Guidelines for the Analysis of Roundabout Metering Signals

Road and Traffic Engineering Branch

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1. INTRODUCTION

These guidelines have been developed for use by traffic engineering and road safety practitioners to assess whether an existing roundabout is suitable for the installation of traffic signals on any particular leg (or legs) of a roundabout in order to increase overall capacity. Equally, they should be used by the approving authority to determine the robustness of the analysis methodology and hence the appropriateness of the proposed treatment.

It is widely recognised that roundabouts provide significant safety benefits for vehicular traffic by slowing down through traffic, reducing the number of conflict points and reducing the angle of potential conflict. From a “Safe System” point of view, the roundabout is often viewed as the ideal at-grade intersection option. Consequently, intersection options which utilise the inherent safety benefits of a roundabout, but which at the same time provide sufficient operational capacity should be actively investigated.

As a result, this document may also be used as a guideline for assessing whether an existing priority-controlled (Stop or Give Way) or signalised intersection may be converted to a roundabout with metering signals, or indeed if a new intersection is a suitable candidate, although in these cases assumptions regarding the lane usage in the case of multi-lane roundabouts will need to be justified since it is not possible to develop a calibrated base case roundabout model.

1.1 Purpose

The purpose of this guideline is to document the process that should be followed in assessing whether an existing roundabout is a suitable candidate for the installation of traffic signals on any particular leg (or legs) of a roundabout in order to increase capacity on another leg / other legs, and hence, overall capacity. This form of traffic control is referred to as “roundabouts with metering signals”. In WA, the latest version of SIDRA INTERSECTION is used for roundabout analysis, including roundabouts with metering signals. However, if observations during the site visit indicate that adjacent intersections or driveways have a direct impact on the performance of the proposed signalised roundabout, other softwares and traffic analysis methods (eg. microsimulation) may be considered to assess the suitability of metering signals on any particular leg of a roundabout.

It should be noted that since the traffic signals are installed a significant distance upstream of the roundabout Give Way line, the traffic on the signalised approach is still subject to Roundabout Give Way control. This should be differentiated from “direct signal controlled roundabouts” where most or all approaches are subject to signal control at the junction of the roundabout entry with the circulating roadway. The circulating roadway is also subject to signal control. This form of control is more suited to large roundabouts where storage space is available for traffic to stop within the circulating roadway between the departure and entry legs of the roundabout (VicRoads, 2005). These guidelines are confined to assessing the suitability of roundabouts for control with metering signals only. For guidance on Signal Controlled Roundabouts, readers are referred to (Department for Transport, 2009).
1.2 Background

The following comment related to the installation of metering signals at roundabouts is taken from (VicRoads, 2005):

Roundabout performance is sensitive to unbalanced traffic flows. This may occur where the entering traffic from a dominant leg prevents traffic from the adjacent or another affected approach to the left of the dominant flow from entering the roundabout. This situation results in excessive queues and delays in the affected approach.

The dominant traffic flow at a roundabout may be either:

- A high uninterrupted traffic flow.
- A low but consistent flow from a minor approach that takes priority over a major flow.

This deficiency can usually be addressed by the provision of part-time metering signals that regulate the dominant flow and provide gaps in the circulating traffic. This enables traffic from the affected approach to enter the roundabout. The metering signals are activated by queue loops in the affected approach that is being delayed. Metering signals provide the following benefits:

- Management of the peak flows to provide appropriate priority for a major movement.
- Provide better balances of queues and delays between approaches.
- They can extend the life of a roundabout rather than require its replacement.

Metering signals are generally considered as a ‘short term fix’ stage when problems develop due to changing traffic flows over time. However, at some locations they could be considered as part of a new roundabout control to proactively manage the traffic. This form of control may avoid the need for installation of intersection traffic signals and retain safety and operational benefits at times of lower flow at the roundabout.

Metering signals use 2 aspect (yellow/red) lanterns set back on the approach to control the traffic. When traffic is released it enters the roundabout under usual ‘give way’ priority conditions in a self regulating manner.

The provision of metering signals can also be beneficial for pedestrians, as the metering system can be combined with pedestrian signals to provide a pedestrian facility across a leg (or legs) of a roundabout. In these installations the signals would also stop traffic leaving the roundabout, so queuing of traffic may extend back into the circulating roadway. As the crossing distance and times are usually relatively short, this queuing is generally not a significant operational problem, depending on the frequency of operation. Subject to the pedestrian ‘desire line’, at some sites it may be possible to locate the crossing further back from the circulating roadway so that storage on the roundabout exit is maximised.
Figure 1 over the page illustrates typical arrangements for roundabout metering signals. The following definitions from (Akcelik, 2005) apply:

The term “metered approach” is used for the approach stopped by red signals (approach causing problems for a downstream approach), and the term “controlling approach” is used for the approach with the queue detector, which is the approach helped by metering signals (approach experiencing problems due to a relatively heavy directional flow from the metered approach).

The operation of roundabout metering signals is described in (Austroads, 2003):

When the queue on the controlling approach extends back to the queue detector, the signals on the metered approach operate so as to create a gap in the circulating flow. This helps the controlling approach traffic to enter the roundabout. When the red display is terminated on the metered approach, the roundabout reverts to normal operation.

The introduction and duration of the red signal on the metered approach is determined by the controlling approach traffic. The duration of the blank signal is determined according to a minimum blank time requirement, or extended by the metered approach traffic if detectors are used on that approach.
Figure 1: Typical Arrangement for Roundabout Metering Signals

Source: (Akcelik, 2005)
2. DATA REQUIREMENTS

The analysis process required to justify the installation of metering signals must be robust. A prerequisite for this is accurate, comprehensive, current traffic data as well as sound forecast traffic data.

Most intersection traffic counts only need to record the direction of travel of each vehicle after passing the Stop / Give Way line. However, critical to the operation of multi-lane roundabouts is not only the exit direction at the Give Way line, but also the lane usage. For a given circulating flow, it has been shown that different capacities and levels of performance may be estimated depending on the conditions of the component streams (Akcelik, 2005), as illustrated in Figure 2.

![Figure 2: The Effect of the Origin – Destination Pattern on Capacity](source)

Since lane usage as well as destination needs to be recorded for each vehicle entering the roundabout, the most common method used to conduct a traffic count is by a video survey with the relevant information extracted afterwards. This has a number of added advantages:

- Minimises the number of staff required on site.
- Provides a permanent record, which may be accessed later to verify data, should the need arise.
- Provides a continuous record of queue lengths (in terms of number of vehicles) for each lane.
It is easier to classify vehicles using freeze-frame video footage after the fact than to categorise vehicles in situ. Edited highlights can pinpoint any unusual operational needs or safety deficiencies.

In order to achieve complete coverage, it is often necessary, particularly with large roundabouts, to use more than one camera at a time (preferable), or to count the traffic on the different approaches on successive days.

2.1 Current Traffic Data

As a minimum, the following current traffic data is required to be collected in order to develop and calibrate a base case model of the existing roundabout:

1. Undertake a one day video survey between 7.00 a.m. to 7.00 p.m. The video survey must be carried out on a fine weather day during the school term and not during a week with a public holiday. The selected day is to be representative of a ‘typical’ day (Tuesday, Wednesday or Thursday) void of any local event, incident, celebration or function.
2. The traffic counts should be at 15 minute increments per movement per lane, with vehicles broken into the Main Roads standard 12 categories.
3. The identification of maximum vehicle queue lengths (in number of vehicles) during both the a.m. (between 7:00 and 9:00) and p.m. (between 16:00 and 19:00) peak periods (at 3 minute intervals) on all legs and all lanes. In addition, if a “mid-day” peak has been identified (period of time greater than 15 minutes during which significant congestion occurs), maximum queue lengths should also be identified during this period. Ideally queue lengths are to be done on the same day, however, if this is not possible they should be done on the same day of the week, preferably the following week.

It should be noted that manual pick up may be required where queues extend beyond camera range.

2.2 Video Survey Output Data

On completion of the video survey the following outputs are required:

2.2.1 Video Survey Component

- Video Surveys provided on DVD’s;
- An edited “Highlights DVD” (showing all significant events that occurred that impact on operations or safety);
- A detailed report giving all traffic counts in 15 minute increments per movement per lane including pedestrian and cyclist activities, plus any significant event(s). The percentage heavy vehicles (Class 3 and above) shall also be given for each movement.
- The report should also extract the a.m. (between 7:00 and 9:00) and p.m. (between 16:00 and 19:00) peak hour traffic giving all traffic counts in 15 minute increments per movement per lane including pedestrian and cyclist activities. The percentage heavy vehicles (Class 3 and above) shall also be given for each movement.
Typical “off-peak” traffic volumes (between 9:00 and 16:00) should be determined by averaging the hourly traffic volumes during this time, excluding any “mid-day” peak traffic, as indicated below.

Should the video survey highlight a period of the day, other than either of the peak periods, where significant congestion occurs for a period greater than 15 minutes, then this “mid-day” peak should also be extracted. For example, such a peak may occur where a number of schools are in close proximity to one another.

2.2.2 Vehicle Queue Component

- Video Surveys provided on DVD’s;
- A edited “Highlights DVD” (showing all significant events that occurred);
- A report detailing Vehicle Queue lengths for both the a.m. and p.m. peak periods (at 3 minute intervals) on all legs and all lanes of the intersection, and any “mid-day” peak periods identified.

2.3 Forecast Traffic Data

For any proposed roundabout metering, in addition to evaluating the performance of the unsignalised and signalised roundabout using current traffic data, it is essential that the proposal be tested using forecast traffic data. Main Roads requires a minimum 10-year forecast horizon. This should be obtained from the Main Roads ROM model (Traffic Modelling Section of the Asset and Network Information Branch) as follows:

2.3.1 Intersections included in the ROM Model

For intersections included in the ROM model, a “theoretical base year” model for all turning movements at the intersection should be developed for the same year as the traffic count data by interpolating between the 2011 and 2021 ROM models. A “theoretical 10-year horizon” model should be developed by interpolating between the 2021 and 2031 models.

For each movement, the percentage increase (or decrease) between the “theoretical base year” model and the “theoretical 10-year horizon” model is found and is applied to the current traffic count data to get the forecast traffic volumes. Unless knowledge to the contrary indicates that it is likely to be otherwise, the percentage heavy vehicles and peak hour factors for the traffic count data should be used for the 10-year forecast traffic.

2.3.2 Intersections not included in the ROM Model

For smaller intersections that may not be specifically represented in the ROM model it is necessary to select a minimum of two adjacent modelled intersections and develop “theoretical base year” models and “theoretical 10-year horizon” models for each of the two intersections. The percentage increase for each movement is then calculated and the average percentage increase for all movements should be applied to all movement count data. Again, unless knowledge to the contrary indicates that it is likely to be otherwise, the percentage heavy vehicles and peak hour factors for the traffic count data should be used for the 10-year forecast traffic.
3. ANALYSIS

The existing roundabout is required to be analysed using the current traffic data to establish “Base Year” conditions. Any proposed improvements to the roundabout shall be analysed using both the “Base Year” traffic as well as the “10-Year Horizon traffic”. A proposal will only be considered acceptable if the Degree of Saturation (DOS) ≤ 0.85 in the horizon year. As noted in Section 1.1, the analysis should include other upstream or downstream intersections if queues from the roundabout impact on the adjacent intersections, or vice versa.

For single lane roundabouts a methodology has been developed comparing the volume on the controlling approach with the circulating flow in front of the controlling approach to check whether there would be any benefit from installing metering signals (Natalizio, 2005). This is illustrated in Figure 3 and described below from the same source:

The results indicate that metering signals are required at a single lane roundabout when the combined volumes of traffic flow on the delayed (controlling) approach together with the circulating flow in front of the delayed (controlling) approach is between 1300 and 1400 vehicles per hour. The benefits of metering signals begin to decline once the combined volumes of traffic flow on the delayed (controlling) approach together with the circulating flow in front of the delayed (controlling) approach is between 1550 and 1650 vehicles per hour.

Based on the above, it is recommended that for single lane roundabouts the relevant point on Figure 3 be found. If this point falls outside of the green area then it is suggested that alternative means to increase roundabout capacity be explored, rather than installing roundabout metering signals.
3.1 Existing Roundabout

3.1.1 Peak Hour Modelling

The main purposes of modelling the roundabout using current a.m. and p.m. traffic data (and any “mid-day” peak, if applicable) is to (a) develop a calibrated base model, which gives a snapshot of current operating performance and which (b) can then be used with confidence to model alternative, future proposals.

For existing multi-lane roundabouts, or single lane roundabouts that are likely to benefit from the installation of metering signals (based on the application of Figure 3), as a minimum, the existing roundabout should be modelled using the latest version of SIDRA INTERSECTION for both the a.m. and p.m. peak periods. It should be noted that the a.m. peak period is taken to be that period between 7:00 and 9:00 for which the combined totals of all the traffic volumes on all approaches for four successive 15-min periods is the maximum. Similarly, the p.m. peak period is found for the period 16:00 to 19:00. The peak flow factor (expressed as a %) for each movement is calculated based on the following formula:

\[ PFF = 100 \times \frac{\text{Total Peak Hour Volume}}{\text{(Peak 15-min Volume x 4)}} \]
The parameters “Unit Time for Volumes” and “Peak Flow Period” in the “Intersection” data input screen should be set to 60 and 15 minutes respectively.

The models should be calibrated by first adjusting the Environment Factor in an iterative manner until the calculated capacity approximates the observed capacity and then the Lane Utilisation Ratio is used to modify the lane flows (Akcelik & Associates, 2010). The modelled 95%-ile queues on each approach should also be checked against the maximum observed queues during the peak period. The number of modelled vehicles should be ± 20% of the observed number of queued vehicles.

The Degree of Saturation (DOS) gives an indication of the available reserve capacity of the roundabout. A DOS of 1.0 indicates that the roundabout is at capacity. A DOS > 1.0 indicates that the demand traffic volumes exceed the roundabout capacity. In WA, roundabouts should operate at a DOS ≤ 0.85.

It is assumed that most of the roundabouts (or intersections) analysed following the process outlined in this document would be exhibiting poor performance and are likely to have a DOS close to, or greater than 1.0, during the peak periods.

3.1.2 Off-peak Modelling

The roundabout should also be analysed using the “off-peak” traffic volumes. For this analysis the parameters “Unit Time for Volumes” and “Peak Flow Period” in the “Intersection” data input screen should both be set to 60 minutes. The Peak Flow Factor should be set to 100% in the “Volumes” data input screen.

The purpose of this analysis is to get a comparison between the “off-peak” and peak period performance of the roundabout. If there is a marked difference in performance between the “off-peak” and peak periods, then this lends weight to the implementation of a time-based solution, i.e. roundabout metering signals, as opposed to a permanent solution involving geometric improvements.

3.1.3 Modelling Roundabouts within a Network of Closely Spaced Signalised Intersections

Roundabout metering signals work by providing a break in the flow of traffic on the metered approach, which enables traffic on the controlling approach to pick a gap and enter the intersection. In networks of closely spaced intersections, particularly where signalised intersections are close to roundabouts, the timing of the adjacent signalised intersections can have a marked effect on a roundabout’s performance.

Although the SIDRA INTERSECTION program was originally developed for analysing isolated intersections, current versions allow for the analysis of networks consisting of up to 20 intersections. However, other microsimulation software may also be used provided the same parameters (DOS and 95%-ile queue length) are reported and it is demonstrated that the base case is suitably calibrated.
3.2 Means of Improving the Performance of Roundabouts without Installing Signals

Currently, there is only one roundabout with metering signals in WA (Point Lewis rotary). As expected, the part-time operation of the signals (generally only required during peak periods) initially lead to some driver confusion and error, although there were no serious implications. However, in any new installation, this is still a concern. Added to this are the ongoing increased maintenance costs for the traffic signals. Consequently, the installation of roundabout metering signals should not be considered as the first option. There are a number of means of improving the performance of the roundabout that should be considered first, before considering installing roundabout metering signals (Austroads, 1993):

- Addition of continuous (left-turn slip) lanes
- Flaring (tapering) of the entries
- Adjustments to signal timings on adjacent intersections
- Signalised Pelican crossing.

3.2.1 Addition of continuous (left-turn) slip lanes

Where there is a heavy left-turn movement and sufficient land is available, it may be advantageous to construct a continuous left-turn slip lane. The main advantage of this is to remove the left-turn traffic volumes from the approach and circulating traffic, effectively offering more opportunity for traffic to enter at the downstream legs. Care must be taken to ensure that the left-turning traffic does not impact on the circulating or exiting traffic. For Higher order roads this is best achieved by fully separating the left-turn traffic from the circulating traffic by means of a splitter island and merging the left-turn traffic onto the adjacent exiting leg by means of an added lane. For lower order roads this could be easily addressed by introducing give way signs.

3.2.2 Flaring (tapering) of the entries

Effectively this involves the addition of a short lane on the roundabout approach as well as the construction of an additional circulating lane on at least a portion of the roundabout. Depending on traffic movements, it may also be necessary to construct an additional short lane on the departure leg of the roundabout. Considerable care needs to be taken with the design of the lane markings around the roundabout to ensure that no weaving or lane changes are necessary within the circulating part of the roundabout. Spiral markings have been used successfully in other states in Australia, in New Zealand and in the U.K. to overcome this, but have yet to be fully accepted in WA. Preliminary guidance on the use of spiral markings may be obtained in Commentary 1 of the document Roundabouts & Traffic Signals: Guidelines for the Selection of Intersection Control on the Main Roads website. The Traffic Engineering Standards Manager at Main Roads should be consulted on any proposal to use these markings.
3.2.3 Adjustments to Timing Signals on Adjacent Intersections & Signalised Pelican Crossing

It has already been mentioned that in networks of closely spaced intersections, particularly where signalised intersections are close to roundabouts, the timing of the adjacent signalised intersections can have a similar marked effect on a roundabout's performance. By judiciously adjusting the timing of the adjacent signals, it may be possible to provide sufficient time to the traffic on the controlling leg of the roundabout to enable the roundabout to function effectively.

Similarly, the installation of a signalised pedestrian crossing on what would be the metered approach if roundabout metering signals were to be implemented, may act as a de facto metering signal. It should be noted that this is only likely to be effective if there is a sufficiently high pedestrian demand – the Main Roads warrants for the installation of a signalised pedestrian crossing should be met. Where pedestrian operated signals are used for metering the following conditions apply (Austroads, 2013):

- The crossing must be located a sufficient distance from the exit, and on divided roads pedestrian movement may have to be staged to ensure that traffic queues will not unduly affect the operation of the roundabout. Pedestrian desire lines and the provision of pedestrian fencing should be considered to encourage pedestrians to use the crossing.
- The crossing should be located a sufficient distance from the holding line and roundabout regulatory signs to avoid driver confusion (usually greater than that required for purpose built signals).
- Appropriate signage should be erected to inform drivers that the pedestrian signals may change for metering purposes (i.e. signals not faulty).

It is not easy to model the effect of changes in adjacent signal timings or the installation of a signalised pedestrian crossing on an adjacent roundabout's performance. It may be necessary to develop a micro simulation model for these purposes. Although this may be time-consuming, the costs are likely to be significantly less than any infrastructure improvements. The Main Roads’ Transport Modelling Manager and Traffic Systems Operations Coordinator should be consulted prior to embarking on any modelling exercise of this nature.

3.3 Means of Improving the Performance of Roundabouts by Installing Signals

3.3.1 Initial Appraisals

Once all the methods discussed in Section 3.1 have been explored, and (for single lane roundabouts) provided the flow conditions satisfy the criteria for “Benefits from Metering Signals” in Figure 3, the option of roundabout metering signals may be considered. It should be noted that the final choice of improvement method should be subject to a comprehensive economic analysis.
For any roundabout, there is likely to be little benefit from metering traffic on an approach that is close to capacity (high DOS on the approach) since by restricting the time available, the approach capacity will be reduced and the DOS will increase. Through simulations using SIDRA, it has been found (Natalizio, 2005) that, for single lane roundabouts, if the metered approach has a DOS less than 0.6, it is likely to maintain good operating conditions (DOS < 0.85) when metering signals are introduced.

Although no similar research has been conducted on multi-lane roundabouts, and the effects are complicated by the origin-destination pattern, as illustrated in Figure 2, intuitively a similar relationship is likely to exist for multi-lane roundabouts. What can be stated with certainty is that if the metered approach has a DOS ≥ 0.85, the installation of roundabout metering signals should not be considered.

3.3.2 Modelling Roundabouts with Metering Signals

The installation of Roundabout Metering Signals should be modelled using the SIDRA INTERSECTION program, although other microsimulation packages may be used, provided the package reports the required performance parameters. The “Stop Line Setback Distance” on the metered approach and the “Queue Detector Setback Distance” on the controlling approach should be within the range indicated in Figure 1. Due consideration should be taken of any intersections or major driveways on the controlling and metered approaches, which may be blocked by queues.

The proposed operation of the roundabout metering signals shall be discussed with the Main Roads’ Traffic Systems Operations Coordinator, based at the Traffic Operations Centre.
4. REPORTING

In order to justify the installation of roundabout metering signals, the Consultant shall prepare a report containing the following information:

- Introduction
- Background
- Traffic Volumes¹
  - Existing Traffic: Summary of Peak Hour Volumes Used
  - Forecast Traffic: Methodology used to estimate 10-year horizon traffic and Summary of Peak Hour Traffic Volumes
- Model of Existing Roundabout
  - Calibration of saturation flow rate, lane flows and queue lengths
  - Existing roundabout performance, including tables highlighting the following for each movement and the intersection as a whole:
    i. Degree of Saturation
    ii. Average Delay
    iii. Level of Service
    iv. Queue Length
    v. Number of vehicles per queue length.
- Model of Proposed Roundabout(s), including all tables as indicated above.
- Discussion on all observations of the analysis results and outcomes.
- Conclusions and Recommendations (including dimensions of turn pockets and proposed Roundabout Metering operating parameters).

¹ This section should basically contain a summary of output from the Traffic Video Survey Report
This guideline shall be applied in consideration with other available design guidelines and standard drawings applicable to the scope of project for roundabout metering.

Design guidelines to be considered when designing for roundabout metering are:

- Design Guidelines for Roundabouts.

Drawing no. 201131-0048 gives details of traffic signals, ITS, lighting and electrical requirements for roundabout metering.

Drawing no. 201031-0171 gives details of signs and pavement marking requirements for roundabout metering.

The preparation of design drawings shall be in accordance with Main Road's Design and Drawing Presentation Guideline.
6. REFERENCES


