Paper Title:

EVALUATION OF PERFORMANCE OF MODERN ROUNDABOUTS USING PARAMICS MICRO-SIMULATION MODEL

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Abstract:

Use of modern roundabouts as a viable traffic control measure instead of traffic signals or priority intersections is increasing in many jurisdictions in North America. Their strength lies in their ability to reduce the number of vehicular conflicts at intersections and thereby enhance intersection capacity and safety. There are additional intangible benefits of roundabouts such as their traffic calming effect, gateway feature and aesthetics. Although on the rise, adoption of modern roundabouts as a common intersection form is hindered by the general lack of suitable analysis tools that can be used to evaluate their operational performance and thereby facilitate an objective comparison between them and other intersection control strategies.

This study investigated the viability of using Paramics micro-simulation model in evaluation of operational performance of roundabouts. The Paramics model is an advanced micro-simulation tool with capabilities of modelling both roundabout and traffic signals to acceptable level of detail. Motion of an individual vehicle is simulated in small time steps and each vehicle is followed from the time it is generated into the network to the point of its exit. Vehicular behaviour at roundabouts is modelled on the basis of a gap acceptance approach.

Drawing from recent experiences, the paper reviews the practical steps and efforts required to model a modern roundabout and compare it with a traffic signal alternative in a typical Canadian urban environment using the Paramics model. It describes the model's ability to capture the effects of various geometric and traffic features like approach angle, inscribed circle, number of circulatory lanes, position of the stop line and proportion of turning flows, and evaluates their impacts on the resulting capacities. However, because Paramics is a lane based model, it was unable to analyze the effects of entry width. Evaluation of the results indicates that the model is able to capture most of the important features of a roundabout and provides a good basis for comparing their operational performance to that of other intersection forms.

KEY WORDS: Roundabout, traffic analysis, micro-simulation modeling

4158 words + 6 Figures + 4Tables = 6658 Words

1. INTRODUCTION

Use of modern roundabouts as a viable traffic control measure instead of traffic signals or priority intersections is increasing in many jurisdictions in North America. Their strength lies in their ability to reduce the number of vehicular conflicts at intersections and thereby enhance intersection capacity and safety. There are additional intangible benefits of roundabouts such as their traffic calming effect, gateway feature and aesthetics. Although on the rise, adoption of modern roundabouts as a common intersection form is hindered by the general lack of suitable analysis tools that can be used to evaluate their operational performance and thereby facilitate an objective comparison between them and other intersection control strategies. Performance of modern roundabouts are affected by traffic and geometric features including approach flows, circulatory flows, inscribed circle diameter, approach angle, flare length and lane width.

As the use of roundabouts increases, there is a growing need for reliable analysis tools that can be used to analyze roundabout capacity and operational performance for comparison with other alternative strategies. Analysis of roundabouts is primarily achieved by using empirical or analytical approaches. Empirical approaches rely on field data to develop linear relationships between geometric design features and performance measures such as capacities and delays. Such approaches have been used widely in Europe and especially in the United Kingdom which has a long tradition of using roundabouts. Analytical models are based on gap acceptance theories that attempt to predict capacity on the basis of acceptable gaps and vehicle move up times at priority intersections.

Several analytical and micro-simulation models now offer options of roundabout analysis based on either the gap acceptance or empirical approaches but further calibration work under various operating conditions is still required to confirm their reliability. Examples of such models are SIDRA, RODEL, VISSIM, SYNCHRO and PARAMICS. RODEL is an empirical model based on empirical studies in the UK which have been criticized as being over sensitive to certain geometric features possibly because the database they were developed from contained a large number of poorly designed roundabouts (**1**). SIDRA was developed primarily for Australian operating conditions but has been expanded to include the UK regression equations as well as various gap acceptance models. Much of the information contained in the FHWA Report – Roundabouts, an Information Guide (**2**) was based on analysis using SIDRA. The *Highway Capacity Manual* (**3**) also outlines a procedure for analysis of simple roundabouts with circulating volumes of up to 1200 vehicles per hour using gap acceptance principles but without any geometric features. Roundabout analysis in the latest versions of VISSIM and SYNCHRO follow the HCM approach and are insensitive to the geometric features.

Unlike the above noted models, analysis in PARAMICS is based on the gap acceptance approach and takes some roundabout geometric features into account. The Paramics model is an advanced micro-simulation tool with capabilities of modelling both roundabouts and traffic signals to acceptable level of detail. Motion of an individual vehicle is simulated in small time steps and each vehicle is followed from the time it is generated into the network to the point of its exit. More detailed review of the Paramics model is provided in the second chapter of this paper.

This paper reviews evaluation of a roundabout performance using the PARAMICS model. It aims at demonstrating how a roundabout can be modeled and draws from recent experiences to present practical steps and efforts required to model a modern roundabout and compare it with a traffic signal alternative.

The paper is divided into four sections, the first being the introduction. The second section provides an overview of the PARAMICS model and its application to both roundabout and traffic signal analysis. The study scenario is described in the third section. This includes as description of how the model was used to evaluate a roundabout option at a ramp terminal of Highway 417 in the City of Ottawa to demonstrate its application. Finally, conclusions and recommendation are outlined in the fourth section.

2. OVERVIEW OF PARAMICS

PARAMICS is one of the micro-simulation models available for commercial usage. Other well known examples include VISSIM, INTEGRATION, AISUM, and TSIS (formerly CORSIM/FRESIM). Micro-simulation modelling is recognized as the only available method that allows examination of complex traffic problems including intelligent transportation systems, complex junctions, effects of incidents, and congested networks. Whereas traditional models provide aggregated representation of traffic that is typically expressed in terms of total flows per hour, micro-simulation models depict movement of individual vehicles and follow them from the time of generation to the time they exit the network. Stream characteristics are derived from behaviour of individual vehicles which are controlled through various models, and the overall traffic performance is dependant upon driver and vehicle capabilities. Movements of individual vehicles are usually controlled by car-following models, lane change models and gap acceptance rules. These rules range from simple deterministic relationships and numerical approaches (**4**) to more complex functions involving advanced methods like fuzzy logic and neural networks (**5**).

Model Structure

PARAMICS in an acronym for parallel microscopic simulation and was developed as part of large research and development projects under the European Community Drive – I project. The complete model range is composed of six modules, although the program is available in suites which may include some or all of the model modules. The six components are:

- **Modeller**: The core simulation tool;
- **Processor**: The batch assignment tool;
- **Analyser**: The post simulation data analyser tool;
- **Programmer**: The API interface;
- **Monitor**: The pollution modeling interface; and
- **Estimator**: OD estimation tool.

The Modeller and Analyser are the basic components required to run simulations and analyze the output. Network build-up, simulation control and demand information is carried out using the Modeller. Simulation output from the modeller is then loaded into the Analyzer for detailed analysis. The Processor is a batch assignment tool and is useful for running the simulation in a batch model. This allows running of predefined scenarios which may included simulation runs with different random numbers and other control parameters, varying flow levels and analysis for various time periods. The PARAMICS Programmer is an Application Programming Interface (API) which provides the modeller with an opportunity to simulate additional features and user defined algorithms and functionality such lane change models and car following rules. In addition, it allows for development of plug-ins to interface PARAMICS with third party software or real word systems such as network control systems. The PARAMICS Monitor is an emissions calculating tool that allows inputting of emissions data based on speed and acceleration of different engine categories. It is primarily based on emissions inventories of the United Kingdom.

The Estimator is an OD matrix estimation package that operates at the microscopic level and integrates seamlessly with the Modeller.

PARAMICS is available for a variety of platforms including Windows and other operating systems, although it was developed to run on a Unix environment. For that reason, operating the program on a Windows environment requires a connecting interface which is provided by a third party vendor software known as the Hummingbird Program.

The simulation algorithm

Vehicular movements in PARAMICS is achieved through car following and lane change models that are based on a driver-vehicle-unit's desire to achieve target headway and speeds. Driver-vehicle-units (DVU) terminology is used to reflect the fact that movements are affected by both vehicular and driver characteristics. From a stopped position, a DVU will accelerate to desired speeds and headways in free flow conditions or to those it can safely maintain in constrained flow conditions. A DVU will attempt to change lanes if sufficient gaps are available to enable it complete the manoeuvre safely and if doing so would enhance its target movement parameters (**6, 7**).

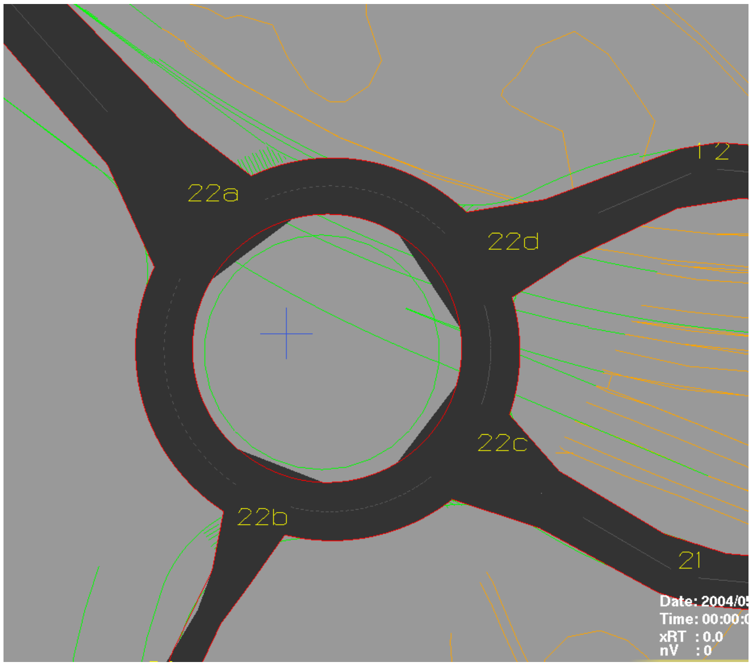
Intersection Modelling

PARAMICS can be used to model signalized intersections, allway or two way stops, roundabouts and other priority intersections. PARAMICS permits modelling of actuated traffic signals and right turn on red which is coded by combining priority with signalization plans. To achieve that, some basic programming effort is required and program codes that take the general format of the C/C++ language is used. The programming offers flexibility in coding vehicle actuated plans, ramp metering and other types of demand responsive systems.

Roundabouts are created in the model by expanding a single node into more nodes at each approach. The geometric layout of the roundabout depends on the number of approaches and their alignment at the intersection. As can be seen in **Figure 1**, node 22 is expanded into four sub–nodes with the subscripts **a** to **d** for each approach. Turning movements are specified to reflect the required usage of the circulatory lanes.

Traffic behaviour at the roundabouts is simulated on the basis of a gap acceptance regime. DVU on an approach arm slows down and could possibly stop to wait for acceptable gaps in the circulatory arm. Where gaps are readily available the entry speed is controlled by the roundabout geometric elements and DVU characteristics. In a sense this implies that roundabouts operate in PARAMACS as a series of T intersections but higher speeds can be accommodated depending on the geometrics features.

Figure 1: Screen Image of a Roundabout in the Paramics Modeller



Calibration and Validation Requirements

Calibration and validation form a crucial element of the simulation task through which confidence in the model results can be ascertained. Because of the stochastic nature of traffic, variations between the model and observed data is always expected and the onus is upon the model developer to establish the desired reliability level and the validation effort required to achieve it (**5, 7, 8**). The calibration process for PARAMICS follows similar procedures to conventional traffic models with the implementation of a two phase process covering a thorough check of the input data and comparing modelled results with observed data.

Comparison of modelled and observed data is possible for operational analysis where an existing system is being studied. PARAMICS applies the GEH static, a modified chi-squared statistic that incorporates both relative and absolute differences, in comparison of modelled and observed volumes. Generally the GEH static should be used in comparing hourly traffic volumes only. It is represented by the equation as below:

$$GEH = \sqrt{\frac{(M - O)^2}{0.5 * (M + O)}}$$

Where

M:	simulated flows
O:	observed flows

Various GEH values give an indication of a goodness of fit as outlined below:

GEH < 5	Flows can be considered a good fit
5 < GEH < 10	Flows may require further investigation
10< GEH	Flows cannot be considered to be a good fit

Once the model has been calibrated for the existing situation it can then be used to model future scenarios.

3. ANALYSIS OF STUDY AREA

Description of Study Area

PARAMICS model was used to evaluate a proposed roundabout alternative being considered at the Highway 417 E-NS off-ramp at Island Park Drive in the City of Ottawa. The off ramp is proposed as part of the Highway 417 Preliminary Design Study of highway from Highway 416 to Andersen Road in the City of Ottawa. A roundabout seems to be a feasible solution because of the traffic volume and alignment considerations. Figure 2 shows the representation of the study area in the Paramics model. The network was created using an Autocad DXF overlay of the surrounding area, which can be seen in green and orange.

The analysis of alternatives at the study area was conducted for both AM and PM peak periods for the horizon year 2021. The feasibility of locating a roundabout was evaluated for the intersection of Highway 417 E-NS off ramp terminal at Merivale Road and Island Park Drive. The Projected traffic volumes for the horizon year are summarized in **Table 1.**

Figure 2 : Paramics Representation of Study Area

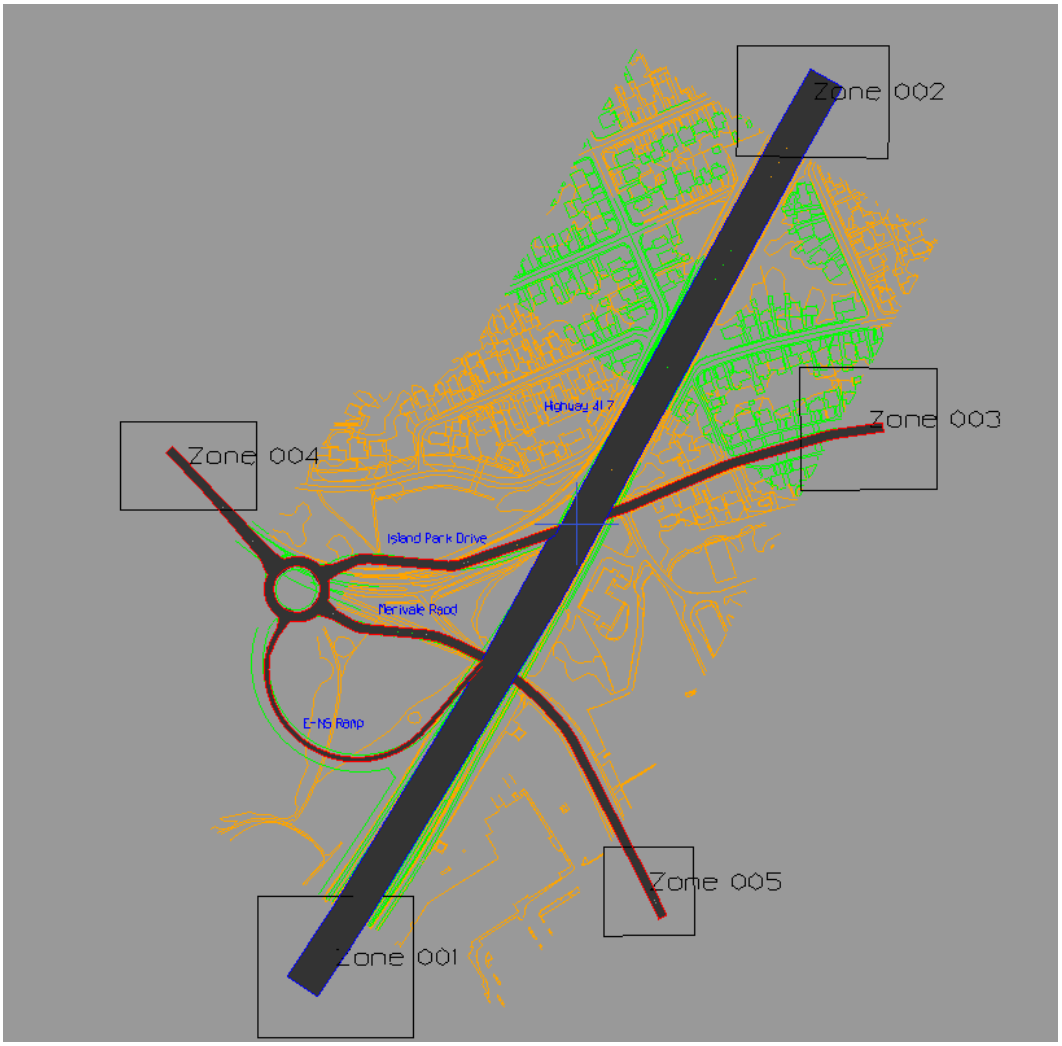


Table 1: Projected Turning Movements at the Intersection

Approach	Dir	AM peak	PM Peak
E-NS Ramp (EB)	RT	150	90
	TH	0	0
	LT	160	113
Merivale NB	RT	234	366
	TH	5	19
	LT	0	0
Island Park Road (WB)	RT	647	944
	TH	0	0
	LT	0	0
Merivale SB	RT	0	0
	TH	589	566
	LT	420	267
Total Intersection Volume		2205	2365

In addition, the analysis was conducted using various vehicle types including cars and heavy vehicles, each with appropriate dimensions and performance parameters. The assumed traffic composition and the performance parameters of each vehicle type are provided in **Table 2**. These traffic characteristics together with volume information were incorporated in the model and used in the analysis.

Typical outputs of the PARAMICS include realistic animations and graphical representation of measures of performance such as speeds, delays, queues, volumes and level of service which make it easy to understand the simulation results. For example **Figure 3** provides a screen shot of the traffic performance in the study area and shows the expected queuing on the Highway 417 off-ramp. In addition, **Figure 4** provides a colour coded plot of link speeds which is very helpful in identifying bottlenecks and areas where problems may occur.

Table 2: Vehicle Performance Characteristics used in the Analysis

Type	Proportion in Traffic	Dimensions		Performance – Maximum Values		
		Length [m]	Width [m]	Speed [km/h]	Acceleration [m/s/s]	Deceleration [m/s/s]
Car	90%	5.0	1.6	160	2.5	4.5
Bus/Coach	1%	10.0	2.5	130	1.2	3.7
Light goods vehicle	4%	8.0	2.3	130	1.8	3.9
Straight Truck	2%	11.0	2.5	120	1.4	3.7
Truck with trailer	3%	19.0	2.4	105	1.1	3.2

Figure 3: Three dimensional screen shot of the study area showing queuing on the ramp

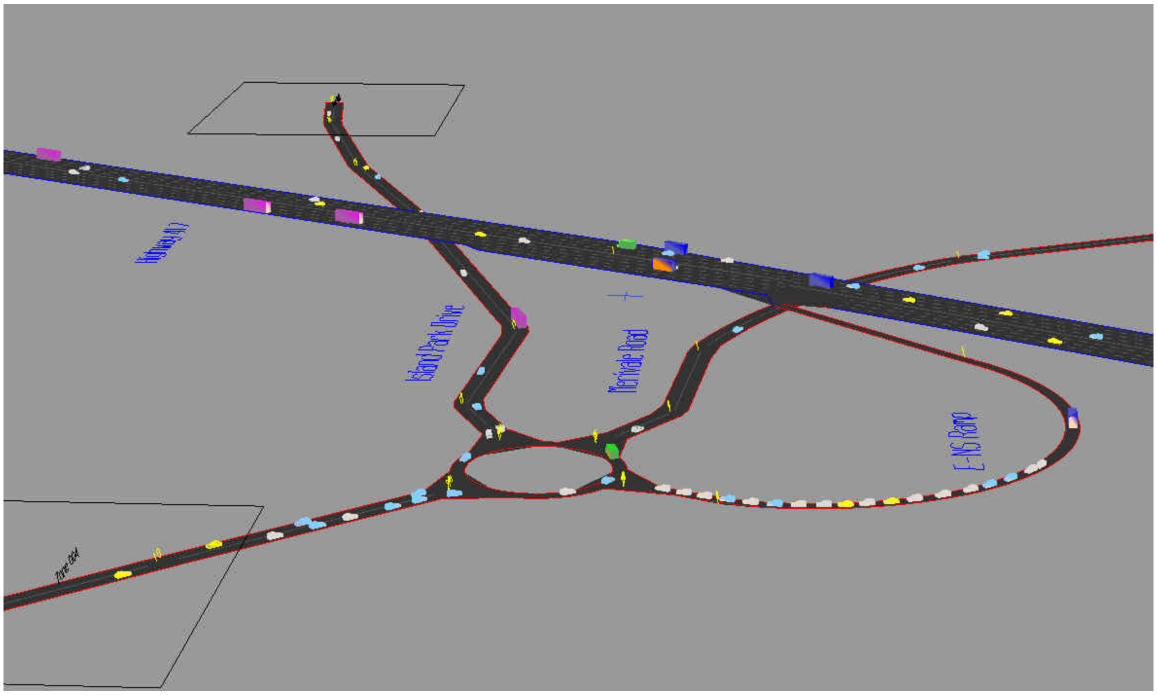
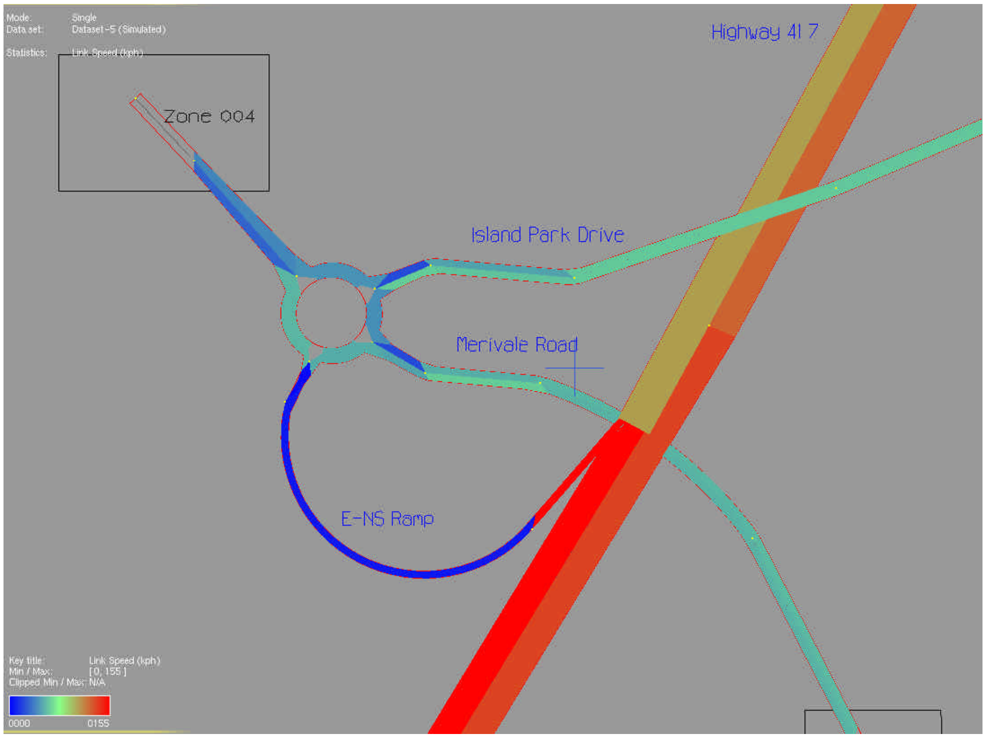


Figure 4: Colour Coded Plot of Links Speeds



Mode: Single
Data set: Dataset -5 (Simulated)
Statistics: Link Speed (kph)
Key title: Link Speed (kph)
Min / Max: [0, 155]
Clipped Min / Max: N/A

Analysis of Results

The first step of the evaluation involved modelling the ramp terminal as a signalized intersection using both PARAMICS and SYNCHRO. As far as possible, an attempt was made to model the intersection in exactly the same way in the two models and the total splits for each approach were maintained constant as well as the overall cycle time. However, for the SYNCHRO model runs, a separate left turn lane was provided for the southbound approach to minimize the obtained queues and delays. **Table 3** shows a comparison of the results obtained from using the respective programs.

Table 3: Intersection Performance with Signalized Alternative during AM peak

Approach	AM Volume	Split [s]	SYNCHRO	PARAMICS
			Delay [s]	Delay [s]
E-NS Ramp	310	24	224*	25
Merivale NB	239	22	46	24
Island Park WB	684	16	29	10
Merivale SBL**	420	28	50	13
Merivale SBT	589	50	50	13
Intersection summary	90s Cycle		68	15

*v/c ratio > 1.0

**separate lane for SYNCHRO

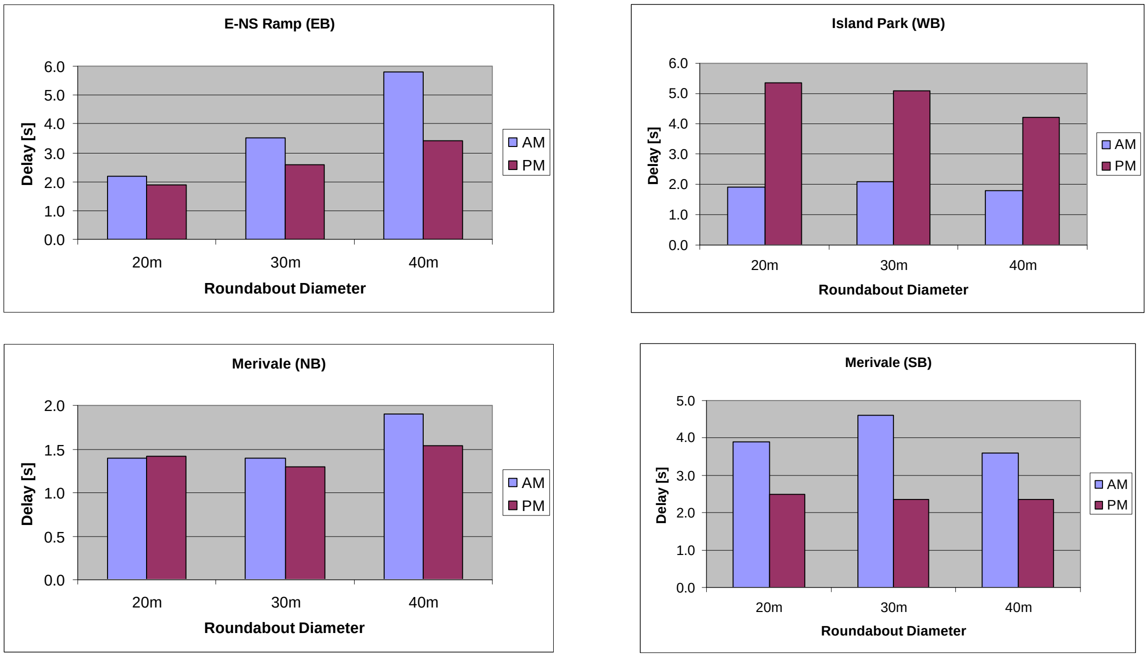
The results indicate that with a signalized option, the delays at the intersection will be substantial with intersection delays of 68 and 15 seconds for the SYNCHRO and PARAMICS analysis respectively. SYNCHRO produces much higher delays than the ones predicted by the PARAMICS model although use of optimized signal settings would result in slightly less delays. These are in agreement with previous studies that indicate that results obtained from deterministic operational models such as SYNCHRO generally tend to be more conservative than those of micro-simulation approaches.

Further analysis was conducted to compare the signalized option with roundabout options. The PARAMICS model is able to model both roundabouts and signalized alternatives and therefore enables comparison of the two alternatives on the same platform. Three different roundabout diameters of 20m, 30m and 40m were modelled and compared with the signalized intersection option. The ensuing delays obtained from the analysis during the AM peak period are shown in **Table 4**. The effect of the size of a roundabout was investigated by comparing the delays obtained by conducting the analysis with roundabouts of various diameters at the intersection. This analysis was done for both AM and PM peak operations and the results summarized in **Figure 5**.

Table 4: Delay in seconds from Signalized and Roundabout Options

Approach	Signalized Option	Roundabout Diameter		
		20m	30m	40m
E-NS Ramp	25	2.2	3.5	5.8
Merivale NB	24	1.4	1.4	1.9
Island Park -WB	10	1.9	2.1	1.8
Merivale SB	13	3.9	4.6	3.6

Figure 5 : Effect of Roundabout Size on Delay

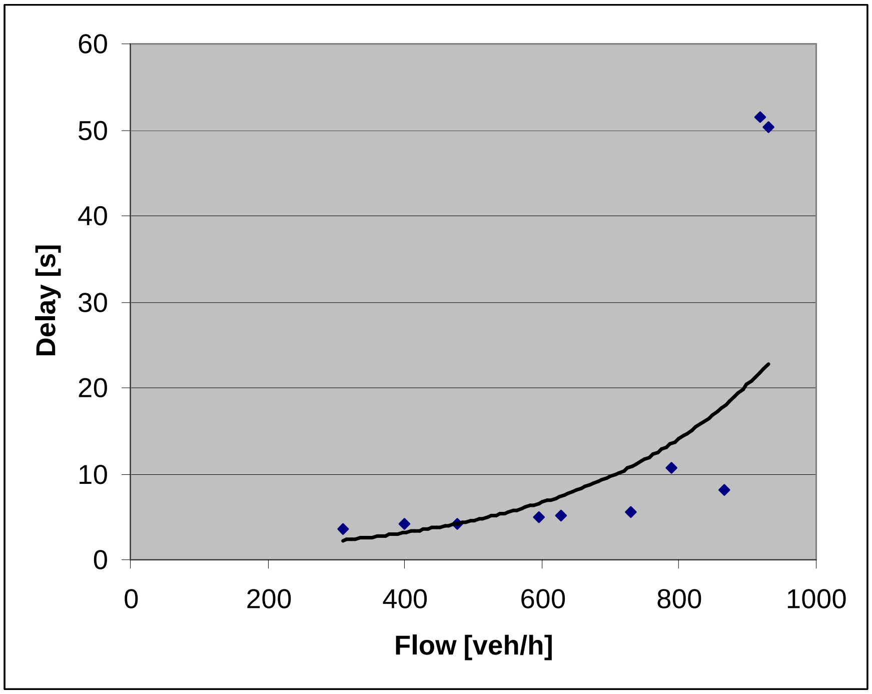


The results indicate that use of a roundabout option would result in substantial improvement in the overall performance at the intersection with delays reducing from an average of 15 seconds to less than 6 seconds for all roundabout configurations considered. These results indicate that a roundabout would be better suited for implementation at the intersection than traffic signals on the basis of performance.

Moreover, the results indicate that delays would generally increase with roundabout size at the EB and NB approaches. For the WB and SB approaches the results are somewhat mixed and no general trends are clearly discernible. The differences arise primarily because of the circulating flows. Whereas EB and NB approaches have large conflicting circulatory flows, the latter do not. As the size of the roundabout increases, vehicles on the circulatory lanes may achieve higher speeds and therefore it becomes harder for the ones on the approaches to find acceptable gaps. It can be concluded therefore the effect of roundabout size on approach delay may vary depending on the volume of the conflicting flow on the circulatory lanes and the origin and destination of the flows.

The effect of approach volume was also investigated by increasing the volume on the off ramp gradually while maintaining the circulatory flow and the roundabout size. The size of the roundabout used in this analysis was 30m and generally the traffic conditions were based the AM peak conditions except on the EB approach where volumes were varied for every run. The obtained results are plotted in **Figure 6**. The delays are low initially but increase exponentially as the volume approaches capacity. These are generally expected and are in agreements with theory and as well as other published materials (**1, 2**). It can be inferred that the expected capacity of the approach is approximately 900 vehicles per hour.

Figure 6 : Variation in Delay with Approach Volume



4. CONCLUSIONS

The analysis in this paper demonstrates that PARAMICS model can be used to analyse the performance of a roundabout and compare it with signalized alternative or other priority options. The practical application in evaluation of a roundabout provides an overview of the data requirements and the likely calibration and validation issues. Use of the model provides insights into the effects of roundabout size and circulating flows. It shows that the diameter of a roundabout has some effects on approach delay but the nature of the effect depends on characteristics of the conflicting flow within the circulatory area. This demonstrates that the model is sensitive to both traffic and geometric features of a roundabout. However, not all the geometric features can be modelled in PARAMICS. The results and trends obtained are in agreement with results of the gap acceptance models and other available roundabout models.

It can be concluded that PARAMICS offers a viable method for analyzing roundabouts. However, further analysis is required to establish sensitivities to other traffic and geometric features as well as to validate the model results with existing roundabouts.

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