Junction Assessment Tools from First Principles

Background

1.1 More effective and efficient tools are needed to enable developers and their agents to understand what is expected of them when they undertake junction assessments. The quality of transport assessment work undertaken on behalf of developers by consultants is often inconsistent making it difficult for the Council to comprehensively understand the potential impacts of development on the performance of existing junctions and how any new junctions might perform. There are several possible reasons for this inconsistency:

- There is a wide range of junction modelling software available on the market and they all include their own assumptions and methodologies that sometimes contradict each other making it difficult to compare the outputs on a consistent basis if different models are used;
- The assumptions used in models are not always explained in a transparent way;
- Traffic models use varying degrees of sophistication in their methods of analysis;
- Model outputs are reported as absolute values and do not provide an understanding of variance;
- Junction modelling is a highly specialised technical skill that is subject to significant error if the modeller and/or their supervisors do not have the qualifications, engineering judgement and experience to determine the appropriate assumptions and inputs to use in the models and interpret the results to make suitable recommendations; and
- The data collected for use in the models may not be robust and/or appropriate.

1.2 The following guidance provides tools developed from first principles that will help to address these inconsistencies. The templates provided should be used in the first instance to assess the existing capacity and undertake option tests. Preferred options can then be tested in more depth using traditional junction assessment and/or micro-simulation modelling tools.

1.3 It is the responsibility of developers to detail the measures proposed to improve access by public transport, walking and cycling and reduce the number of motorised journeys and their impacts associated with the proposals (Section 9 of TAN 18). The following guidance will help support the developers in undertaking junction assessments to identify relevant junction improvements or mitigating measures to achieve this obligation.

1.4 The outcomes expected from applying this guidance are as follows:

- More effective, efficient and transparent junction assessment;
- Reduced number of options to model in detail;
- Appropriate, effective and efficient data collection;
- Guidance that overcomes contradictory advice from research and/or within modelling software;
- Variance in traffic flows, saturation flows and signal timings are explicitly understood;
- Mutual understanding of junction performance and the improvements and/or mitigating measures required.

1.5 It should be noted that this is a working document and the tools and techniques in this guidance may change over time if other information, guidance, research or methodologies demonstrate a need to modify it.

Methodology for Assessment of Priority Controlled Junctions

1.6 Traditional gap acceptance methods and formulae derived from empirical evidence are the two key ways of estimating the capacity of priority controlled junctions and roundabouts. The Council has reviewed these methods, the caveats and lack of consideration of variance concluding that there is no single type of model that accurately represents the capacity and performance of these types of junctions as they behave from day to day. The following text explains a pragmatic methodology that has been developed by the Council.

1.7 The traditional method for identifying the capacity of existing priority controlled junctions involves measuring the time in seconds between vehicles on a major road that is opposing the minor road traffic (the gap). The traffic that exits from a minor road between traffic on the major road is recorded as accepting a gap in the traffic (referred to as gap acceptance). The gap acceptance for vehicles on the minor road that follow a vehicle that has already accepted a gap in the traffic is typically lower than the gap acceptance of the vehicle that it followed (referred to as follow-up headway). For example, if a vehicle on the minor road has a gap acceptance of 4 seconds and the gap available on the major road is 6 seconds, the vehicle following behind may also be able to exit the minor road during the same gap if their follow-up headway is 2 seconds but not if it is higher. The gap acceptance varies depending on a number of factors including the local environment, visibility and driver ability. Many research studies report the results of applying this method and typically use probability theory to define capacity formulae that best represents observations. They also graph the relationship between opposing major road traffic flows and the capacity for traffic exiting from minor roads. This research and the resulting formulae and graphs can be used to predict the capacity of priority controlled junctions and roundabouts.

1.8 In 1976 (and subsequently for roundabouts in 1980), R M Kimber offered an alternative approach because gap acceptance was not easily measured (note: current technology has significantly improved the ability to measure gap acceptance using vehicle detection or video techniques). The alternative was based on empirical evidence from measurements of traffic flow and geometry and correlating these parameters to the junction capacity. The work resulted in a series of linear equations that could be used to estimate the capacity of turning movements given an opposing flow and associated geometry (see Design Manual for Roads and Bridges, DMRB 6.2.6 - TD42/95 and roundabouts in the Transport Research Laboratory (TRL) research reports LR942 and LR1120).

1.9 Typically models also assume the maximum capacity estimated can be attained. In practice, when measured queues and delays are compared with those estimated based on Queuing Theory there can be significant variance when the demand exceeds 80% of the theoretical capacity. There can be no accurate way to forecast queues and delays when demand exceeds this level of capacity. Simulation techniques provide a method for modelling the potential range of variance in traffic demand and help identify how queues and delays might vary but the accuracy is reliant on the number of simulations undertaken and assumptions used in the methodology. Therefore, the threshold of 80% of capacity (Ratio of Flow to Capacity of 0.8 also described as the 80% Degree of Saturation) is the practical capacity limit below which queues and delays experienced by those using the junction are likely to be reliable.

1.10 The pragmatic graphical method described below is appropriate for assessing priority junctions and roundabouts in situations when the traffic demand is no more than 80% of the capacity. Where the traffic demand exceeds 80% of the capacity, alternative improvements or mitigating measures may be required in order to ensure journey times through the junction are reliable and users do not experience large variations in queues and delays.

1.11 The Design Manual for Roads and Bridges (see Figure 2/2 in DMRB 6.2.6 - TD42/95) provides a graphical method to identify appropriate types of junction for a given range of minor and opposing major traffic flows based on Annual Average Daily Traffic (AADT) flows. It recommends that simple priority junctions provide capacity at the lower limits and roundabouts (or other type of control) provide capacity at the higher limits. This approach is helpful for quickly identifying how well a junction is likely to perform and what types of junction improvement may be required. **Figure 2** below can be used in a similar way.

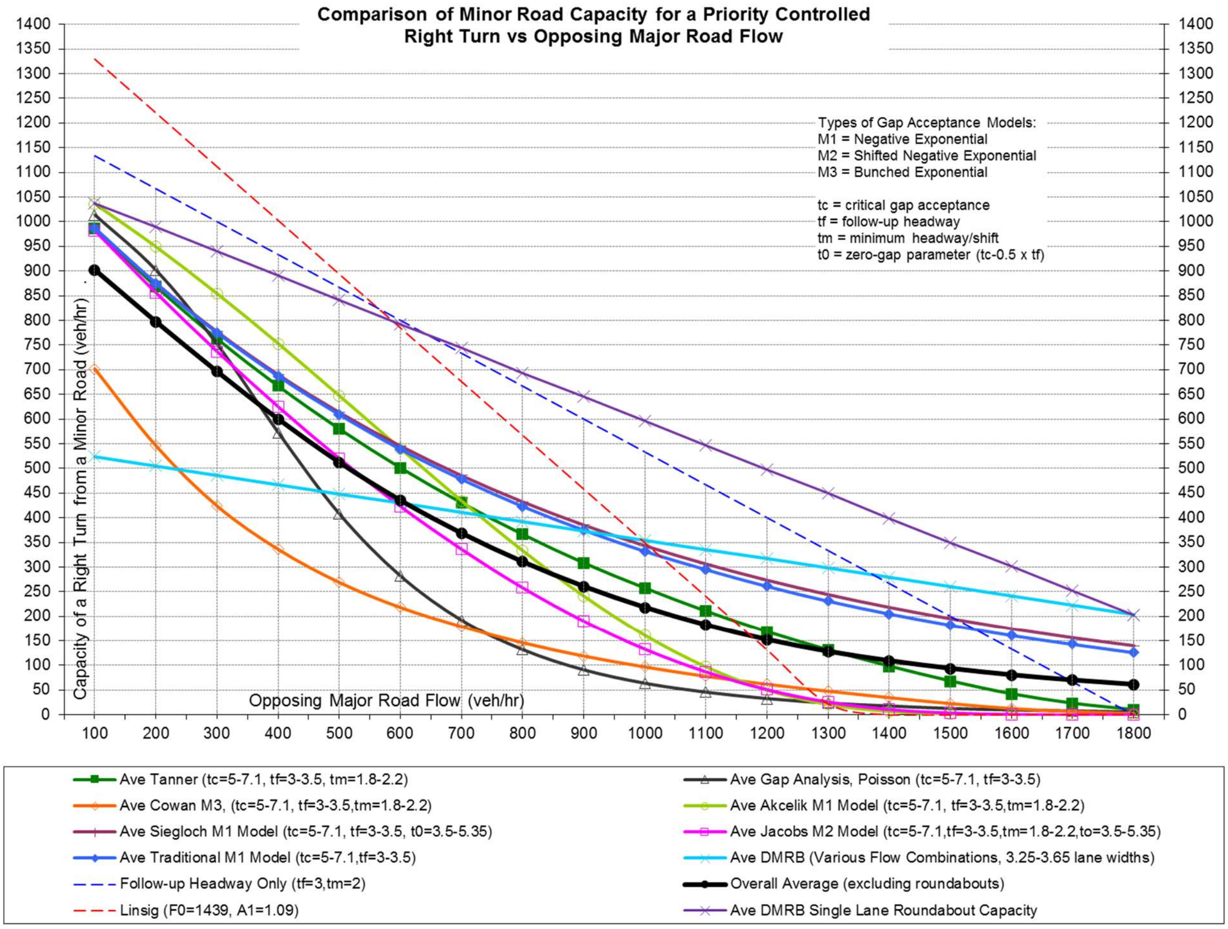


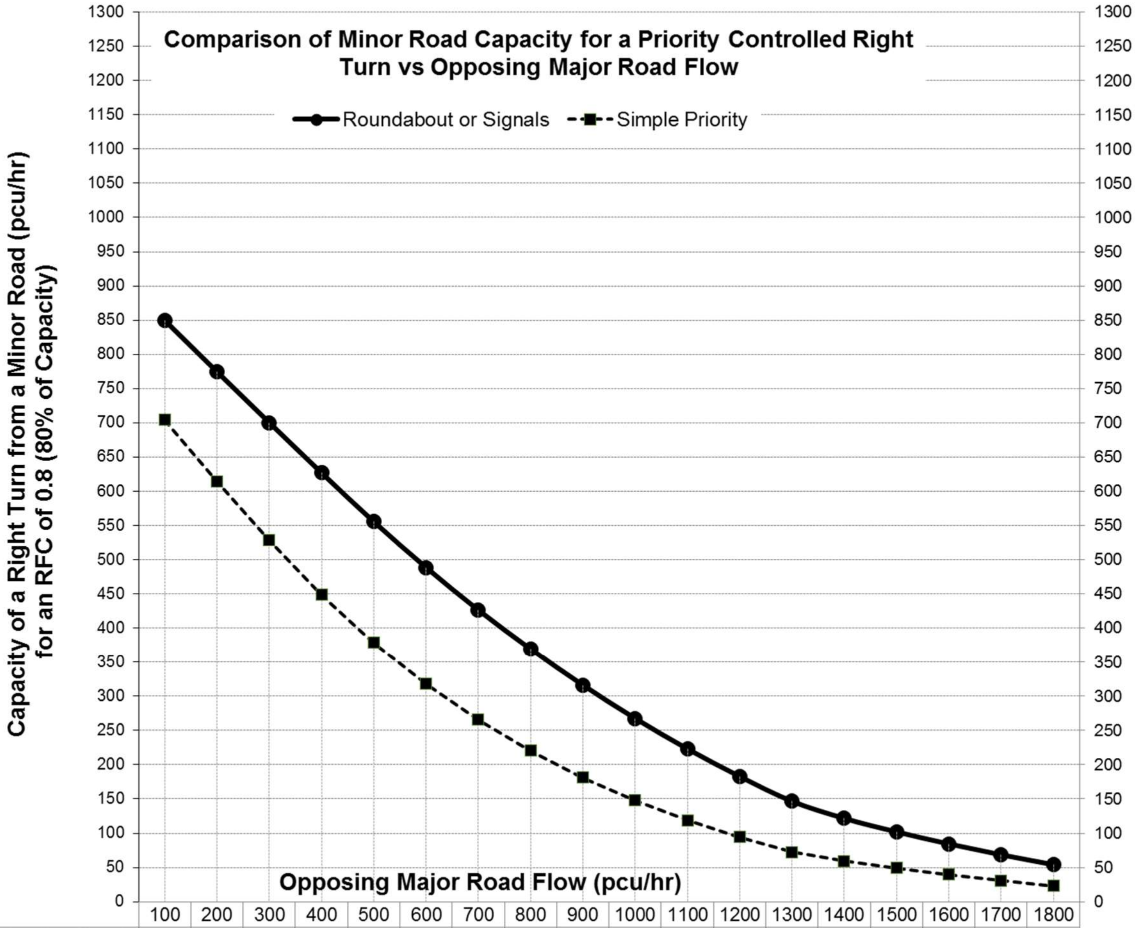
Figure 1: Comparison of Results from Queuing Theory and Other Established Methods

1.12 It can be seen from **Figure 1** that the results of models can be very different depending on the method used. Further analysis was undertaken using these models to develop upper and lower thresholds of capacity for a simple priority controlled junction that can also be used for assessing roundabouts. The analysis used the gap acceptance and empirical formulae for priority junctions as described above with the relevant range of upper and lower parameters along with linear models including the formula used in Linsig. The results were then averaged, multiplied by a factor of 0.8 and plotted on the graph illustrated in **Figure 2** to show the lower and upper limits of practical capacity for priority controlled junctions and approaches on roundabouts.

1.13 To use the graph in **Figure 2**, the traffic flow for a right turn at a priority junction is plotted against the major road opposing traffic flow (see notes a, b and c below). The upper and lower limits of flows based on measured variance for each movement can be plotted resulting in an area that illustrates the likely combination of potential flows within a range. It is likely that a simple priority junction would operate within the limits of practical capacity if most of this plotted area is below the lower line shown on the graph (note: the key in **Figure 2** illustrates it as a dashed line). An alternative junction treatment is likely to be more appropriate if most of the plotted square of traffic flow combinations is above the line. Alternatively, other mitigation measures may be required to reduce traffic demand. The same method is applied for traffic travelling straight ahead crossing the opposing major road traffic.

1.14 For roundabouts, the traffic per lane on the approach is used as the minor road traffic flow rather than the individual turning traffic flows assuming that all of this traffic gives way to the opposing circulating traffic. The junctions on the approach roads with the gyratory are treated as priority T-junctions for the purpose of using **Figure 2**. It is likely that a roundabout would operate within the limits of practical capacity if most of the plotted square of traffic flow combinations is below the upper line shown on the graph (note: the key in **Figure 2** illustrates it as a solid line). An alternative junction treatment is likely to be more appropriate if most of the plotted area of traffic flow combinations is above the line. Alternatively, other mitigation measures may be required to reduce traffic demand.

1.15 The same method described above can be used to test priority controlled options to identify what option/s for improving the junction/s may require more detailed modelling depending on the type of mitigation needed.



	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800
Roundabout or Signals	850	775	700	627	556	489	426	369	316	268	223	183	147	122	102	84	69	54
Simple Priority	704	614	528	449	379	318	266	221	181	148	119	94	72	59	49	39	31	23

Figure 2: Minor Road Capacity vs Major Road Flow

Notes:

a) All traffic data used in the junction assessments needs to be converted to passenger car units (pcu) using the vehicle conversion factors provided in Department for Transport WebTAG guidance (see TAG Unit A5.4 as of December 2015).

b) Under heavily congested conditions, the process of simple gap-acceptance may be replaced by a more interactive one in which major road vehicles adjust their headways (the gap they leave between them and the vehicle in front) to allow minor road vehicles to enter. This type of behaviour is indicative of a network that cannot sustain additional traffic demand. Therefore, such circumstances have been excluded from the analysis by putting an upper limit on the opposing flow of 1,800 pcu per hour.

c) This analysis does not account for traffic conditions that result in platoons of traffic in the opposing flow (note: platoons result from bunching effects where there are groups of vehicles that follow closely behind each other with larger gaps between these groups). In such circumstances, the capacity of a turning movement from a minor road can be higher than the above analysis would suggest because the follow-up headway becomes a greater proportion of the gap acceptance pattern. For example, if three vehicles needed 4 seconds each to exit from the minor road and the gap in the opposing major road was 4 seconds, the average gap acceptance would be 4. However, if the vehicle at the front of the queue on the minor road needs 4 seconds to exit from the minor road and the two vehicles behind need 2 seconds follow-up headway, the average gap acceptance would be approximately 2.7

seconds assuming bunching occurs on the major road providing gaps of 8 seconds. Further evidence may be needed to demonstrate such circumstances.

d) This analysis does not account for situations that can occur at roundabouts where drivers on an approach anticipates the behaviours of drivers on other approaches resulting in lower gap acceptance and follow-up headway being achieved. Further evidence may be needed to demonstrate such circumstances.

The following is an outline of the steps involved in using **Figure 2** to estimate the capacity of a movement at a priority controlled junction or roundabout.

<u>Step 1: Obtain the Data</u>

The data required includes:

a. The major road opposing flow +/- variance (vph)
b. The minor road approach flow +/- variance (vph)

The traffic data needs to be classified so that it can be converted into passenger car units (pcu). The accuracy of the variance in traffic data will be lower if sample sizes are small. More accurate representations of variance can be obtained from statistical analysis of data collected over a longer time period. In some locations in congested conditions it may be appropriate to sample traffic flows for the same time of day over a number of days for a shorter period of time (e.g. 15 minutes during the peak period for 5 to 10 weekdays). Traffic flows should be assumed to vary by a minimum of 10% on a daily basis to account for fluctuations and seasonal differences.

<u>Step 2: Calculate the Range of Traffic Flows from Variance</u>

Convert both (a) and (b) into pcu/hr. Add and subtract the range of variance to get the higher and lower figures for both. It is recommended that a minimum 10% variance is assumed from counts that are based on observations of up to a few days.

<u>Step 3: Use these values to plot them onto Figure 2 as a box.</u>

<u>Step 4: Interpret the Results</u>

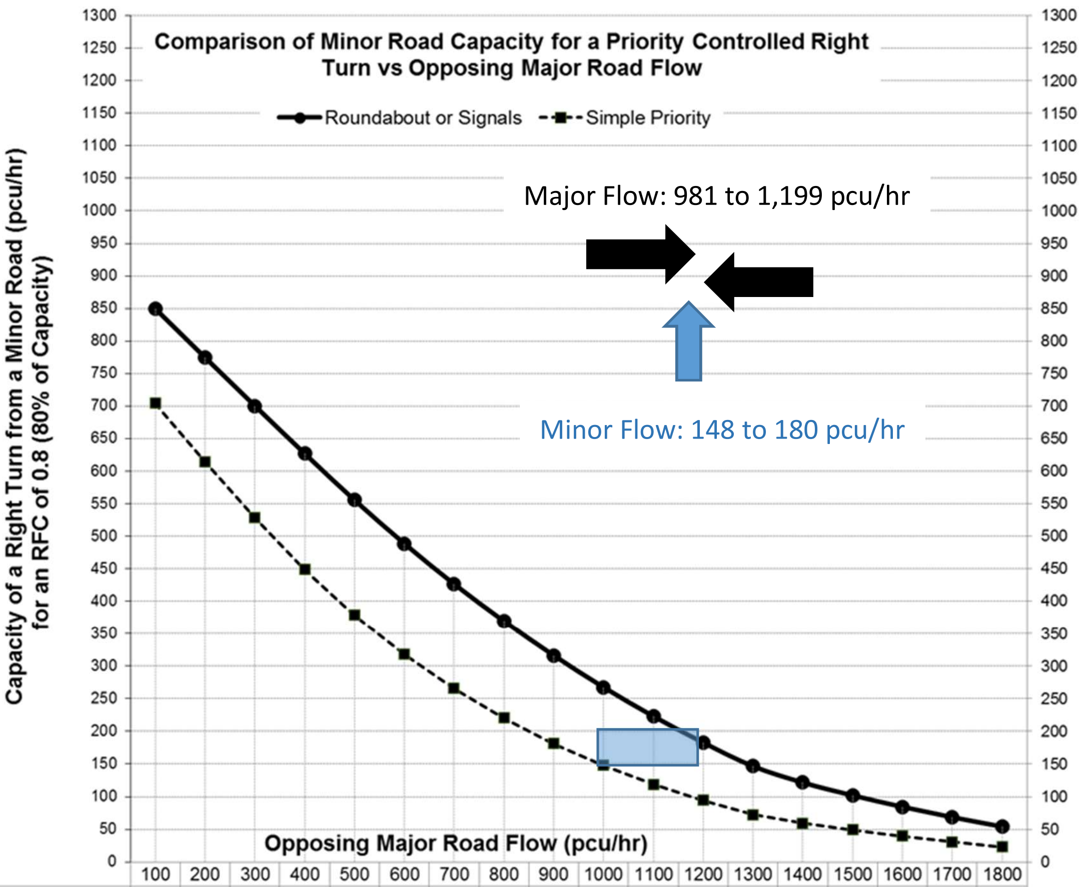
If the box that is plotted on the graph is mostly below the dashed line, it is likely that the simple junction will operate within practical capacity most of the time during the relevant period of the day. If it is between the dashed line and the solid line, it is likely that additional capacity improvement measures may be required. Additional measures to reduce traffic demand may also be required because most of the time the junction will be congested. If most of the plotted box is above the solid line the junction will need a roundabout (if appropriate for the pattern of traffic flows) or traffic signals to improve capacity and/ or demand management to reduce traffic flows.

<u>Worked Example: Priority junction capacity analysis</u>

Step 1: Survey Data
Major flow = 900 cars and vans + 100 hgv's, minor flow = 135 cars and vans + 15 hgv's

Step 2: Range of Traffic Flows (pcu)
Major flow = 900 cars & vans x 1.0 + 100 hgv's x 1.9 = 1,090 pcu +/- 10% = 981 to 1,199 pcu
Minor flow = 135 cars and vans x 1.0 + 15 hgv's x 1.9 = 164pcu +/- 10% = 148 to 180 pcu

Step 3: Plot the results



	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800
Roundabout or Signals	850	775	700	627	556	489	426	369	316	268	223	183	147	122	102	84	69	54
Simple Priority	704	614	528	449	379	318	266	221	181	148	119	94	72	59	49	39	31	23

Figure 3: Example of Plotting the Range of Traffic Flows

It can be seen from the plotted blue box on the graph in **Figure 3** that the simple priority junction arrangement will be congested most of the time. Therefore, junction improvements and/or demand management measures are required.

Methodology for Assessment of Traffic Signal Controlled Junctions

There are a number of software packages available that can model traffic signals. However, it is often difficult to interpret the results without fully understanding all of the parameter settings and assumptions made. The following methodology for assessing the performance of signal controlled junctions is more transparent based on first principles and applies the advice of the manual preliminary assessment method described in the Department for Transport Traffic Advisory Leaflet 01/06, "General Principles of Traffic Control by Light Signals" (TAL01/06). The terminology in this guidance is consistent with TAL01/06 which should be used as a companion reference.

Reference for TAL01/06: https://www.gov.uk/government/collections/traffic-advisory-leaflets

Additional guidance is provided below regarding how to assess junction performance in a realistic way by applying a graphical method. It is expected that more detailed junction assessment will need to be undertaken following this initial assessment using specialist software packages. This graphical approach will also be useful for interpreting the output from the software packages used in the detailed assessment and identifying any unrealistic results which could also indicate errors in the models.

Step 1. Collect the relevant data for the existing junction

The data collected at the junction needs to enable a thorough assessment of the demands (traffic and people movement), performance and safety. The following data needs to be collected as a minimum requirement:

- Classified counts for all movements through the junction by mode (including pedestrians, cyclists, vehicle occupancy and bus patronage);
- Lane utilisation (proportion of a movement demand that uses each lane);
- Proportion of traffic in mixed movements;
- Queue lengths (enabling the calculation of total demand and existing delays);
- Saturation flows;
- Signal timings; and
- Collision history.

The data collected needs be thorough enough to enable the variance in the counts, queues, delays and saturation flows to be understood. Vehicle queue lengths need to be collected for the critical movements as a minimum. The method of measuring queue lengths needs to enable the calculation of existing traffic delays. This information can then be used to calibrate and validate models used for detailed junction assessment.

Lane utilisation needs to be recorded at the same time that the turning counts at the junction are surveyed.

All traffic data needs to be converted to passenger car units (pcu) as described in TAL01/06 for the purpose of the junction performance assessment.

The results of the surveys need to be reported to enable an understanding of the existing numbers of people using the junction by mode.

The movements of pedestrians and cyclists need to be surveyed and reported separately (with a diagram if the desire lines are difficult to describe).

Observations of desire lines used by pedestrians and/or cyclists (such as using unpaved areas or verges or crossing the highway where there is no formal crossing facility) may indicate an opportunity to improve their journey time, accessibility and/or safety through or near the junctions. Such opportunities need to be included in the assessment.

Step 2. Identify the range of traffic flows to use in the assessment

Traffic flows can vary significantly. Sufficient traffic data should be collected to establish design reference flows as described in the Design Manual for Roads and Bridges guidance (DMRB 6.2, TA23/81), Department for Transport WebTAG (TAG Unit M1-2, Jan 2014) and COBA manual. The design reference flows need to be defined as a range that accounts for the variation in flow for the purposes of the preliminary assessment (see page 14 of TAG Unit M1-2, Jan 2014). Traffic flows should be assumed to vary by a minimum of 10% on a daily basis to account for fluctuations and seasonal differences.

For some critical movements, it may be appropriate to establish the variance more accurately but minimise the costs of data collection by surveying a shorter period over a number of days e.g. 15 minutes over 5 days at the same time of day. In such circumstances, an appropriately sized sample will need to be collected that demonstrates and appropriate level of statistical significance.

Traffic queues will form when the demand is higher than the available capacity. Therefore, for the purposes of the assessment the number of vehicles in the queue at the end of the counting period needs to be included in the total traffic demand rather than just the numbers of vehicles crossing the stop line.

Step 3. Identify the range of Saturation Flows to use in the assessment

The saturation flows used in the assessment need to be realistic (see part 3 of TAL01/06). It is more realistic to use a range of saturation flows than a specific average or mean because the variance can be significant. Transport Research Laboratory Report RR067, "The Prediction of Saturation Flows for Road Junctions Controlled by Traffic Signals", by R M Kimber, M McDonald and N B Hounsell, 1986 indicates that standard error of the sample mean was 1.1% and the standard deviation was between 8 and 9% of the mean. Therefore, applying a 10% range will ensure that realistic saturation flows are used in the assessment. The lower value will be the key constraint on the junction performance. Assuming the range of saturation flows are normally distributed, at least 85 percent of the time the saturation flow will be higher than this value (i.e. the cumulative distribution above one standard deviation below the mean is at least 85%).

RR067 indicates that saturation flows reduce by 6% in wet weather conditions. For the period from 1981 to 2010, the Met Office reported that weather was wet in Cardiff for 148.6 days per year on average (approximately 40% of the year). Therefore, the range of upper and lower limits of saturation flows in dry conditions should be reduced by 6% to account for wet conditions and then combined in proportion (60% dry and 40% wet) to establish a realistic range of saturation flows throughout the year.

Met Office Reference: www.metoffice.gov.uk/public/weather/climate/gcjszmp44

For existing signalised junctions, the range of saturation flows need to be measured to achieve a statistically representative sample size. The type of weather conditions that the surveys were conducted in need to be recorded. The range of saturation flow values used in the analysis need to be adjusted to account for the weather conditions to represent a realistic range of saturation flows throughout the year.

If the junction is not already signalised, the range of saturation flows needs to be calculated using RR067. The range of upper and lower saturation flows for each unopposed critical movement can be calculated using the standard errors of the relevant parameters in the research report (a spreadsheet to assist with these calculations is available upon request).

An alternative approach will be required to determine the capacity of critical movements that are opposed during a signal stage (e.g. micro-simulation). Gap acceptance analysis is not likely to be appropriate given the bunching effect of platooned traffic. Site observations will confirm whether gap acceptance analysis is appropriate for existing signalised junctions.

Step 4. Identify the critical movements (phases) in each stage of the cycle

If the saturation flows for each movement during a stage were identical, the critical movements would be those with the highest traffic demand. However, saturation flows vary and there can be circumstances where they are significant enough to make a lower flow movement require a longer green time than the higher flow movement. Therefore, the "y-ratio" method of identifying critical movements according to TAL01/06 needs to be used.

Step 5. Identify the appropriate cycle time

If the junction is already signalised, the cycle time needs to be based on measurement. Typically, traffic signals will operate at their maximum during peak periods but this will vary by site and the level of pedestrian and traffic demands (see **Figure 4** that illustrates the variance in cycle time that can occur). The length of the cycle time will depend on the traffic demand, saturation flows and number of stages. The maximum cycle time is often set to 128 seconds. However, the average cycle time used by SCOOT may be closer to 120 seconds. Some junctions may operate at 60 seconds particularly if there are short lane effects or there are only 2 or 3 stages.

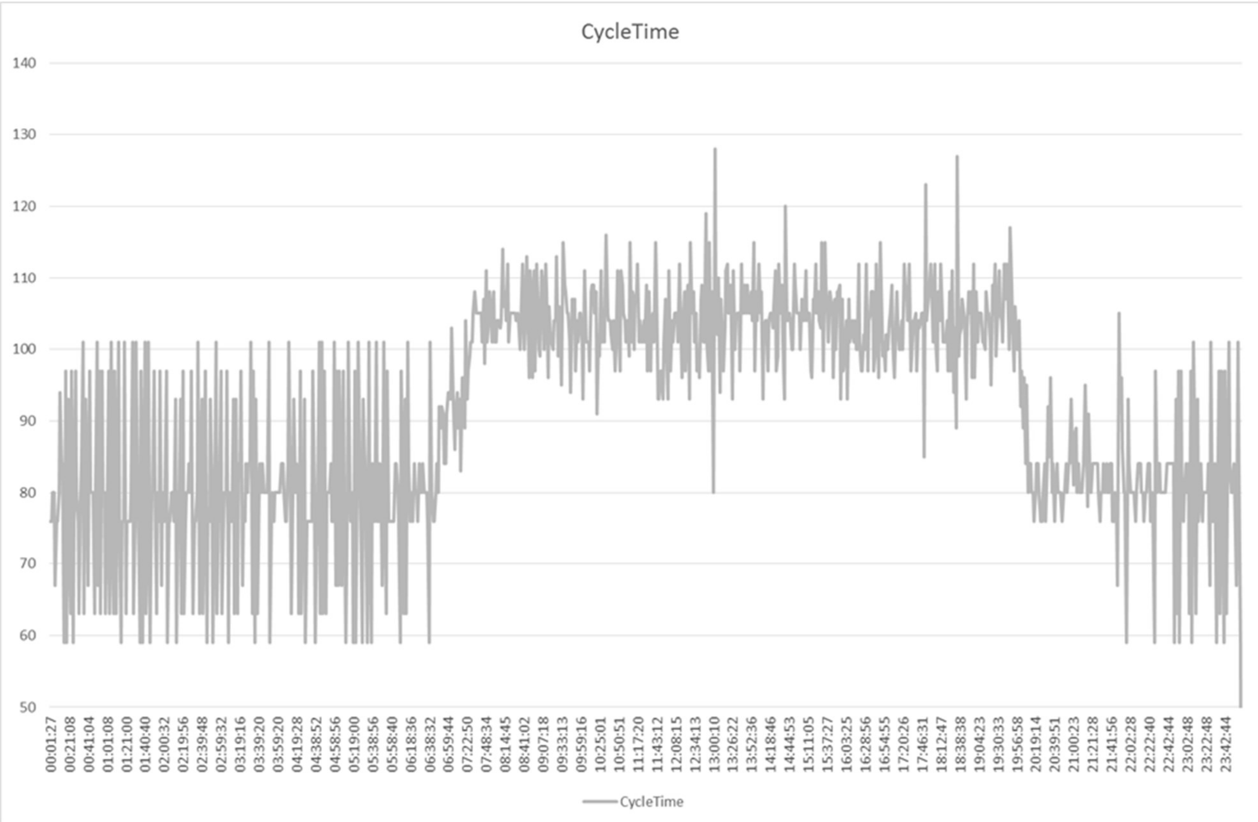


Figure 4: Example of daily variance in cycle time at a signalised junction in Cardiff

The TAL01/06 guidance offers a method for identifying minimum and practical cycle times. However, the method has limitations and does not reflect the variance in cycle times that are assigned by the SCOOT traffic signal control system. It is more realistic that SCOOT uses a range of cycle times to allocate the green time to each stage efficiently according to demand. For the purposes of the preliminary assessment it is recommended that a cycle time of 60 or 120 seconds is used. Local conditions or specific circumstances (e.g. coordination of traffic signals within a signal control region or shorter cycle times to minimise queuing where there are short flares - "short lane effects") may require a different cycle time to be used. Such circumstances will require agreement with the relevant officers in the Council.

Step 6. Calculate the available green time

If the junction is already signalised, the total available green time during the cycle is calculated by subtracting critical pedestrian stages and the sum of the inter-green times for each stage from the cycle time. If it is not already signalised, a range of cycle times may be more appropriate for testing options (e.g. 60 to 120 seconds). Lower cycle times may be more efficient if there are short lane effects (e.g. flared lanes).

Step 7. Proportion the available green time to each stage

The green time to be allocated to each stage needs to be in proportion to the sum of the y-ratios of the critical movements. There may be circumstances where the existing green time does not correlate with what would be expected. The reasons for this difference needs to be identified as there may be network management requirements or signal faults. Such circumstances will need agreement with the Council regarding what green times would be appropriate to model.

The minimum green time to use in the assessment is 7 seconds as described in TAL01/06.

Step 8. Graphically Plot the Range of Traffic Flows, Saturation Flows and Green Times

The range of traffic flows, saturation flows and green times for the critical movements need to be plotted on the graph illustrated in **Figure 5**. The graph has been derived from first principles based on the relationship between movement capacity, cycle time, green time and saturation flow. Given the discussion above regarding the uncertainty of traffic conditions over 80% of capacity, the grid has been adjusted to reflect this capacity threshold. Other grids can be generated for differing cycle times and capacity thresholds. The spreadsheet for deriving alternative timings and capacity thresholds can be made available upon request.

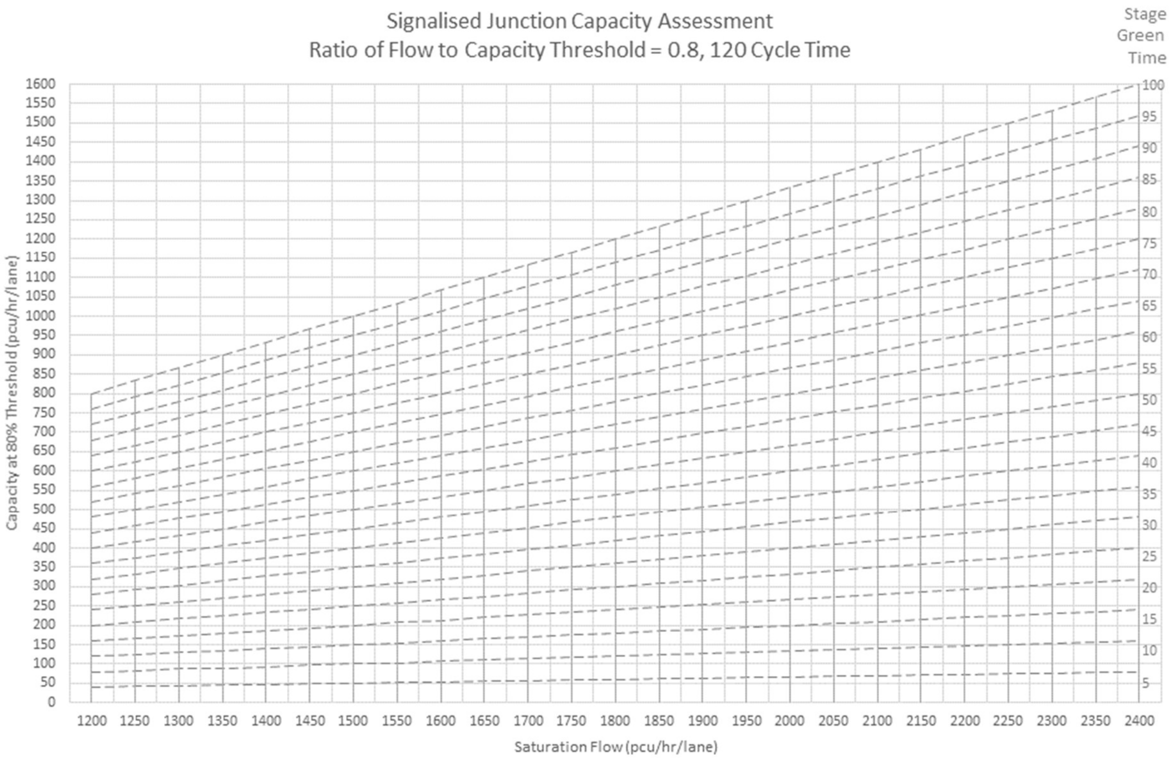


Figure 5: Graph for Assessing the Capacity of Movements at Signalised Junctions

The capacity envelope is drawn on the grid using the range of movement green times observed based on the axis on the right hand side of the graph. This is just a line on the grid if the green time does not vary during the period being assessed drawn from the axis on the right hand side of the grid parallel to the angled lines across to the right hand side of the grid. For example, the capacity envelope is plotted as shown in **Figure 6** if the green time for a movement is observed to vary between 35 and 50 seconds.

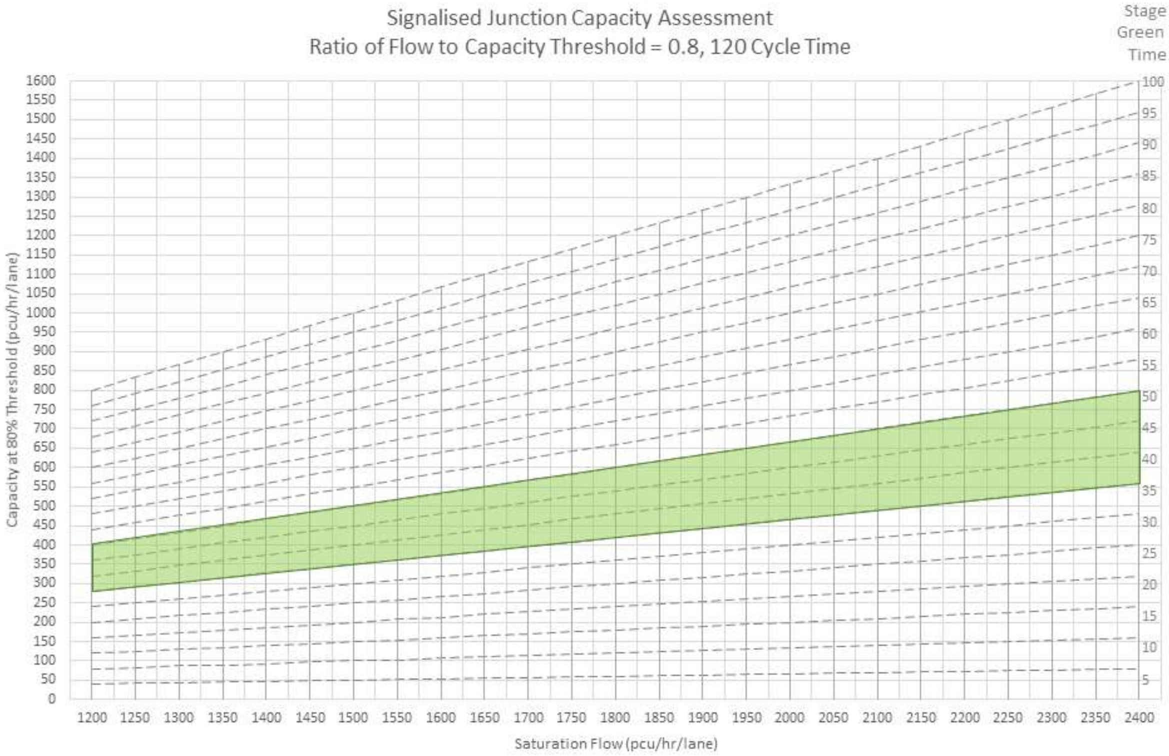


Figure 6: Capacity Envelope for a Green Time (35-50 sec) and Cycle Time (120 sec)

The traffic demand flows and saturations flows are drawn as a box on the grid according to the vertical and horizontal respectively using upper and lower ranges. The values should vary no less than 10%. For example, the box is plotted as shown in **Figure 7** if the traffic demand flows for a movement is observed to vary between 500 and 600 pcu/hr and saturation flows vary between 1,700 and 1,800 pcu/hr/lane.

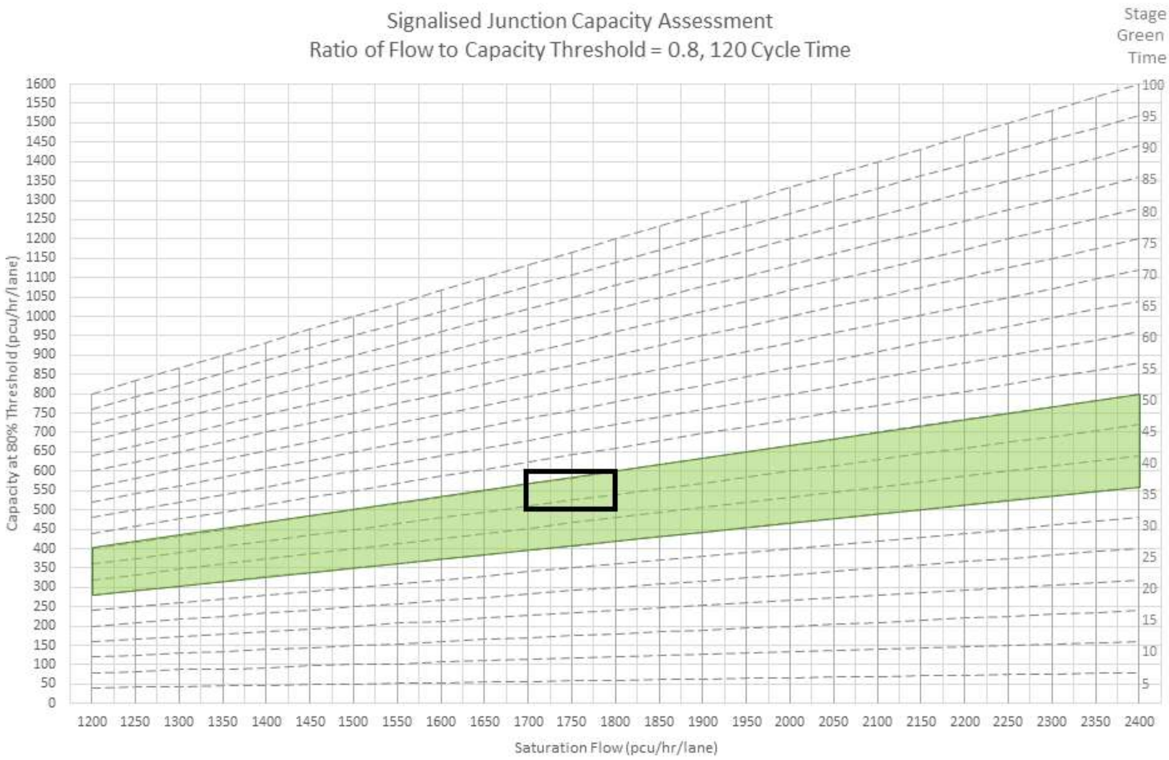


Figure 7: Box Plot of Traffic Demand Flows and Saturation Flows of a Movement

Step 9: Interpret the Results

For the example illustrated in Figure 7, most of the box is below the upper limit of the capacity envelope suggesting that for most of the time the movement operates within 80% of the available capacity. However, the movement would always be congested during the same period if the green time was fixed at 40 seconds.

Scope of Using the Graphical Approach for Signalised Junction Analysis

Separate graphs can be used for different movements if the grid becomes cluttered by overlaying them. If they are overlaid, they would need to be appropriately colour coded and referenced to avoid confusion.

Short lane effects may be accounted for to some extent using these graphs by adjusting the saturation flows due to the underutilisation of the relevant lanes for the movement. However, other methods may be better able to provide the detail needed to understand the interactions (e.g. micro-simulation).

Coordination with Telematics

The assessment of signalised junctions will require extensive coordination with the Telematics team in order to obtain the necessary junction plans, controller information, signal timing information and verify that any future proposed signal staging can be accommodated within UTC in practice.

Collision Analysis

The junction assessment will need to include collision analysis using COBA predictions. This information will identify if there are any safety improvements that can be made to the junction.

Other considerations

The following is a list of issues and considerations that could help inform the junction assessment to understand the impacts of development and/or identify appropriate mitigation measures:

- Observations of interactions/local behaviours of users;
- Pattern of traffic arrivals on the approaches due to upstream platooning effects;
- Route choices (travel time comparisons, network capacity remote from the junction/gating effects, pinch points);
- Public transport (e.g. movements to and from bus stops, lane changing and bus priority);
- Access for emergency services, taxis and goods vehicles;
- Trip Growth (traffic forecasts, mitigating measures to encourage mode shift, people moving capacity, location, proximity and access to jobs, shopping, education, leisure, and community facilities); and
- Geometry or local conditions that may impact on safety or capacity of the junction (e.g. visibility, gradients, signage, lane widths, radii, vehicle tracking, street furniture, landscaping, lane markings, flares/merges/diverges, upstream/downstream conditions, lane length/queuing capacity, pedestrian crossings, driveways/side road access, parking, laybys, bus stops, loading, disabled parking).

This is not an exhaustive list and there may be other relevant matters that need to be considered.

Walking, cycling and public transport need to be prioritised as attractive alternatives to travelling by car irrespective of the results of the junction assessment.

Note: References above are correct as of the time of writing but may be subject to change by the organisation it is sourced from.

Using Micro-Simulation Models

Since simulation models describe a dynamic process in statistical and pictorial formats, they can be used to analyse a wide range of applications in the following circumstances where:

- deterministic models (LinSig, Transyt etc.) are not able to accurately represent the complexity of a situation;
- congested network of closely linked junctions;
- the profile of arriving traffic over the hour is particularly exaggerated, and extensive queuing or blocking-back is likely to be a frequent occurrence;
- short-lane effects have a significant impact on the capacity available; or
- There is a need to view vehicle animation displays to gain an understanding of how the system is behaving in order to explain why the resulting statistics were produced.