ROUNDABOUT PLANNING AND DESIGN FOR EFFICIENCY & SAFETY CASE STUDY: WILSON STREET/MEADOWBROOK DRIVE/ HAMILTON DRIVE CITY OF HAMILTON

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1.0 ABSTRACT

Roundabouts are becoming more widely recognized for their capacity and safety advantages over traffic signals for moderate to high traffic flows. Accordingly, the city of Hamilton considered the feasibility of establishing a roundabout at the intersection of Wilson Street, Meadowbrook Drive and Hamilton Drive in the Town of Ancaster. Wilson Street, a former Provincial secondary highway, connects the village of Ancaster to the City of Brantford.

SRM Associates, also branded as Roundabouts Canada, performed a preliminary analysis of the potential operational performance of a modern roundabout for this intersection. The evaluation criteria determining whether a roundabout is feasible at any one intersection required the comparison of traffic capacity performance between a roundabout and a traffic signal and cost benefit comparison of a signalised intersection versus a roundabout including lifecycle cost analysis.

The preliminary geometric parameters and the safety performance prediction for a roundabout were developed using RODEL, a capacity and safety prediction model, based on extensive research of existing roundabouts, that relates geometry to capacity and safety performance.

Through this investigation it was determined that the subject intersection could benefit from implementation of a roundabout in terms of traffic capacity and operational performance. The predicted performance of this intersection as a roundabout is documented with a high degree of confidence that the forecast 20 to 25 year traffic flows will not generate excessive queuing or delay when compared to traffic signal control.

An initial study into the feasibility of a roundabout at this intersection included public consultation to establish a roundabout as the preferred intersection control in consideration of alternatives such as traffic signals, all-way stop control and two-way stop control. The study prudently recommended a single lane roundabout with single lane entries and exits, acknowledging the scarcity of roundabouts on arterial roads in Southern Ontario and the need for predictable, uncomplicated operation.

This design brief accurately demonstrates that a roundabout will provide a safe form of intersection control to service traffic forecasts for beyond the useable life of the proposed operational improvements.

The design of the proposed roundabout at the intersection of Wilson Street, Meadowbrook Drive and Hamilton Drive in the City of Hamilton has been prepared using state of the art empirically based methods for predicting capacity, delay and queuing with a high degree of confidence. The proposed design suits local conditions, being capable of accommodating twice the existing traffic volume without undue vehicle queuing or delay.

Field studies of before and after spot speeds indicate that the design operating speed of 30 to 40 km/h for traffic through the roundabout has been achieved owing to specific consideration for entry deflection and fastest path of a passenger car. Over the sixth months following the opening of the roundabout, one single motor vehicle crash without injury was reported.

2.0 INTRODUCTION

In the following sections, a summary of the advantages and disadvantages of modern roundabouts is presented to acquaint the reader with the planning considerations and feasibility of roundabouts in general.

2.1 WHY DID MODERN ROUNDABOUTS EMERGE?

A study of 86 intersections, an $11M research project undertaken in the late 1970's by the U.K. Transportation Research Laboratory allowed Britain to resolve many of the geometric and safety related deficiencies of existing roundabouts. Many roundabouts were rehabilitated and new sites were considered as a result of this watershed research.

A recent U.S. safety research study[1] of 24 intersections compared before and after crash histories to find significant reductions of 39 percent for all crashes severities combined. The study yielded the following additional conclusions:

- 76% percent reduction for all injury crashes
- 90 percent reductions in fatal and incapacitating injury crashes

These results are consistent with other international studies strongly suggesting that the safety benefits of roundabouts cannot be overlooked when evaluating alternative intersection controls.

2.2 BENEFITS OF MODERN ROUNDABOUTS

A correctly designed and installed roundabout has the potential to generate the following benefits:

- Lower traffic speeds reducing crash frequency and severity for all users
- Drivers having more time to enter a gap in roundabout circulating traffic
- Pedestrians crossing distances shortened by narrowed roadway approaches and the requirement to look in one direction only when crossing.
- Roundabouts are the safest intersection for novice users
- Drivers only make right turns
- Vehicle emissions are reduced through reduced stops and delays

2.3 WHERE CAN ROUNDABOUTS BE USED?

There is much to be said for the feasibility of roundabouts. Many jurisdictions in Canada are attempting to wait for the 'right' location while ignoring the potential safety benefits that are well proven in the United States. Typically, a modern roundabout can be used to address or resolve the following issues:

- High crash locations and/or high delays
- Where traffic signals are warranted
- Rural high speed intersections
- Freeway ramp terminal intersections
- Four-way stop intersections
- Intersections with more than four legs
- High left-turn flows
- In transition between high speed rural and low speed urban
- Intersections that are important from an urban design or visual point of view

The above list is only a partial summary that reflects our recent experience investigating the feasibility of roundabouts mostly in Canada. The U.S. Federal Highways Administration Informational Guide to Roundabouts was released in 2000[1]. It gives additional detailed information on the suitability and benefits of modern roundabouts.

2.4 DISADVANTAGES OF ROUNDABOUTS

Not everywhere and under all circumstances are roundabouts the correct intersection control. Unfortunately, more potential sites are overlooked or rejected for the wrong reasons or because the investigator lacks knowledge of how roundabouts function, or what makes them operate more safely than traffic signals. Nevertheless, there are conditions under which roundabouts are not practical or feasible. The following are the main reasons why not to choose a roundabout or when to consider a roundabout with caution:

- Space required for an acceptable outside diameter is not available or too costly to acquire.
- Profile grade on entries and the profile must be are greater than 4%.
- Intersection traffic flows are severely unbalanced
- Platooned traffic flow is impacted in signal coordinated networks
- Driver sight of the yield line at entry points is not available due to horizontal or vertical impediments
- Where it is demonstrated that visually impaired pedestrians are in number sufficient to warrant a pedestrian crossing traffic signals. This is not a reason to reject a roundabout but another complicating factor that North Americans have yet to address. Pedestrian crossing signals are numerous in urban areas throughout the U.K. Canada needs to establish more roundabouts before tackling the question of pedestrian traffic signals.
- Construction staging for retrofits is costly and complicated. Typically, a 4-lane roadway with constrained right-of-way will require temporary traffic signals. The key to minimizing traffic impact of construction staging is to make the intersection operate as a roundabout as soon into its construction as possible. This will slow speeds and switch left turns to right turns, reducing crash conflict potential.

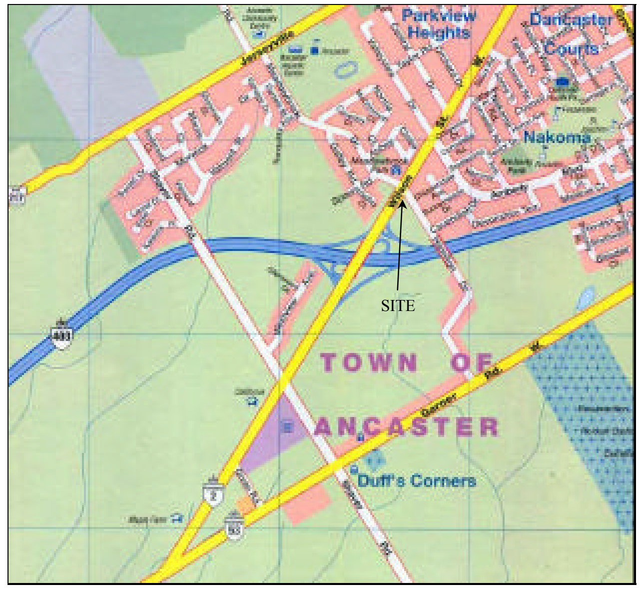
2.5 ROUNDABOUT FEASIBILITY AND PLANNING STEPS

The U.S. Federal Highways Administration[2] prescribes several key decision steps to evaluating the need for, and planning of, a roundabout intersection:

- Identify and evaluate site-specific and community impact reasons why a roundabout of any particular size would not be a good choice.
- Generate a preliminary lane configuration based on capacity requirements
- Identify the type of roundabout – urban or rural, mini versus conventional design with or without a raised central island
- Determine the space feasibility with respect to existing right-of-way
- Compare the roundabout with alternative intersections using capacity, safety and lifecycle cost to benefit analyses

The results of this investigation should be documented in a roundabout design brief or selection study.

3.0 CASE STUDY - DESIGN BRIEF



This design brief was used to justify the use of a roundabout to the Ministry of Transportation and to provide the City of Hamilton with traceable documentation as to the design elements critical to the successful operation of their first modern roundabout. It has been presented as close as possible to its original format and context.

The subject intersection is adjacent to the Highway 403 corridor at the west limit of the Village of Ancaster as shown on the adjacent key plan. It was desirable to have the intersection represent a gateway to the community. Accordingly, a roundabout was also favoured to facilitate improved streetscaping and a degree of traffic calming for traffic entering the community from the freeway corridor.

Although the intersection is not within Provincial operating jurisdiction, the Ministry of Transportation has requested documentation that the operational influence of the proposed roundabout does not impact on access or egress to Highway 403 ramp terminals.

The purpose of this design brief was to provide the technical documentation of the geometric design elements of a proposed roundabout at the above-captioned intersection giving specific consideration to the traffic demand, safety performance and intersection configuration. This technical documentation herein was prepared in partnership with Mr. Barry Crown, C.Eng., an accomplished roundabout designer and author of the interactive roundabout design software RODEL.

3.1 EXISTING CONDITIONS

Functionally, the intersection operates with two through traffic lanes in each direction. Auxiliary lanes for left and right turns are provided for east/west traffic on Wilson Street. The through lane widths are between 3.5m and 3.75m. The intersection alignment was partially skewed, having north/south approaches not aligning nor intersecting at 90^{o}.

Traffic volumes at the subject intersection are shown as “FLOWS” on Figure 2 for the A.M. peak period and Figure 4 for the P.M. peak hour according to the four intersection legs. The traffic volumes were recorded in 2001. Truck percentages were not identified but were assumed to be 10% on Wilson Street.

Posted speed limits are 50 km/h for the north, south and east approaches. The east and west approaches have a posted limit of 60 km/h that transitions to 50 km/h east of the intersection. Spot speed study data was not identified for the intersection area. The north/south approaches are stop controlled.

Pedestrian crossing traffic is relatively light based on observations. Bicycle traffic is also light at this corner of the community.

Crash history at this intersection for the period between 1988 and 2002 indicated 31 crashes of which 10 incidents involved personal injury with a consistent crash type of angle or turning movement. The calculated collision rate for the intersection was approximately 0.55 per million vehicles entering based on the existing traffic volumes.

Development in the vicinity of the intersection is relatively stable in three of the four intersection quadrants. The south-east corner of Wilson Street and Hamilton Drive is the site of a former gas service station. The site has access to Wilson Street which will be protected for in the proposed design. An alternate access to Hamilton Drive will not be available due to its proximity to the roundabout entry. Wilson Street access to the existing fire station is also protected for in the proposed works.

3.2 PROPOSED DESIGN CRITERIA

The design criteria for the proposed intersection operational improvements to the twenty year horizon is summarized as follows:

- Wilson Street has a functional classification of UAU70
- Meadowbrook Drive and Hamilton Drive share the functional classification of UCU60.
- The design speed for the roundabout approaches is 70 km/h. The desired speed of traffic circulating around the roundabout is 30 to 40 km/h.
- Desirable maximum approach queues are to be less than 5 vehicles in any one direction for peak 15 minute period flows.
- Approach lane widths are 3.75m minimum for Wilson Street and 3.5m minimum for the side street approaches.
- The roundabout capacity must accommodate traffic collected by Meadowbrook Drive and Hamilton Drive, representing build-out of the lands designated for residential development. Concurrently, the roundabout must accommodate background traffic growth on Wilson Street to a twenty-year plus horizon.
- The percentage of trucks was assumed to be 10% for the arterial and 2% for the collector side streets.
- Pedestrian crossings are to be provided for on all approaches to the roundabout.
- A future exclusive bike lane was assumed for Wilson Street and shared bicycle/vehicle lanes are assumed for the side streets. The roundabout design should provide for the retrofit of bike lanes without the need to relocate curbing.
- The roundabout circulating roadway, entries and exits must accommodate the swept paths of a WB19 design vehicle predominantly for the east/west direction. The roundabout configuration must also accommodate snow ploughing using a truck mounted with a wing blade, transit vehicles and fire trucks.
- Roundabout approach visibility criteria providing stopping sight distance as per operating speed of approach and circulation.

3.3 TRAFFIC CAPACITY ANALYSIS

An exhaustive U.K. study undertaken in the late 1970's[3] has been made of the entry capacities of roundabouts at 86 public road sites, and a unified formula for capacity prediction developed. The most important factors influencing roundabout capacity are the entry width and flare. The entry angle and radius have small but significant effects. The inscribed circle diameter, used as a simple measure of overall size, is also effective as a predictive variable for roundabout capacity. Methods were developed which allow the empirically generated capacity equations to be used specifically to predict the effects of changes in the entry geometry of existing sites. Having been developed through thousands of hours of field observations, the predictive model for roundabout capacity is therefore robust in estimating capacity, delay and queuing accounting for driver behaviour under all flow conditions.

RODEL[4], a computer software simulation tool containing the U.K. empirical equations of roundabout capacity, was employed to derive the optimum layout within the conflicting constraints of cost, delay and safety. The results from RODEL are for a specified V/C Ratio Confidence Level, consequently the risks involved when trading-off delays, costs and safety are clearly known.

The geometric data required for Kimber's Roundabout Capacity equations are defined as follows (See Figure 1):

Entry width	E	(metres)
Flare length	L'	(metres)
Half width	V	(metres)
Entry radius	R	(metres)
Entry angle	PHI	(degrees)
Diameter	D	(metres)

3.4 CAPACITY ANALYSIS RESULTS AND INTERPRETATION

Rather than using just the maximum V/C ratio as a measure of intersection performance, RODEL uses delays and queuing. The 'error' in capacity is taken into account by means of the Confidence Level. Geometry has been generated for the chosen delays with the specified level of confidence that they will not be exceeded. In this analyses, a 50%ile confidence level was chosen because it represents the most probable V/C ratios of the roundabout approach. The 85%ile confidence level V/C ratios were also tested for queuing and delay. The higher confidence level represents an improbable or pessimistic prediction of V/C ratios for each approach. The maximum queuing corresponding to the higher confidence level therefore represents a worst case of an already improbable capacity condition. Thus the analysis covers a range of operating conditions predicting worst case delay and queue spillback.

A comparison of predicted operational performance of a roundabout versus either a two-way stop control or a traffic signal is presented in Table 1. The Highway Capacity Manual[5] method was used to assess intersection performance for existing and near future traffic flows. In order to prove a point regarding the potential for superior capacity of a modern roundabout, the results were compared to for different forecast horizons imposing higher flows on the roundabout. In spite of higher traffic flows, the

TABLE 1- COMPARISON OF OPERATIONAL PERFORMANCE PREDICTIONS FOR ALTERNATIVE INTERSECTION CONTROLS

Type of control	North Leg (a.m./p.m.)	West Leg (a.m./p.m.)	South Leg (a.m./p.m.)	East Leg (a.m./p.m.)
TWSC (1998 Measured)	19/14	0/0	11/15	0/0
Signal Control (2011 Flows)	14/23	14/6	10/19	15/6
Roundabout (2021 Flows)	6/5	4/8	5/5	7/6

Note: Two way stop control and traffic signal control analyses conducted by Stantec Consulting

Figures 2 to 5 provide a summary of the capacity analyses using a compound growth rate of 3.5% per year for 20 years applied as a factor (FLOF) of 2.0 to existing traffic volumes to derive conservative traffic forecasts. This was done purposely to demonstrate the effectiveness of roundabouts in accommodating low to moderate traffic volumes even in unbalanced flow conditions. The output data of particular interest, from Figures 2 to 5, is the queuing prediction for the probable (50% Confidence) and improbable (85% Confidence) cases.

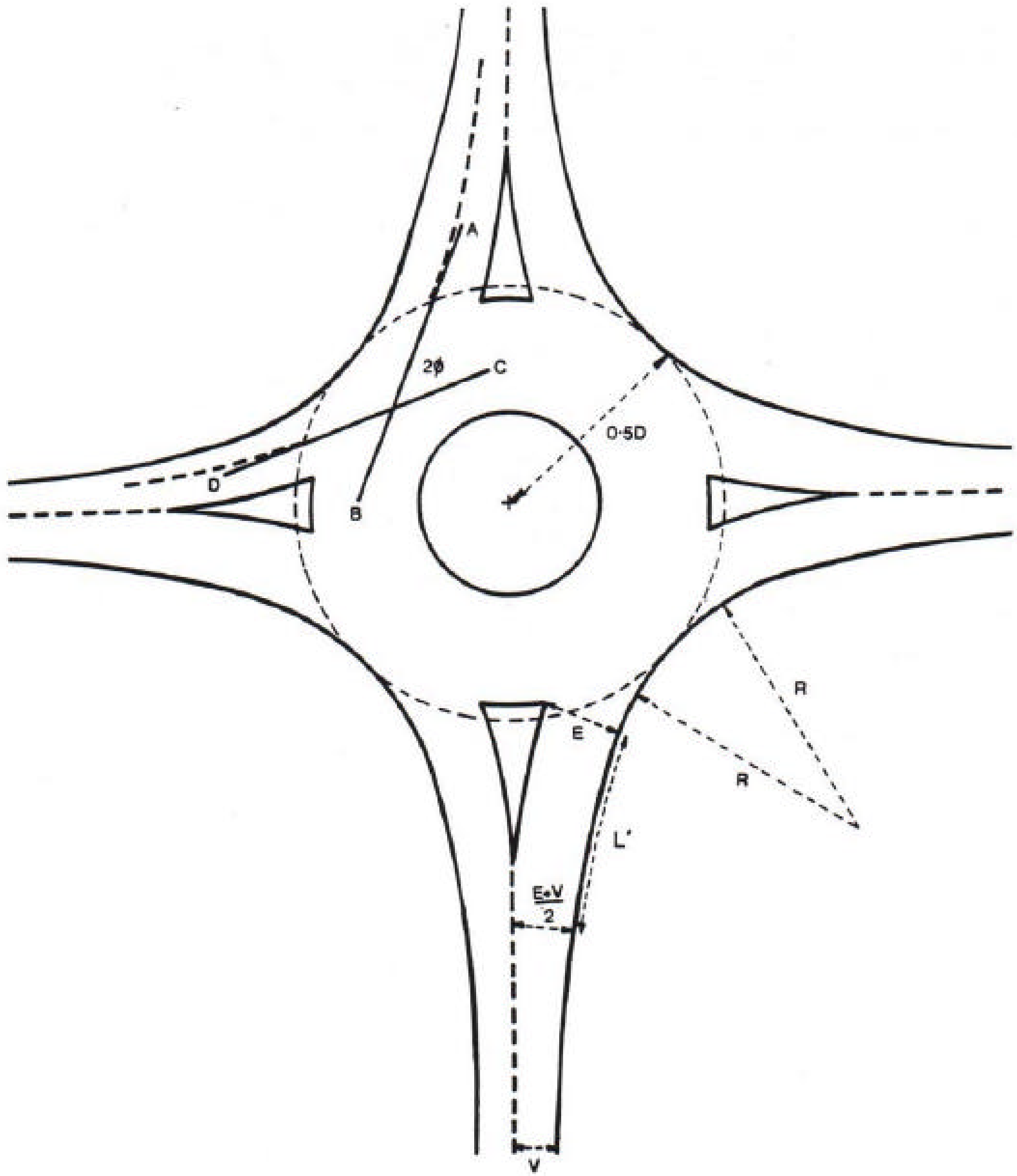


FIGURE 1 – Geometric Definitions

TABLE 2 – SUMMARY OF **PROBABLE** CAPACITY RESULTS FOR WILSON STREET ROUNDABOUT

Roundabout Leg	A.M. Peak Period			P.M. Peak Period		
	V/C	Max Delay (mins./hr.)	Max Queue /95%ile Queue (Veh.)	V/C	Max Delay (mins./Peak hr.)	Max Queue /95%ile Queue (Veh.)
Meadowbrook Drive	0.48	0.14	1/2	0.32	0.11	1 /2
Wilson Street West Leg	0.41	0.10	1/2	0.66	0.20	3/6
Hamilton Drive	0.19	0.10	0	0.08	0.11	0
Wilson Street East Leg	0.61	0.16	2/4	0.57	0.10	2/4

TABLE 3 – SUMMARY OF **PESSIMISTIC** CAPACITY RESULTS FOR WILSON STREET ROUNDABOUT

Roundabout Leg	A.M. Peak Period			P.M. Peak Period		
	V/C	Max Delay (mins./hr.)	Max Queue /95%ile Queue (Veh.)	V/C	Max Delay (mins./Peak hr.)	Max Queue /95%ile Queue (Veh.)
Meadowbrook Drive	0.58	0.24	2/4	0.40	0.15	1 /2
Wilson Street West Leg	0.47	0.13	1 /2	0.77	0.39	6/12
Hamilton Drive	0.24	0.15	0	0.10	0.15	0
Wilson Street East Leg	0.70	0.27	4/8	0.65	0.21	3/6

As discussed, the improbable capacity prediction of the 85%ile capacity analysis yields a worst case delay and queuing providing a high degree of confidence in the chosen geometric elements. A conservative queue reach of 12 vehicles, approximately 84m corresponds to traffic forecasted beyond the 20 year horizon and does not impact the Highway 403 exit ramp to Wilson Street. Queuing for the remaining approaches is below 5 vehicles for the 50% confidence condition.

3.5 LIFECYCLE COST COMPARISON

We prepared a comparison of costs associated with either constructing and maintaining a traffic signal or a roundabout. A 20-year lifecycle analysis (6% discount rate) was used to examine the major costs associated with either traffic control type. We did not associate a cost-benefit with the aesthetic improvement of the intersection or the value of traffic calming. The crash cost savings are based on the difference between the current safety performance of the existing unsignalized intersection versus the roundabout. The future safety performance of the traffic signal control is expected to be the same or slightly worse based on use of Safety Performance Functions for similar traffic volumes and crash history for intersections in Southern Ontario.

TABLE 4 – LIFECYCLE COST COMPARISON

Traffic Signal		Roundabout	
Signal Installation	$95,000	Roundabout Installation (Minimal contract package)	$225,000
Signal Replacement within 20 years	$30,000	Lighting/Pavement Marking	$40,000
Maintenance ($4,500 per year)	$52,000	Crash reduction savings	-$68,000
Resurfacing of the intersection within 5 years	$75,000	Roundabout design/construction administration fee	$30,000
Signal design fees	$7,000		
Total Net Present Value	$259,000	Total Net Present Value	$227,000

Considering safety benefits and long term maintenance costs, the roundabout is more cost-effective than the traffic signal. Future traffic safety performance of the intersection with a roundabout may in fact be more cost-effective than actually reported. Moreover, it is improbable that a fatal crash, having a societal cost of $750,000, would occur at a roundabout. The same cannot be said of a signalized intersection. Furthermore, the use of a traffic signal does not preclude any additional road improvements that may be required in 10 to 15 years. By comparing the two scenarios using a lifecycle cost analysis, the roundabout is by a greater differential a superior choice of traffic control.

3.6 PRELIMINARY DESIGN ELEMENTS

Confirmation that the design is functional in terms of truck swept paths, expected operating speed and guidance was documented using additional sketches and plans not enclosed in this version of the design brief. Verification of the design functionality determines whether the desired operating speeds can be achieved and whether the design vehicle can be accommodated. Readers are invited to contact the author for this additional information.

- Truck turning paths
- Fastest path and vehicle speeds
- Traffic signs and pavement markings
- Geometric design elements
- Driver and pedestrian visibility
- Illumination
- Sidewalk alterations

The preliminary design incorporating the foregoing elements in correlation with the traffic capacity and safety review is illustrated on Figure . Aesthetic features such as landscaping, boulevard paving and future bicycle path locations were determined and designed at the final design stage subject to consultation with the City.

3.6.1 VEHICLE SAFETY

The crash prediction model was derived from Transport Research Laboratory studies documented under report LR1120[6]. The estimates of crashes according to this model are 0.47 slight injury crashes per year with an injury crash rate of 0.116 per million vehicles entering. With the doubled future flows the crashes rise to 1.1 slight injury crashes per year with a predicted crash rate of 0.138 per million vehicles entering. A crash rate of greater than 1.5 is considered problematic and requires investigation.

At the writing of this report, it was not evident that corner daylighting triangles were obtained through development of the corner properties on Meadowbrook Drive. Driver visibility of the exit lanes and pedestrian crossings required removal of vegetated boulevards in the north-east and north-west quadrants. Involvement of the land owners was necessary to discuss and determine transplanting options and remedial plantings to mitigate any perceived impacts.

3.6.2 BICYCLE SAFETY

Accommodation of cyclists in roundabouts is discouraged regardless of whether an exclusive lane exists or is planned. Studies have shown that bike lanes integral with the outer edge of the circulatory roadway should be avoided[1]. Incorporating bikeways at this roundabout in the future will require a paved boulevard path connecting the crosswalks to the on-road paths. The adjacent photograph depicts one variation of this type of design, which is suitable for full urban design conditions.

3.6.3 PEDESTRIAN SAFETY

The following points were considered in assessing pedestrian safety and providing for pedestrian crossings of all four roundabout legs:

- Pedestrian flows
- Pedestrian routes
- Vehicle flows
- Vehicle speed
- Deflection Island size
- Crossing width
- Visibility criteria
- Crossing Sites

Pedestrian crossings that give priority to pedestrians for part of the peak period have been shown to reduce capacity only marginally at single lane roundabouts.[2] In fact, when circulating flows are high, approach vehicle queuing actually facilitates pedestrian crossings. The most noticeable effects of pedestrians is said to occur in the off-peak periods when traffic flows freely on the conflicting approach.

Where pedestrian volumes are approximately 100 pedestrians per hour, the factor applied to reduce capacity is 1%. Accordingly, there is ample residual capacity for pedestrian activity without adverse impact to roundabout queuing and delay.

Pedestrian crossing paths are at grade through the splitter islands with the use of ramped concrete aprons. Tactile edges of the island refuge areas are necessary to reinforce the refuge area limits.

4.0 RESULTS OF OPERATION AFTER 6 MONTHS

4.1 SPEED STUDIES

The City of Hamilton undertook before (June 2002) and after (January to March 2003) studies of operating speeds in the vicinity of the roundabout. Table 5 summarizes the data collected indicting significant reduction in operating speeds closest to the roundabout. The largest change in operating speed occurred east of the roundabout in a 60km/h speed zone where the after 85th percentile spot speed was found to be an average of approximately 40km/h as compared to the before speed of 75km/h for both directions of travel. Clearly, the roundabout is impacting driver speed with desirable effects in the area of transition between the high speed rural section of Wilson Street and the west end of the village in close proximity to a school crossing.

TABLE 5 - BEFORE AND AFTER STUDY OF 85TH PERCENTILE SPEED AT ANCASTER ROUNDABOUT

Location	Direction	Previous Speed (km/h)	Existing Speed (km/h)	Change of Speed (km/h)
100m West	EB	77.58	62.94	-14.64
	WB	76.50	57.92	-18.58
35m West	EB	76.08	41.95	-34.13
	WB	77.12	51.99	-25.13
35m East	EB	74.41	45.60	-28.81
	WB	79.82	38.51	-41.31
100m East	EB	70.03	60.19	-9.84
	WB	75.81	58.51	-17.30
350m East	EB	67.42	68.48	1.06
	WB	69.91	67.59	-2.32
500m East	EB	66.78	67.24	0.46
	WB	69.12	65.81	-3.31

4.2 RECENT CRASH HISTORY

Immediately following the opening of the roundabout most drivers adjusted their speed to accommodate the entry, circulating road and exit lane geometry. Drivers are expectedly cautious in the introductory period, which further reduces the potential for injury crashes.

Observations of driver behaviour indicate the need to incorporate landscaping to reinforce the guidance elements of the curbs, signs and markings. The landscaping anticipated for 2003 will improve the visibility of the central island and the roundabout as a whole. The City of Hamilton reports only one single motor vehicle crash involving loss of control for an eastbound motorist since October 2002.

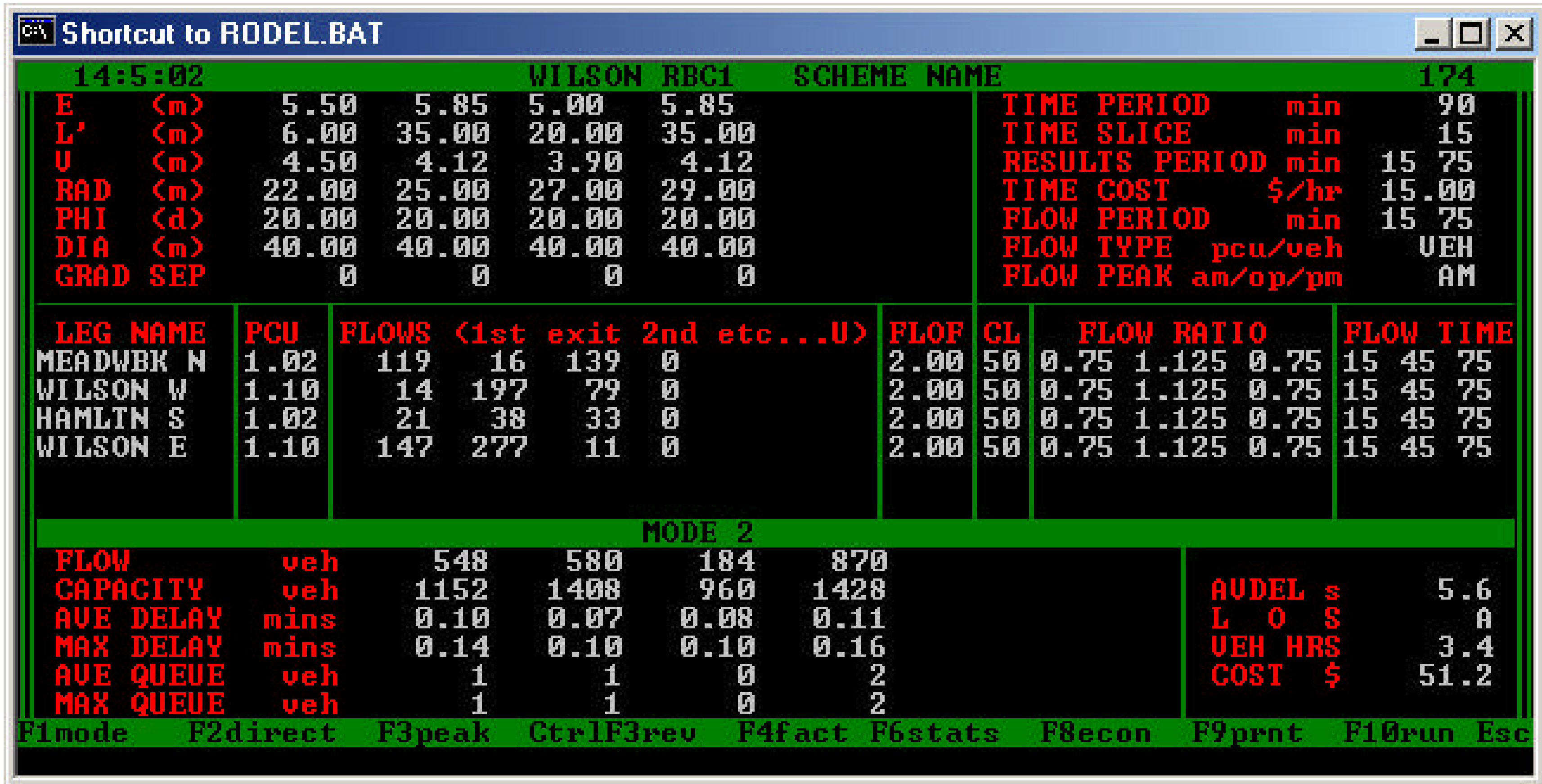


FIGURE 2 – RODEL RESULTS FOR THE A.M. PEAK PERIOD
MOST PROBABLE V/C RATIOS (50% CONFIDENCE)

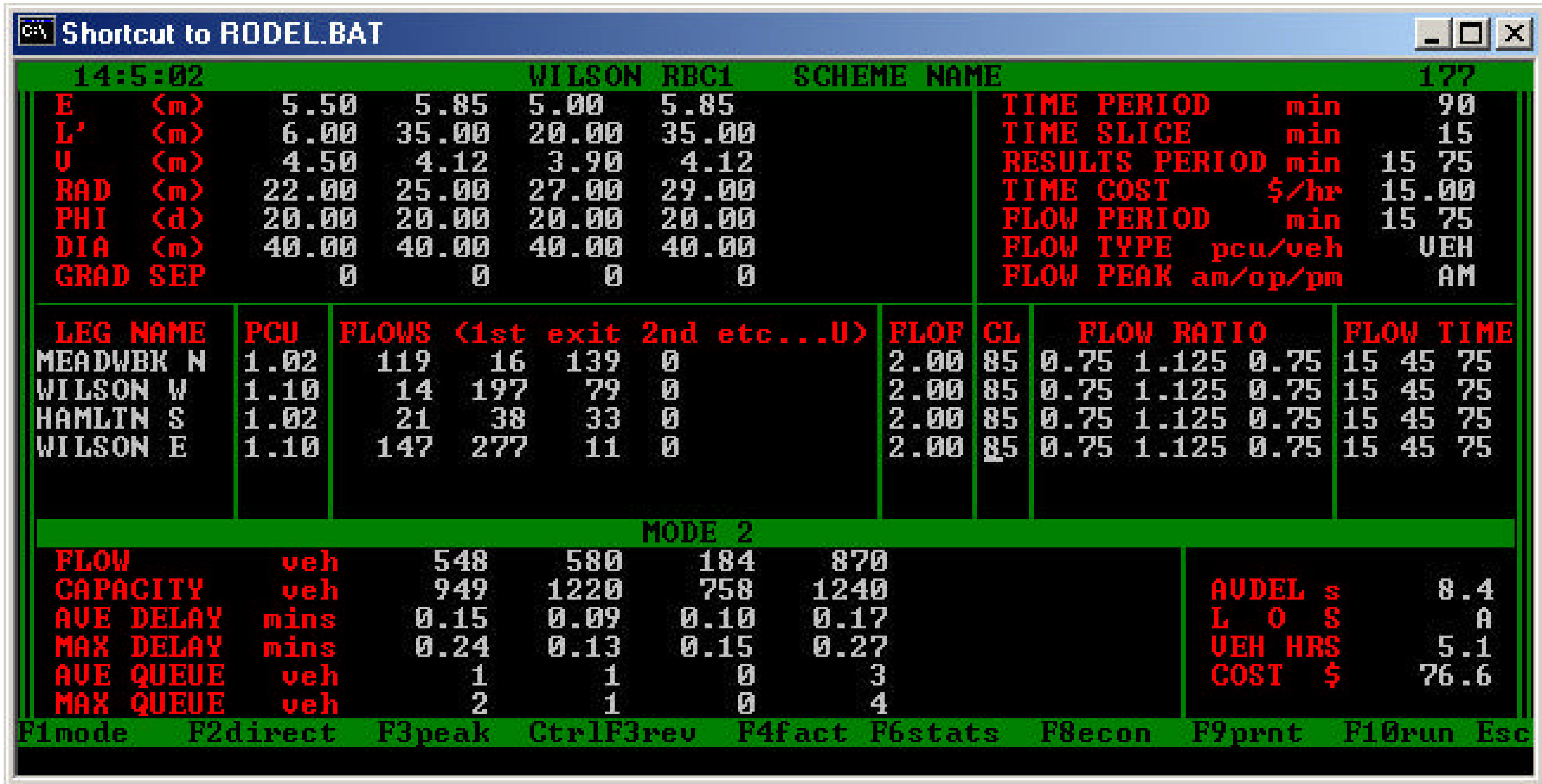


FIGURE 3 – RODEL RESULTS FOR THE A.M. PEAK PERIOD
PESSIMISTIC CAPACITY (85% CONFIDENCE)

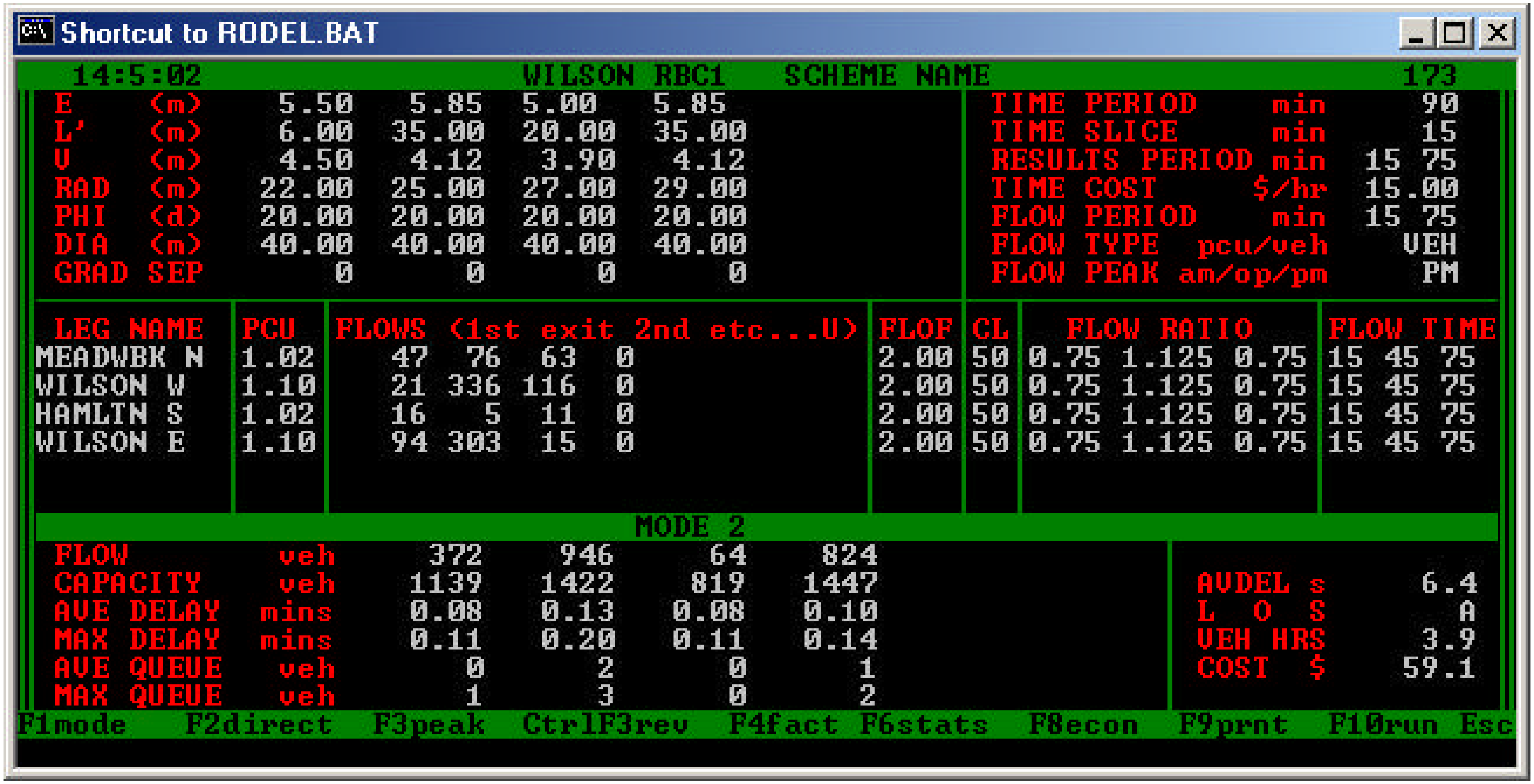


FIGURE 4 – RODEL RESULTS FOR THE P.M. PEAK PERIOD
MOST PROBABLE V/C RATIOS (50% CONFIDENCE)

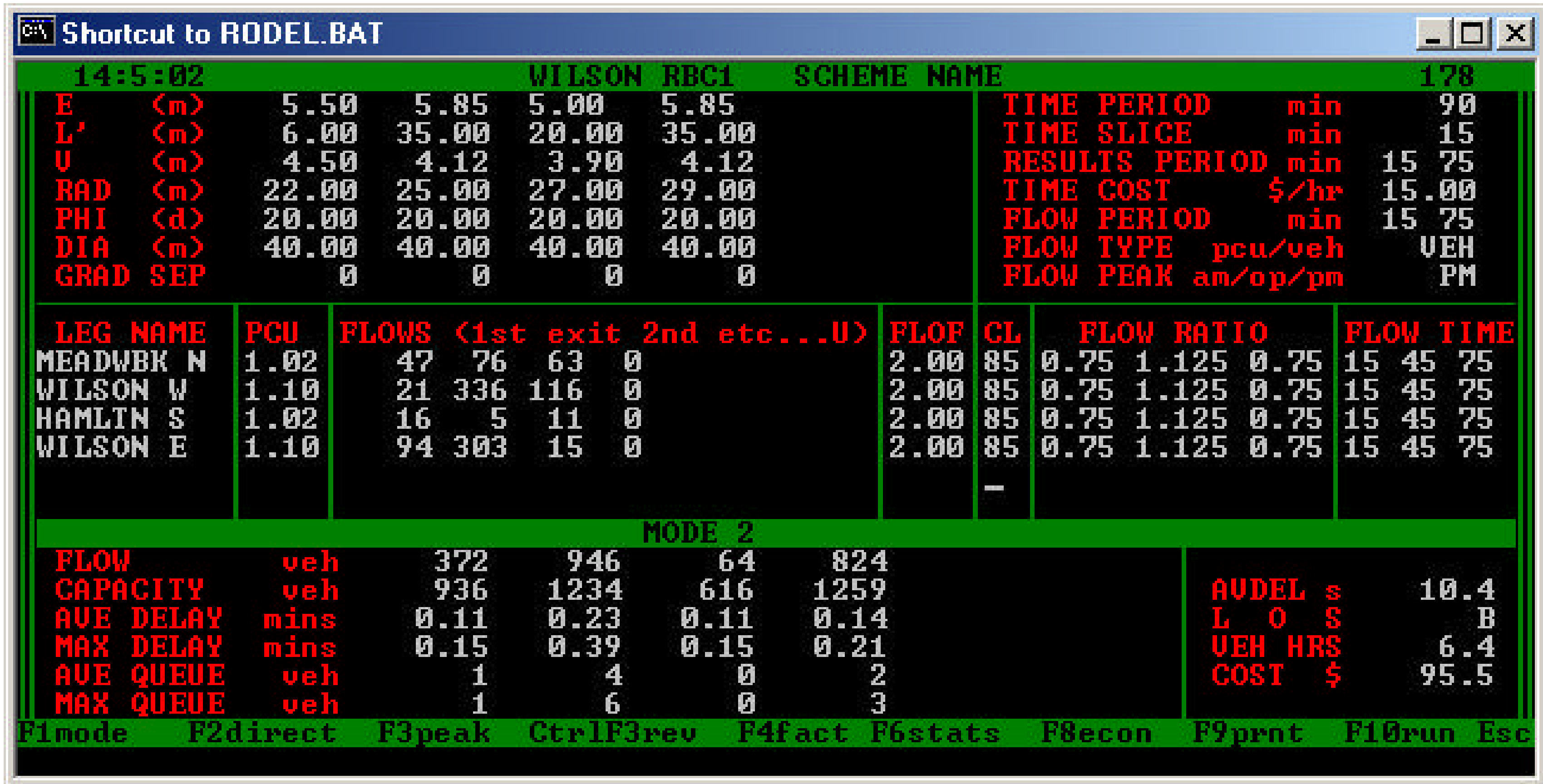
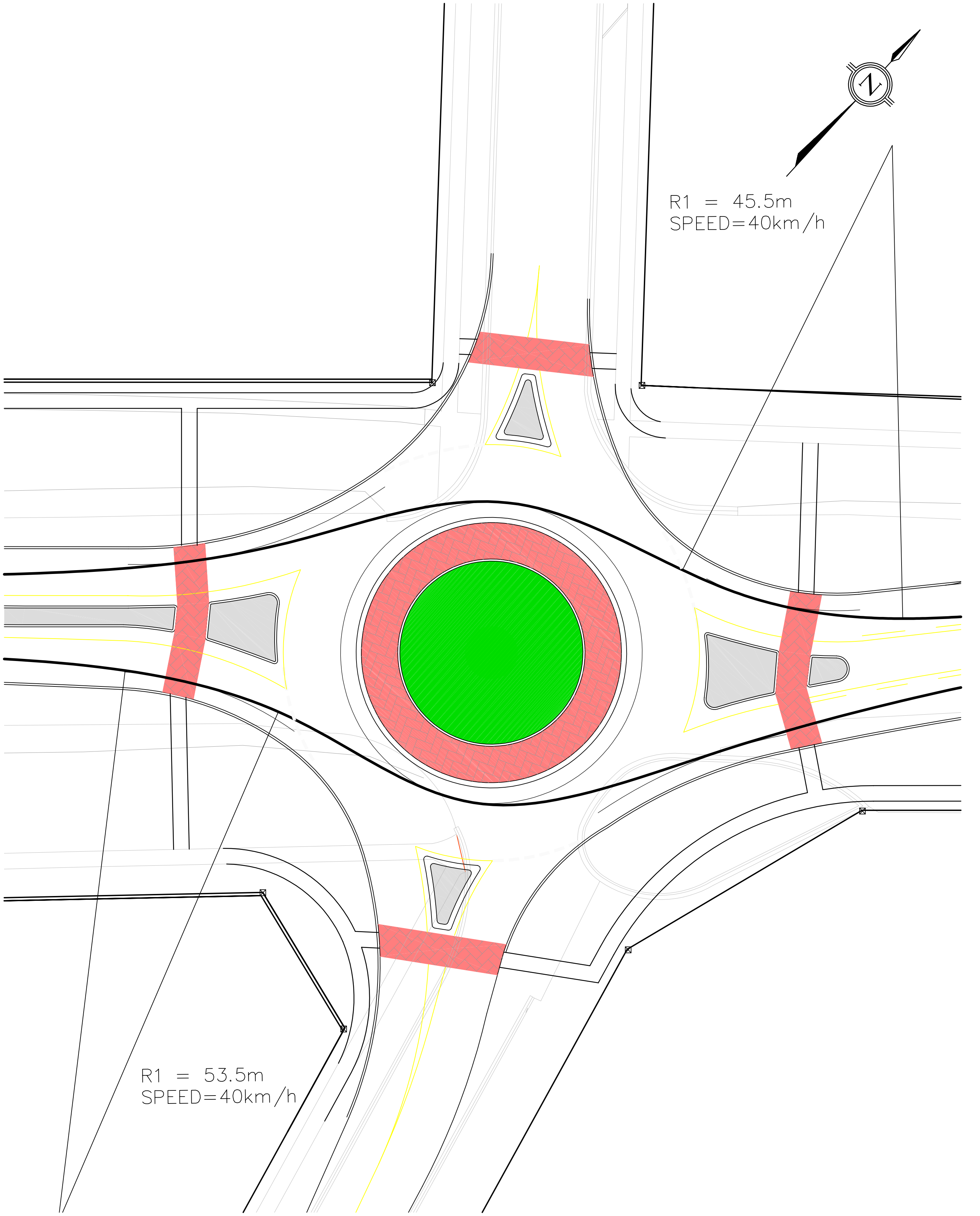
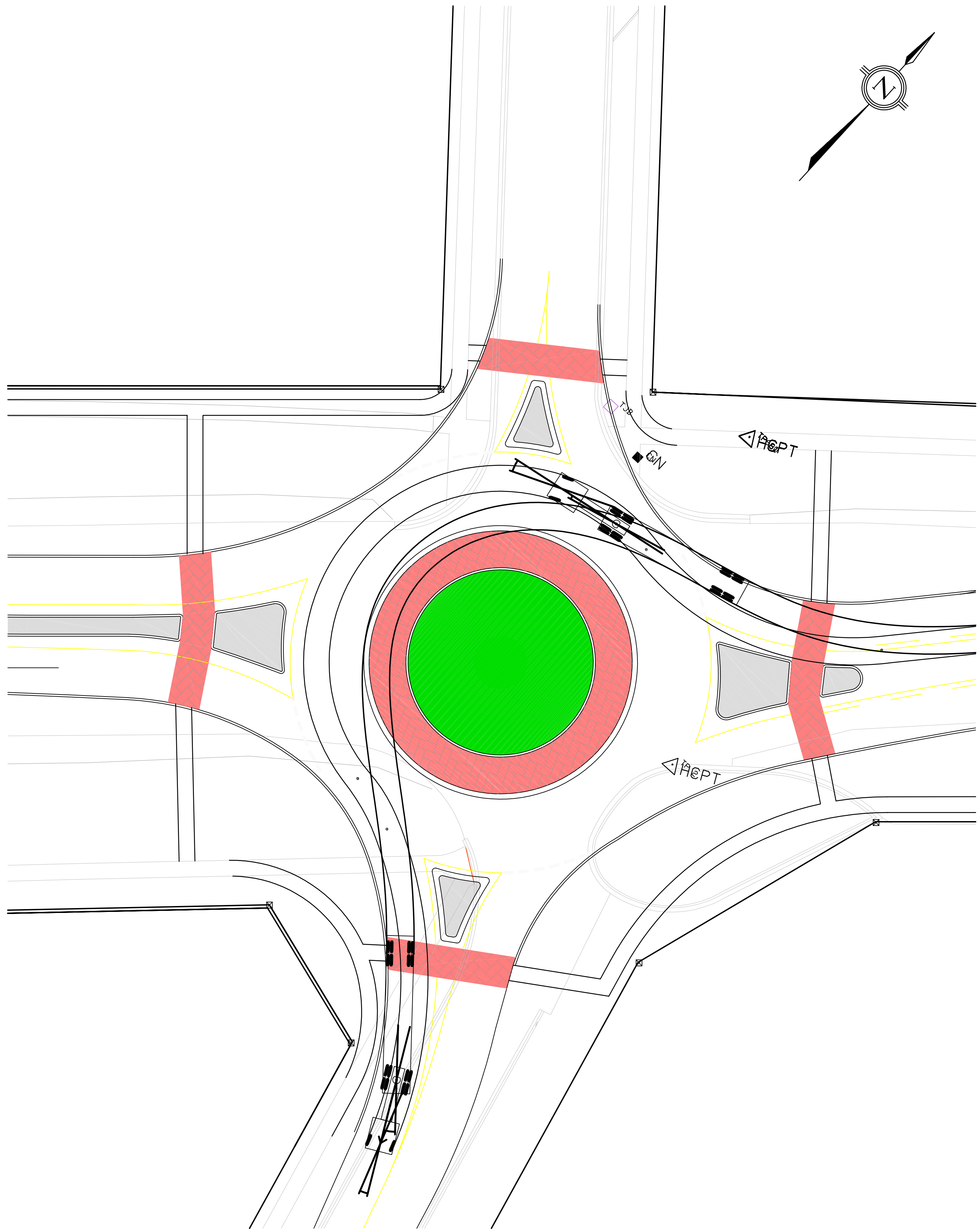


FIGURE 5 – RODEL RESULTS FOR THE A.M. PEAK PERIOD
PESSIMISTIC CAPACITY (85% CONFIDENCE)



DATE MAY, 2002	FASTEST PATH & VEHICLE SPEEDS ATTACHMENT 3	SRM ASSOCIATES 110 Scotia Court Unit 41 Whitby, ON L1N 8Y7 T 905.686.6402 F 905.432.7877 srmassociates.org
SCALE 1:500		

R/P Date – MAY 14, 2002   File: 02055ALL.DWG



DATE MAY, 2002	SCALE 1:500

TRUCK TURNING PATH
ATTACHMENT 1

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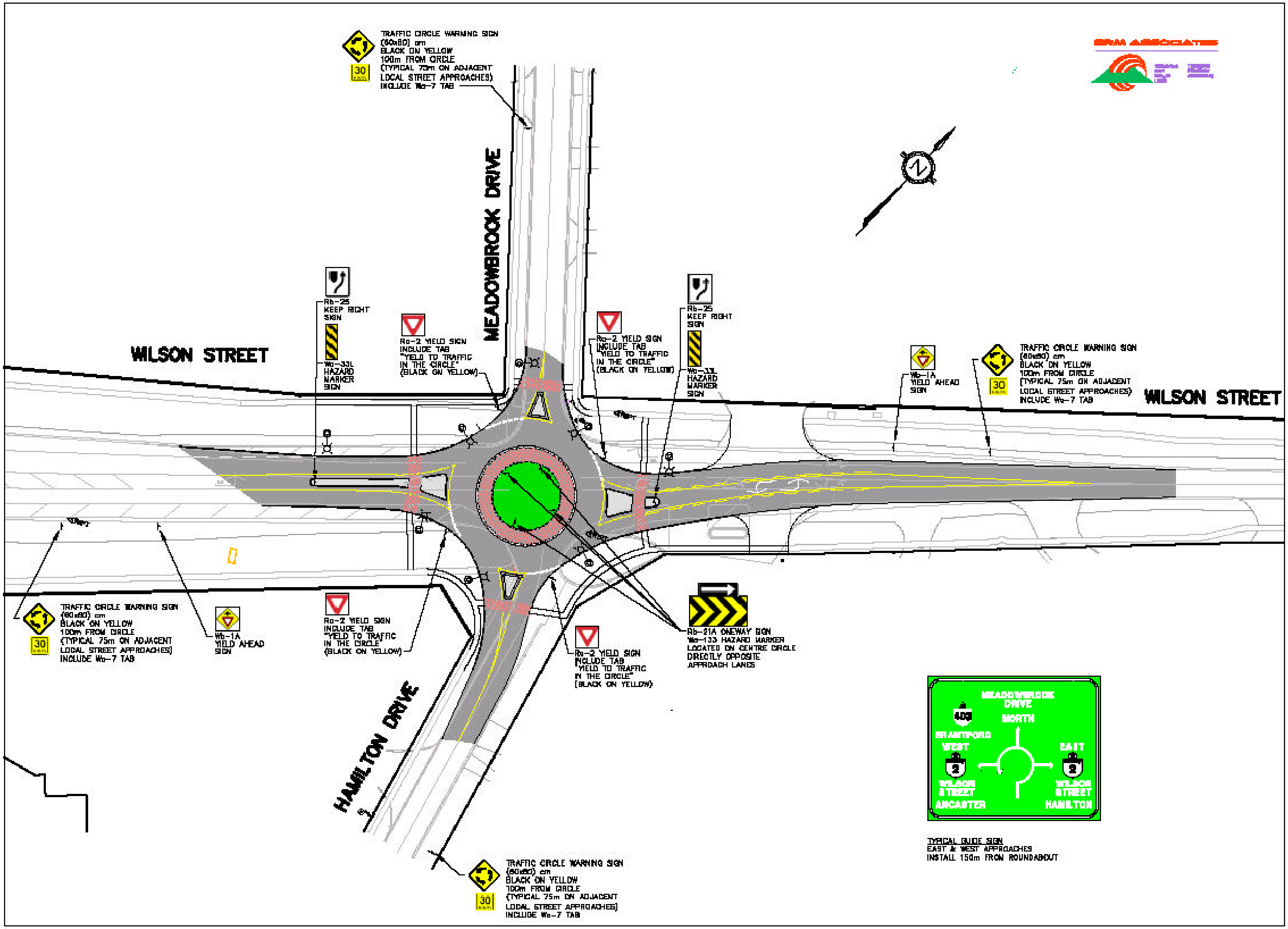

FIGURE 8 - PRELIMINARY DESIGN PLAN

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