Introduction

The Highways Agency has responsibility for the efficient movement of traffic on the motorway and all-purpose trunk road networks in England. To help improve efficiency, the Agency has developed a tool kit of measures from which engineers can select the most relevant for any problems that they encounter. A recent development is a tool to assess the performance of traffic signal controlled junctions.

2 Introduction to traffic signal Performance Indicator

Efficient traffic control not only reduces delay and frustration to motorists, it also reduces emissions of pollutants and aids the economy. Traffic signal control of junctions is the major technique used to manage traffic on the road network and so it is important that traffic signals operate as efficiently as possible. Unfortunately this is not always the case due to a shortage of traffic signal engineers and resources to assess the traffic performance of signals.

This work for the Highways Agency followed on from the original commission from DfT to develop a performance indicator for isolated traffic signals that was presented at JCT in 2004 and published by TRL (Wood et. al. 2004). That work produced a tool that could be used by relatively inexperienced staff to grade the performance of isolated signals relatively quickly so that experienced engineers could concentrate on those installations most in need of enhancement. The work for the Highways Agency concentrated on extending the method to coordinated signals, particularly those at signalised roundabouts, a particular interest of the Agency, which is responsible for many such installations at motorway junctions.

When signals are coordinated the assessment of how well the coordination is operating is difficult by observation alone. TRANSYT produces graphical output that can be used to see how far the current operation is from the modelled average performance. SCOOT provides real time graphics that indicate how well the model is representing traffic movements. Differences between the model and on-street observations are investigated and the appropriate parameters adjusted to optimise performance. The objective of the work was to produce a general assessment method. As expected the resulting methodology is more complicated than that for isolated signals and does require more experienced personnel to apply it. Some of the elements of the PI are assessed in the office, but much of the effort is required on street.

The next section provides an overview of the different elements that are included in the PI. The remainder of this paper then concentrates on the application of the PI at signalised roundabouts.

3 Overview of the performance indicator

The documentation consists of a comprehensive guidance document, crib sheets summarising the guidance suitable to be taken out on street and a set of observation sheets to record the findings. The individual elements of the performance indicator are summarised below.

3.1 Office based

Some aspects of traffic signal performance can be assessed in the office, both those relevant to the performance of the authority as a whole and some for individual junctions:

Authority wide elements:
- Maintenance fault clearance
• Response to reports of poor signal performance
• Local policy objectives
• Active enrolment of others to monitor signal performance

Individual junctions:
• Provision of remote monitoring
• Documentation
• Accident history
• Reports of poor performance
• Maintenance record

3.2 Method of control
The main elements of the PI are assessed by on-street observations, but before making the observations it is important to understand the method of control and how that can be assessed. For isolated junctions, the preparation concentrates on understanding the staging arrangements, but for coordinated signals and signalised roundabouts the method of control will influence how the assessment is made and what is expected from good control.

3.3 On street
The on-street observations have been designed to be as simple as possible, but some time needs to be invested in understanding the guidance before applying the method for the first time. The observations consider:
• Over saturation
• Unbalanced queues and spare green
• Coordination for roundabouts and other linked signals
• Excessive pedestrian or cyclist green time
• Inappropriately long cycle time and unused stages
• Inappropriately short cycle times
• Exit blocking
• Junction and road marking condition
• Abuse of regulations
• Overview of safety
• Overview of roundabout operation

3.4 Performance indicator
The final step is to combine the individual elements into a PI for the junction.

4 Office based assessment
The office based assessment for coordinated junctions is very similar to the original method developed for DfT for isolated junctions. However, setting up coordinated signals, particularly linked
MOVA installations, is complicated. The main revision of the office based part of the PI is to 
emphasise the need for good documentation, not simply a copy of the dataset, but also the reasons 
why particular parameters are set and linking methods chosen. In the future if the traffic management 
objectives change, it is important to know why a junction was set up in a particular way.

5 Method of control for coordinated signals

Where signals are coordinated, extra knowledge is required to assess their performance, particularly at 
signalised roundabouts. There are several methods of controlling coordinated signals:

- SCOOT
- Fixed time UTC
- Linked MOVA (only for small groups of closely spaced junctions, mainly roundabouts or 
gyratories)
- Cable less linking

In all cases the coordination between adjacent signals needs to be assessed. On two-way roads the 
coordination needs to be assessed in both directions.

The coordination is designed to provide network benefits, where the network may be an area of a 
town, a radial road, a signalised roundabout, etc. It is not possible to provide each individual link 
within a network with its best offset. Therefore, it is not possible to judge the performance of the 
coordination of the network by observing the behaviour of vehicles on individual links in isolation. 
The best method of assessment is to compare with the VEGA display for SCOOT systems and the 
TRANSYT Cyclic Flow Profile diagrams for fixed-time systems. The older the TRANSYT plan is 
the less likely is good agreement with current behaviour. For linked MOVA systems, there is no 
equivalent of the SCOOT or TRANSYT graphical displays and the performance of the linking must 
be judged locally. With roundabouts and gyratory systems, the coordination of the circulatory traffic 
is most important even where individual approach arms are coordinated with other near-by junctions.

The observer should familiarise him or her self with the method of control and how to assess 
coordination before going on-street. The following sub-sections provide the theory that needs to be 
understood.

5.1 SCOOT

For coordinated junctions controlled by SCOOT, the best method of assessing the coordination is by 
comparison of the traffic with the VEGA output, but first it is necessary to be familiar with the VEGA 
and how to relate it to traffic behaviour. An example VEGA diagram is shown in Figure 5-1. The 
upper part of the VEGA diagram shows the arrival of vehicles at the stopline throughout a signal 
cycle. A marker along the axis indicates the current position. The lower part shows the resulting 
queue when arrivals cannot cross the stopline because of a red signal or an existing queue.

The example in Figure 5-1 shows a recorded VEGA in which a queue has developed from vehicles 
arriving early in the red, then a period with no arrivals followed by a small inflow before the main 
inflow starting to arrive some seconds before the start of green. The arrivals are mirrored in the queue 
discharge in the bottom half of the diagram. The discharge starts at the start of green from the front of 
the queue. The slope of the discharge represents the saturation flow (in SCOOT units). On this 
particular short link, the back of the queue stops increasing shortly after the start of green despite 
further inflow being shown in the top of the diagram. This is because the model queue has reached its 
maximum value.

Judgement of the level of agreement between a VEGA and traffic improves with experience. The 
main features to concentrate on are the timing of periods of heavy and light flow and the discharge of 
the queue from the stopline, which should coincide with the clearance of the queue in the display. At 
some sites where the main platoon arrives just as the queue is clearing, the judgement of when the
queue has cleared is difficult. However, with experience it is possible to see from the display when the queue is nearly cleared as the main platoon arrives. If, in this situation, on street the model clears just before the arrival of the platoon and just fails to clear in the model before it arrives, or vice versa, then the agreement can be taken to be acceptable. The interpretation of arrivals on to the back of a queue needs to allow for the time to travel from the back of the queue to the stopline at cruise speed.

![Figure 5-1: Example VEGA output](image)

5.2 TRANSYT
For roundabouts and other coordinated signals under fixed-time control the traffic behaviour should be compared with the graphical Cyclic Flow Profile (CFP) and queue output from TRANSYT. These graphs are of the uniform (average) queue and average CFP so the agreement has to be judged over a few (typically 5) cycles. The agreement in any one individual cycle cannot be expected to be perfect. The same characteristics should be considered as for SCOOT, periods of low and heavy flow and the time taken to clear the queue.

The Cyclic Flow graph plots the variation over a complete cycle of the rate at which traffic ‘arrives’ at the stopline (the IN-profile) and leaves the stopline (the OUT-profile). An example of a CFP graph is shown in Figure 5-2. Each graph represents, for one link, the variation during one signal cycle (horizontal axis) of:

a) The flow up to the stopline (red and green bars) - the IN-profile
b) The flow leaving the stopline (green and blue) - the OUT-profile

The two flow profiles are overlaid so that the flow distortion caused by the red/green periods of the signal can be observed easily. Vehicular flows, shown in red, are stopped by the red light and leave at a later time at saturation rate as shown in blue.

The vertical axis of each graph shows either the traffic flow per hour or traffic flow per step depending on the graph selection option chosen. The Mean Modulus of Error (MME) is printed for each graph. This refers only to the arrival flow at the stopline and is a measure of how far the profile of the arrival flow deviates from the mean value.
The queue graph plots the queue on the y-axis against time in the cycle. The position of the queue is shown in blue for ordinary links, while major links of a group of shared links are shown in magenta and the minor links in black. An example of a queue graph is shown in Figure 5-3.

The plot of the queue usually takes the form of a forward-skewed triangle (two if there are two green periods). This is as a result of traffic behaviour on the commencement of green. At the start of green the vehicles at the front of the queue move off from the stopline. Those at the end remain stationary until the vehicles in front have moved. It must be remembered that the queue graph is only of the uniform queue.

Figure 5-2: Example TRANSYT Cyclic Flow Profile
5.3  Linked MOVA

Where signalised roundabouts or gyratory systems are controlled by MOVA, then an experienced observer will need to make a judgement on the suitability of the control. Junctions around a roundabout can be linked by various means when under MOVA control:

1. No explicit linking, MOVA at each junction responds to the traffic approaching it from the upstream junction and the entry link.
2. By use of a queue detector to insert an emergency vehicle demand to force a particular stage
3. A specified stage at the “master” junction inserts an emergency vehicle demand for a particular stage at the “slave” junction
4. By operating two junctions as a single 4-stage junction within MOVA

The suitability of the chosen method of linking will require further analysis beyond that described here. The purpose of the observations is to assess the performance of the junction, the analysis of how to improve it requires further expert input.

5.4  Coordination at roundabouts

For roundabouts it is necessary to differentiate between the circulatory traffic and the entry links as queues on circulatory links can have catastrophic results leading to lock-up of the roundabout. Generally queues on the entry links are not so serious.

Figure 5-4 shows a section of a roundabout to indicate the different links and how they interact:

- An entry flow, link 1
- Traffic circulating round the roundabout to at least the next exit, link 2
- The circulatory traffic, link 3, which is downstream of both links 1 and 2.
- An exit, link 4
At some point link 3 will be stopped to allow traffic to enter from the next entry and a queue will build back towards entry 1. If this queue does extend back to exit block the junction of links 1 and 2, then it should block when link1, the entry, has green, not when link 2, the circulatory traffic, has green. The objective of coordination is to provide smooth progression round the roundabout for the maximum amount of traffic whilst avoiding exit blocking of gyratory links.

Where a roundabout is controlled by MOVA, or the relevant graphical output for SCOOT or TRANSYT is not available, then the coordination will have to be judged on individual links. It will be necessary as a first step to identify the main platoon that should receive a good offset (good progression through the stopline without delay).

Traffic approaches a stopline on the roundabout from several sources. With reference to Figure 5-4, the sources for traffic approaching stopline S3 are:

- the entry that is immediately upstream (L1 to S3),
- other entries to the roundabout in a mixed platoon from the upstream circulatory stopline (L2 to S3).

Consider stopline S3, traffic approaches this stopline from links L1 and L2, some of which will turn off before the stopline and exit at L4. The traffic from L1 that exits at L4 will be randomly distributed amongst the total entering vehicles at L1. However, the traffic from L2 will have entered at various points round the roundabout and be stacked in order defined by the entries and the offsets between them. The proportion of traffic exiting at L4 will normally be different from the different entries. Therefore, the proportion of vehicles from L2 that exits at L4 will vary at different positions in the platoon, i.e. at different times from the start of green to L2. A good offset will provide a good progression through S3 for the bulk of the traffic passing through it. It is necessary to determine which vehicles constitute that bulk of the traffic. It should not be necessary to count vehicles because if it is hard to tell whether more are from L1 or L2, then L2 would normally be favoured. The various possibilities for traffic approaching S3 are:

- Clearly most of traffic from L1 – offset provides good progression from green to L1 to green for L3.
- Clearly most of traffic from L2 – offset provides good progression from S2 to S3 for that part of the traffic from L2 that predominantly goes through S3, not necessarily the start of the platoon from L2.
- Similar proportions from L1 and L2 – offset provides a compromise between L1 and the part of L2 traffic that predominantly goes through L2. Subject to avoiding wasted green at S3, e.g. most of the vehicles from the front of the L2 platoon go through S3, then a good offset for L2 would result in wasted green whilst the back of the L2 platoon exited at L4 before the arrivals from L1. It would be better to start green at S3 for the L1 platoon, closely followed by the front of that from L2.
6 On-street observations

The extension of the PI method to coordinated signals has retained the same marking system as for isolated junctions:

1 = Good / acceptable
2 = Scope for minor / desirable improvements
3 = In need of attention soon
4 = In urgent need of attention

Because of the extra requirements on coordinated systems and signalised roundabouts, some assessment categories have been modified and new criteria added. The main changes for signalised roundabouts are detailed below.

6.1 Unbalanced queues

Signalised roundabouts present special problems for signal design. Queues on the circulatory carriageway can cause the roundabout to lock-up resulting in serious delays. Therefore, whilst the objective at isolated junctions is normally to balance the queues on the different arms, at a signalised roundabout in busy conditions the queues at individual junctions on a roundabout will be held preferentially on the entry links leading to a degree of imbalance. The method developed for the PI specifies how to assess the need to keep the circulatory carriageway free and how that is affected by the method of control. In particular, for fixed-time control there should be a bias so that the entry is more saturated than the circulatory to accommodate temporary surges in traffic. It is important to have some spare capacity on the gyratory to accommodate temporary surges in traffic. With MOVA and SCOOT control it is possible to balance the queues under normal conditions and rely on the control system to respond to increases in demand. The details of the assessment are provided in the PI documentation and observation sheets.
6.2 Lane signing and marking

Signalised roundabouts operate best when drivers are marshalled into appropriate lanes by good signing and weaving movement on the roundabout are minimised. Drivers need clear directions on which lane(s) to take for their destinations at busy roundabouts. Lane use round the roundabout, and on the entry arms, should ideally be even and well ordered. However, origins and destinations around the roundabout may prevent perfect distribution between lanes. A measure is required of poor distribution between lanes that could justify consideration of remarking the lanes, which would in turn require re-optimising the signal timings for the whole roundabout.

Major entry links should have signs and/or lane markings to indicate which lane to take for at least the main exits. For the circulatory links round the roundabout, the signing/marking should be clear and appropriate for the normal traffic movements. The assessment of the clarity of the information is relatively straightforward, but assessing its appropriateness is more difficult. The objective of the observations is to raise an alarm where the signing and markings result in lane usage that appears to be causing problems. It is not possible in a short visit to fully analyse the problem and design appropriate signing for optimal lane use.

Potential problems caused by inefficient lane usage are:

- Difficult weaving movements resulting in disruption of flow and potential risk of collisions
- Loss of throughput due to inefficient use of the available capacity
- Exit blocking due to long queues in single lanes rather than shorter queues in multiple lanes

Further guidance is given in the PI documentation.

6.3 Coordination

6.3.1 Safety

The coordination can affect the safety of operation of a roundabout. It should be such that drivers are not observed to race for the next signal to try to get through it before it changes. An additional problem is where drivers, usually in a long queue, do not stop when they should and continue across the stopline during the amber and start of red. A count of the vehicles crossing the stopline in the red provides a simple measure of the problem. The relevant observation sheet provided to observers defines how to use the measure to assess the problem.

6.3.2 Efficiency

The instructions for the PI build on the description of the different methods of control given above. For SCOOT and TRANSYT based systems, the preferred assessment is by comparison with the graphical output. For MOVA, and where the graphical output is not available, an experienced observer is required to assess the individual nodes using the principles presented in section 5.4. However, it is not possible to obtain a comprehensive view of the overall effects of coordination at the roundabout from observations at individual junctions. The optimisation of the control may result in sub-optimal progression at a non-critical node to achieve minimum delay overall. It is not possible by direct observation to assess the effectiveness of such compromises, hence the preference for comparing with the output from the optimisation programme where possible. The relevant observation sheet and guidance document provide full instructions on the methods to be adopted and the scoring regime.
7 Summary

The existing Performance Indicator for isolated traffic signals has been extended to networks of coordinated signals and signalised roundabouts. Signalised roundabouts pose particular problems because of the need to avoid lock-up. In addition the signing and lining should provide clear guidance on lane usage to avoid the need for weaving on the roundabout. It is important that data set up is well documented for all junctions, including the reasons for choice of parameters and method of control, such as details of MOVA linking. The documentation of the principles adopted will be particularly helpful for modifying the junction to meet future policy demands. It is particularly important to document the reasons for operating in a particular way for complex installations such as signalised roundabouts.

At roundabouts the set up of the signals and their performance will vary with the method of control. For instance, with fixed-time control it is important that there is normally some spare capacity on circulatory links to accommodate periods of heavier than average flow without danger of lock-up. However, with MOVA there would normally be a balance between the entry and circulatory links as MOVA can respond rapidly to changes in demand.

With SCOOT and with TRANSYT optimised fixed-time control, the best measure of the overall efficiency is good agreement with the optimisation programme’s graphical output. In other cases, the assessment requires careful analysis of the traffic movements to determine which movements should be most favoured by the coordination.

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References


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