Traffic Signals Under SCOOT Control: Effective Design Principles

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Summary

Traditionally, SCOOT has been considered to be suited to congested urban networks and MOVA has been considered to be suited to stand alone junctions. With the introduction of linked MOVA, the lines have blurred significantly between SCOOT and MOVA. This has led to a long running debate as to which is 'best'.

In reality, the 'best' form of control at a junction depends on a wide range of factors. The purpose of this paper is to detail junction design issues that can assist or be detrimental when designing a site for SCOOT control.

How SCOOT Works: The Basics

SCOOT is a real time traffic responsive computer model that receives live traffic signal green times and vehicle presence measurements from detectors on-street on a second by second basis from the traffic signal control system.

The SCOOT model automatically adjusts the traffic signal timings to provide more green on the busier approaches when required. The model also takes into account the relative effect that the green time on each approach has on the surrounding traffic signal network and adjusts the green time to minimise delay across the network, whilst also generating offsets between the sets of signals to maximise junction capacity, by minimising exit blocking.

In order for SCOOT to model the traffic within the network correctly, and therefore give the correct amount of green, there are a number of model parameters that must be entered. The most critical parameters for modelling the SCOOT link are:

- Journey Time (JNYT/ JTIM): The average free-flow journey time for a vehicle travelling between the detector and stop-line.
- Maximum Queue Clear Time (QCMQ/ MAXQ): The time taken for a queue that reaches all the way back to the SCOOT detector to cross the stop-line.
- Saturation Occupancy (STOC/ SATO): This is the discharge rate across the stop-line for traffic during green.

SCOOT applies the above parameters to the traffic signal and vehicle presence data. Using these values, along with the signal green times and vehicle presence data, the model determines the current queue length, the time required to clear the queue and the point at which the back of the queue begins to move off. SCOOT uses this to determine the most appropriate stage length, cycle time and offset between traffic signals.

SCOOT makes a number of assumptions that must be correctly managed to keep it running well. These are:

- SCOOT Link Saturation: The SCOOT model tried to keep all SCOOT links at a junction operating at the same level of saturation at all times. This may be inappropriate where a junction approach is a rat run, or is severely exit blocked at busy times. Parameters can be put in place to manage this, but there must be space to queue the traffic which builds up during peak times on less important approaches.
- SCOOT Cycle Time: The SCOOT model assumes that a higher cycle time will improve the junctions' efficiency. This may be an incorrect assumption and the maximum cycle time may need limiting. This could be due to the presence of flare lanes, or exit blocking. All SCOOT nodes in the region should be able to run this same cycle time.
- SCOOT Offsets: The SCOOT model will try to provide an offset for all links at the same time. In trying to provide a good offset on all approaches, there is risk that the SCOOT model can end up providing a poor offset on the most critical approach. This

means that junctions requiring multiple offsets to work well can be problematic. This needs consideration at design stage.

SCOOT Junction Design Principles

Junction and Region Cycle Times

The SCOOT system provides offsets via the provision of a common cycle time for all traffic signals within a SCOOT region. It determines the most appropriate point in the cycle time to commence the downstream traffic stage, enabling the upstream stage to progress onto the back of a moving queue.

This need for a common cycle time is the most restrictive factor in terms of the SCOOT model's efficiency. It creates a number of issues to be aware of when designing a junction which will be part of a SCOOT network. It is important to ensure that the Junction being designed can work within the SCOOT region that it is sat within. This decision is usually based on two key questions.

- Cycle Time: What cycle time will the site need to run at during the peak and off-peak periods to manage traffic demand? Does this match with what the rest of the SCOOT region needs? If the site has more or fewer stages, or is significantly busier or quieter than the surrounding sets of traffic signals, it may not be possible to run a common cycle time.
- Proximity: How close is the site to the surrounding junctions and do the queues from this site interact with the surrounding sites, making offsets critical to the operation of the network? Where the queue lengths cause exit blocking for other movements at the upstream junctions, offsets are critical and the cycle time may need limiting to manage queue lengths.

The answers to these questions are central to how well the SCOOT model will be able to generate offsets for the site.

Cycle Time: Where No Common Cycle Time Can Be Found

If no common cycle time can be found, the SCOOT engineer has to either:

- Put the site into the same region and force it to double cycle. This is common at pedestrian crossings as it minimises delay for pedestrians, but still allows the retention of an offset for traffic progression.
- Put the site into a different region and sacrifice the offsets for an optimum cycle time. This will allow the site to run the timings it needs to, but the site may cause or experience exit blocking at busy times, affecting the local network.
- Put the site into the same region and run an inappropriate cycle time, which will make the junction less efficient, but will retain an offset with surrounding junctions. If the cycle time required by the anomalous junction is too high for the rest of the region, it will cause the rest of the region to run long greens when they are not required, which leads to driver frustration when waiting at a stop-line with no traffic coming on the other approaches. If the cycle time required by the site is lower than for the rest of the region, the same effect is caused, but at the anomalous junction only.
- Put the site into a sub-region, so that it can run in isolation from the rest of the region during quiet periods. This is helpful where the issues only occur during quiet times of day, but can only help where a Junction needs a lower cycle time for part of the day.

Each of these choices has a disadvantage, which will impact the efficiency of either the individual site, or the rest of the region. It cannot be fully mitigated by the SCOOT engineer.

Proximity: Where Proximity to Surrounding Junctions Causes Congestion

Where the distance between junction stop-lines is short, it is common for the queues from the downstream junction to reach back to the upstream junction and cause problems for all movements at that site. The SCOOT engineer must ensure that the queue length does not cause exit blocking for other movements at the upstream junction, so they may have to cap the maximum cycle time. This manages queue lengths by preventing the queues from getting long enough to interact with other movements. Where cycle times in the rest of the region make this inappropriate, this is problematic.

It may be possible to model exit blocking issues by installing an exit detector, but this will have only a limited effect at managing the problem.

Ensuring that the junction is designed in such a way that it can run in cooperation with the rest of the local network is vital to maintaining the efficiency of the local network.

Factors Around Junction Staging

The SCOOT model cannot contravene any of the safety critical timing values entered into the controller specification. As SCOOT provides a common cycle time, it has to ensure that all stages that may need to run in a cycle can be accommodated within that cycle. This means the model is limited by the controller's minimum stage lengths and minimum permitted cycle time. The minimum stage length is the sum of the following:

- Controller stage minimum: This is the highest stage minimum of all phases running in the given stage, not counting any phases which run in the preceding or following stage.
- Controller preceding inter-stage: This consists of the highest values that might run, including on-crossing extensions, phase delays, all red extensions, lamp monitoring additional inter-greens and SDE/ SA extensions.

The minimum cycle time is the sum of all of the minimum stage lengths added together plus four seconds.

The minimum stage length for each stage is accommodated by the SCOOT model, as it allocates a period when that stage can run. If the stage is not demanded, this 'spare' time must be allocated to another stage in the plan line, to maintain the common cycle time across the region. This creates a problem at quiet times, as the SCOOT model will optimise the named stage, then call the next (demand dependent) stage, which may not be demanded. If it is not demanded, the SCOOT model will dwell on the named stage for the duration of that stage. It will only then move to the next stage. This creates a situation where the traffic signals can be sitting on a stage, with no traffic coming, at quieter times. This can make SCOOT inefficient during quiet periods.

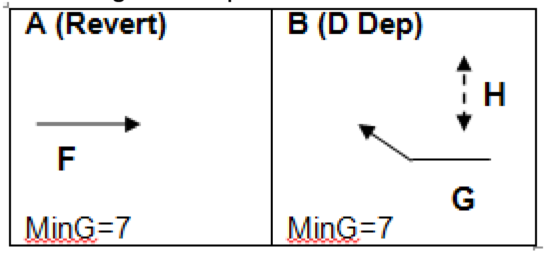
When creating SCOOT plan lines, accommodating these demand dependent stages can be tricky. This creates a number of issues to be aware of when designing a junction to operate under SCOOT control. These are discussed below.

Number of Stages & Staging Order

When creating a SCOOT translation plan line, it is essential that the Force bit being sent matches to the Reply bit being received, once the inter-stage has timed off. For this reason, when there are demand dependent stages on the site, it is essential to specify the demand dependent stage you wish to call, and provide an alternative for if that stage is not demanded.

Junctions with two or three stages are therefore easy to accommodate in SCOOT. It is very simple to remain on the named stage, rather than change to the demand dependant stage. As the named stage is usually the main road, this can be beneficial to traffic flow in the region.

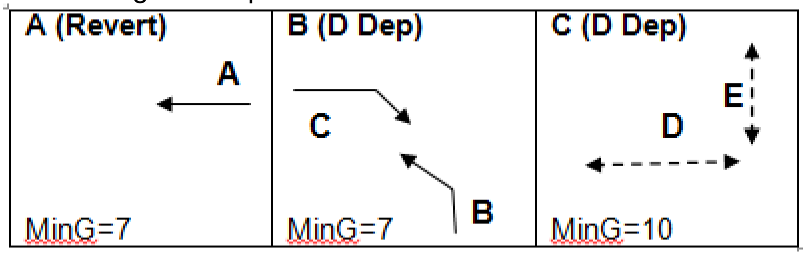
Two Stage Example:



Plan: {FA0}1, {FB0, FAB1}2

Explanation: Stage 1 = Force Controller Stage A
Stage 2 = Force Controller Stage B, or stay in Controller Stage A

Three Stage Example:



Plan: {FA0}1, {FB0, FAB1}2, {FC0, FAC1}3

Explanation: Stage 1 = Force Controller Stage A
Stage 2 = Force Controller Stage B, or stay in Controller Stage A
Stage 3 = Force Controller Stage C, or return to Controller Stage A

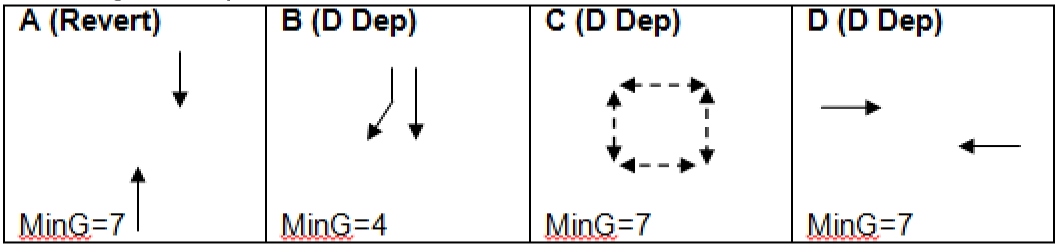
Where a junction has four stages or more, things are trickier, as any bonus time from demand dependent stages that haven't been called has to be dealt with differently. The options are:

- Remain on the previous stage
- Move to the next stage
- Send a demand, to force the junction to run the un-demanded stage

If the alternative stage you enter into the plan line is demand dependent, and also not demanded, then the controller will be unable to obey the stage change instruction and this will cause a plan compliance fault. The site will isolate from UTC control, unless a demand for the stage is also sent by UTC. It is therefore necessary to consider carefully how to build a plan line that will work at all times, whilst maintaining efficiency for the site. This means that staging order and the number of stages need to be carefully considered.

The below example shows the kind of issues that can arise:

Four Stage Example:



Plan: {FA0}1, {FB0, FAB1}2, {FD0+DD}3, {FD, FAD1}4

Explanation: Stage 1 = Force Controller Stage A
Stage 2 = Force Controller Stage B, or stay in Controller Stage A
Stage 3 = Force Controller Stage D, with UTC demand.
Stage 4 = Force Controller Stage C, or return to Controller Stage A

The staging order in UTC is more efficient than the controller staging order as it allows the traffic stage to be forced, and the pedestrian stage to act in the usual demand dependent way.

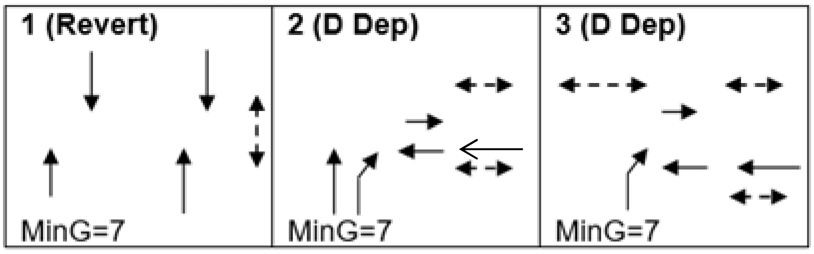
The order of stages chosen for SCOOT sites is important and needs to be carefully considered.

Prohibited Stage Changes

Prohibited and via moves make it more difficult to build plan lines that remain compliant at all times, as demand dependent stages failing to appear can lead to prohibited moves being requested by the plan line. Careful checking of the plan lines is needed to ensure that whether or not demand dependent stages are called, the plans are always able to run. The more banned and via moves there are, the more difficult this becomes.

Fixed Length Stages

The SCOOT model makes its stage change decision four second before the end of the stage, and will either retain, advance or retard the stage length. If the link in question terminates in a fixed length stage, then the SCOOT optimiser cannot change the stage length, so the link cannot be optimised. Therefore a staging order must be selected where no SCOOT links terminate in a fixed length stage. An example of where this has happened is shown below:



In this example, stage 3 contains an exit pedestrian crossing, which causes the stage to be a fixed length stage. However, as the site runs under SCOOT control and both the right turn and the westbound movement terminate in stage 3, this makes it impossible to optimise their stage lengths. Therefore when running under SCOOT control, the following staging order is used:

Plan: {FA0}1, {FC0, FAC1}2, {FB, FAB}3

Explanation: Stage 1 = Force Controller Stage A
Stage 2 = Force Controller Stage C, or stay in Controller Stage A
Stage 3 = Force Controller Stage B, or return to Controller Stage A

All Red Stages

All red stages can be used to make it possible for the junction to move through a prohibited stage change, by going via an all red stage. The all red stages can be set up in the controller either with or without a UTC stage confirm bit.

Where a stage confirm bit is present, the all red stage and it's timing information needs to be entered into the UTC system, and the stage needs to be included in the SCOOT plan line to prevent plan compliance faults from occurring when an all red reply bit appears.

Where an all red stage reply bit is not included, the UTC system will see the all red stage as an inter-stage, which needs to be accommodated within the UTC timing data, again, to prevent plan compliance issues.

It is common to base the decision to include a stage reply bit for the all red stage on whether the site dwells on the all red stage for long periods. This is because sites with no all red stage reply bit, that dwell on an all red stage will isolate from UTC control as UTC will see the site as stuck in inter-stage.

Alternate Staging

Where a junction is programmed with alternate staging, this can be problematic for SCOOT. Alternates can be set up so the junction will run one of two stages based on conditions within the controller, but these can be set up to reply either under one junction reply bit, or they each have their own junction reply bits. Both can be accommodated in SCOOT, but need to be set up carefully.

Where a single reply bit is used for both alternates, the SCOOT model may think a SCOOT link has been green during a stage when it didn't run. This is problematic when validating the links and causes the SCOOT model to be very inaccurate. In this situation, it is best to have a dedicated reply bit for each stage.

Where each alternate has its own stage reply bit, the building of plan lines can be problematic, as they need to be complex and often will miss out some stages entirely. Furthermore, this can be problematic in the TMS SCOOT system, as only two stage force bits can be sent in each stage for simple plan lines (three where relaxed plan checking is used), which makes it difficult if both alternates are demand dependent.

Issues with Variable Inter-stages

In order for SCOOT to work effectively, the model needs to know exactly how much green the link is getting and when the effective green will start and end.

To derive this information, the UTC system receives a green confirm bit from the junction. However, the green confirm drops at the end of the preceding stage, as soon as the first phase in that stage loses green. The green confirm for the next stage will not appear until all phases in the next stage have gained green. Not all phases gain or lose green together, due to varying inter-greens or phase delays, etc, so an adjustment is needed to the inter-stage value for each link, in order to obtain the correct effective green duration for each link. This is done by entering a start and end lag into the model for each SCOOT link.

These start and end lag values are fixed, which makes it very difficult to accommodate variable inter-stages. (Variable inter-stage modelling does exist in SCOOT, but its effectiveness is limited). Where the junction is using features such as on-crossing extensions, all red extensions, SDE or red lamp monitoring additional inter-greens, the inter-stage will be variable. SCOOT will be unable to model the link as accurately, due to the variability of the effective green time.

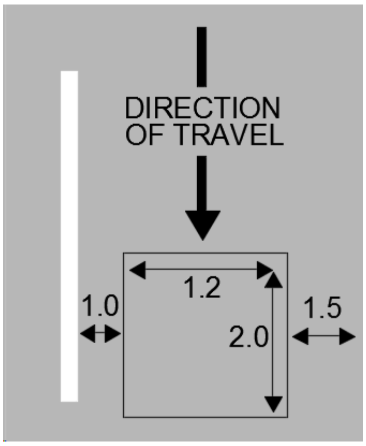
When designing a junction which will operate under SCOOT control, the designer needs to weigh up the importance of using features that cause variable inter-stages, against the need for the SCOOT model to accurately model the link. The decision made will depend on factors such as:

- How busy is the junction? Where it is extremely busy, features such as on-crossing or all red extensions will allow the designer to squeeze a bit more capacity out of the junction.
- How much do offsets matter? If the SCOOT model cannot accurately predict the start of stage, the offsets will be slightly incorrect, which will have a detrimental impact on junction capacity. This needs to be weighed up against the capacity increase caused by the feature.
- Does it matter if stages are run for too long? Where variable inter-stages cause quiet side roads, or pedestrian movements to run for longer than necessary, this can be detrimental to the operation of the site. But if the additional time can be added to the main or busier stages, this can mean the impact is minimal.

<u>SCOOT Detection: Positioning SCOOT Detection</u>

When a junction is designed, the SCOOT engineer must decide where to position the SCOOT detectors. A SCOOT detector is usually required for each separately signalled approach to the junction and sometimes on the exit lane to model traffic leaving the junction, if there are exit blocking issues at peak times.

SCOOT detectors are traditionally inductive loops, 2 metres long in direction of travel, and not less than 1.2 metres wide. It is recommended that they should be cut 1 metre from the centre line, and 1.5 metres from the kerb. For multi-lane approaches, there should be a minimum of 2 metres between loops. It is also possible to use Magnetometers or Above Ground visual detectors, configured for similar sized detection zones.



The detectors are monitored 4 times a second and the information is sent back to the SCOOT system in ¼ second increments showing detector presence or absence. This data is converted by the SCOOT system, into Link Profile Units (LPU's) using as linear discounted occupancy method. This then provides the traffic demand data used by the SCOOT model for the link.

For optimum operation, the detector should be positioned as follows:

- Where vehicles on that approach cannot miss it, and where vehicles on other approaches cannot clip it.
- There should be no significant sinks or sources (i.e., side roads) between the detector and stop-line (contributing more than 10% of traffic to the link), especially if the traffic flow is very variable on the sink/ source.
- For multi-lane approaches, one loop should cover no more than 2 lanes.
- The cable run between the loop and detector pack should ideally be no more than 150 metres.

- The SCOOT model needs time to make its calculation, so the detector is recommended to be no less than 6 seconds journey time from the stop-line. The optimum is 8-15 seconds, or on the exit from the next junction upstream if it is reasonably close.
- There should be a consistent journey time between the detector and stop-line. So the loop should not be positioned where traffic flow is often disrupted, such as where on-street parking or bus stops affect the journey time.
- SCOOT detectors are often positioned around 100 metres from the stop-line, however as detectors should be positioned where traffic is normally free-flowing (except in very congested conditions), this should be increased where there is persistent queuing. Effectively, traffic should only queue onto the detector at the height of the peak. This is because the SCOOT model measures congestion on the detector and uses this as a multiplier to increase green time on specific approaches based on queue lengths.

The following process will assist an engineer to position the SCOOT loops at a junction:

1) The SCOOT engineer must consider how the SCOOT model will work, by deciding what links will be set up for the junction.
2) Once this is decided, the engineer can then work out which approaches and exits will need detection.
3) Then the engineer can decide where the detectors should be positioned on each of the approaches, bearing in mind the issues described above.

SCOOT Detection: Where Normal Detectors can't be Installed

If a traffic movement has very poor lane discipline, or a very short flare lane, it may not be possible to position a detector on the link in the usual way. In these instances, historic detection may be used. This is where the loop is positioned downstream of the junction, rather than upstream. These loops are not as effective as normal links because they cannot measure congestion or effectively determine appropriate offsets between sets of signals. They operate by measuring how the effective green time on the link is used by the traffic, and generating a Saturation value for the previous cycle, which is then used to inform the stage length for the current cycle.

They are usually recommended only where normal detection cannot be used. There are two types of detector that are available in SCOOT and the following sections details where they may be needed.

Filter Detectors

These detectors are positioned in front of the stop-line and an average journey time is entered for the link, giving the journey time from the stop-line to the detector. The SCOOT model then only looks at the detector during the effective green period, minus the journey time. The system then calculates the saturation value from the detector data and uses this to determine the appropriate stage length.

Filter detectors need a consistent journey time between the stop-line and detector and this does need to be a relatively short journey time. It is also important that exit blocking does not cause the detector to have traffic queued over it regularly, as this prevents the model from calculating the Saturation value effectively.

As the detector is positioned in front of the stop-line, it cannot measure congestion in the traditional sense, and this makes it difficult for the SCOOT model to bias towards Filter approaches during congested conditions, as a Congestion Importance Factor (CGIF) cannot be used. For this reason, Filters are not usually recommended on main road movements.

However, the SCOOT system does now include a facility to mimic the Congestion Importance Factor (CGIF), making it possible to bias the SCOOT model towards increasing the stage length on Filter links during congested periods. This has facilitated the use of Filter detection in a wider range of contexts.

The command needed to set this up are:
Filter Saturation (FSAT/ FWSA): This parameter specifies a Saturation level above which you want the SCOOT model to begin biasing towards this approach.
Filter Multiplier (FMUL/FWMU): This parameter specifies how strongly you want the SCOOT model to bias towards the approach when it is above the specified Saturation value.

Stop Line Detectors

SCOOT Stop-line detectors can be positioned at the stop line or up to 20 metres upstream of it. In order to set these detectors up, the journey time must be set to zero.

The detectors work in the following manner. During the first 6 seconds of effective green, the SCOOT model assigns an average LPU value to any vehicles detected, to reduce the impact of the slow moving traffic on the model. After the first 6 seconds, the model assesses the usage of the green time to determine the level of saturation. The Saturation value calculated in the cycle is then used to help determine the stage length for the next cycle.

As with Filter detectors, they cannot model congestion, so cannot use this to increase green during congested condition. However, unlike Filters, there is no alternative facility available. For this reason, stop-line detection operates best on side roads, or less important movements, as it will not increase green as effectively during congested conditions. However, the use of stop-line detection is of value where the cost of ducting is high, and you need detection on side roads, right turns or similar minor movements.

Stop-line detectors installed for SCOOT, MOVA or VA can be used as SCOOT stop-line detectors. VA stop-line detectors are normally placed at 2 metres from the stop-line and are cut in a very similar way to SCOOT stop-line detectors.

To use a VA stop-line detector as a SCOOT detector, the TOPAS2500 configuration/ O.T.U configuration needs to be written in such a way that the VA detectors you want to use are available in the configuration as SCOOT detectors as well as VA detectors. For a Siemens configuration, this means adding the detectors to the Serial MOVA page, then adding the required detectors to the O.T.U configuration. Alternatively with Siemens controllers, if dealing with a faulty detector that there is no budget to re-cut, you can use the 'IOA' command to allocate the detector you wish to use as a substitute across to the input for the SCOOT detector that has failed. With Dynniq PTC-1's, the detectors need to be added to the TOPAS2500 configurations at design stage. With Telent Optimas, any detector can be picked up for use as a SCOOT detector by selecting it in the outstation configuration pages.

This is usually very cost effective where stop-line loops are required, and can save money as there is no need to duct or cut additional detectors.

SCOOT Detection: Setting up 'Spare' Detectors

In the current climate, many local authorities are in the position that they can obtain capital funding for major schemes, but revenue budget for maintenance can be problematic. For this reason, it is worth configuring as many ‘spare’ detectors for the SCOOT model as possible when the scheme is built.

Many other types of detector can be used as SCOOT detectors, and provided they are available to the UTC system, they can be used as a fall-back option, if the normal SCOOT detector has failed and there is no budget for the replacement of the detector.

For this reason, it is recommended that the following detector types be set up as SCOOT detectors in the junction configurations when they are created.

- MOVA Detectors
  MOVA IN detectors work well as SCOOT detectors, as they are often cut in roughly the right location and are a similar dimension to a normal SCOOT detector.
- SDE/ SA Assessors
  SDE/ SA detectors are very effective as SCOOT detectors. They are cut in a very similar way to SCOOT detectors, and are positioned at a good distance from the stop-line for SCOOT purposes.
- MOVA/ VA Stop-line Detectors
  MOVA or VA stop-line detectors can be used as a SCOOT detector, as described above.

For all of these detection types, if they are added to the TOPAS2500 configuration, they can be picked up and used by the SCOOT engineer when needed. The configuration of these detectors at design stage provides a simple and cost effective method to dealing with detector faults over the life of the scheme.

SCOOT Junctions: Conclusions

When designing a site to operate under SCOOT control, it is important to consider the following:

- Cycle Times: Can the junction work with the surrounding junctions in terms of cycle time?
- Offsets: Where multiple offsets are needed at once, the model may struggle to accommodate this. Is this an issue with this junction?
- Proximity: Is the proximity to surrounding junctions going to cause a problem in terms of maximum possible cycle time?
- Staging Order: Is this appropriate for SCOOT in terms of number of stages, staging order, prohibited moves, fixed length stages, alternates and all red stages
- Are the variable inter-stages proposed suitable?
- Are the SCOOT detectors correctly positioned?
- Where the positioning of normal SCOOT detectors is not possible, are historic detection options being used?
- Are alternative/ spare detectors being set up?

As a general rule of thumb, SCOOT is best suited to closely associated, busy urban networks where good offsets between sets of traffic signals are needed to get the most from the network. SCOOT will struggle to work well in situations where the cycle time needed by a SCOOT junction is significantly different than that of closely associated junctions. Also, it will struggle where the site has 4 or more stages and the demand dependent stages regularly aren’t called in every cycle. During quieter times, this will seem slow to react and may give rise to complaints.

Designing the junction with the above principles in mind will maximise the efficiency of the junction as it operates within the wider network.