



General Principles of Traffic Control by Light Signals Part 3 of 4

This document is Part 3 of Traffic Advisory Leaflet 1/06. It should be read in conjunction with Parts 1, 2 & 4. The Reference section is in Part 1.

TRAFFIC ENGINEERING AT SIGNAL-CONTROLLED JUNCTIONS

Signal-controlled junctions can reduce accidents by allowing certain traffic movements to proceed whilst holding others that would be in conflict. To allow each movement separately will remove all conflicts but is not normally satisfactory since delays to all traffic will be high and effective capacity of the junction will be low. For example, at a simple crossroads, with a pedestrian stage, there would be five stages and the probable delays unacceptable to all road users.

The art of designing an installation is in reducing the delay and increasing the capacity while still maintaining a high degree of safety.

Reduction in total delay and improvement in capacity can be achieved by:

- normally using the lowest number of conflicting phases and practicable stages in any signal cycle;
- ensuring that each vehicular approach is capable of carrying the maximum predicted flow for that approach;
- allocating time to each phase/stage appropriate to the actual traffic flow and
- if appropriate, co-ordinating control of adjacent junctions to maintain traffic platoons.

The aim is always to keep as much traffic moving as practicable at the same time. Techniques may be employed, singly or in combination. For example:

- a right-turn on full green, with an opposing straight ahead movement, can be acceptable as long as it can be executed safely with the exercise of due care;

- Traffic Regulation Orders (TRO's), e.g. banning turns, can be employed to regulate other conflicting movements and
- the provision of "walk with traffic" pedestrian facilities can be used rather than an exclusive pedestrian stage.

The following are examples chosen to illustrate the above principles at a four-arm junction.

Two Vehicular Stages

i With all movements permitted

This is a very common junction and two stage operation forms the basis of signalling techniques. Red, Amber, Green (RAG) signal heads are used. Vehicles on opposite approaches have a green signal whilst those on the other two approaches have a red. When an all-round pedestrian stage is introduced, all vehicular movements are stopped, see TAL 5/05⁴.

Each approach may have one or more lanes, a shared stop line and simultaneous discharge. Right-turning traffic may impede vehicles wishing to proceed over the junction if an outside lane is shared, or even worse there is only a single lane.

ii With right-turn traffic prohibited

Where there is a relatively minor right-turn flow the capacity of the junction is reduced by the road space occupied by the vehicle waiting to turn right and by the time which has to be provided to this movement in the cycle. If the right-turn manoeuvre is removed then reduced delay and improved capacity can be expected. Where one exists, an alternative route can be indicated to traffic before the junction is reached.

The main alternatives are to:

- turn left before the junction, make two right-turns to appear at the junction on the left-hand arm (known as a 'g' turn).
- pass through the junction, turn left and make two further left-turns to appear at the junction on the left arm (known as a 'q' turn).

In the latter case the diverted traffic will pass through the junction twice and may adversely affect the expected improvements. If the diversion routes are residential the additional through traffic may be unacceptable.

The staging can be applied to a single lane approach and the signal display is a three-light with a full green signal and a sign to diagram 612 in TSRGD⁶ mounted on the signal head.

iii With both left-turn and right-turn prohibited

This results in exclusive movements; Red, Amber, Green Arrow (RAGA) signal heads are used. See SIGNING section in Part 1 for the use of regulatory signs to diagram 606 (TSRGD)⁶. If both opposing arms operate this way, the opportunity can be taken to run parallel pedestrian phases (walk with traffic), see TAL 5/05⁴.

Dealing with right-turning movements

Without special provision, some right-turning vehicles will turn in gaps in the opposing flow but if this is not possible they will complete their movement in the intergreen period.

A typical junction will have space for two or three vehicles beyond the stop line. With, say, a 70 second cycle time this means that between 100 and 150 vehicles an hour will turn right in the intergreen. With a longer cycle time this "free" right-turn capacity decreases.



If the number of right-turners exceeds the number that can clear the junction in gaps, or during the intergreen, special provision will probably be required. Note that if right-turners are left in front of the stop line after a change to another stage, not only will the driver feel in a vulnerable position but the presence of the vehicle may obstruct pedestrians wishing to cross.

There are three basic choices. If only one approach has a right-turn flow justifying special provision, typically an

early cut-off can be used. However, if the right-turning movements from opposing directions both justify a right-turning stage then a staging with concurrent exclusive right-turning movements may be appropriate. The third option is to run the opposite arms separately but this normally has serious capacity problems.

Three Vehicular Stages

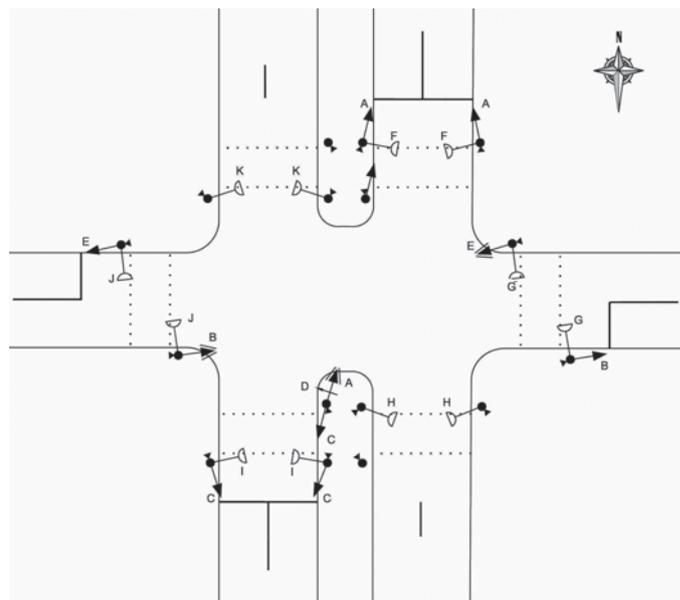
Early Cut-off

The definition is "a condition in which one or more traffic streams, that were running during the preceding stage, are stopped whilst one or more other traffic streams are allowed to continue moving". The arrangement is shown in Diagram 4, Part 4.

It allows opposing arms to run together on the first stage but only one to proceed on the next. This will permit right-turning vehicles to discharge without conflict and to allow any other vehicles, which have been delayed by the right-turn traffic, to clear.

With early cut-off signalling, one straight ahead movement has more green time (because it runs in two stages) than the opposing straight ahead movement. If this is roughly equivalent to the balance of straight ahead flows then this arrangement is likely to be efficient. The facility should not be applied if the arm has only a single lane approach and a separate stage should be considered.

The signal display, on the arm that loses right of way at the end of the first stage, should be sited with care. If a secondary signal is to be used it must be "closely associated", that is on the same side of the junction as the primary signal. Farside secondary signals in this situation are potentially dangerous and should not be used.



The only exception is at a junction where there is no right-turn from the approach losing right-of-way, the westbound approach in the diagram. The southbound approach will have a three-light primary and a secondary, which is always

placed beyond the junction, with an additional right-turn arrow illuminated during Stage 2, see Diagram 4, Part 4. If the right-turn, from phase C, is still thought to be a problem the designer may consider a TRO to ban the movement.

It is not normally recommended that the second stage (green arrow) be allowed to mature in the absence of a demand for the third stage for side road traffic. This is because of confusion and danger to drivers on the main road due to the rapid reversion to stage 1, which would otherwise occur.

If traffic demand is sufficient, it is possible to show an additional left-turn green arrow to the side road traffic on stage 2. The requirements under “Additional Green Arrows” must be adhered to and care must be taken to avoid danger to pedestrians from the left-turn traffic. Such traffic must be provided with its own independent lane. The display will have a standard signal head with the additional green arrow on the primary. During the second stage a red signal will be displayed together with the green arrow. The green arrow will be extinguished when the full green signal appears at the start of the third stage.

Late start

The definition is: “a condition in which one or more traffic streams are permitted to move before the release of other traffic streams which are permitted to run with them during the subsequent stage”.

This method of operation is not recommended. It displays an indicative arrow to one approach whilst delaying the start of the opposing traffic. The two problems are: once a dominant flow has been established, those drivers having been initially shown a green arrow assume an unopposed exclusive movement and for the right-turning driver on the opposing flow, it is difficult to make the movement and unnecessary risks are taken.

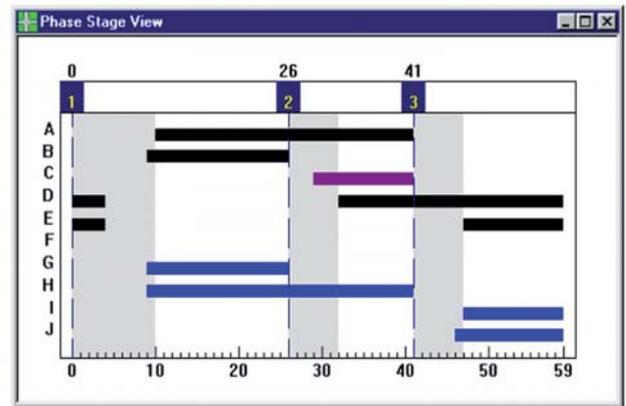
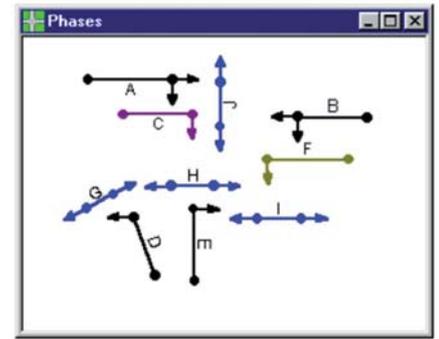
Concurrent Exclusive stages

Where both right-turn movements are heavy a better solution can be to hold them against a red signal whilst the ahead and left-turn vehicles flow unhindered. They are then stopped before the right-turn vehicles are released simultaneously on the same stage. This requires separate right-turning lanes and signal displays. These are often separated from the other lanes by traffic islands, this method should be employed on high-speed roads, see TAL 2/03⁵.

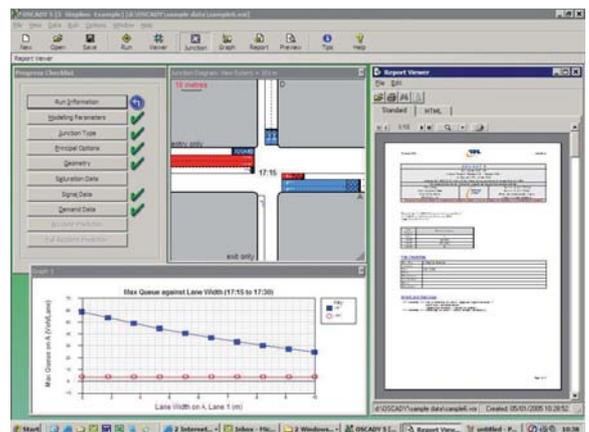
DESIGN FOR TRAFFIC SIGNAL CONTROL

The analysis of a traffic signal junction to provide details of optimum timings and predicted performance in terms of capacities, delays and queues is best performed by the use of specialist software packages such as LINSIG³³, or OSCADY³⁴ (Optimised Signal Capacity and Delay), perhaps the two best known in GB. These packages require

the user to input not only the geometrical details of the junction and traffic flow information but also the proposed control method in terms of phasing and staging.



LINSIG³³ provides an output compatible with the TR2500²² form used to specify the phasing, staging, timings etc for the controller (see Part 4). The latest version models parallel stage streaming and progression through multiple stop lines. OSCADY³⁴ was developed by TRL as one of a suite of three programs. The other two are ARCADY³⁵ (Assessment of Roundabout Capacity and Delay) & PICADY³⁶ (Priority Intersection Capacity and Delay). OSCADY³⁴ is often used to assess schemes at the initial planning stage as various methods of control, ie signals against roundabout can be assessed together.



Both LINSIG³³ and OSCADY³⁴ are Windows-based programs and provide the user with user-friendly screen information.

It is possible to submit a wide range of staging arrangements for individual analysis by the software. However, there are advantages in carrying out a manual preliminary assessment to identify the preferred staging or a limited number of staging arrangements for detailed analysis. The manual method will give a general indication of whether the

junction would operate comfortably or close to its capacity limit. This is very valuable in interpreting the output from the software packages and identifying any unrealistic results which would indicate errors in the input data.

Drawing Symbols

An example of drawing symbols can be found in Part 4. Many practitioners have developed others. If you are not sure check with the design authority concerned.

Manual Preliminary Assessment

Before investigating any special staging requirements it is worth checking that the main vehicular flows do not exceed the overall junction capacity potential.

A preliminary assessment can be carried out using the basic concepts of the analysis developed by Webster and Cobbe³⁷. This is based on the assessment of y values.

y value is defined as the ratio of the demand to the saturation flow - the proportion of time a signal has to be green to allow the demand flow to pass. The

critical y value is the highest value for each stage in the cycle.

A flow of 1000 pcu/h crossing a stop line with capacity 2000 pcu/h needs a signal which is green for at least 50% of the time, a y value of 0.5. (To convert a mix of vehicles into pcu's, or passenger car units, the following figures are used: Car or light goods – 1, medium light goods – 1.5, HGV – 2.3, Buses and coaches – 2, Motor cycle – 0.4, Pedal cycle – 0.2.)

Note that y values need to be assessed using a realistic assessment of the saturation flow. Site conditions will often mean lower saturation flows than expected from an inspection of a two dimensional plan. Some can possibly be changed by TRO, for example parked vehicles but some such as a steep incline will have a permanent effect. Some layouts will also affect the consistency of the saturation flow. A flared approach, or an exit merge will not give a constant saturation flow. If there is a very lightly trafficked stage it will have to run for at least the minimum green of, say, 7 seconds. With a cycle time of 70 seconds this will mean assigning it a y value of at least 0.1.

Y is the summation of the y values for all the stages in the cycle. If Y is >1 then the junction has insufficient capacity whatever timings are applied. In Webster and Cobbe³⁷ "a practical capacity maximum of 90% of this maximum possible flow" is recommended.

Y_{pract} - the maximum practical value of Y .

Y and Y_{pract} can be calculated using Webster and Cobbe³⁷:

$$Y = 1 - \frac{L}{c} \text{ and } Y_{\text{pract}} = 0.9 \left(1 - \frac{L}{c}\right)$$

Where:

c is the cycle time and

L is the lost time, the total cycle time which is not effective green, often taken as the total interstage period* minus 1 sec. for each individual interstage period*. Note that lost time does vary from site to site and the figure given is only an approximation.

(in Webster and Cobbe the example given uses a maximum cycle time C_m of 120 seconds:

$$Y = 1 - \frac{L}{C_m}, \text{ therefore } Y = 1 - 0.0083L \text{ and } Y_{\text{pract}} = 0.9 - 0.0075L)$$

Broad approximations are sometimes necessary but sufficient for preliminary assessment where the detailed analysis is to be later undertaken using LINSIG³³ or OSCADY³⁴.

In practice, Y values as high as 0.9 could indicate a short life for an installation before remedial action is necessary to return the junction to an efficient level of working. 0.8 is often taken as a more practicable value to start indicating potential capacity problems.

As can be seen from $Y = 1 - \frac{L}{c}$, Y falls off markedly with increasing values of L and decreasing values of c . To take an extreme example, operating a junction with (say) an L of 30 seconds and choosing a cycle time of 50 seconds would result in an available Y_{pract} of as little as 0.4.

It is therefore useful to calculate a reasonable cycle time:

C_{min} , the minimum cycle time – the cycle time which is theoretically just long enough to pass the traffic through the intersection is given by:

$$C_{\text{min}} = \frac{L}{1 - Y}$$

This minimum cycle time will produce excessively long delays. In practice it will be appropriate if the minimum cycle time chosen is such that the installation is loaded to 90% of its capacity, i.e.

C_{pract} , the practical minimum cycle time is:

$$C_{\text{pract}} = \frac{0.9L}{0.9 - Y}$$

To obtain a measure of "fit for purpose" and life expectancy.

Webster and Cobbe³⁷ give:

Percentage Reserve Capacity as: $\frac{100(Y_{\text{pract}} - Y)}{Y}$

*Note: for more complex junctions, stages may not be defined at this early stage and groups of conflicting phases are used instead. With simple junctions it will often be easy to identify a single set of conflicting phases. However, more complex junctions will have more than one set of conflicts and basing assessments on stages could be misleading. For the preliminary assessment therefore it would be necessary to identify each group of conflicting phases, testing them for practicality by substituting their 'Y values' and related lost time (L), using relevant intergreens, into the relevant equations.

Right-turning Movements

These are often the critical factor in determining a staging arrangement for a junction. For the purpose of a preliminary assessment, the choice is between an overlap arrangement, like an early cut-off, a concurrent exclusive method and separate stages for each of the opposing arms.

Pedestrian and bicycle facilities, see also TAL 5/05⁴:

The staging arrangement for a junction will have implications for how pedestrian and cycle facilities are provided. An exclusive pedestrian stage will typically require 20 seconds of the cycle time and will increase the lost time L disproportionately. L for a simple junction could increase from, say, 12 $((2 \times 7) - 2)$ to 32 seconds and the cycle time would increase proportionately. This preliminary analysis will indicate whether an exclusive pedestrian stage is feasible, or desirable, for either vehicular, or pedestrian traffic. Longer cycle times will increase waiting times for pedestrians as well as vehicular traffic. In this case the staging and layout of the junction will require walk with traffic pedestrian facilities where required. Separate bicycle facilities would be considered in the same way.

Summary

The preliminary analysis is not intended to produce a definitive staging arrangement for a junction but it is helpful in ruling out ideas which are not practicable. It can indicate situations where traffic signals are not appropriate, or suggest that carriageway widening may be necessary to obtain the required capacity. Any 'marginal' arrangements should be tested by detailed analysis.

Worked example for a crossroads with two lanes on each of the southbound and northbound approaches but single lanes on the others. (Note: This is not the example given under 'Three vehicular stages'.)

Approach	pcu/movement		
	Left	Straight ahead	Right
Southbound	25	700	25
Westbound	140	100	28
Northbound	50	800	400
Eastbound	30	100	12

It is estimated that there is storage space for two right turning vehicles from the main road in each direction and one right-turning vehicle from the side road. Apart from the northbound right-turn, it is estimated that there is sufficient "free" right-turning capacity to clear the right-turning vehicles in the intergreen.

The separate traffic streams have been identified and saturation flows estimated using the method set out in TRL Report RR 67³⁸ "The prediction of saturation flows for road junctions controlled by traffic signals" but see earlier warning on realistic saturation flows. In this case saturation flows have been assumed as 1900 pcu/lane for straight

ahead flows and 1650 for turning flows. Lanes with mixed movements have been interpolated between these.

Using the measured flows and the estimated saturation flows from RR 67³⁸, the y values for each traffic stream were calculated. (Saturation flows can be measured on site by counting vehicles in free flow conditions during a saturated period, say, after a few seconds into the green until there is a reduction in flow. Special packages are available to assist.)

Two different staging arrangements were tested and a Y value obtained for each. L values were considered with and without exclusive pedestrian arrangements. For an initial analysis the interstage periods have been set at 6 seconds each. The practicable arrangements would then be subject to detailed analysis.

First assessment (Using an early cut-off arrangement).

Stream	Flow (pcu)	Sat. flow (pcu)	stage	y value	Critical y?
	750	3750	1	0.20 (750/3750)	-
	850	1900	1 and 2	0.45	0.45
	400	1650	2	0.24	-
	268	1800	3	0.15	0.15
	142	1800	3	0.08	-
				Y	0.60

Y is estimated at 0.60. (Note, at this level of approximation there is little point in calculating y values to more than two significant figures) and L would be 15 seconds. The resultant C_{prac}. indicates that this arrangement is likely to be practicable. However, when an exclusive pedestrian stage is added, L will rise from 15 to somewhere nearer 35 seconds giving a C_{prac}. of over 100 seconds.

Second assessment (Using separate staging for each direction on the main road)

Stream	Flow (pcu)	Sat. flow (pcu)	stage	y value	Critical y?
	750	3600	2	0.21	0.21
	268	1800	3	0.15	0.15
	1250	3550	1	0.35	0.35
	142	1800	3	0.08	-
				Y	0.71

Y is estimated as 0.71 but L would still be 15 seconds as staggered pedestrian facilities could be provided across the main road within the Cprac. cycle time.

This staging does not allow for protected pedestrian facilities across the side roads. The staggered movements across the main road would be less convenient for

pedestrians but the cycle time would be shorter and the waiting time for a pedestrian may well be reduced.

There would be more spare capacity than the early cut-off plus exclusive pedestrian stage arrangement but costs and visual impact would be higher because of the additional equipment needed and the necessarily larger refuges.



Details of Traffic Advisory Leaflets available on the DfT website can be accessed as follows: www.dft.gov.uk
 From the DfT homepage, click on Roads and Vehicles, then Traffic and Parking Management and then Traffic Advisory Leaflets.

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