We know it's good, but just how good is it?

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Capacities at traffic signal controlled intersections may be readily calculated by use of established empirical equations. However, auto-adaptive systems such as Microprocessor Optimised Vehicle Actuation (MOVA) respond dynamically to vehicle demands that make the prediction of their performance very difficult. Indeed, there is currently no analytical technique available for predicting in advance the extent of the improvement at any site, save for expensive and time consuming micro-simulation techniques or particularly vehicle detector occupancy studies.

To overcome this, an examination of the vehicle discharge rates and hence saturation flow rate was undertaken that aimed to produce factors that could be applied to current traffic signal calculations for the estimation of MOVA. The saturation flow rate was particularly used because it is one of the principal factors that govern traffic signal capacity.

INTRODUCTION

Because MOVA responds dynamically to variations in vehicle arrival rates, there is currently no analytical technique for predicting in advance the extent of the improvement at any particular site. Indeed, when set up correctly, MOVA will achieve an improvement in terms of traffic performance but the question is 'by how much?'

The best available information is given in RR 170 'MOVA: Traffic responsive, self optimising signal control for isolated junctions' (Vincent & Peirce, 1988); RR 279 'MOVA: The 20 site trial' (Peirce & Webb, 1990); PR/TT/096/97 'M1 Junction 21 assessment of 'MOVA' signal control' (Vincent, 1997a); and PR/TT/172/97 'M1 Junction 21 further assessment of 'VA' vs. 'MOVA' control' (Vincent, 1997b). However, the method used in these documents is detector occupancy (Young, 1988), which cannot satisfactorily determine peak period performance because of the likelihood of queues stretching back beyond the outermost detector. Moreover, the technique only allows delay information to be obtained although Vincent (1997a, 1997b) has used this method to estimate increased throughput by comparing the regression lines produced from covariance studies.

However, because of its inherent problems of peak period estimation, cost and delay estimation only, detector occupancy is not of great use to the traffic signal practitioner. What the practitioner needs is a robust, readily calculated capacity indicator for auto-adaptive systems such as MOVA.

This paper describes the technique and results of an investigation into how MOVA operation can be estimated in established traffic signal calculations.

RATIONALE

So what does MOVA do differently to VA to bring about any improvements? One answer is to look at how traffic discharges under the green signal.

Consider a critical traffic stream discharging under saturated conditions as shown in Figure 1. After about two seconds, traffic will begin to discharge across the stop line at the maximum saturation flow rate. At around 36 seconds, the discharge rate will begin to fall and after 44 seconds the saturation flow rate will also fall (tests conducted at the 95% level - Brahimi, 1989). At this point MOVA will begin to make judgements on the termination of the green by looking at either its delay-and-stops performance index or the green use efficiency, dependent on its mode.

If either the performance index or green use efficiency suggest that a stage change is required, MOVA will end the green as shown, whereas VA has a tendency to extend the green inefficiently as also shown (dG). It is this intelligent approach to maximising the green use that brings about some of MOVA's improvement.

In essence, some of MOVA's improvement is the result of higher maintained saturation flow rates throughout the green period when compared to VA. It is this 'saturation flow efficiency' that is the key to estimating MOVA's performance in traffic signal calculations.

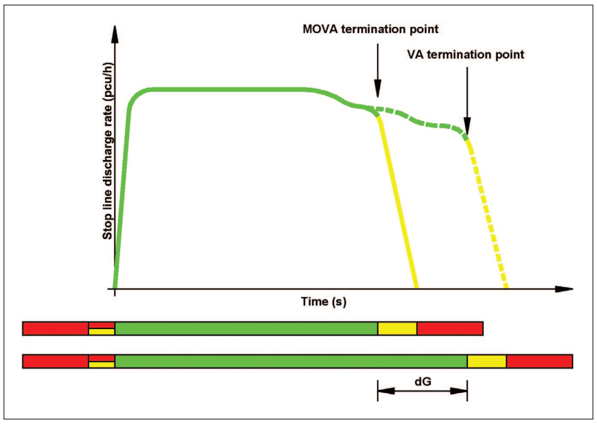

Figure 1: A simplified discharge flow profile for both VA and MOVA.

By investigating vehicle discharge rates and hence saturation flows during the green through periods of saturation, factors may be established that can be applied to saturation flow rates. These amended saturation flow rates may then be used in established intersection calculations, giving an indication of the intersection performance at MOVA sites during the peak periods. Moreover, it would also be possible to use these same factors to estimate improvements during off-peak periods (albeit conservative), potentially removing the need for time-consuming and costly vehicle detector analyses. It is anticipated that the factors may be used in both manual and computer calculations, such as Linsig for Windows™ (Moore and Simmonite, 2000).

SITE SELECTION CRITERIA

The following site selection criteria were used throughout the study so that any inference made was based on consistent, unbiased data.

Approach conditions

Because a constant saturation flow rate was being sought, sites were chosen that did not contain any flaring at the stopline. The obvious effect of flaring is to produce a 'dip' in the discharge rate for the lane concerned as traffic enters the adjacent lanes. Therefore, only lanes termed 'infinite' (ie the lane is homogeneous along its length) were examined.

Capacity conditions

Saturated/oversaturated approaches only were considered in the study because it is this state that allows the saturation flow technique to be used. It was not necessary to have all approaches to the intersection saturated/oversaturated and in the event unlikely. If a single approach was saturated/oversaturated, it was included in the study, subject to its acceptance from other selection criteria.

Green durations

The duration of the green period was crucial to the study. If the green duration was short (< 44 seconds), it was likely that the maximum saturation flow rate would be maintained (Brahimi, 1989). Consequently, no discernible difference would be likely and no inference made. Above this figure, the initial discharge subsides, leaving only 'sporadic' vehicles to extend the phase, which would indicate the level of green use efficiency.

Therefore, sites with green durations at or above 40 seconds were considered in the study but where sites had green durations slightly below this value, they were also considered as this value was by no means absolute and was only a product of previous work and traffic observations by the author.

Validation

The term 'validation' related to how well MOVA controlled the prevailing traffic. Undoubtedly, a good dataset/hardware was vital if MOVA was to achieve the maximum benefit possible.

In order to determine the level of validation, an examination of the dataset was necessary at each site and also a visual estimate. Factors such as congested control and maintenance (detector responses, transmission errors, etc) were all investigated prior to accepting any site.

Exit conditions

Because downstream conditions are known to affect stopline discharge rates, particularly if the restriction is nearby, only sites with good exit conditions were included in the study.

Good exit conditions were defined as those without parked cars impeding through traffic, no merges or 'funnels', no blocking from downstream intersections and no blocking due to traffic turning right into accesses, etc.

Approach gradients

Uphill gradients are known to affect saturation flow rates. Therefore, only approaches with flat or downhill gradients were included in the study.

This was considered necessary because of possible bias being introduced as a result of vehicles stalling. The result would not be significant if the same number of vehicles stalled during the survey periods, but if the numbers varied significantly, this would have biased the result.

Auxiliary conditions

Because the study called for the switching of controller modes (viz. MOVA to VA), the intersection would be without the potential safety benefits MOVA has. The current UK specification (HA, 2001) requires either SDE or SA equipment be used at high-speed sites (≥ 35 mph). However, most MOVA sites are equipped solely for MOVA operation and do not contain any SDE/SA fallback.

Because of this restriction, only sites with approach speeds at or below 35 mph were included in the study. However, where it was believed that this restriction was not well founded (ie if all approaches were queued resulting in low speeds through the intersection), the site was included in the study, subject to it satisfying the other criteria.

STUDY METHODS

Saturation flow rate collection

The accepted method of collecting saturation flow rates is described by the TRRL (1963). The fluctuations in discharge rates are often complex and simplification (by averaging the discharge rates, hence finding the saturation flow rate) is necessary for the calculation of delay, optimum signal timings and capacity because the number of vehicles discharged in any fully saturated green period is then directly proportional to the effective green time.

However, the TRRL method is very demanding (Wood, 1986); not only must the observer count vehicles whilst continuously monitoring a stopwatch, but also record the count during that period whilst still concentrating on the traffic during the next time period. Moreover, the method is error prone, particularly if the traffic is of a mixed nature. Given this, at least two observers are often required.

Because of the problems highlighted above, the TRL's SATFLOW program was used for the collection of both VA and MOVA saturation flow rates since it enabled one observer to collect the saturation flow rate values.

Statistical methods

In order to derive a reliable statistical inference that suggests MOVA control contributes to higher maintained saturation flow rates or otherwise, an appropriate control method was necessary. For this study, the matched pairs technique was used. The matched pairs technique is useful for investigating the saturation flow rate in two groups (VA and MOVA in this case) where there is a meaningful one-to-one correspondence between the data points in one group and those in the other.

The matched pairs technique means that the saturation flow rate is measured at different times, ie when the intersection is working under VA and MOVA. Each saturation flow rate at one time is consequently paired with the same saturation flow rate at the other time.

Matched pairs are recognised as the most robust method of obtaining control data because they minimise the effects of external factors that may bias the results, possibly leading to either an under- or over-estimation of any impact that the introduction of MOVA control may have on the saturation flow rate.

The parametric paired *t*-test was used in the analysis because of its high power and sample mean analysis plus its ease of use. Because of the uncertainty attached to the population type, the paired *t*-test was justified by use of the Kolmogorov-Smirnov test on the interval data for each sample. The Kolmogorov-Smirnov test is used to estimate whether or not the sample is taken from the Gaussian (normal) distribution.

A one-tailed paired *t*-test was used because of the expectation a priori that the mean of the saturation flow rate under the MOVA regimen would be higher than that under the VA regimen. The associated significance level used for the analysis was 5% as is widely accepted.

Checks were made on the sampled data prior to the paired *t*-test using the Extreme Studentised Deviate (Grubb's test) that identified the possibility of outliers that lead to an increase in the standard deviation of the data.

SITES SELECTED IN THE STUDY

Nanpantan Road/Snells Nook Lane, Loughborough

The intersection of Nanpantan Road and Snells Nook Lane, Loughborough, is a semi-rural crossroads on the outskirts of a busy University town. In the morning peak period, very heavy congestion exists on the inbound approach to Loughborough and can become apparent on the side roads, albeit for a much shorter period.

The intersection is controlled using a four-stage arrangement; stage 1 – main road both directions, stage 2 – Right Turn Indicative Green Arrow (RTIGA) to main road outbound, stage 3 – 1st side road all directions, stage 4 – 2nd side road all directions.

The lane under consideration was the main road inbound single lane approach. The approach lane contained mixed left, ahead and right turning traffic but the numbers that made turns were very low, particularly those turning right.

The approach lane has a downhill gradient and is treated as a nearside lane. The exit conditions were considered as good, as no downstream parking is allowed or likely due to a large public house car park being adjacent. The exit lane is infinitely long and contains no building accesses. Nevertheless, the intersection does have severe restrictions on visibility, both within the intersection and on some of the approaches but was not considered important for the purposes of the study.

A607 Newark Road/Humberstone Lane, Thurmaston

The intersection of Newark Road and Humberstone Lane, Thurmaston, is an urban crossroads on the outskirts of Leicester City. The A607 Newark Road is the main route into Leicester from the northeast and joins the A46 at the nearby Hobby Horse roundabout. In the morning peak period, very heavy congestion exists on the two-lane inbound approach to Leicester.

The intersection is controlled using a three-stage arrangement; stage 1 – main road both directions, stage 2 – fully signalled right-turn to main road outbound and full green to main road outbound, stage 3 – both side roads in all directions.

The lane under consideration was the main road inbound offside lane approach. The approach lane contained mixed ahead and right turning traffic but the right-turn proportions were insignificant. The approach lane has a negligible downhill gradient and exit conditions were considered as excellent due to the exit being a dual urban clearway.

The offside lane was considered for two main reasons. The first reason being that VA is known to extend the green phase inefficiently when traffic is discharging at considerably less than the full saturation flow rate, particularly at multi-lane approaches (Vincent and Peirce, 1988 pp. 1). The second reason is the high number of left turning traffic that uses the nearside lane. During an initial site survey, vehicles turning left toward a local industrial estate often impeded the ahead traffic, resulting in lower discharge rates. Given that this situation occurred in several signal cycles, it was decided that the lane would not be considered further in the study.

High Street/Delven Lane, Castle Donington

The intersection of High Street and Delven Lane, Castle Donington, is a semi-urban crossroads located on the entrance to the village. From the intersection, traffic progresses either toward a residential and industrial area or toward the village centre. Heavy congestion exists on the inbound approach during the evening peak period.

The intersection is controlled using a five-stage arrangement; stage 1 – main road both directions, stage 2 – RTIGA to main road outbound, stage 3 – 1st side road and bus only exit all directions, stage 4 – 2nd side road all directions, stage 5 – All red pedestrian stage.

The lane under consideration was the main road inbound single lane approach. The approach lane contained mixed left, ahead and right turning traffic. Turning traffic makes up a significant amount of traffic but didn't impede the ahead movement sufficiently to be rejected. The exit conditions were considered as adequate due to the exit having the potential to be blocked by right-turning traffic.

Burbage Road/Brookside, Burbage

The intersection of Burbage Road and Brookside, Burbage, is an urban crossroads on the outskirts of Hinckley town. In the morning peak period very heavy congestion exists on the single-lane inbound approach to Hinckley.

The intersection is controlled using a five-stage arrangement; stage 1 – main road both directions, stage 2 – RTIGA to main road outbound and left turn filter to 1st side road, stage 3 – 1st side road all directions, stage 4 – All red pedestrian stage, stage 5 – 2nd side road all directions.

The lane under consideration was the main road inbound single-lane approach. The approach lane contained mixed ahead and right turning traffic but the turning proportions were insignificant. The approach also contains an advanced cycle stopline and reservoir.

The approach lane has a downhill gradient and exit conditions were considered as adequate because of a downstream pelican crossing (approximately 150 metres downstream).

RESULTS OF THE STUDY

Discharge rate/Saturation flow rate comparison

Table 1 below shows the saturation flow rates found at the sites surveyed when under both VA and MOVA regimens.

Site	Site type	Saturation flow rate (pcu/h) VA	MOVA	% Difference
Nanpantan Road, Loughborough	Large town	1791	1843	2.90
A607 Newark Road, Thurmaston City	City	2041	2034	-0.34
High Street, Castle Donington Village	Village	1702	1781	4.64
Burbage Road, Burbage	Small-to-medium size town	1535	1595	3.91

Table 1: Saturation flow rate comparison for the sites included in the study.

Statistical analysis

At the 95% level, the one-tailed paired *t*-test found that the differences between MOVA and VA saturation flow rates were statistically significant. The corresponding P-value of 0.045 was below the threshold value of 0.050 and advocated that MOVA saturation flow rates are higher than those under the VA regimen.

Derived factors

The established saturation flow efficiency factors (ηs) for use at MOVA controlled intersections are presented below (Table 2). The factors may be multiplied with either observed VA saturation flow rates or estimated rates calculated from Re-

Location type	Likely driver awareness levels (Low, Medium, High)	Saturation flow efficiency factor (ηs)
City	High	+1.000
Large town	Medium-to-high	+1.029
Small-to-medium size town	Medium	+1.039
Village	Low	+1.046
	Mean	**+1.028**

Table 2: MOVA saturation flow rate improvements

search Report 67 (Kimber, McDonald and Hounsell, 1986) subject to certain conditions. The factors should be used to modify the 'y' value ($y = q/S.\eta s$).

SUMMARY AND USAGE OF FACTORS

Auto-adaptive systems like MOVA have not yet been addressed in the existing signal analysis procedures used in the UK, making true traffic capacities incalculable since it is assumed that green durations remain the same throughout the entire peak period. Indubitably, there must be some betterment by having the signal timings fit the traffic volumes on a cyclic basis rather than using an average hourly volume and calculating fixed maximum green durations but the question in capacity terms is 'by how much?'

To answer this question, the study aimed to quantify the difference, if any, between MOVA and VA saturation flow rates. The saturation flow rate was chosen because it is one of two principal factors that govern capacity, the other being cycle time. Any statistically significant differences found in the saturation flow rates would be used as factors that could be input into current traffic signal calculations to estimate the likely effects MOVA would have on a VA intersection. The statistical significance was based on the a priori assertion that saturation flow rates under the MOVA regimen were higher than those when under the VA regimen.

The sites chosen represented typical intersection configurations and locations. The choice of different location 'type' was important because of the prevailing driver behaviour at each site, which could well affect the saturation flow rate.

With the exception of one site, all the sites surveyed had saturation flow rates higher under the MOVA regimen than when under the VA regimen. The mean increase was +2.78% under saturated conditions. The exception was due to both the high driver awareness levels present (hence the green was used to its maximum) and the maximum green being below 40 seconds under both MOVA and VA operation.

During the early evaluation of MOVA, Vincent and Peirce (1988, pp. 17) undertook limited studies of the delay savings at four sites in order to calculate its annual benefits for cost-benefit analysis purposes. The mean peak period delay saving found at the four sites was +9.5%. In the context of capacity, the TRL have advocated that the capacity improvement is approximately 1/3 of the delay savings, hence returning a mean peak period capacity improvement of 3.17%, which compares very well with the observed value of 2.78%. It should be noted that the mean value reported by Vincent and Peirce was a product of discrete values that were not always statistically significant. The discrete differences found in this study were significant at the 95% level.

The derived factors (Table 2) represent the best possible approach to estimating peak period MOVA improvements over VA. Moreover, the factors can also represent conservative off-peak period improvements. The figures are conservative because MOVA is much more effective in terminating the green in its delay-and-stops routine than when in its capacity-maximising routine. It must be noted that MOVA has other benefits when considering capacity; its ability to alter the maximums to better suit the prevailing conditions, which also contributes to greater capacity. This must be considered alongside this research.

The research may be used with a VA 'base' that may be taken as either the observed saturation flow rate or that estimated from Research Report 67 (Kimber, McDonald and Hounsell, 1986). However, the reader is advised to exercise caution when using the factors with Research Report 67 since the values may only be valid when the green is below 44 seconds. The factors should only be used on critical or 'relevant' links that make up the green termination decision for the stage and should only be used when the green will be long enough to invoke the efficiency factor; 44 seconds and above is recommended.

In summary, MOVA should become the preferred method of isolated intersection control in the UK not just for its proven capacity and delay benefits but also for its other qualities, such as its proven ability to reduce red light infringements (provided the system is correctly set-up) and its ability to operate satisfactorily even if its vehicle detectors have become damaged. For these reasons and more, MOVA is the best control algorithm currently available for isolated traffic signal intersections.

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The views expressed herein are those of the author and do not necessarily reflect those of JCT Consultancy Ltd.

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