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# Analysis of Roundabout Metering Signals

**RAHMI AKÇELIK**
*Director*
*Akcelik & Associates Pty Ltd*
*rahmi.akcelik@sidrasolutions.com*

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## ABSTRACT

There are many examples of roundabouts with unbalanced flow patterns in Australia, where part-time roundabout metering signals are used to create gaps in the circulating stream in order to solve the problem of excessive queuing and delays at approaches affected by highly directional flows. The use of metering signals is a cost-effective measure to avoid the need for a fully-signalized intersection treatment. A case study is presented comparing a roundabout with and without metering signals in terms of operating cost, fuel consumption and pollutant emissions as well as delay and degree of saturation.

## 1 Introduction

This paper presents a case study comparing a roundabout with and without metering signals in terms of operating cost, fuel consumption and pollutant emissions as well as delay and degree of saturation. The analyses were carried out using the SIDRA INTERSECTION software package (Akcelik & Associates 2006).

The method to model operating cost, fuel consumption and emissions (CO2, CO, HC, NOx) in the SIDRA INTERSECTION software (also known as SIDRA or aaSIDRA) using a four-mode elemental model and in the SIDRA TRIP software (previously known as aaMotion) using microsimulation was described in some detail in Akçelik and Besley (2003).

The method used for analysis of roundabout metering signals is described in some detail in this paper.

## 2 Roundabout Metering Signals

There are many examples of roundabouts with unbalanced flow patterns in Australia, where roundabout metering signals are used to create gaps in the circulating stream in order to solve the problem of excessive queuing and delays at approaches affected by highly directional flows (Akçelik 2003, 2004, 2005a, 2005b; Akçelik, Chung and Besley 1996, 1997). The use of metering signals is a cost-effective measure to avoid the need for a fully-signalized intersection treatment.

Roundabout metering signals are often installed on selected roundabout approaches and used on a part-time basis since they are required only when heavy demand conditions occur during peak periods. The Australian roundabout and traffic signal guides acknowledge the problem and discuss the use of metering signals (Austroads 1993, 2003). The signalized roundabout solution has also been used extensively in the UK (e.g. Huddart 1983, Lines and Crabtree 1988, Shawaly, Li and Ashworth 1991, Hallworth 1992).

Table 1 summarizes design and control parameters used for metering signals at various roundabouts in Melbourne, Australia. More detailed information about roundabout metering signals can be found in (Akçelik 2005b).

Figures 1 and 2 show typical arrangements for roundabout metering signals and an example from Melbourne, Australia (the case study used in this paper). 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. When the queue on the controlling approach extends back to the queue detector, the signals on the metered approach display red (subject to signal timing constraints) 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.

**Table 1 - Typical design and control parameters used for roundabout metering signals**

| ***Metered approach*** | |
|---|---|
| Signal stop-line setback distance | 14 -24 m (46 - 79 ft) |
| Detector setback distance (if detector is used) | 2.5 m (8 ft) |
| Loop length (if detector is used) | 4.5 m (15 ft) |
| Minimum blank time setting | 20 - 50 s |
| Maximum blank extension time settings | 30 s |
| Blank signal gap setting | 3.5 s |
| Yellow time | 4.0 s |
| All-red time | 1.0 - 2.0 s |
| ***Controlling approach*** | |
| Queue detector setback distance | 50 - 120 m (164 - 394 ft) |
| Loop length for the queue detector | 4.5 m (15 ft) |
| Minimum red time setting | 10 - 20 s |
| Maximum red extension time settings | 20 - 60 s |
| Queue detector gap setting | 3.0 - 3.5 s |
| Queue detector occupancy setting: $t_{oq}$ | 4.0 - 5.0 s |
| Yellow time: $t_{yR}$ | 3.0 - 4.0 s |
| All-red time: $t_{arR}$ | 1.0 - 2.0 s |

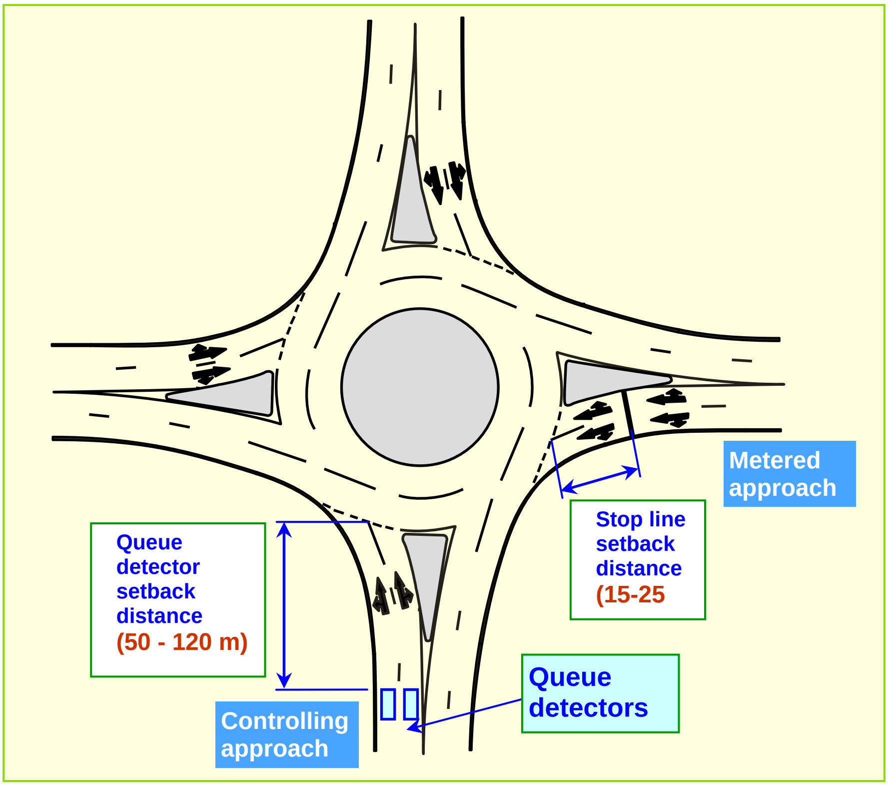

**Figure 1 - Typical arrangements for roundabout metering signals**

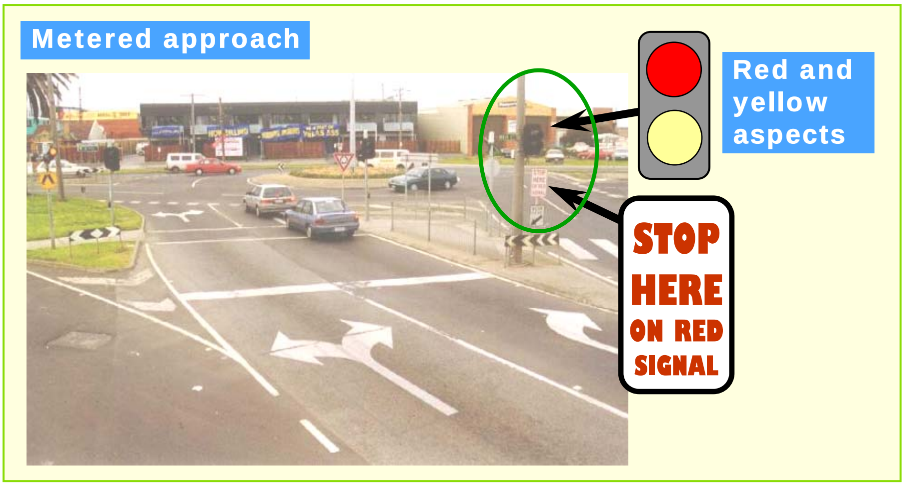

**Figure 2 - A roundabout metering signals example from Melbourne, Australia (the case study presented in this paper)**

# 3 Case Study

A revised version of the method described in (Akçelik 2005b) for the analysis of roundabout capacity and performance characteristics with metering signals is applied to the intersection of Nepean Highway and McDonald Street in Melbourne, Australia. In this case, the metered approach is McDonald Street and the controlling approach is Nepean Highway Southeast.

The following analysis method is used for modelling the effects of metering signals, which involve estimating operating characteristics for several traffic operation scenarios using SIDRA.

(i) No Metering Signals: This is the base case which represents the normal roundabout operation without metering signals. The roundabout geometry and the am peak 30-min volumes (given as hourly flow rates) used in the analysis are shown in Figure 3.

The proportion of time RED signals can be displayed on the metered approach (McDonald St) without deteriorating its performance to unacceptable levels depends on the degree of saturation of the metered approach under base case conditions. The proportion of time BLANK signals are displayed is calculated from $g/c = x_M / x_p$ and the proportion of time RED signals are displayed is calculated from $1 - g/c$, where g is the BLANK time, c is the cycle time (BLANK time plus RED time), $x_M$ is the degree of saturation of the metered approach in scenario (i) and $x_p$ is the practical (target) degree of saturation. In this example, $x_M = 0.326$ (low value) and using $x_p = 0.85$, $g / c = 0.38$ is found, and it is decided to use $g / c = 0.40$ (i.e. to display BLANK signals 40 per cent of the time and RED signals 60 per cent of the time).

(ii) RED Signals: This represents roundabout operation with metering signals when the metering signals display RED, i.e. the metered approach (McDonald St) traffic is stopped and the rest of roundabout operates according to normal roundabout rules as shown in Figure 4. For this purpose, the metered approach is specified as a one-way exit road.

(iii) BLANK Signals: This represents roundabout operation with metering signals when the metering signals display BLANK signals on the metered approach (McDonald St). The roundabout geometry specification is as in the base case. The flow rate from the metered approach is increased to the platooned departure flow rate due to the effect of queuing during red signals as shown in Figure 5. The platooned flow rate is the average flow rate crossing the signal stop line during the BLANK period, calculated from $q_d = q_a / (g / c)$, where g is the BLANK time and c is the cycle time (BLANK time plus RED time) and $q_a$ is the arrival (demand) flow rate. The platooned flow rate for the metered approach in this case is determined using $g / c = 0.40$ as chosen in (i).

(iv) AVERAGE Conditions: To determine the average operating conditions for Nepean Highway approaches, the results of RED Signals and BLANK Signals scenarios (ii and iii) are combined to determine the weighted average capacities of these approaches using the proportions of time the RED and BLANK signals are displayed. An additional scenario is then created by emulating the weighted average capacities using the environment factor parameter for Nepean Highway approaches. The geometry and volumes for this scenario are the same as in scenario (i).

(v) Signalized Intersection: This scenario is created to emulate the overall operation of metered approach with metering signals in order to determine the performance of the metered approach. The phasing information with red and blank phases is shown in Figure 6. A cycle time of c = 120 s was chosen. The BLANK signals were displayed for 40 per cent of the time (g = 48 s) and RED signals were displayed for 60 per cent of the time (r = 72 s). The volumes are as in scenario (i).

In this scenario, the saturation flow rate for each lane of the McDonald St approach during the blank signal phase is specified as the capacity rate estimated for the BLANK signals scenario (iii). The capacity values were 958 veh/h for Lane 1 (shared left-turn and right-turn) and 871 veh/h for Lane 2 (right-turn only). The basic saturation flows specified made allowance for turn adjustment factors. The same lane flow rates as in scenario (iii) are obtained.

For estimating geometric delay, operating cost, fuel consumption and emissions, it is important that the intersection negotiation data (turn radius, negotiation speed and negotiation distance) for the McDonald St approach in the signalized intersection scenario are specified to match the data used in the base conditions scenario (i).

The capacity and performance results from the analysis, including annual sums, are presented in Figures 7 and 8. The hourly values were converted to annual sums assuming 240 days per year (1 h per day) for the peak conditions. The analysis results indicate that, as expected, metering signals reduce delay, queue length, fuel consumption, CO2 emission and operating cost on the controlling approach (Nepean Hwy SE) significantly but increase the values on the metered approach (McDonald St). The overall benefits that can be obtained from metering signals appear to be significant. This implies a good benefit-cost ratio due to the low cost of implementing metering signals.

# 4 Conclusion

The method described in this paper for the analysis of roundabout metering signals is an approximate method. A more detailed method developed by the author is expected to be implemented in a future version of the SIDRA INTERSECTION software package.

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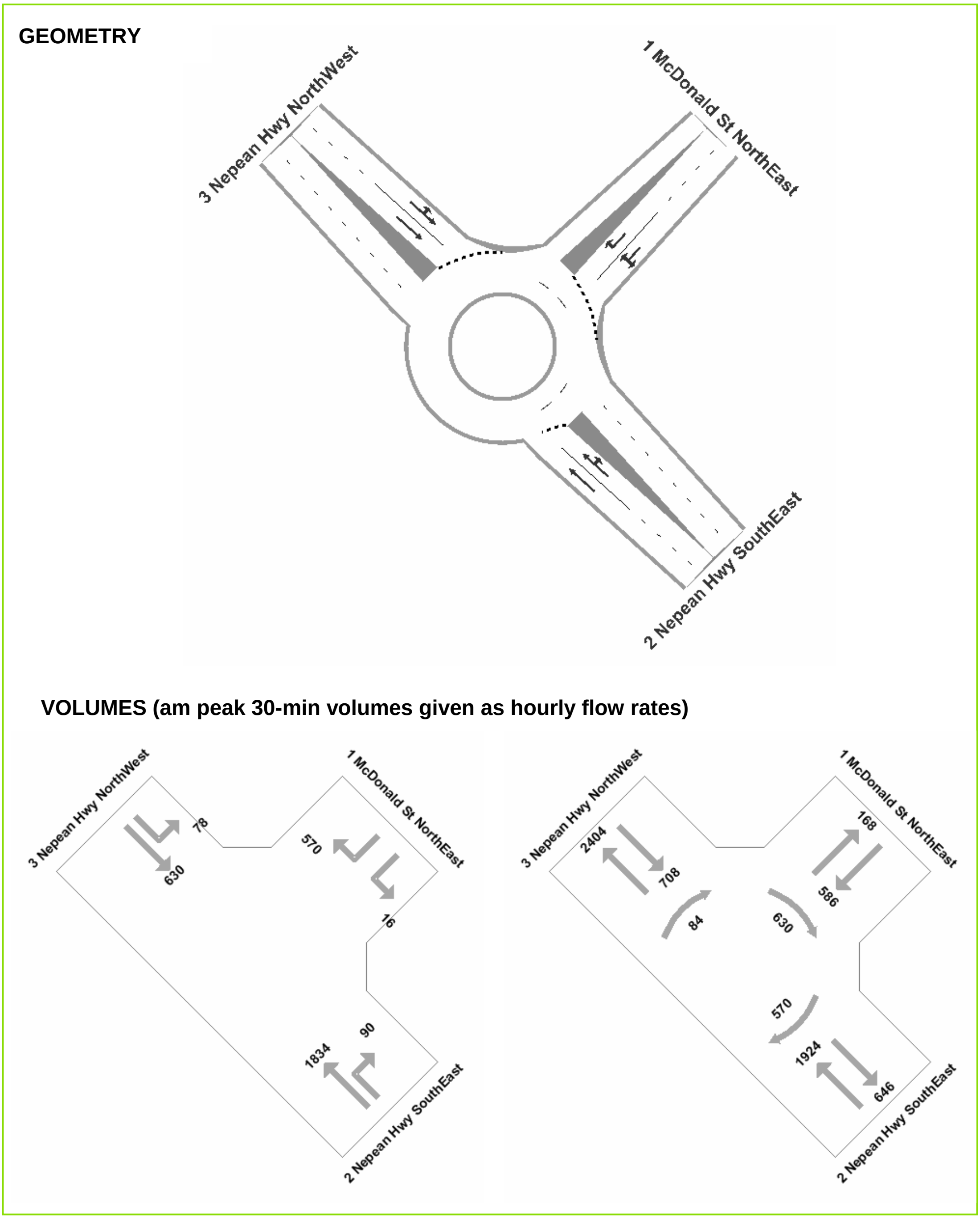
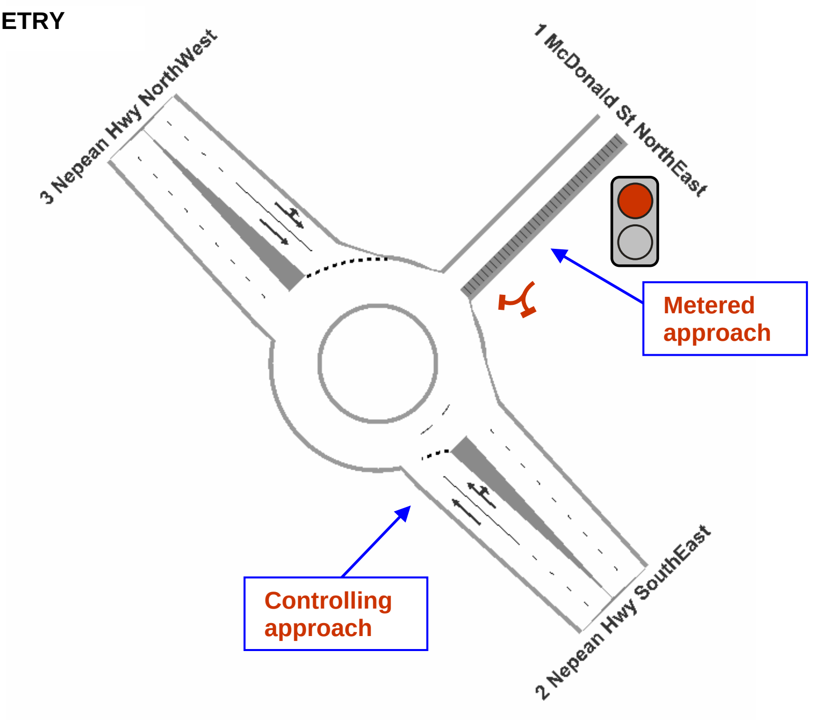


GEOMETRY

VOLUMES (am peak 30-min volumes given as hourly flow rates)

**Figure 3 - Roundabout operating without metering signals (base condition)**

**GEOMETRY**



**VOLUMES (am peak 30-min volumes given as hourly flow rates)**

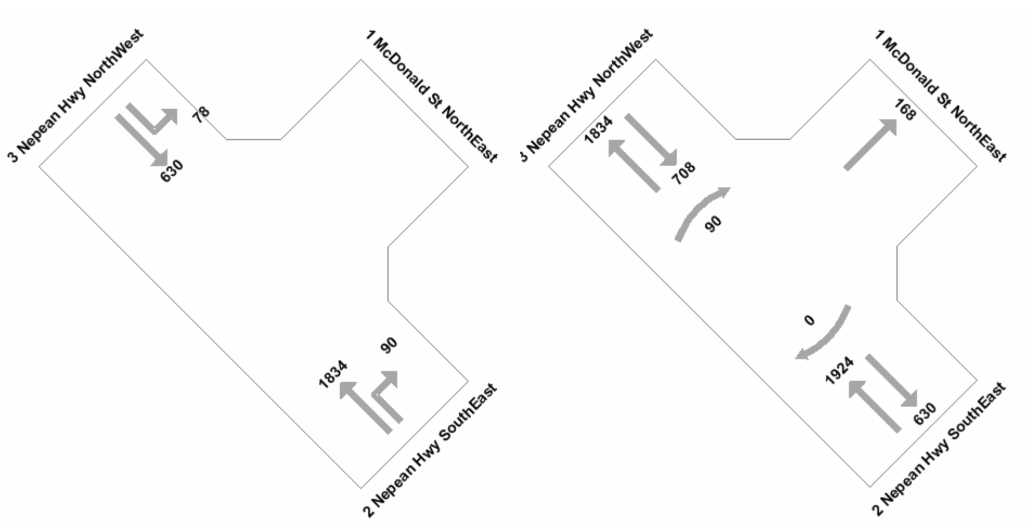


**Figure 4 - Roundabout operating with RED metering signals on the metered approach (McDonald St)**

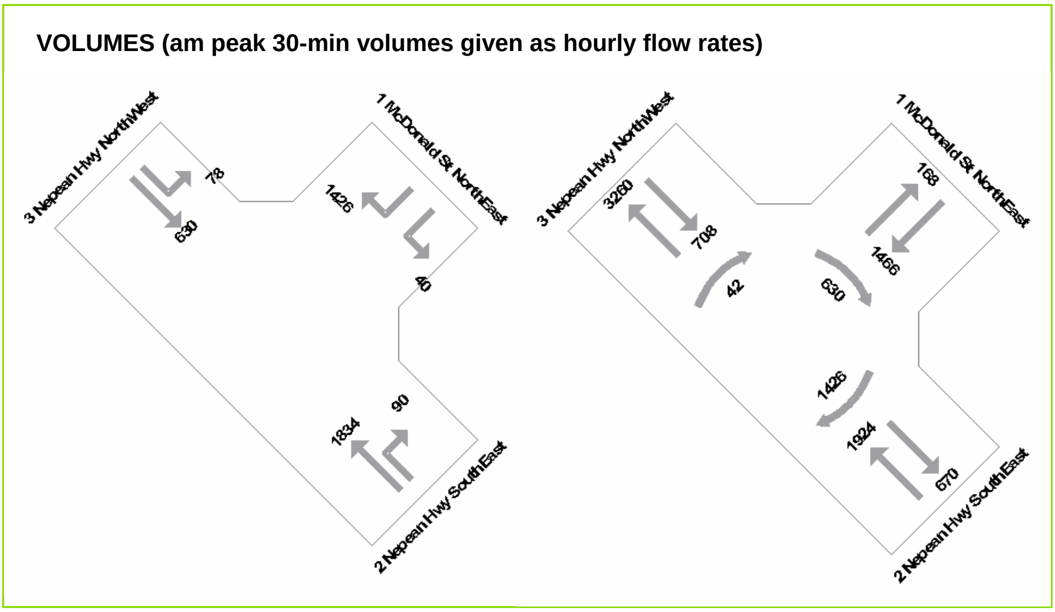
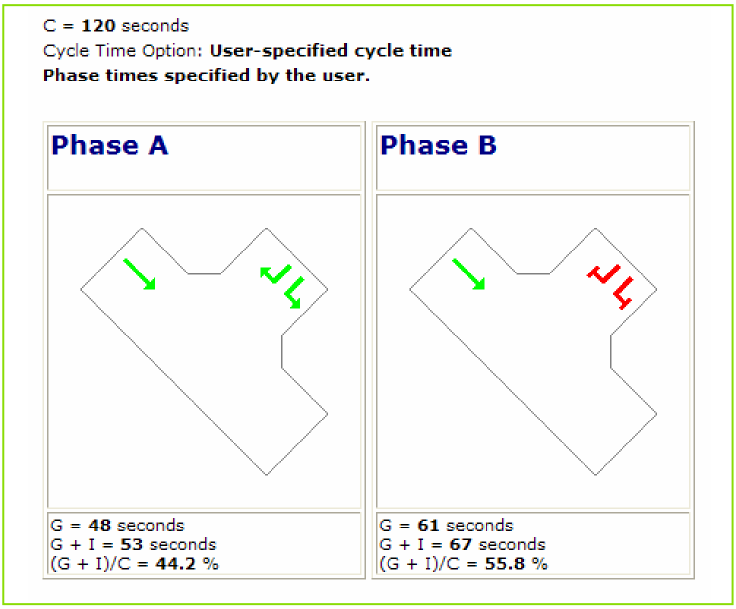


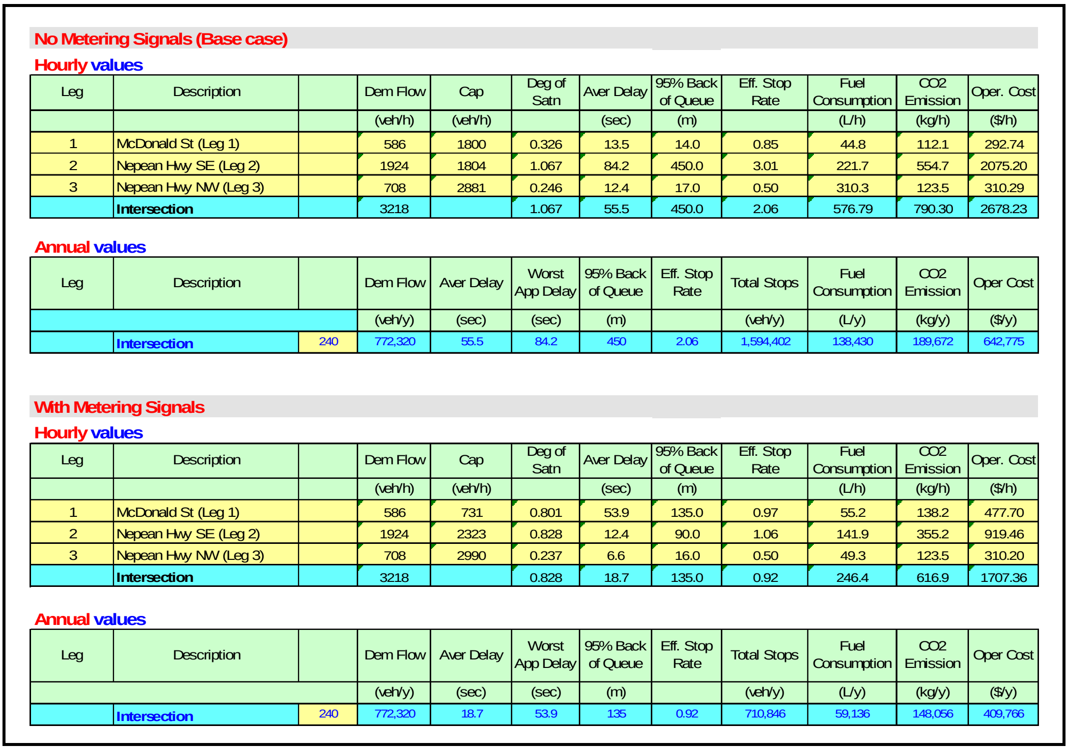
**Figure 5 - Roundabout operating with BLANK signals on the metered approach (McDonald St) - platooned flow rate entering from the metered approach**



C = **120** seconds
Cycle Time Option: **User-specified cycle time**
**Phase times specified by the user.**

| **Phase A** | **Phase B** |
|---|---|
| G = **48** seconds<br>G + I = **53** seconds<br>(G + I)/C = **44.2** % | G = **61** seconds<br>G + I = **67** seconds<br>(G + I)/C = **55.8** % |

**Figure 6 - Metering signal phasing analysis for the Nepean Highway - McDonald Street roundabout**



No Metering Signals (Base case)

Hourly values

| Leg | Description | | Dem Flow | Cap | Deg of Satn | Aver Delay | 95% Back of Queue | Eff. Stop Rate | Fuel Consumption | CO2 Emission | Oper. Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (veh/h) | (veh/h) | | (sec) | (m) | | (L/h) | (kg/h) | ($/h) |
| 1 | McDonald St (Leg 1) | | 586 | 1800 | 0.326 | 13.5 | 14.0 | 0.85 | 44.8 | 112.1 | 292.74 |
| 2 | Nepean Hwy SE (Leg 2) | | 1924 | 1804 | 1.067 | 84.2 | 450.0 | 3.01 | 221.7 | 554.7 | 2075.20 |
| 3 | Nepean Hwy NW (Leg 3) | | 708 | 2881 | 0.246 | 12.4 | 17.0 | 0.50 | 310.3 | 123.5 | 310.29 |
| | **Intersection** | | 3218 | | 1.067 | 55.5 | 450.0 | 2.06 | 576.79 | 790.30 | 2678.23 |

Annual values

| Leg | Description | | Dem Flow | Aver Delay | Worst App Delay | 95% Back of Queue | Eff. Stop Rate | Total Stops | Fuel Consumption | CO2 Emission | Oper Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (veh/y) | (sec) | (sec) | (m) | | (veh/y) | (L/y) | (kg/y) | ($/y) |
| | **Intersection** | 240 | 772,320 | 55.5 | 84.2 | 450 | 2.06 | 1,594,402 | 138,430 | 189,672 | 642,775 |

With Metering Signals

Hourly values

| Leg | Description | | Dem Flow | Cap | Deg of Satn | Aver Delay | 95% Back of Queue | Eff. Stop Rate | Fuel Consumption | CO2 Emission | Oper. Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (veh/h) | (veh/h) | | (sec) | (m) | | (L/h) | (kg/h) | ($/h) |
| 1 | McDonald St (Leg 1) | | 586 | 731 | 0.801 | 53.9 | 135.0 | 0.97 | 55.2 | 138.2 | 477.70 |
| 2 | Nepean Hwy SE (Leg 2) | | 1924 | 2323 | 0.828 | 12.4 | 90.0 | 1.06 | 141.9 | 355.2 | 919.46 |
| 3 | Nepean Hwy NW (Leg 3) | | 708 | 2990 | 0.237 | 6.6 | 16.0 | 0.50 | 49.3 | 123.5 | 310.20 |
| | **Intersection** | | 3218 | | 0.828 | 18.7 | 135.0 | 0.92 | 246.4 | 616.9 | 1707.36 |

Annual values

| Leg | Description | | Dem Flow | Aver Delay | Worst App Delay | 95% Back of Queue | Eff. Stop Rate | Total Stops | Fuel Consumption | CO2 Emission | Oper Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (veh/y) | (sec) | (sec) | (m) | | (veh/y) | (L/y) | (kg/y) | ($/y) |
| | **Intersection** | 240 | 772,320 | 18.7 | 53.9 | 135 | 0.92 | 710,846 | 59,136 | 148,056 | 409,766 |

Nepean Hwy SE (Leg 2): Controlling approach; McDonald St (Leg 1): Metered approach

**Figure 7 - SIDRA INTERSECTION estimates of the performance of the Nepean Highway and McDonald St Roundabout with and without metering signals**

| Total per YEAR | | Demand Flow | Aver Delay | Worst Approach Delay | 95% Back of Queue | Total Stops | Fuel Consumption | CO2 Emission | Oper Cost |
|---|---|---|---|---|---|---|---|---|---|
| Option | Description | (veh/h) | (sec) | (sec/veh) | (m) | (veh/y) | (L/y) | (kg/y) | ($/y) |
| 1 | No Metering Signals | 772,320 | 55.5 | 84.2 | 450 | 1,594,402 | 138,430 | 189,672 | 642,775 |
| 2 | With Metering Signals | 772,320 | 18.7 | 53.9 | 135 | 710,846 | 59,136 | 148,056 | 409,766 |
| | Difference | 0 | -37 | -30 | -315 | -883,555 | -79,294 | -41,616 | -233,009 |
| | Per cent difference | 0.0% | -66.4% | -36.0% | -70.0% | -55.4% | -57.3% | -21.9% | -36.3% |

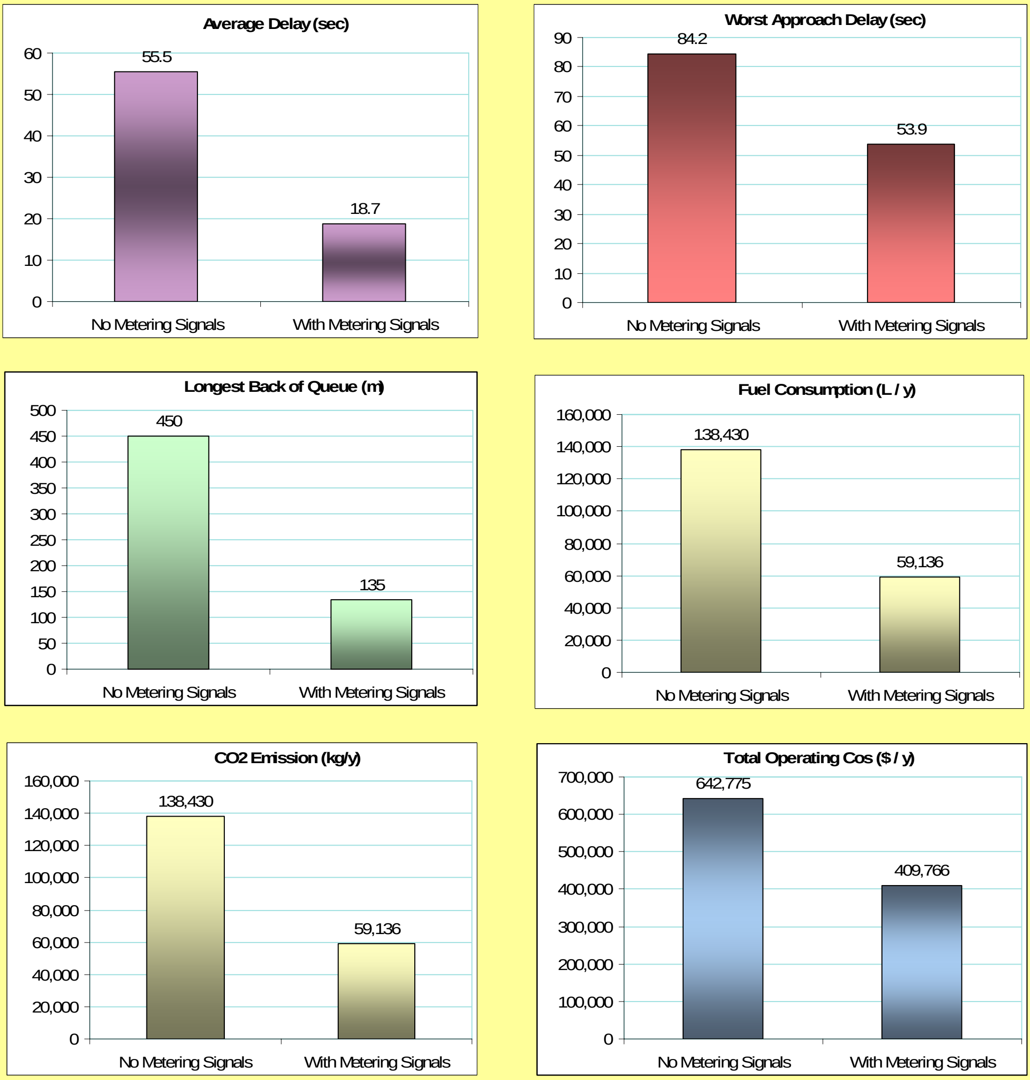


**Figure 8 - Benefits from metering signals for the Nepean Highway and McDonald St Roundabout**