturation-flow stays constant throughout the green, however long, then capacity will be maximised for the link by allowing the green to continue as long as possible, subject only to some over-riding limit imposed for reasons of public acceptance. In this way, the signals will operate to long cycle times, and the lost-time wasted while changing from one stage to another will be kept to a minimum.

Often, however, the rate of discharge from a link will be high early-on in the green but will decrease later. In such cases, capacity may be maximised by ending the green as soon as the discharge falls below the initial saturation flow value, or it may be better to continue the green despite the reduced rate. MOVA assesses the situation automatically depending on the current conditions and decides whether to continue the green or not.

The decision-making algorithm is based upon a relationship between the duration of the current green stage and the likely durations of the other stages making up the cycle. From this, MOVA estimates a flow efficiency factor which is proportional to the observed efficiency of use of the current green time and hence to the link capacity. Repeated calculation of this efficiency factor every half-second throughout the green allows the approximate capacity-maximising green time to be estimated. Figure 6 illustrates the process. Because of "noise" on the basic information, the efficiency factor is somewhat erratic and must fall a meaningful amount below the peak efficiency before the decision to end green can be made.

If several links are simultaneously oversaturated, this is taken into account by adjustment to the relationship between the duration of the current stage and that of the overall cycle time. It is assumed that other oversaturated links will in their turn be controlled by the same capacity-maximising process as the oversaturated link currently receiving green, and hence the cycle time is deduced.

5 SPECIAL CONTROL FEATURES FOR APPROACHES WITH 'SHORT LANES'

5.1 THE ‘BONUS’ CONCEPT
On many approaches, localised carriageway widening provides more lanes near the junction than on the approach road itself. Thus, saturation flow during the early part of the green can be considerably larger than later-on in the green. The local widening is therefore giving some initial 'bonus' capacity for the approach. MOVA is designed to recognise such situations and to modify the signal control appropriately; this is particularly important when maximising capacity in oversaturated conditions.

![Figure 6 Variation of flow efficiency with green time](image-url)
Figure 7(a) illustrates a single-lane approach which widens to two lanes near the junction. With both lanes receiving the same green signal, the saturation flow across the stop-line might be as in Figure 7(b); the extra effective green attributable to the local widening is known as ‘bonus green’ in MOVA, and is calculated as shown. Sub-sections 5.2-5.4 describe how the bonus green is used to influence the signal control.

5.2 CAPACITY-MAXIMISATION AND SHORT-CYCLE CONTROL

Theoretical studies suggest that the choice of green time, and hence cycle time, to maximise capacity for a link depends upon the relative magnitude of the ‘bonus green’ and the junction lost-time (i.e. the time lost to traffic while changing from stage to stage through one full cycle, plus any time given to pedestrian crossing stages). The relationship between link capacity and bonus green for a particular value of lost time is illustrated in Figure 8. In this example, traffic on links that conflict with the oversaturated link is assumed to be undersaturated and the stages during which they receive green are given a fixed proportion (40 per cent) of the cycle time.

It can be seen from Figure 8 that, if the link bonus green equals the lost time (8-seconds), then the link capacity is constant for all cycle times, provided the link green is sufficiently long to discharge the short-lane queue and gain the full bonus. If the bonus green exceeds the junction lost-time, then the link capacity falls as the green time is increased beyond the bonus green. Conversely, if the bonus green is less than the lost time, including a zero bonus, then link capacity increases as green time increases. In this way, MOVA is designed to initiate short-cycle control, where appropriate, to give the relevant approach frequent short greens to maximise use of an initially-high saturation flow. Otherwise, if the use of the short lanes is insufficient, MOVA will choose to operate long green times as being the better way to maximise capacity and clear queues.

![Fig. 7(a) Example of a tapered approach](image)

![Fig. 7(b) Variable saturation flow and ‘bonus’ effect](image)
5.3 CONFLICTS OF INTERESTS IN BONUS SITUATIONS

In the simple example of a bonus situation described above, no consideration was given to the problem which arises if several approaches are simultaneously oversaturated and require capacity-maximising control to clear congestion. It can occur that opposite approaches, which receive green during the same stage of the signals, require conflicting methods of control: one approach may have local widening and hence a sufficient bonus green to require short-cycle control for maximising throughput; the opposite approach, in contrast, may have no local widening and hence no bonus, and therefore requires long greens and long cycle control. In such circumstances, the user must make a policy decision as to which approach is to be given priority, and to specify whether short-cycle control can be invoked or not.

5.4 MORE COMPLEX BONUS SITUATIONS

At some junctions, different approaches receiving green during different stages may each exhibit a bonus. Sometimes, one of these bonuses on its own may be sufficient to justify short-cycle control to increase capacity for the junction; in other cases, a combination of small bonuses occurring in different stages may collectively justify short-cycling. MOVA can be set-up to recognise such situations, subject to user-imposed constraints, and to select both the cycle time and the distribution of green time between stages so as to operate appropriate short-cycle control.

6 OTHER NOVEL FEATURES IN MOVA

6.1 TREATMENT OF RIGHT-TURN EARLY-CUT-OFF SITUATIONS

Early-cut-off is a very common facility provided to cater for a substantial right-turn flow; Figure 1, stages 3 and 4, illustrates the stage sequence used. During stage 3, the right-turn (RT) traffic receives a full green signal which allows vehicles to advance into the junction and turn through any gaps in the opposing flow; subsequently, the opposing flow is stopped and RT traffic is given a green-arrow signal during stage 4 and can turn freely. MOVA uses an unconventional method for deciding whether or not there is sufficient RT traffic to warrant the extra RT-only stage. In such circumstances, MOVA uses vehicle counts from an extra detector just before the stop-line and from the 40 m-detector to estimate the number of RT vehicles queueing between the two detectors. If this number exceeds a preset minimum (usually 1) then the exclusive RT stage is demanded. In this way, when the flow of RT traffic is small, the extra stage can be omitted with resulting substantial benefits to traffic on all other stages.
This method avoids the deficiency which can occur with the current UK ‘call/cancel’ technique using a single loop: during low flow conditions, this technique frequently demands the extra RT stage just as the last vehicle in the RT queue is clearing at the end of the opposed-RT stage; the free-RT stage is then superfluous and wastes considerable time for other traffic.

### 6.2 SOURCES AND SINKS

There are often opportunities for vehicles to enter an approach lane without crossing both IN and X-detectors in the normal way. Such entries are known as ‘sources’, and may occur where traffic turns-in from minor unsignalled side-roads, or from private drives. Provided the source vehicles subsequently cross at least the X-detector, there is no need for special provision in MOVA. If they enter downstream of the X-detector, however, an extra stop-line demand detector (as mentioned in 2.1) would be installed to ensure that appropriate green signals appear.

The complementary situation to a source is known as a ‘sink’, where vehicles can leave an approach before they reach the stop-line but after they have been detected at the IN-detector and perhaps also the X-detector. If significant numbers of vehicles leave via sinks, such as side roads or non-signalised slip-roads, it is often possible to correct for this. Sometimes, IN or X-detector locations would be adjusted suitably, or, in other cases, additional ‘sink’ detectors would be installed to count traffic leaving the main approach; this provides MOVA with better information on which to base its optimisation of green times.

### 6.3 ‘SUSPECT’ DETECTORS

Any vehicle-actuated control system is heavily dependent on its detectors for efficient control. MOVA makes particularly stringent demands on its detectors in requiring reasonably accurate counts of traffic flows and estimates of queues lane-by-lane. To ensure that the performance of MOVA control does not deteriorate dramatically when detectors are unusable, the Program incorporates logic to identify problems and to take alternative action.

MOVA checks the detectors every cycle. Detectors which have remained ‘on’ for a complete cycle of the signals or longer, or have remained ‘off’ for a calculated critical time, are noted as being ‘suspect’. The suspect condition does not necessarily mean that the detector and loop equipment have failed to operate correctly; it will more usually mean that vehicles have parked on or near to a detector and other traffic is not able to cross the detector normally. Suspect detectors are returned to the normal ‘acceptable’ state as soon as they begin to count vehicles again.

While a detector is flagged as suspect, MOVA will in most cases ignore that detector completely and will substitute information from one or more alternative detectors, or will carry-out substitute decision-making logic.

### 6.4 HISTORICAL FLOWS

While detectors are judged to be functioning correctly (i.e. are not ‘suspect’) MOVA uses traffic counts to update an historical flow matrix, one value for every half-hour of the day, for each separate day of the week, and for each lane at the junction. Updating of the exponentially smoothed moving-average flows occurs once per week. If too many detectors (roughly more than half of those on a link) are found to be suspect at any time, MOVA will automatically make use of the historical flows to substitute for currently measured traffic counts. This system therefore provides a final method for coping with detector failures.

The historical flow matrix is likely to be of value to traffic engineers and planners for uses other than control of the signals. It is intended, if MOVA is approved for general use, to make this data accessible from production versions of the Program.

### 7 RESEARCH TRIALS OF MOVA

MOVA has been developed over the period of several years during which various versions of the strategy have been implemented at a number of different junctions. At 4 sites, a full-scale assessment was carried out to compare the relative merits of the conventional D-system vehicle actuation system (VA) with MOVA. This section of the Report describes these 4 trials and the results of the assessment surveys.

#### 7.1 THE EXPERIMENTAL SITES

The 4 main trials were carried out at:

1. Bath, on the A4, at the A46 Cleveland Place T-junction
2. Reading, on the A329 to Wokingham, at Earley crossroads
3. Bournemouth, on the A347 to Wimborne, at Cemetery Junction
4. Slough, on the A4, at the B470 crossroads, near Langley

Traffic conditions vary substantially between the four sites. At Bath, there is continuous traffic throughout the working day, with a high proportion of large lorries as is to be expected on a trunk road. At Reading, the traffic is heavy during morning and evening peaks, but off-peak flows are low, and there are few heavy lorries. In Bournemouth, the peak periods are very busy, and off-peak flows are variable; traffic there consists mainly of light vehicles with some buses. At Slough, the traffic is heavily congested during peak periods only, but there are large numbers of heavy vehicles during the off-peak period.
Figure 1 is a schematic diagram of the site at Reading: Figures 9, 10 and 11 show the other three sites. At all four sites, normal signal control was by the UK D-system VA control, with the addition of the 'variable-maximum' facility on some approaches at Bath and Reading, and with maximum-greens varying by time-of-day at Bournemouth.

7.2 SITE EQUIPMENT AND THE COMPUTER SYSTEM

The signal controllers at all sites have been fitted with standard UK Urban Traffic Control (UTC) interfaces (Department of Transport 1984), so that the signals can be controlled by an external computer. Additional inductive loop detectors were installed in each traffic lane, both to control the signals and to help monitor the performance of the junction.

Although the purpose of the research was to develop a microprocessor-based strategy, the research work was carried out using a standard minicomputer system. This was built into a modified touring caravan so that it could be moved easily from site to site. The caravan contained the computer, a twin disc drive, a visual display unit and line-printer, and hardware to connect the computer to the signal controller and detectors. The caravan was parked close to the signal-controller cabinet, and the circuits were completed by removable cables. Once connected, the caravan computer was able to take control of the signals and to change stage at the dictate of the strategy program.

The computer runs four independent programs:

1. an input routine scans the vehicle detectors and signal stage confirmations 10 times/second and provides vehicle counts and occupancy,
2. the strategy program uses the traffic and signal data from the first program to calculate when to change stage,
3. an output routine instructs the signal controller to change stage and checks that this takes place,
4. an archive program stores traffic flow and signal-timing data on disc for subsequent analysis to help in assessing the merits of a particular strategy.

Only the second program needs to be altered to implement a completely new strategy. In this way, new versions of MOVA were readily made operational and studied.

The programs are written in FORTRAN except for some small machine-code routines where processing time must be minimised.
7.3 ASSESSMENT SURVEYS AND RESULTS

Versions of MOVA have been tested at the four sites listed above. All sites experienced severe congestion at peak periods, and varying degrees of lighter traffic off-peak. This provided a wide range of conditions to test the strategy to the full. Measurements of vehicle delays were made during four 90-minute periods of the working day on at least 10 days with MOVA signal control and another 10 days of D-system VA control. On-street observers recorded times of passing and vehicle registration numbers for a sample of vehicles as they approached the junction and again as they
departed. By matching registration numbers, the journey time between entry and exit was obtained; mean delays were calculated by subtraction of an average undelayed cruise-time from the mean journey time. As these observations were being made, the control computer recorded vehicle counts and signal data automatically.

Mean vehicle delay per 90-minute period was compared under the two control systems, with due allowance being made for any changes in flow by means of covariance analysis (Snedecor, 1966). Figure 12 shows an example of the results: mean vehicle delay is plotted against the total junction throughput flow for each 90-minute period; the improvement due to MOVA control...
is indicated by the vertical separation between the two best-fit parallel regression lines.

Table 1 summarises the survey results. It should be noted that these relate to versions of MOVA which differ in important respects, as improvements have been incorporated. In particular, the version of MOVA tested at Bath did not have the capacity-maximising and bonus features; these were subsequently included in the light of the disappointing (albeit not statistically significant) AM peak result which led to a full examination of these aspects of control. There are also substantial differences in traffic flows, site characteristics, and congestion which would be expected to influence results and, in particular, annual benefits from site to site.
Overall, MOVA reduced vehicle delay by an average of about 13 per cent throughout the working day. Before each of the surveys, the existing system was checked and reset to the local authority's satisfaction, to ensure that MOVA was compared with well-managed, up-to-date, conventional D-system VA. Benefits from MOVA would usually be appreciably larger where, as is often the case, the maximum green settings on the local VA signal controller are based on out-of-date traffic flows. From Table 1 it can be seen that the community benefits, each year, far exceed the likely cost of installing MOVA (estimated to be up to about £15 000 at 1987 prices).

### 8 WIDER-SCALE APPLICATION OF MOVA

Following the successful research trials of MOVA, the Department of Transport (DTp) has decided to develop the MOVA system into a form which would allow it to be further tested at a wide range of sites, prior to making a final decision on its general availability and application. The Traffic Control and Communications Division (TCC) of DTp, with TRRL support, is responsible for the development under contract of prototype MOVA equipment and for the execution of the large-scale trial. The Traffic Management Division of TRRL is responsible for the development of the MOVA software and for analysis of trial results. Ferranti Industrial Electronics Ltd, Edinburgh, won the contract to develop the equipment. As explained in sub-section 2.2, the MOVA unit will be a self-contained device capable of being added to all modern UK traffic signal controllers. The trial will involve 20 junctions selected so as to give a broad geographical spread throughout England, and to cover a wide variety of junction conditions.

### 8.1 AUTOMATIC ASSESSMENT USING DETECTOR OCCUPANCY

The 20-site trial cannot, for resource reasons, include full-scale measurements using road-side observers to assess the benefits of the change from D-system VA to MOVA at all sites. However, a method has been developed which provides an encouragingly simple and inexpensive indication of junction performance. The method has been included as a standard facility in the microprocessor-based MOVA module.

The automatic assessment method uses detectors which are needed for MOVA control, but uses them in an independent way to give a figure-of-merit for the control system then operating. More details are given by Young, 1988, but the method may be summarised briefly as follows. A poor control system which produces long delays will cause queues of stationary vehicles to form for a large proportion of the time over the detectors on the approaches, hence giving a high average occupancy (or 'on' time) per detector. In contrast, a good control system will result in low delays, short queues, and low average occupancy per detector. It has been found, subject to queues not being negligibly short or, at the other extreme, excessively long, that a linear relationship exists between the mean detector occupancy and mean delay per vehicle measured by on-street observers.

Thus, once the MOVA detectors are installed, they can be used, before MOVA control is switched on, to provide occupancy results for whatever control system is operating at the junction. Then, after a survey lasting for perhaps 14-days of measurements with the original system, MOVA can be switched-on to control the signals and a further 14-days survey carried out. Comparison of the two sets of occupancy results, with due allowance for any changes in flow through the junction from one survey to the other, provides a percentage change in occupancy due to the introduction of MOVA; this percentage is equivalent to the percentage change in delay due to MOVA. The method does not give an absolute measure of the delay change itself, merely the percentage change in delay. Nevertheless it is a very economical method for assessing MOVA benefits.

### 8.2 SAFETY CONSIDERATIONS

It is not possible currently to predict the effect which a change in the method of signal control may have on
accidents at a junction. Ultimately, results from an extended ‘before and after’ study are needed to indicate a change in accident propensity with any degree of confidence. At sites in urban areas, where speeds are relatively low, it is thought likely that MOVA will have little effect on accidents compared with current D-system VA control. At high-speed sites, however, further trials are being carried out to check, as far as is possible, whether MOVA control has significant safety effects.

The main safety concern at high-speed sites is the risk that approaching drivers may encounter the amber signal when they are too close to the stop-line to stop easily; they must then either brake heavily and risk collisions with following vehicles, or proceed and risk crossing the stop-line during the red period following amber (Webster 1965).

Existing signals controlled by D-system VA are supplemented by either ‘speed discrimination’ (SD) or ‘speed assessment’ (SA) equipment to minimise the above problem; but even then, because of the need for maximum green constraints, stage changes can still occur which take no account of the positions and speeds of vehicles on the approach.

One measure of the way in which a signal-control system interacts with driver behaviour is the number of drivers who cross the stop-line either during amber or the early part of the immediately-following red period. Early trials comparing MOVA with the current SA system suggest that MOVA results in rather more vehicles crossing the stop-line during amber, but rather fewer crossing during the early part of the red. Such measurements do not in themselves prove anything about the safety performance of junctions controlled by a particular system of signal control; there is no proven relationship between numbers crossing on amber or red and accident frequencies. Nevertheless, it is intended to carry out further checks of this type; if they also show reduced numbers of vehicles crossing during the red period, it will tend to increase confidence that the safety performance of MOVA will be satisfactory. The final aim is to develop MOVA into a comprehensive control system for isolated signals, with appropriate facilities for a wide range of traffic conditions.

9 CONCLUSIONS

MOVA (Microprocessor Optimised Vehicle Actuation) is a new TRRL control strategy for isolated signals. Some 60 per cent of the estimated 9250 signalised junctions in the UK currently have independently operated (uncoordinated) signals with green times varying in response to local traffic flows. Subject to the outcome of a final widespread trial, MOVA is expected to be suitable for controlling the majority of these isolated signals. This report describes the MOVA system, the development trials which have taken place, and the assessments of benefits due to the improved control.

MOVA aims to provide improved, self-optimising, control of signal timings at individual junctions. The system uses a new detector arrangement with two vehicle detectors per approach lane; in urban conditions, these are typically at about 40 metres and 100 metres before the stop-line. Initially, each lane receives sufficient green to discharge vehicles queued between the stop-line and the 40 m detector. Next, the time intervals between vehicle detections are examined to find when queues have cleared and traffic ceases to discharge at the full saturation rate. Finally, there is an optimisation process which balances the merits of extending a green against the disbenefit to the vehicles stopped by red signals; this aims to avoid the tendency of the current ‘gap-seeking’ control systems to extend green times unduly when traffic is flowing at considerably less than full saturation rate, even when there are substantial queues on other approaches. The self-optimising features in MOVA should also ensure that the setting of maximum green times by the user is no longer critical; thus a major difficulty with conventional control is removed.

Although MOVA is structured to make decisions about stage-to-stage changes, nevertheless, many of the underlying calculations are essentially phase (or signal-group) related. In consequence, it is possible to retain some of the phase-to-phase flexibility inherent in modern traffic signal controllers, while providing good optimisation of green durations.

MOVA has special features to cater for situations when one or more approaches to a junction are left with a significant queue at the end of green and are judged to be ‘oversaturated’. MOVA automatically recognises such circumstances and switches to a capacity-maximising routine to clear the congested approach(es) as quickly as possible.

On many approaches, localised road widening provides more lanes near the junction than on the approach road itself. The local widening is therefore giving some initial ‘bonus’ capacity for the approach. If the bonus is sufficiently large, the signals may operate more efficiently with a relatively short cycle; this will allow the relevant approach many short greens per hour to maximise use of the initially high saturation flow discharge. MOVA is designed to initiate such short-cycle control when appropriate.

Other novel features in MOVA include:

- a revised method for the control of early-cut-off signal sequences to cater for right-turning traffic
- an automatic technique to limit cycle-time to a desired value without the need, as now, to rely on maximum-green constraints
- substitution of alternative detectors or logic if detectors become unusable due to parked vehicles or equipment failure
storage of lane-by-lane traffic flows at half-hourly intervals throughout the week, for use as emergency data when detectors fail, or for subsequent general planning purposes.

Traffic surveys in Bath, Reading, Bournemouth, and Slough have indicated that MOVA traffic-responsive signal control is likely to produce delay savings which average 13-14 per cent compared with control by recently reset D-system vehicle actuation (VA)—the current UK standard system for isolated junctions. These savings relate to the whole of the working day, and vary considerably from junction to junction and by time of day. The benefits would be expected to be appreciably larger where, as is common, the maximum green settings on the local VA signal controller are based on old traffic flow data. MOVA control is designed to be particularly suited to control of sites where traffic demands are variable and difficult to predict.

Although a full assessment of the safety performance of MOVA must await its long-term use at a substantial number of sites, studies of MOVA control at junctions with high-speed approaching traffic are continuing.

Following the successful research trials of MOVA, the TCC Division of the Department of Transport (DTp), in conjunction with TM Division of TRRL, is arranging for an extensive trial of prototype microprocessor-based MOVA equipment at a further 20 sites. Subject to a satisfactory outcome of this trial, it is anticipated that the Department's policy would be to give approval for the wide application of MOVA at isolated junctions throughout the UK.

10 ACKNOWLEDGEMENTS

The assistance of many County and District Council staff who have made possible the full-scale trials described above is most gratefully acknowledged.

The work described in this report forms part of the research programme of the Traffic Management Division (Division Head: Mr M Grimmer) of Traffic Group of TRRL.

11 REFERENCES


APPENDIX A

'MOVA' TECHNICAL GLOSSARY

Bonuses, Bonuses
Local carriageway widening often gives a larger saturation flow during the early part of the green than later on: this extra capacity or 'bonus' due to the short lanes is equivalent to extra effective green time for the long lanes called 'bonus green'; see Fig 7 and Section 5.

Call/cancel
System of detection to operate an early-cut-off stage: a detector demands (calls) the stage after a continuous vehicle presence of typically 3-seconds, and cancels the demand after a similar period without a detection.

Capacity
The rate at which the traffic in question (e.g. on an approach or lane) can discharge through the signals from a continuous queue, averaged over both red and green periods (vehicles/hour). It is therefore a lesser value than the rate during saturated greens only (saturation flow).

Critical gap
MOVA checks for end of saturation flow on a lane by comparing gaps between vehicles (as measured by the 'off' times of the X-detector) with a preset 'critical gap' for the lane; the critical gap is often about 3.5 seconds.

Cruise-speed
For MOVA this is the speed used to derive the locations of detectors so as to give 'cruise-times' of: about 8-seconds from the IN-detector to the stop-line, and about 3.5-seconds from the X-detector to the stop-line. The cruise speed is about the 20-percentile of the free-flow speed distribution, based on only those vehicles which approach the signals during green after the queue has cleared. Cruise speed is thus a slightly slower than average approach speed.

Cycle time
Usually considered to be the time between successive starts of the stage 1 green.

Delay
Extra time (seconds) taken to pass through a junction when a vehicle is forced to slow down or stop, compared with an uninterrupted free passage at cruise speed. Total delay on an approach per period (vehicle-hours/hour) is equivalent to the mean queue (vehicles).

Early-cut-off
A sequence of two stages designed to cater for right-turning traffic: see Section 6.1 and Figure 1 for definition and example.

End-saturation
For a single lane, this is the time during the green when MOVA judges saturation flow to have ended. A link reaches end-saturation as soon as any one lane on the link reaches this state. A stage reaches end-saturation when all 'relevant links' have ended saturation.

Fixed-time stage
A stage of pre-set fixed duration for which, in MOVA, the minimum and maximum greens are specified equal.

Gap
The duration of the detector 'off' time between successive 'on' signals from successive vehicles.

IN-detector
The name given to the first detector which traffic crosses on approaching the junction; the IN-detector is usually sited about 8-seconds cruise time before the stop-line.

IN-sink detector
A detector which counts traffic leaving a lane after crossing the IN-detector but before crossing the X-detector.

Lane
A lane in MOVA must have an X-detector: short bays which are too short to have an X-detector are not considered as lanes. A 'long lane' has both IN and X-detectors, while a 'short lane' has just an X-detector.

Limit cycle-time
At a few junctions it may be desirable to limit the cycle time at which MOVA will operate, especially under oversaturated conditions. This may be needed to maintain acceptably short cycles for pedestrians, or to avoid exit or junction blocking problems which become more severe with long cycles. (See Section 3.5)

Link
A group of 1, 2, or 3 adjacent lanes on which traffic forms a combined queue; the lane queues must clear at roughly the same time, during the same green phase. Pedestrians who must demand their green-man signal by means of pedestrian push-buttons, must be represented by a link in MOVA.
Lost-time

The time lost to traffic while changing from stage to stage through one full cycle, plus any time given to pedestrian stages. Refer to Road Research Technical Paper No. 56 Webster F V and Cobbe, B M HMSO London 1966.

Occupancy

For MOVA assessments (Young 1988), occupancy is defined as the mean 'on' time per detector per vehicle. This occupancy is averaged over all the X- and IN-detectors used by MOVA at a junction. Results show that this occupancy can often be used as a proxy for delay.

OUT-detector

A detector located immediately before the stop-line to control operation of an early-cut-off stage sequence. (See Section 6.1)

Oversaturation

The condition when a lane is left with a significant queue at the end of green. (See Section 4.1)

Performance-Index

The net result of delay and weighted stop savings for traffic benefitting from a green extension, minus delays incurred by traffic having to wait longer. (See Section 3.4)

Phase

A group of one or more traffic or pedestrian links which always receive identical signal light indications, are said to belong to a particular phase of the signals. In this report, the word 'phase' is used to denote such a group of traffic/pedestrian movements; elsewhere, it is commonly used also to mean the signal indications displayed to the group.

Relevant link

A link which will lose right-of-way, or will receive only a fixed-time green, if the signals change to the next demanded stage. (See Section 3.3)

Saturation flow

The average flow rate across the stop-line which occurs when traffic discharges from a continuous queue during the green time; usually expressed in vehicles/hour of green time.

Stage

A group of one or more traffic and/or pedestrian phases (and hence links) which receive a green signal during a particular period of the cycle, are said to belong to a particular stage of the signals; a link may receive green during more than one stage and hence, if the stages are consecutive, during the interstage period between them.

Stop-line demand detector

A detector installed immediately before the stop-line to provide a demand in case vehicles may turn-in without crossing the X-detector.

X-detector

The detector located in each lane so as (ideally) to give a 3.5-second cruise time from detector to stop-line. This detector is often sited at about 40 m before the stop-line in urban areas, and is therefore called the 'X-detector' by analogy with the similarly placed D-system detector.

X-sink detector

A detector which counts traffic leaving a lane after it has crossed and been counted by the X-detector (and the IN-detector if there is one on the lane). The X-sink detector is used particularly to count traffic making unsignalled free left-turns.