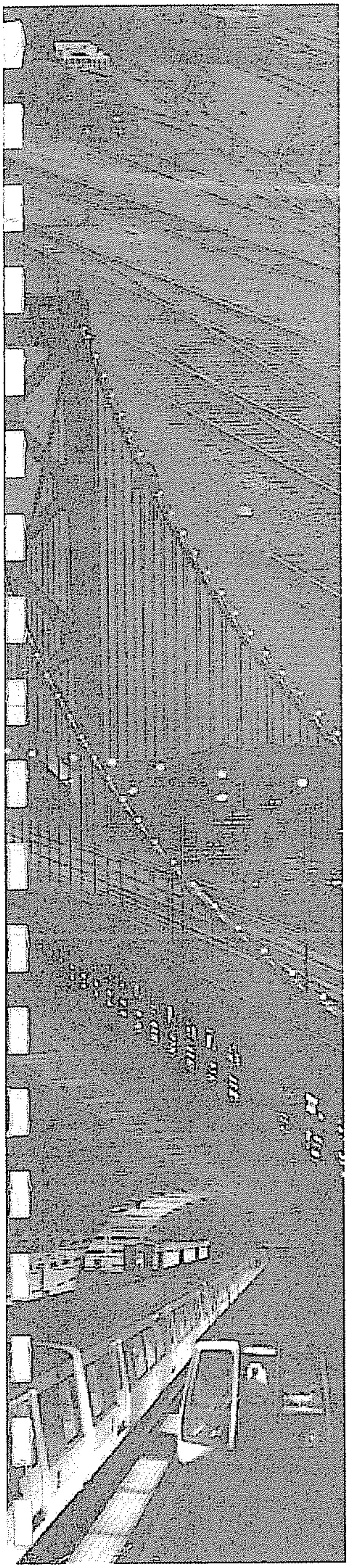


DCT 193

Comparative Analysis and Development of a Rating System for the Conversion of All-Way Stop Controlled Intersections into Roundabouts

By

Evy Vlahos
Abishai Polus
Ardeshir Faghri

Department of Civil and Environmental Engineering
College of Engineering
University of Delaware

May 2006

Delaware Center for Transportation
University of Delaware
355 DuPont Hall
Newark, Delaware 19716
(302) 831-1446

The Delaware Center for Transportation is a university-wide multi-disciplinary research unit reporting to the Chair of the Department of Civil and Environmental Engineering, and is co-sponsored by the University of Delaware and the Delaware Department of Transportation.

DCT Staff

Ardeshir Faghri
Director

Jerome Lewis
Associate Director

Ellen M. Pletz
Assistant to the Director

Lawrence H. Klepner
T^2 Program Coordinator

Matheu J. Carter
T^2 Engineer

Sandra Wolfe
Senior Secretary

DCT Policy Council

Robert Taylor, Co-Chair
Chief Engineer, Delaware Department of Transportation

Michael Chajes, Co-Chair
Dean, College of Engineering

The Honorable Tony DeLuca
Chair, Delaware Senate Transportation Committee

The Honorable Richard Cathcart
Chair, Delaware House of Representatives Transportation Committee

Timothy K. Barnekov
Dean, College of Human Resources, Education and Public Policy

Harry Shenton
Chair, Civil and Environmental Engineering

Ralph A. Reeb
Director of Planning, Delaware Department of Transportation

Stephen Kingsberry
Director, Delaware Transit Corporation

Shannon Marchman
Representative of the Director of the Delaware Development Office

Roger Roy
Representative, Transportation Management Association

Jim Johnson
Executive Director, Delaware River & Bay Authority

Delaware Center for Transportation
University of Delaware
Newark, DE 19716
(302) 831-1446

Comparative Analysis and Development of a Rating System for the Conversion of All-Way Stop Controlled Intersections into Roundabouts

by

Evy Vlahos
Graduate Research Assistant

Ardeshir Faghri
Director

and

Abishai Polus
Visiting Professor

A report submitted to the Delaware Center for Transportation (DCT), Department of Civil and Environmental Engineering, College of Engineering, University of Delaware

May 2006

DCTR422142

Acknowledgement

The authors would like to express great appreciation for all the ideas and help received from Mr. Dan LaCombe of the Delaware Department of Transportation Planning Division. Without his visionary ideas, this project would have never been initiated.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Modern roundabouts are becoming increasingly popular in the United States and merit consideration for use at intersections facing operational and/or safety problems. In this thesis, a knowledge-based expert system is used to create an automated tool for evaluating an all-way stop-controlled (AWSC) intersection for its potential success if converted to a roundabout. Traffic analysis software is used to conduct a comparative analysis between AWSC, roundabout, and signalized intersections. The software analysis was calibrated for local (Delaware/Maryland) conditions using driver gap acceptance characteristics obtained from data collection at two Maryland roundabouts.

Data reduction yielded a local driver critical gap of 3.9 seconds and a follow-up time of 2.0 seconds; both values are slightly lower than those recommended by the Highway Capacity Manual. The findings of the comparative analysis agree with earlier studies in showing that AWSC intersections always perform "worse" (less capacity, more delay, etc.) than both roundabouts and signalized intersections under the same traffic and geometric conditions. Results from the software analysis were then used in developing the rules of the expert system. The developed system was tested using real AWSC intersection traffic data. It was shown that the system is capable of logically evaluating an AWSC intersection and recommending an intersection type (roundabout or signal) to which to convert. The rating system also provides advice on a variety of issues associated with the new intersection type and references for further guidance.

Chapter 1

INTRODUCTION

Traffic growth and congestion in the United States continue to outpace growth in highway capacity, with the majority of congestion occurring at or near intersections [1]. At-grade intersections are the most complex individual locations that drivers encounter within a street or highway system [2]. At a typical intersection of two two-way streets, twelve legal vehicle movements (left-turn, through, and right-turn from the four approaches) interact with one another, creating a large number of potential conflicts between vehicles. The critical task of the traffic engineer, then, is to control and mange these conflicts in a manner that ensures safety and provides for efficient movement of vehicles through the intersection [2].

All-way stop-controlled (AWSC) intersections are a common form of intersection control around the world and throughout the United States as well [3]. Familiar and comfortable with this form of traffic control, the public tends to view stop signs as a panacea for traffic problems, particularly vehicle speeding and safety. Many traffic engineers, however, may disagree with this opinion, pointing out that the confusion that drivers often exhibit under this form of control seems to negate any of the benefits it might provide [2]. Another drawback is the unnecessary delay caused to vehicles when they are required to stop even when no conflicting vehicles are present, most often during non-peak times. Right-angle collisions, the most severe of collisions, commonly occur at AWSC intersections as a result of drivers failing to completely obey the stop control.

When the number of accidents per year at an AWSC intersection is a cause of concern or when delays to vehicles at the intersection reach unacceptable values, a traffic engineer is called upon to assess the situation and make recommendations as to how to improve operations and/or safety. Oftentimes, and if the appropriate warrants specified in the *Manual on Uniform Traffic Control Devices* (MUTCD) [4] are met, a traffic signal will be recommended for installation at the intersection, due to its ability to alternately assign right-of-way to specific movements, which substantially reduces the number and nature of intersection conflicts. Costs involved in the installation and maintenance of traffic signals are much greater than those for stop-controlled intersections, however. These costs include those for power supply, signal controller, detectors, signal heads, support structures, and other items, and can run into the hundreds of thousands of dollars for a complex intersection. "Because of this, and because traffic signals introduce a fixed source of delay into the system, it is important that they not be overused; they should be installed only where no other solution or form of control would be effective in assuring safety and efficiency at the intersection [2]."

Roundabouts are garnering a growing interest in the United States partially because of their successful implementation abroad, particularly in European countries and in Australia. Intersection design practice in these countries has significantly changed due to the good performance of roundabouts as well as the public's acceptance of them [5]. Today's modern roundabouts are distinctly different in design and operation than earlier forms of circular intersection control used in the United

States. When used under the appropriate geometric and traffic conditions, the modern roundabout can provide advantages over conventional cross intersections in terms of operational performance, environmental considerations, safety, maintenance costs, and aesthetics.

1.1 Problem Statement

The Federal Highway Administration (FHWA) published *Roundabouts: An Informational Guide* [6] in 2000 as federal design guidelines meant to encourage uniform roundabout practice in the United States. Prior to this publication, practitioners followed a variety of design guides developed by state departments of transportation, consulting firms, and foreign government agencies and research institutes.

Roundabouts are still a relatively new form of intersection control in the United States, not only for the public, but also for traffic engineers. Traffic engineers having little or no experience with roundabouts can be faced with a daunting task in determining whether or not a roundabout is a feasible alternative to a signal at an AWSC intersection.

In addition to the design aspects and specifications of a proposed roundabout, numerous other issues must be considered. First of all, are the traffic volumes appropriate for a roundabout? What about future volumes? What are the proportions of turning movements? Are vehicles at the intersection currently experiencing excessive delays? Is there a history of accidents at the intersection? Is the intersection in close proximity to others, and if so, are these intersections part of a coordinated signal system? This is an important consideration since a roundabout would disrupt such a system.

If the AWSC intersection does experience many accidents and excessive delays exist also, a traffic signal could be a consideration, if the MUTCD warrants are met. But what if the MUTCD warrants are not met? Like AWSC intersections, even signals can create unnecessary delay to an approach when no conflicting vehicles are present, if they are not actuated. However, making a signal actuated requires more sophisticated equipment, which would further increase costs. If a roundabout could provide equal or superior operational performance to a signal, actuated or not, and for a lower overall cost, why not choose the roundabout?

These specific advantages address the primary reasons why a traffic signal would be installed: to increase capacity (thereby improving LOS), to improve safety, and to provide for orderly movement through a complex situation. The MUTCD states that, "since vehicular delay and the frequency of some types of crashes are sometimes greater under traffic signal control than under stop sign control, consideration should be given to providing alternatives to traffic control signals even if one of more of the signal warrants has been satisfied" [4].

The various considerations listed above are many for an engineer to deal with, in addition to the task of having to gain public acceptance for a proposed roundabout, which many times is a major obstacle in the planning process.

1.2 Purpose and Objectives

The purpose of this study is to create an automated tool to assist traffic engineers and planners in determining how feasible it is to convert an existing all-way stop-controlled intersection to a roundabout. This tool will be based on results of comparison studies using intersection analysis software and will also incorporate recommendations from several state roundabout guides and the FHWA, which have been reviewed along with other work previously published by researchers. Since this thesis evolved from a study requested by the Delaware Department of Transportation (DelDOT), the work for this thesis also included data collection at nearby roundabouts so that the software analysis could be calibrated for local driver characteristics. Thus, the results of this thesis will be useful for traffic planning in Delaware as well as in other states with similar driver characteristics.

The development of the automated tool will be a great help to traffic engineers faced with the decision of how to improve an all-way stop-controlled intersection. It will be of particular help for younger engineers or those engineers having little or no experience with roundabouts. While an older, more experienced engineer would know what traffic and design characteristics to look for in an intersection for its potential success as a roundabout, a less experienced engineer would not.

As previously mentioned, several state departments of transportation have published their own roundabout design and planning guides, however these guides vary from one another in various ways. Most, if not all, of the guides refer readers to the FHWA *Roundabouts: An Informational Guide* [6] for more detailed guidelines, however this still may not be clear enough for the beginning engineer. This thesis will provide an automated tool that will better guide the planner through the steps in determining if an intersection is a prime location for installing a roundabout. The rating system will not provide a clear-cut answer to the engineer; the useful quality of using an expert system is that the program will offer the engineer a selection of recommendations, but the ultimate decision will be left up to the individual to use his or her best engineering judgment.

This thesis will accomplish the following objectives:

- A literature review of past studies of roundabout operational and safety performance, comparisons of roundabouts with other forms of intersection control, and existing federal and state roundabout guides;
- The collection of local driver gap acceptance data at local roundabout sites;
- The determination of local driver critical gap and follow-up times from this data;
- A comparative analysis of an all-way stop-controlled intersection, a roundabout, and a signalized intersection to note behaviors and patterns in response to the variation of several traffic parameters; and
- The development of an expert system designed to rate an all-way stop-controlled intersection for its potential in being converted to a roundabout, incorporating the results of the comparative analysis and findings and recommendations in existing roundabout guides.

1.3 Scope of the Thesis

Research for this project has involved reviewing the FHWA's *Roundabouts: An Informational Guide* [6] as well as a number of state departments of transportation roundabout guides previously published. Numerous studies evaluating the implementation of roundabouts as replacements to other forms of intersection control have also been collected and reviewed. Many of these studies were published in trade journals such as the *Transportation Research Record* from the Transportation

Research Board (TRB) and *The Journal of Transportation Engineering* from the American Society of Civil Engineers (ASCE). Nearly all of these were studies of U.S. locations and for U.S. conditions.

It is assumed, that the AWSC intersection involved in these studies is experiencing a large amount of accidents and/or failing in operational performance (capacity, delay, etc.) or experiencing some other problems that require it to be assessed for improvement. Otherwise, whether or not to convert to a roundabout would not even be an issue for the intersection.

The comparative software analysis for this thesis is limited to the study of an AWSC intersection, a single-lane roundabout, and a signalized intersection. The focus of the comparisons was between the AWSC and roundabout intersections. All intersections consisted of two perpendicular two-way roads; no other configurations were evaluated. The parameters and their ranges chosen for use in the SIDRA analyses are based on the FHWA's *Roundabouts: An Informational Guide* [6]. Pedestrians and bicyclists were not considered in the comparative analysis. While the SIDRA analyses were calibrated for Delaware/Maryland driver characteristics, the developed expert system may be used by other states or agencies, as it is in general applicable to all states.

1.4 Organization of the Thesis

The organization of this thesis is described below:

Chapter 2 presents some background information on all-way stop-controlled intersections, but the majority of discussion is focused on roundabouts—their history of use in the United States; their distinguishing design and operational characteristics; the benefits that they provide in intersection operations, safety, and costs; and the challenge in gaining public acceptance of them. Additionally, the chapter discusses past studies comparing roundabouts with other forms of intersection control, as well as existing federal and state roundabout guides.

Chapter 3 presents an overview of the SIDRA software and details the collection of data for determining local gap acceptance parameters at roundabouts. The set-up and results of the SIDRA analyses comparing all-way stop-controlled intersections, roundabouts, and signalized intersections are also presented in this chapter.

Chapter 4 discusses the nature and history of knowledge-based expert systems, as well as the Exsys CORVID software and the justification for its use in this thesis.

Chapter 5 discusses the development of the roundabout rating system and its verification using real traffic data.

Chapter 6 is a summary of the thesis and provides conclusions as well as general recommendations drawn from this work.

Appendix A contains tables of data obtained from the SIDRA software analyses for AWSC, roundabout, and signalized intersections for all test scenarios.

Appendix B contains graphs of the SIDRA software analyses for AWSC and roundabout intersections showing changes in each MOE as each test parameter was varied.

Appendix C contains the variables and logic blocks for the developed expert system.

Chapter 2

BACKGROUND AND LITERATURE REVIEW

2.1 All-Way Stop Control Intersections

All-way stop control (AWSC) intersections are the most frequently used form of intersection control in the United States [3]. AWSC is also commonly used throughout the world to control intersections where traffic volumes are relatively low and approximately equal among all approaches. Since the public tends to view stop signs as the answer to most traffic problems, residents in neighborhoods are likely to request AWSC as a means of slowing vehicle speeds and reducing the amount of cut-through traffic. Traffic engineers, however, disapprove of using AWSC for residential traffic management, for a number of reasons: such installations are not warranted in the FHWA *Manual on Uniform Traffic Control Devices* (MUTCD) [4], they increase non-compliance with stop signs because drivers tend to disregard traffic control devices that they deem unnecessary, and they increase vehicle delay, operating costs, and air pollution. Cottrell [7] presented the results of five studies of stop sign compliance, which found that the majority of drivers (percentages ranged from 30 to 89 percent) performed a rolling stop instead of a full stop at stop signs.

All approaches at an AWSC intersection are considered equal in the hierarchy of the priority of departure, and so every driver must come to a stop before determining if it is safe to enter the intersection. AWSC intersections typically operate with the "yield-to-the-right" rule. At or near capacity, however, an alternating pattern develops as drivers from opposite approaches enter the intersection at roughly the same time. Some interruption of this pattern occurs when there are conflicts between turning movements, but in general north-south streams alternate with east-west streams [8].

The requirement that every vehicle must come to a complete stop at an AWSC intersection can at times cause unnecessary delay. Every vehicle arriving at the intersection must come to a complete stop, regardless of whether or not there are any conflicting vehicles present. When roundabouts are installed in the U.S., they most often replace a two-way stop control (TWSC) or an AWSC intersection [9]. Surveys of local and state agencies using roundabouts showed that the most common reason for installing roundabouts was to reduce delay and improve safety. Right-angle crashes and left-turn head-on crashes frequently occur at TWSC and AWSC intersections and are the most severe of accidents.

2.2 Roundabouts

2.2.1 History of Roundabouts in the United States

The first circular intersection in the United States, the Columbus Circle in New York City, opened in 1905 [6]. However, this rotary and many other similar intersections that were implemented primarily in the northeastern U.S. soon after, were poorly designed and controlled. Because of these deficiencies, rotaries and traffic circles experienced safety problems and tended to "lock up" at higher traffic volumes. By the 1950s, circular intersections had gained a bad reputation among traffic engineers and the general public alike, and many were signalized or completely replaced by signalized intersections [5].

The modern roundabout was developed in the 1960s by researchers in the United Kingdom with design features specifically intended for avoiding the operational and safety problems typical of the older traffic circles and rotaries [6]. The terms "modern roundabout" or simply "roundabout" are used to differentiate this intersection type from its faulty predecessors. Unfortunately, despite its improvements in operation and safety, as well as popularity in Australia, Europe, and the Middle East, the modern roundabout has been slow to catch on as a preferred type of intersection control in the U.S. The majority of the public has a negative opinion of roundabouts, most likely due to lingering memories of past experiences with problem-plagued traffic circles and rotaries.

The first two modern roundabouts in the U.S. were constructed in March 1990 in Summerlin, Nevada [5]. Since then, the use of roundabouts has spread to some parts of the country, thanks to the efforts of traffic engineers who recognize the success of roundabouts abroad. France, leading the world in roundabouts with an estimated 15,000, has been building them at a rate of about 1,000 per year [5]. As of 2003, there were over 300 modern roundabouts in the U.S. Of these, 46 percent were constructed between 2000 and 2003, and nearly all were constructed in the past ten years. Over half are located in the western United States and 94 percent are in urban or suburban areas. The most common geometric configuration is a single-lane roundabout with four approaches, which accounts for over two-thirds of the total number. Sixty-one percent of the nation's roundabouts were converted from a stop-controlled intersection [10].

2.2.2 Elements of Roundabouts

Older traffic circles and rotaries often incorporated one or several of the following problematic design and operational features that are not permitted in modern roundabouts:

- Entering vehicles had the right-of-way (this locks up the circle at high volumes).
- Entries were regulated by stop signs or traffic lights (this reduces fluidity and capacity).
- Entries were tangential to the circle (this encourages high entering speeds).

- Pedestrians crossed onto the central island (this is unsafe for pedestrians and disruptive to drivers).
- The through movement cut through the circle (capacity, fluidity, and safety benefits are lost by the need to signalize the central intersection).
- Circulating traffic was controlled by a traffic signal or stop sign (this decreases the fluidity of circulating traffic and lock up the circle).
- Parking was permitted in the circle (this reduces the capacity and safety of the circle by adding conflicts) [5].

Several key geometric and operational principles distinguish modern roundabouts from other types of circular intersections. Most notable among these are the yield-on-entry rule and the deflection of entering traffic.

The *yield-on-entry rule* gives the right-of-way to vehicles in the circulatory roadway and requires that all vehicles waiting to enter the roundabout wait for a gap in the circulating flow before doing so. This avoids the major problem of "locking up" that afflicts older traffic circles and rotaries under high traffic volumes, when both the entering and circulating vehicles cannot move because of the incessant flow of entering vehicles that are not required to yield. In contrast, when entering vehicles yield to those circulating in modern roundabouts, excess demand is placed on the approaches rather than on the limited area of the circulatory roadway [9].

The *deflection of entering traffic* helps transition vehicles from the straight approach roadway to the circulating roadway in the roundabout and also slows vehicles to a safe speed for entering the roundabout. No tangential entries are permitted as they were in traffic circles and rotaries, which facilitated high entry speeds and consequently led to high occurrences of crashes [5].

Other characteristics of roundabouts are the counter-clockwise flow of all circulating traffic, no parking permitted on the circulatory and entry roadways, and the restriction of pedestrian crossings to behind the yield signs on the approaches. To increase capacity, flared entries are often used to accommodate a greater number of entering vehicles. One drawback to using flared entries, however, is an increase in potential vehicle-vehicle conflict points, and so several states such as Maryland and Florida do not allow flared approaches in their roundabouts [9].

The following key geometric features of modern roundabouts are shown in Figure 2.1:

- The *central island* is the raised area in the center of a roundabout around which traffic circulates.
- The *splitter island* is a raised or painted area on an approach used to separate entering traffic from exiting traffic, deflect and slow entering traffic, and provide storage space for pedestrians crossing the road.
- The *circulatory roadway* is the curved path used by vehicles to travel in a counterclockwise fashion around the central island.

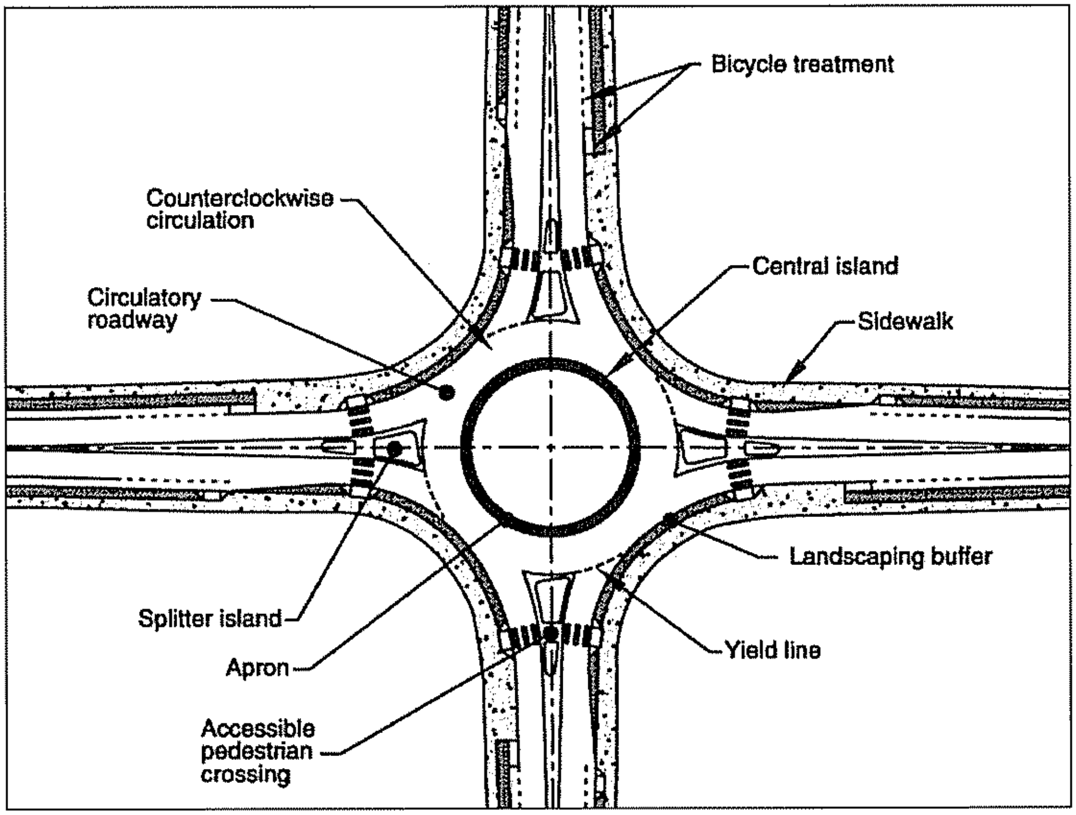


Figure 2.1 Drawing of key roundabout features [6].

- The *apron* is the mountable portion of the central island adjacent to the circulatory roadway. It is usually required in smaller roundabouts to accommodate the wheel tracking of large vehicles.
- The *yield line* is a pavement marking used to mark the point of entry from an approach into the circulatory roadway and is generally marked along the inscribed circle.
- *Accessible pedestrian crossings* should be provided at all roundabouts, set back from the yield line.
- *Bicycle treatments* provide bicyclists the option of traveling through the roundabout either as a vehicle or as a pedestrian.
- *Landscaping buffers* are provided at most roundabouts to separate vehicular and pedestrian traffic and to encourage pedestrians to cross only at the designated crossing locations [6].

2.2.3 Potential Benefits of Roundabouts

2.2.3.1 Capacity and Delay

Unlike other forms of intersection control, roundabouts allow vehicles from all approaches to enter the intersection simultaneously, and do not require all vehicles to come to a complete stop. This creates a generally smooth, continuous flow of traffic as well as improved operational performance in comparison to conventional intersections. Delays can be reduced by as much as 75 percent when a roundabout replaces a stop- or signal-controlled intersection [11]. Much of the delay experienced at these intersections is due to the stop requirement, which at times is unnecessary.

For example, when a vehicle approaches a stop sign or red light, it must come to a complete stop, regardless of whether or not there are any conflicting vehicles present, thus increasing the delay it experiences. In contrast, the same vehicle at a roundabout would only slow to a safe speed to enter the roundabout and then proceed to travel through it.

Delay at roundabouts is generally evenly distributed among all approaches while at signalized or two-way stop-controlled intersections, minor road vehicles experience significantly greater delay than major road vehicles. The "equal opportunity" granted to all entering vehicles at roundabouts also contributes to a decreased overall delay.

Another primary reason for the reduction in delay associated with roundabouts is the elimination of left-turn delay that is common at stop- and signal-controlled intersections. Left-turns are the most difficult movement for drivers at conventional intersections, as they must cross two streams of traffic flow to complete the maneuver. Consequently, left-turning vehicles generally experience the greatest delay, and in the case of shared movement lanes, this delay is also passed on to all vehicles waiting in line behind the left-turning vehicles. Modern roundabouts eliminate these scenarios by converting all movements to right turns and requiring entering vehicles to interact with only one stream of traffic.

A decrease in delay at roundabouts translates to an increase in capacity, as more traffic can be handled in the same amount of time as compared to stop-controlled intersections. The reduced speeds of circulating vehicles may also help in increasing capacity at roundabouts. Vehicles on an approach require a gap in the stream of circulating vehicles in order to accelerate and merge with this traffic. The faster the circulating vehicles, the larger the gaps that entering drivers comfortably accept. Thus, slower circulating vehicles create more acceptable gaps, allowing more vehicles to enter the roundabout and increasing the capacity [12].

A 1998 study by Flannery et al. [9] of five U.S. intersections compared control delay at the sites before and after they were converted to single-lane roundabouts. Field measurements of control delay at the sites before the conversions were not available and so they were estimated using the definition originally used in the 1997 update of the Highway Capacity Manual (HCM): control delay consists of move-up time in the queue and service time at the front of the queue. Shortly after the 1997 HCM was published, however, the definition was changed to include deceleration and acceleration times of vehicles entering an intersection. Deceleration time is the time spent slowing down to join the back of the queue on the approach and acceleration time is the time spent speeding up from the front of the queue to cruising speed. Field measurements were taken at the newly installed roundabouts and showed a reduction in control delay at all but one of the sites. The reason for no reduction at one site appears to be due to a change from 15 s/veh of delay on one approach and zero delay on the others to a more uniform delay among all approaches after installation of the roundabout. At another site, control delay was reduced from an estimated 163.52 to 3.36 s/veh. The large "before" delay was primarily due to a heavy left-turning volume from a minor approach, which was estimated to experience nearly 320 s/veh delay before the conversion, after which it experienced 4.41 s/veh delay.

A 2005 study [13] for the Kansas Department of Transportation by researchers at Kansas State University compared the operational performances of 11 intersections (4 AWSC, 4 TWSC, and 3 signalized) before and after their conversions to modern roundabouts. Traffic flow data were collected for each location before and after conversion and analyzed with aaSIDRA traffic analysis software, version 1.0. The results showed statistically significant decreases of 65 percent in average intersection delay, 44 percent in 95% queue length, 53 percent in degree of saturation, and 52 percent in proportion of vehicles stopped.

A 2006 report [14] from researchers at the Insurance Institute for Highway Safety (IIHS) and Kansas State University discussed the performances of newly installed roundabouts in three small communities having limited prior experience with roundabouts. The previous intersection control consisted of a T-intersection at two of the sites and an AWSC intersection at the third site. Traffic flow data were collected before and after the conversions via video camera, and to ensure that the two sets of data were based on comparable traffic volumes, the peak traffic counts of each site taken before and after the conversions were subjected to a series of statistical tests. The report presents data for the morning and evening peak periods combined. Operational measures of performance were estimated for the periods before and after conversion using aaSIDRA traffic analysis software, version 2.0. Results from the analysis indicated significant decreases in delay and the number of vehicle stops for each of the three sites following installation of the roundabouts; the three sites experienced reductions of 83 to 93 percent in average delay during peak hours. Traffic congestion, measured by degree of saturation (volume-to-capacity ratio), was reduced by 58 to 84 percent at the sites. The study found conversion to a roundabout was particularly effective at the former AWSC location in reducing the number of vehicle stops. Wilcoxon nonparametric and t-tests found the changes at each site to be statistically significant.

2.2.3.2 Fuel Consumption and Emissions

Mobile sources pollute the air through combustion and fuel evaporation. These emissions contribute greatly to air pollution nationwide and are the primary cause of air pollution in many urban nations. The term "tailpipe emissions" refers to the pollution that is created as a by-product of the engine combustion process and from evaporation of fuel. Tailpipe emissions include: unburned hydrocarbons (HC), nitrogen oxides (NO_X), carbon monoxide (CO), carbon dioxide (CO_2), and particulate matter (PM). According to studies by the Environmental Protection Agency (EPA), on-road mobile sources (cars, trucks, and motorcycles) account for 29 percent of HC emissions, 51 percent of CO emissions, 34 percent of NO_X emissions, and 10 percent of PM emissions [15]. The reduction in delay experienced at roundabouts translates to a reduction in both fuel consumption and emissions, since vehicles spend less time waiting and idling on approaches. Several studies have been published evaluating this relationship.

Várhelyi [16] investigated the effects on CO and NO_X emissions and fuel consumption at twenty-one Swedish intersections—one signalized and twenty yield-regulated—that were converted to small roundabouts. Traffic counts showed no significant changes between volumes before and after the installations of the roundabouts. In order to register driving patterns, a "car-following" method was used in which randomly selected cars were followed with an instrument-equipped car that attempted to imitate the followed car's driving pattern as closely as possible. The replacement of the signalized intersection resulted in an average decrease of 29 percent in CO emissions, 21 percent in NO_x emissions, and 28 percent in fuel consumption. Delay increased for cars traveling on major streets and decreased for those traveling on minor streets at the yield-regulated intersections, because of the "equal opportunity" given to all approaches. This translated into overall increased emissions and fuel consumption for major streets and decreased emissions and fuel consumption for minor streets. Considering average traffic volumes in an average junction, total CO emissions increased by 6 percent, NO_X emissions increased by 4 percent, and fuel consumption increased by 3 percent. Comparing the relatively large decreases for the signalized intersection and the relatively small increases for the yield-regulated intersections, Várhelyi concluded that, "reductions at a rebuilt signalised [sic] intersection can "compensate for" the increase of emissions and fuel and fuel consumption at several yield regulated intersections rebuilt as roundabouts."

Mandavilli et al. [17] studied the impact of modern roundabouts on reducing vehicular emissions at six U.S. intersections. Prior to the installation of single-lane roundabouts, four of the intersections were TWSC and two were AWSC. Traffic data for both morning and evening peak hours were collected before and after the conversions and analyzed using aaSIDRA traffic analysis software, version 2.0. The analysis found statistically significant decreases in delay, queuing, and stopping after the modern roundabouts were installed. These decreases correspond to decreases in the emissions rates provided by the software. For the morning peak hour data, the analysis showed statistically significant decreases of 21 percent in CO, 16 percent in CO_2, 20 percent in NO_X, and 18 percent in HC. For the evening peak hour data, the software results also showed statistically significant decreases of 42 percent in CO, 59 percent in CO_2, 48 percent in NO_X, and 65 percent in HC.

2.2.3.2 Safety

Intersections are among the most complex situations that drivers encounter in a roadway system. The various turning and entering movements of drivers, pedestrians, and bicyclists create numerous conflict points where crashes can occur. Making things considerably more dangerous are those drivers who intentionally and unintentionally disobey traffic controls such as stop signs and red lights. In 2004, over 45 percent (2.7 million) of the total vehicle crashes in the United States were intersection-related, as were approximately 45 percent (900,000) of all injury crashes and 21 percent (9,117) of all fatal crashes [18]. Furthermore, side-impact crashes primarily occur at intersections and consistently comprise over one-third of vehicle occupant deaths [18]. Despite efforts from traffic engineers to create safer intersection designs and controls, the number of yearly intersection-related injuries and fatalities has not significantly improved. Numerous studies have demonstrated the safety improvements experienced when roundabouts replace conventional intersections, particularly those with a history of accidents.

Roundabouts increase safety in two ways: by reducing vehicle speeds and by reducing the number of conflicts possible in the intersection. Vehicle speeds are effectively reduced by the two distinguishing design features of a roundabout, the deflection of entering traffic and the yield-on-entry rule, which force vehicles to slow to speeds of 20 mph (30 km/h) and below in order to safely negotiate the circulatory roadway [18]. The yield-on-entry rule also preempts the need for a traffic signal, thus eliminating drivers who feel compelled to "beat the red light" or be the first to cross the line when the light turns green [11]. In principle, lower vehicle speeds create the following safety benefits, among others:

- Reduce crash severity for pedestrians and bicyclists, including older pedestrians, children, and impaired persons;
- Provide more time for entering vehicles to judge, adjust speed for, and safely enter a gap in the circulating traffic;
- Provide more time for all users to detect and correct for their mistakes or mistakes of other users;
- Make collisions less frequent and less severe; and
- Make the intersection safer for novice users [6].

Left turns against opposing or oncoming traffic, right-angle conflicts, and front-to-rear conflicts (occurring when a lead vehicle stops for a signal or stop sign) account for two-thirds of police-reported crashes on urban arterials [19]. Left-turn head-on collisions and right-angle collisions are common at conventional intersections and are typically the most severe of accidents. The severity of a collision is determined largely by the speed and angle of impact. Red-light-running crashes, for example, involve right-angle impacts at relatively high speeds and are among the most injurious [19]. In contrast, since vehicles enter and exit roundabouts only through right turns, these dangerous vehicle movements and conflicts are eliminated and the collisions that can occur are typically only small-angle collisions at relatively low speeds.

The number of conflict points in an intersection correlates to the number of accidents at that intersection. Conflict points are locations where the paths of two vehicles, or a vehicle and a pedestrian or bicyclist, can merge, diverge, or cross. A comparison of the vehicle-vehicle conflict points in a conventional intersection and a roundabout intersection, both with four legs and two-lane roads, is shown in Figure 2.2. The figure shows how, by converting all movements to right turns, roundabouts decrease the total number of vehicle-vehicle conflict points by 75 percent, from thirty-two to eight. Specifically, both the merging and diverging conflict points are halved, and the crossing conflict points are entirely eliminated. This reduced number of conflicts translates to reduced opportunities for crashes to occur.

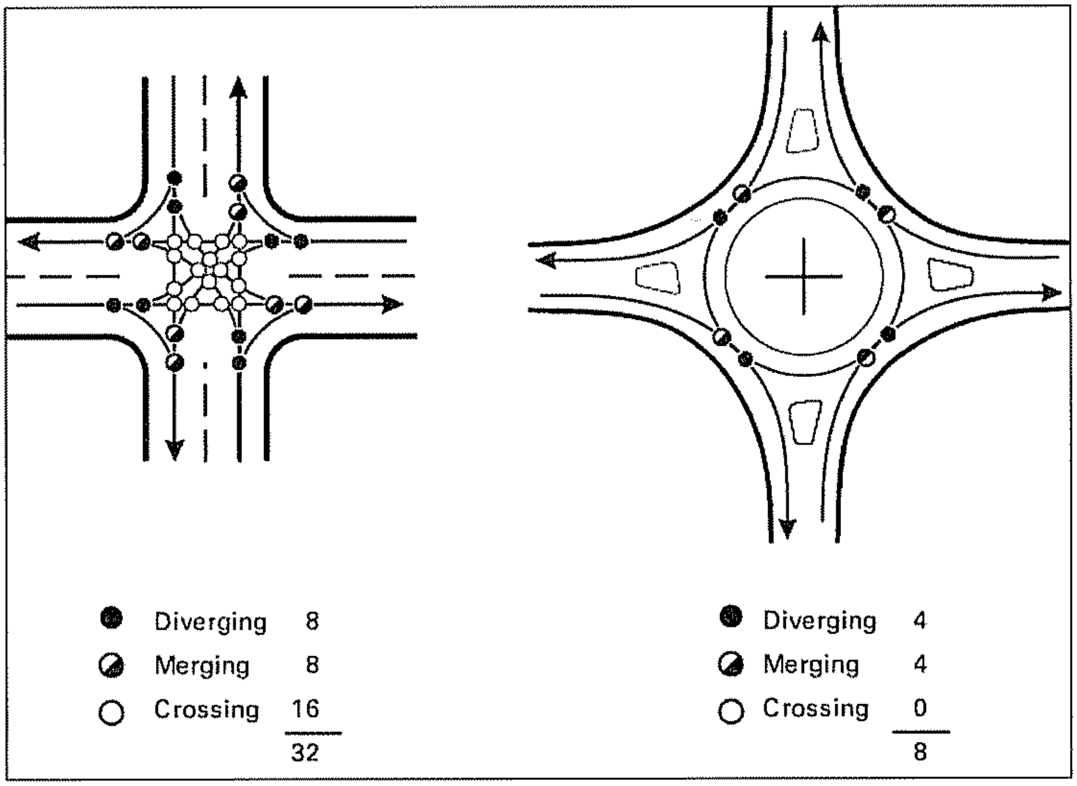


Figure 2.2 Comparison of vehicle-vehicle conflict points for a traditional intersection and a roundabout with four single-lane approaches [6].

Flannery et al. [9] assembled accident data for five U.S. intersections—two T-intersections and three TWSC intersections—that were converted to single-lane roundabouts. The data consisted of accident rates as well as fatality and injury data for the intersections before and after their conversions. The study found that accident frequency (accidents per year) and accident rates (accidents per million entering vehicles per intersection per year) were reduced at all but one location. A one-sample t-test was used to test for statistical significance and found that the before and after frequencies appear to not be the same at the 95 percent confidence level for both reductions. The five intersections experienced a combined 20 injury accidents, including one right-angle fatal accident, while under the stop-control. After being replaced by roundabouts, only one injury accident was reported among the five intersections, as a result of a rear-end accident on an approach leg.

The Insurance Institute for Highway Safety (IIHS) [11] reported a 2000 study by researchers at Ryerson Polytechnic University, IIHS, and the University of Maine comparing crashes and injuries at 24 intersections before and after their conversions from stop sign or signal control to roundabouts. The study found a 39 percent decrease in all crashes and a 76 percent decrease in injury-producing crashes. Crashes involving fatal or incapacitating injuries were decreased up to 90 percent.

Persaud et al. [19] compared accident data before and after 19 stop sign-controlled and 4 traffic signal-controlled intersections were converted to modern roundabouts between 1992 and 1997. The 23 intersections are located in seven states and include a mix of urban, suburban, and rural settings. Fourteen of the roundabouts are single-lane and nine are multi-lane. The study was conducted using the empirical Bayes procedure, which accounts for regression to the mean and for traffic volume changes that usually accompany conversion of intersections to roundabouts. For the group of eight urban, single-lane roundabouts converted from stop control, the procedure estimated highly significant reductions of all crashes by 72 percent and of all injury crashes by 88 percent. Similarly, for the group of five rural, single-lane roundabouts converted from stop control, the procedure estimated a 58 percent reduction of all crashes and an 82 percent reduction of injury crashes. For all 23 intersections in the study, the empirical Bayes procedure estimated highly significant reductions of 40 percent for all crashes, 80 percent for injury crashes, and 90 percent for fatal and incapacitating injury crashes. Injury data were not available for 4 intersections before conversion; however, for the 19 intersections with injury data, there were 27 incapacitating injury crashes and three fatal crashes before the conversions. After the conversions, there were only three incapacitating injury crashes and no fatal crashes. Crashes involving pedestrians and bicyclists were also reduced following conversion, however, these samples were too small to give conclusive evidence concerning these groups.

The Maryland State Highway Administration (SHA) released a 2004 report [20] evaluating the effectiveness of roundabouts in the state, particularly in safety improvements. Single-lane roundabouts were found to perform better than

TWSC, AWSC, and signalized intersections in safety performance. Accident data were collected for fifteen locations in Maryland where single-lane roundabouts were installed between April 1993 and December 2001. The data showed a 68 percent reduction in the total accident rate, a 100 percent reduction in the fatal accident rate, an 86 percent reduction in the injury accident rate, and a 41 percent reduction in the property damage only accident rate. Other findings include a 93 percent reduction in right-angle accidents, a 27 percent reduction in rear-end accidents, a 52 percent reduction in sideswipe accidents, and a 97 percent reduction in left-turn accidents. The data also showed a 474 percent increase in fixed object accidents (usually involving curbs) that were mainly caused by drivers not slowing to proper speeds for using the roundabout and by alcohol or drugs.

2.2.3.4 Costs

The costs associated with roundabouts include those for engineering and design fees, land acquisition, construction, operating, maintenance, and landscaping. Operating costs for roundabouts generally consist of illumination costs. Maintenance costs consist of re-striping and repaving as necessary, and snow removal and storage. These costs also exist for other unsignalized intersections, though those for roundabouts may be somewhat higher. Landscaping costs depend on the amount of landscaping used at the roundabout and consist of pruning, mowing, and irrigation system maintenance costs [6].

The major savings in costs associated with roundabouts are most apparent when making comparisons with signalized intersections, as roundabouts eliminate the high installation and maintenance costs of traffic signals. Installing a traffic signal costs an estimated $150,000, while electricity consumption and routine maintenance, which includes periodic light bulb and detection maintenance and regular signal timing updates, can run up to $3,000 per year [14]. Illumination costs for roundabouts and signalized intersections are more or less the same. The approximate service life of a roundabout is over twice as long as that for a signalized intersection: 25 years for a roundabout versus 10 years for a typical signal [6].

Construction costs could end up being higher for a roundabout than for a signalized intersection, depending on the amount of new pavement area needed to accommodate the circulatory roadway or the extent of other roadway work within and around the dimensions of the roundabout. If a signalized intersection can be installed without requiring significant modifications to the pavement area or curbs, a roundabout is very likely to be more expensive; however, if a completely new intersection is being built or if a signalized intersection requires widening on its approach roadways, a roundabout can be comparable or less expensive in construction costs [6].

A 2004 report [20] from the Maryland SHA included cost/effectiveness and benefit/cost evaluations of 15 intersections in the state where single-lane roundabouts replaced conventional intersections. The cost/effectiveness evaluation indicated the number of dollars spent to reduce a single accident. The analysis found that for every accident reduced, $13,146 was spent and estimated the weighted average accident cost for a single accident to be approximately $100,000. The benefit/cost evaluation indicated the ratio of the anticipated rate of return in safety benefits (accident reduction) for a 15-year service life of the roundabouts as compared to the amount of dollars spent on these projects taking into account the invested capital that could be recuperated over the same 15-year service life. This analysis found that for every dollar spent on the roundabout installations over the entire 15-year service life, there is a return of approximately 15 dollars to be realized through accident reduction. These calculations were based on comparisons of the expected number of accidents had no roundabouts been installed compared to the actual number of accidents at the study sites.

2.2.3.5 Community Enhancement

In some cases, roundabouts have been proposed as an effort in enhancing the appearance of the surrounding area at an intersection, rather than as a solution to operational or safety problems. Such projects are located in both commercial and civic districts, as a gateway treatment to convey a change of environment and to encourage traffic to slow down.

The central island, splitter islands, and perimeter of the roundabout provide space for landscaping to enhance the aesthetics of the intersection. In addition, residents have also used sculptures and fountains in order to provide an attractive entrance to their communities.

The ability to improve aesthetics at a location can also be helpful in increasing public acceptance of a proposed plan for a roundabout.

2.2.4 Public Acceptance of Roundabouts

Oftentimes, a lack of proper knowledge causes residents in communities near planned roundabouts to become one of the biggest challenges to proposed projects. Most likely the majority of the opposing public incorrectly associates roundabouts with older problem-plagued circular intersections that they have either experienced first-hand or heard about from others. When communities have gone ahead and installed roundabouts despite public opposition, they often find that "seeing is believing," as public acceptance generally increases once local residents adapt to this new form of traffic control [6].

A 2005 study [14] led by the Insurance Institute for Highway Safety (IIHS) evaluated the effect of new roundabouts in three small communities with limited prior experience with roundabouts. The roundabouts were installed in 2004, replacing two T-intersections and one AWSC intersection. The researchers contacted local residents via telephone surveys to compare public opinion of the roundabouts before and after their installations. In all three communities combined, the proportion of residents who opposed new roundabouts decreased from 54 to 36 percent, the proportion of those who favored new roundabouts increased from 36 to 50 percent, and the proportion of those who neither opposed nor favored new roundabouts increased from 9 to 14 percent. This pattern of change was statistically significant for the communities combined, and was more or less consistent in each of the three communities.

When residents were asked for their reasons for opposing roundabouts, the most common answer given was that roundabouts are unsafe; 24 percent of residents gave this reason before the roundabouts were built and 23 percent after. Other reasons given by drivers included that they found roundabouts confusing and that they simply prefer traffic signals. Despite a substantial decrease in delay and vehicle stops, residents also cited traffic congestion as a reason for their opposition. A possible explanation for this is that the surveys were conducted within two months of the installations and so residents may still have had recent memories of the temporary delays and other inconveniences during the construction process. Another explanation could be that drivers viewed the reduced speeds induced by the roundabouts as traffic congestion.

Information campaigns should be performed when planning to install roundabouts in communities with little knowledge or experience with modern roundabouts. Public workshops and informational brochures should be used to show the public the design of the proposed roundabout, general information about roundabouts, and how to use a roundabout. These measures can help familiarize the public on the operational and safety benefits of modern roundabouts and help mitigate opposition based on incorrect presumptions.

2.3 Past Studies Comparing Roundabouts with Other Intersection Types

It is important that roundabouts are properly designed and located where they can improve traffic flow and safety. Despite their operation and safety benefits, roundabouts are not the best solution at all locations. Intersection characteristics that have been identified as unfavorable to roundabouts include very unbalanced traffic flows (i.e., very high traffic volumes on the main street and very light volumes on the side street), locations where topographic or site constraints limit the ability to provide appropriate geometry, and locations in close proximity to persistent bottlenecks [14].

Roundabouts usually require more space for the circular roadway and central island than the rectangular space inside traditional intersections. Therefore, roundabouts often have a significant right-of-way impact on the corner properties at an intersection, particularly when compared with other forms of unsignalized intersections [6].

Sisiopiku and Oh [21] compared the performance of roundabouts with intersections under yield-control, TWSC, AWSC, and signal control in order to determine traffic and design conditions for which roundabouts are viable alternatives to traditional intersection types. The intersection types were evaluated under a number of scenarios of varying volume, turning volume splits, number of approach lanes, and lane widths. Basic assumptions for each intersection type were as follows:

- Roundabouts: minimum island diameter of 24 m (78.7 ft), circulating lane width of 9 m (29.5 ft), lane width for flare equal to 3.96, 4.96, and 5.96 m (13, 16.3, and 19.6 ft), volume ratio by approach of 1:1:1:1, and left turn percentage of 10, 20, and 30 percent.
- TWSC: volume ratio by approach of 1:1:1:1 and 1:99:1:99, and left turn percentage of 10 percent.
- AWSC: volume ratio by approach of 1:1:1:1, and left turn percentage of 10 percent.
- Yield Control: Volume ratio by approach of 1:1:1:1 and 1:99:1:99, and left turn percentage of 10 percent.
- Signal Control: Volume ratio by approach of 1:1:1:1, left turn percentage of 10 percent, two-phase signal, and cycle length of 60 to 120 seconds.

SIDRA traffic analysis software was used to compare the intersection types on the basis of capacity and average delay. The degree of saturation (volume-to-capacity ratio) was also used to compare the performance between roundabouts and signalized intersections. Among other conclusions, the study found that for both light and heavy volumes, AWSC experiences greater delay than roundabouts or signals.

For intersections with two-lane approaches and heavy traffic volumes, roundabouts showed a better performance than any other intersection type. For heavy left-turn volumes, roundabouts with two-lane approaches showed better performance than any other intersection type in terms of capacity and delay.

2.4 Existing Roundabout Guides

2.4.1 Federal Highway Administration (FHWA)

Roundabouts: An Informational Guide [6] was published in 2000 and is frequently referred to simply as the FHWA Roundabout Guide. The guide aims to provide general information, planning techniques, evaluation procedures for assessing operational and safety performance, and design guidelines for roundabouts. The FHWA Roundabout Guide offers the following planning level guidance for comparisons of control modes: "A roundabout will always provide a higher capacity and lower delays than all-way stop control operating with the same traffic volumes and right-of-way restrictions" [6].

The FHWA Roundabout Guide recommends that roundabouts be designed to operate at no more than 85 percent of their estimated capacity. Degree of saturation is the ratio of the demand at a roundabout entry to its capacity (V/C). When the degree of saturation exceeds 0.85 the operation of the roundabout will likely deteriorate rapidly, particularly over short periods of time. Queues may form and delay begins to increase exponentially.

The guide includes analyses of roundabout capacities for planning purposes. Figure 2.3 shows maximum service average annual daily traffic (AADT) volumes for a four-leg roundabout. The analyses for this figure consisted of number of assumptions. The proportion of the AADT assigned to the design hour, or the K factor, is equal to 0.1. The proportion of two-way traffic that is assigned to the peak direction, or the D factor, is equal to 0.58. The proportion of traffic on the major street was assumed to be between 0.5 and 0.67. All analyses assumed a four-leg intersection. Right turns were assumed to be 10 percent in all cases. The maximum service volumes shown in Figure 2.3 are for a range of left turns from 0 to 40 percent of the total volume. The lines relevant for this thesis involve single-lane roundabouts, or the bottom set of two lines. Note that as the left-turn percentage increases, the capacity of the roundabout steadily decreases. Also note that as the proportion of traffic on the minor road increases, the capacity of the roundabout also increases.

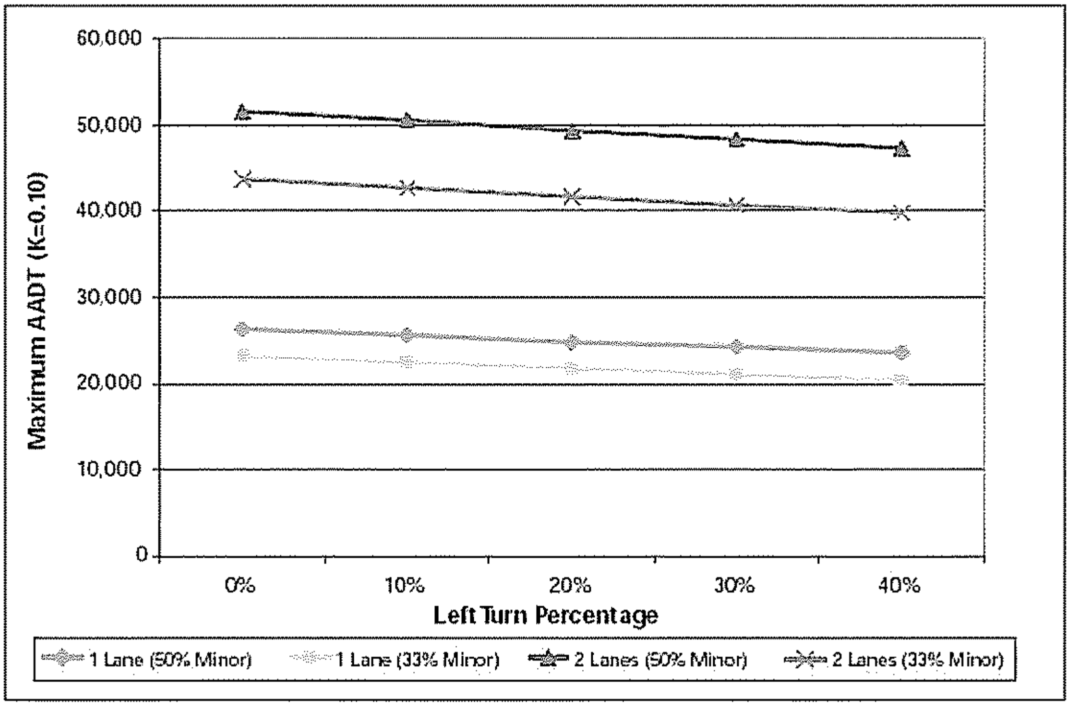


Figure 2.3 Maximum daily service volumes for a four-leg roundabout [6].

The FHWA Roundabout Guide also includes a short section comparing roundabouts with conventional intersection control. Section 3.5.2 of the guide compares roundabouts with AWSC intersections. The selection of a roundabout as an alternative to AWSC should emphasize cost and safety considerations, because roundabouts always offer better performance for vehicles than AWSC, given the same traffic conditions (in accordance with the aforementioned assumption made in the guide that roundabouts always provide higher capacity and lower delays than AWSC intersections operating with the same traffic volumes and right-of-way limitations). A substantial part of the benefit of a roundabout compared to an AWSC intersection is obtained during the off-peak periods, because the restrictive stop control applies all day. Left turning vehicles degrade the operation of all traffic control modes, but they have a smaller effect on roundabouts than on stop signs or signals. The aaSIDRA traffic analysis software was used to study both roundabout and AWSC control. The results of this comparison are shown in Figures 2.4 and 2.5. The results are in terms of potential annual savings in delay of a single-lane roundabout over an AWSC intersection with one lane on all approaches, as a function of the proportion of left turning traffic for single-lane approaches for volume distributions of 50 percent and 65 percent on the major street. Each figure has lines representing 10, 25, and 33 percent left turn proportions. As the figures show, the potential annual benefit is in the range of 5,000 to 50,000 vehicle-hours per year. The benefit increases substantially with increasing AADT and left turn proportions. The comparisons terminate when then capacity of the AWSC operation is exceeded. No comparisons were made beyond 18,000 AADT, because AWSC is not practical beyond this point.

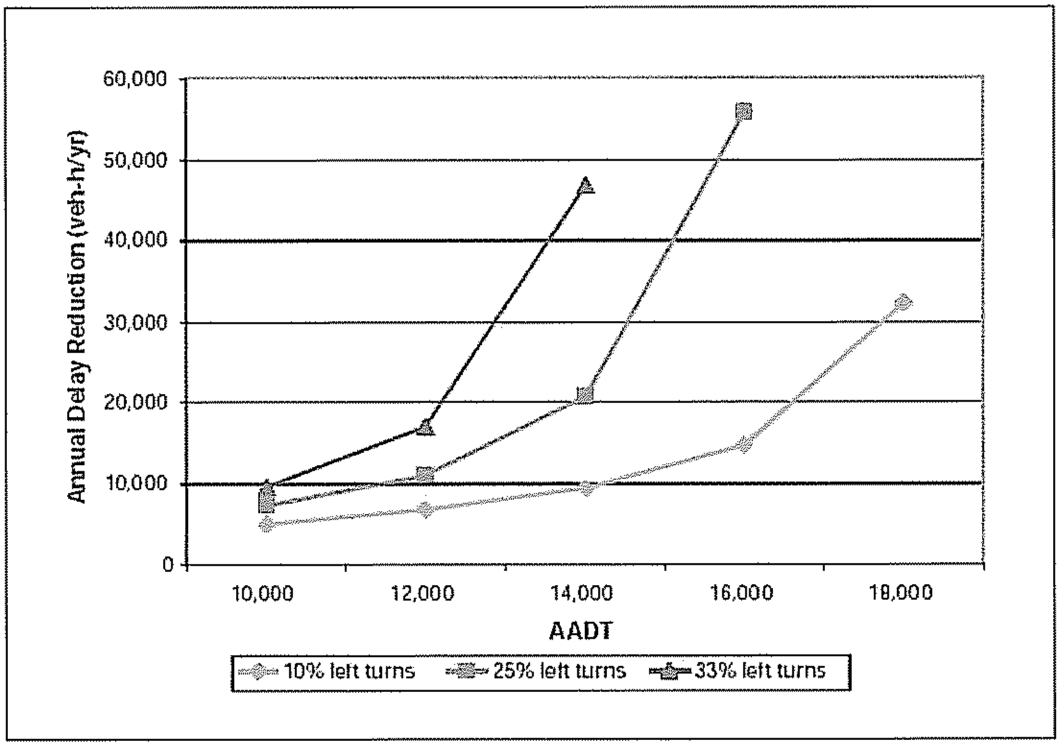


Figure 2.4 Annual savings in delay of single-lane roundabouts versus AWSC, 50 percent of volume on the major street [6].

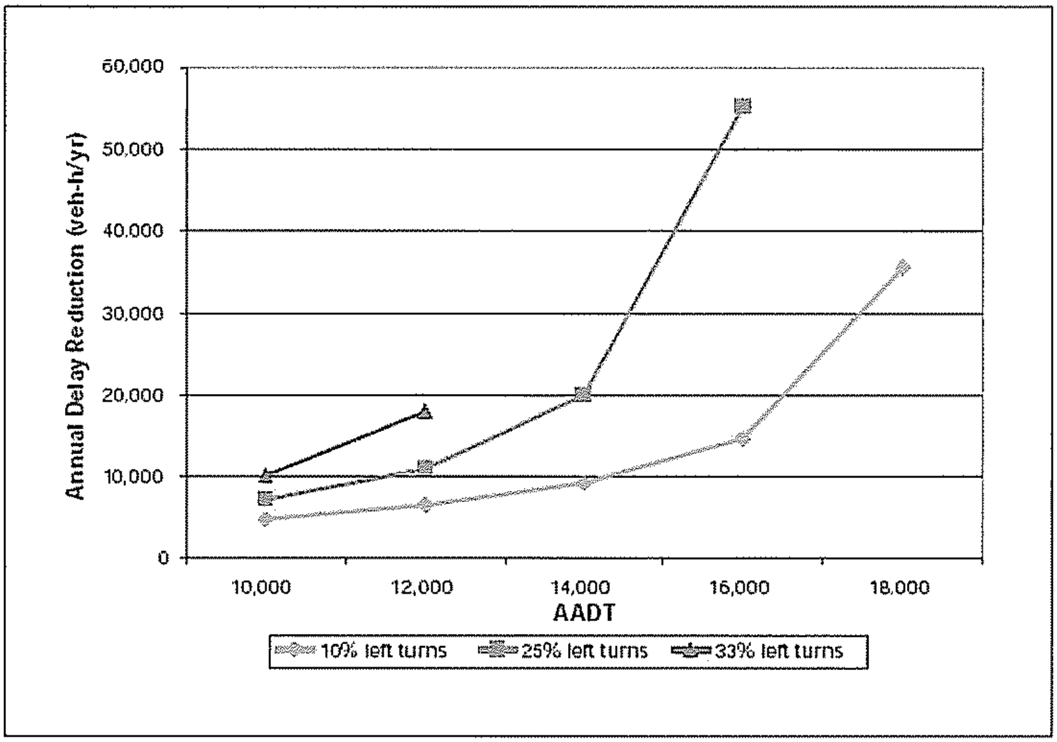


Figure 2.5 Annual savings in delay of single-lane roundabouts versus AWSC, 65 percent of volume on the major street [6].

2.4.2 Maryland State Highway Administration (SHA)

Roundabout Design Guidelines [22] was published by the State of Maryland SHA in 1995 and was the first roundabout guide to be published in the U.S. Its procedures are largely the same as the Australian Design Guide, which was published in 1993, with conversions to U.S. standard units and right-hand driving. Where necessary, the design guidelines were altered to conform to the practices of the MUTCD and the American Association of State Highway and Transportation Officials (AASHTO).

The 64-page guide recommends the use of SIDRA traffic analysis software for the analysis of roundabout performance and also provides simple graphs to obtain a general estimate of roundabout capacity when a high degree of accuracy is not required. Guidance on geometric design, landscape design, signing and pavement marking, lighting, pedestrian and bicycle considerations, and work zone traffic control is provided. A roundabout benefit/costs analysis that requires a three-year period for the collection of accident data is included as an appendix. At this time, the Maryland SHA has adopting the FHWA Roundabout Guide [6] as its standard roundabout guide.

2.4.3 Florida Department of Transportation (FDOT)

The *Florida Roundabout Guide* [23] was published by FDOT in 1996 to assist in identifying appropriate sites for roundabouts and determining their preferred configuration and operational features. In addition to providing guidance for performance analysis (the use of SIDRA traffic analysis software is recommended), geometric design, signing, marking, landscaping, and lighting of roundabouts, the 60-page guide includes a chapter titled, "Roundabout Justification." This chapter contains a discussion of intersection traffic control alternatives and identifies seven categories representing reasons to install a roundabout:

- Community enhancement
- Traffic calming
- Safety improvement
- All-way stop alternative
- Low volume signal alternative
- Medium volume signal alternative
- Special conditions (unusual geometry, five or more legs in the intersection, etc.)

An eight-step "roundabout justification procedure" is also outlined in this chapter to aid in the decision to install a roundabout:

1. Obtain common data
2. Identify justification category
3. Obtain data requirements specific to a particular category
4. Perform preliminary geometric design to establish feasibility
5. Analyze the performance of a roundabout
6. Analyze the performance of alternative control modes
7. Assess contraindications and propose mitigation treatments
8. Final recommendations

2.4.4 Pennsylvania Department of Transportation (PennDOT)

Guide to Roundabouts [24] was published by PennDOT in May 2001 and is designed as a supplement to the FHWA Roundabout Guide [6] to aid in determining whether or not a roundabout is a feasible alternative for a specific location. Unlike other state DOT guides, this 98-page guide does not provide specific guidelines for roundabout design; the reader is referred specifically to the FHWA Roundabout Guide for further design criteria.

In addition to several case studies, the guide provides an eight-page questionnaire with an array of questions and insights to help the analyst understand the probable implications of a roundabout at a given intersection. An operational analysis and conceptual geometric layout is generally required to answer the questionnaire. If a roundabout is deemed feasible, alternative intersection control methods must be evaluated and their performances compared with that of the roundabout.

The following categories are identified in the guide as primary reasons for selecting a roundabout for control at an intersection:

- Safety improvement
- Operational improvement
- Community enhancement
- Traffic calming
- Special conditions (unusual geometry, right-of-way limits, etc.)

2.4.5 Washington State Department of Transportation (WSDOT)

Washington State does not currently have a state guide for roundabouts. However, a 29-page chapter [25] was added to WSDOT's *Design Manual* in late 2001. The information presented is a summary of that found in the FHWA Roundabout Guide [6], and the reader is referred to that document for more thorough guidance. One section of the chapter recommends the following procedure when selecting a roundabout for intersection control:

1. Consider the context (are there constraints that must be addressed?).
2. Determine the roundabout category and preliminary lane configuration based on capacity requirements.
3. Identify the justification category (safety improvement, intersection capacity improvement, queue reduction, or special conditions).
4. Perform the analysis appropriate to the selection category.
5. Determine the right-of-way requirements and feasibility.
6. Perform an economic evaluation (if additional right-of-way is required or if other forms of intersection control are viable).
7. Contact all approving authorities to obtain concurrence that a roundabout is an acceptable concept at the proposed location.

2.4.6 Kansas Department of Transportation (KDOT)

The *Kansas Roundabout Guide* [26] was published in October 2003 as a supplement to the FHWA Roundabout Guide [6]. The 146-page guide includes chapters discussing public involvement, planning, operational analysis, safety, geometric design, traffic design (signing, pavement markings, lighting), and system considerations (proximity to other traffic control devices, access management). The guide recommends three performance measures for use in assessing the operating performance for roundabout design: degree of saturation, average delay, and the 95^{th}-percentile queue length. For design purposes, the guide recommends that the degree of saturation not exceed 0.85. A brief guide for law enforcement in interpreting the Kansas Motor Vehicle Code for roundabouts is included as an appendix.

2.5 Summary of Chapter 2

All-way stop-controlled intersections are not the panacea for traffic problems, contrary to what much of the public tends to believe. Studies have found that a large percentage of drivers fail to fully comply with the stop control at these intersections, and "roll through" them instead. This may help explain why a large proportion of injuries at AWSC intersections involve right-angle collisions. The stop requirement on all approaches of the AWSC intersection, regardless of whether or not conflicting vehicles are present, creates undue delay for vehicles arriving at the intersection.

Modern roundabouts are different from older rotaries and traffic circles in distinct ways that help them avoid the problems that are common at these older circular intersections. The two key features of modern roundabouts are the yield-on-entry rule and the deflection of entering traffic. Since 1990, roundabouts have been increasingly used as a form of intersection control in the United States, as more traffic engineers and planners become familiar with them and recognize their potential advantages over conventional intersections in operations, air quality, safety, costs, and aesthetics.

Despite the proven success of roundabouts throughout the world, public opinion in the United States remains lukewarm. Residents are apprehensive of installing these still-unfamiliar intersections and skeptical of their success due to past experience with the older problematic circular intersections. However, many communities have found that once the roundabout has been constructed and the public has become familiar with it, public opinion significantly increases to a positive view on the use of roundabouts, showing that for the public, "seeing is believing".

A study of roundabout performance versus signalized and unsignalized intersection performances found that the roundabout provided the best performance for intersections with two-lane approaches and under heavy traffic volume and for intersections with two-lane approaches and heavy left-turning vehicle volume. The study also found that AWSC intersection provided more delay than both roundabouts and signalized intersections under light and heavy traffic volumes.

Findings in the FHWA Roundabout Guide [6] are similar, and so the guide recommends using the assumption that a roundabout will always provide higher capacity and lower delays than an AWSC intersection when operating under the same traffic volumes and right-of-way restrictions. The guide also recommends that roundabouts be designed to operate at no more than 85 percent of their estimated capacity, as after this point, queues form and delay begins to increase exponentially. Other findings of roundabout performance include that roundabout capacity steadily decreases as left-turn percentage increases, and roundabout capacity increases as the proportion of traffic on the minor road increases (i.e., volumes become more balanced on the two roads). Since a roundabout always offers better performance for vehicles than an AWSC intersection, the guide recommends that the selection of a roundabout as an alternative to an AWSC intersection emphasize the cost and safety benefits.

Several states have also developed their own roundabout guides, though most refer readers to the FHWA Roundabout Guide [6] for more thorough guidance. Those included in this chapter are from the Maryland State Highway Administration, the Florida Department of Transportation, the Pennsylvania Department of Transportation, the Washington State Department of Transportation, and the Kansas Department of Transportation. Many of these identify roundabout justification categories for use when selecting a roundabout. Among these justification categories are: operational improvements, safety improvements, aesthetic improvements and traffic calming.

Chapter 3

aaSIDRA TRAFFIC ANALYSIS SOFTWARE

3.1 Overview of aaSIDRA Software

The traffic analysis software used for this thesis is aaSIDRA (Signalized and unsignalized Intersection Design and Research Aid), also known as SIDRA, version 2.1. Both the U.S. Highway Capacity Manual 2000 (HCM) and the FHWA Roundabout Guide [6] recognize the SIDRA software package for use in the analysis of intersection capacity, level of service, and other performance characteristics. SIDRA uses an empirical gap-acceptance method to model roundabout performance that takes into account both the roundabout geometry and driver behavior and is applicable for both left-hand and right-hand driving. The software is capable of analyzing signalized intersections (actuated and fixed-time), unsignalized intersections (TWSC, AWSC, and yield-controlled), and roundabouts.

The SIDRA default roundabout critical gap and follow-up time values are not fixed and are estimated as functions of the roundabout geometry, circulating flow, and entry lane flows. The software package offers the option to use the HCM capacity model as well as default gap-acceptance values based upon HCM parameters for two-way stop sign controlled intersections and the HCM delay and queue equations for signalized and two-way stop-sign controlled intersections. Analysis based on SIDRA is therefore aptly suited to U.S. conditions. The SIDRA capacity model may also be calibrated as to better reflect road and local driver characteristics. Consequently, the roundabout analysis conducted in this study has been calibrated for local driver characteristics using critical gap and follow-up times determined from the data collection.

Among the output provided by SIDRA are the following measures of effectiveness (MOEs) used in this study:

- *Effective intersection capacity* (vph): an aggregate measure of intersection capacity determined as the ratio of total intersection demand flow to the intersection degree of saturation, where the intersection degree of saturation is the largest lane degree of saturation considering all lanes of the intersection. This MOE was introduced in aaSIDRA version 2.1. In previous versions, a simple sum of all lane capacities was given as the total intersection capacity, which may give a false impression about the ability of intersections to handle demand volumes since it does not reflect unused capacities.
- *Average delay* (s/veh): average control delay at the intersection, which is the sum of stop-line delay and geometric delay.
- *Maximum 95% back-of-queue* (ft): the 95th percentile extent of the queue relative to the stop line or give-way (yield) line during a signal cycle or gap-acceptance cycle. The longest vehicle queue in any lane at the intersection is used.
- *Degree of saturation*: the ratio of arrival (demand) flow rate to capacity during a given flow period. Also known as the volume-

to-capacity ratio. The highest degree of saturation for any lane at the intersection is used.

- *Emissions* (kg/hr): total emission rates of CO, CO_2, HC, and NO_X for all vehicles using the intersection [27].

3.2 Determination of Local Gap Acceptance Parameters

3.2.1 Roundabout Site Selection

Any roundabout used in this study for data collection had to satisfy two criteria. Firstly, the roundabout must be single-lane, as this is the geometry used throughout the SIDRA analysis. Secondly, it must experience adequate volume during at least one peak hour so that the gap acceptance behavior of drivers entering the roundabouts could be observed. As no sites adequately satisfying these criteria presently exist in Delaware, it was decided to select locations in Maryland. Maryland is among the leading states in roundabout use, with approximately forty-five existing, three planned, and five proposed modern roundabouts [28]. Following consultation with the Maryland State Highway Administration (SHA), two roundabouts were chosen for this study [29]. One is located in Cecil County, at the intersection of MD 273 and MD 276, and the other is located in Queen Anne's County, at the intersection of MD 18 and Castle Marina Road. The two locations were selected for their similar geometric and traffic characteristics, which satisfy the aforementioned criteria, as well as for their relative proximity to Delaware. Both roundabout configurations consist of four approaches, from the intersection of two perpendicular two-way roads. According to data provided by the SHA, the roundabout intersection in Cecil County was constructed in Fall 2002, was previously under signal control, has an Annual

Average Daily Traffic (AADT) of 16,350 vpd (collected in 2000), and has inner and outer diameters of 86 and 140 feet, respectively. Likewise, the roundabout intersection in Queen Anne's County was constructed in December 1999, was previously under two-way stop-control, has an AADT of 14,000 vpd (collected in 1999), and has inner and outer diameters of 30 and 110 feet, respectively. Figure 3.1 shows the locations of the roundabouts indicated on a map of the state of Maryland.

3.2.2 Data Collection

The roundabouts were visited for data collection on two separate days in May 2005. Care was taken that the data were collected for normal traffic conditions, i.e., during fair (not rainy) weather and on a day not close to a holiday or any other event that would be the cause of unusual traffic. Based upon the recommendation of the SHA, data at both roundabouts were collected during the afternoon peak period, between 4 and 5 p.m. At each site, the approach with the highest entering and conflicting volumes was identified and videotaped for one hour. The video camera was placed on a tripod as far away from passing traffic as possible while still maintaining a full view of the subject approach and its relevant section of the circulatory roadway. Figure 3.2 shows a typical set-up for the video camera.

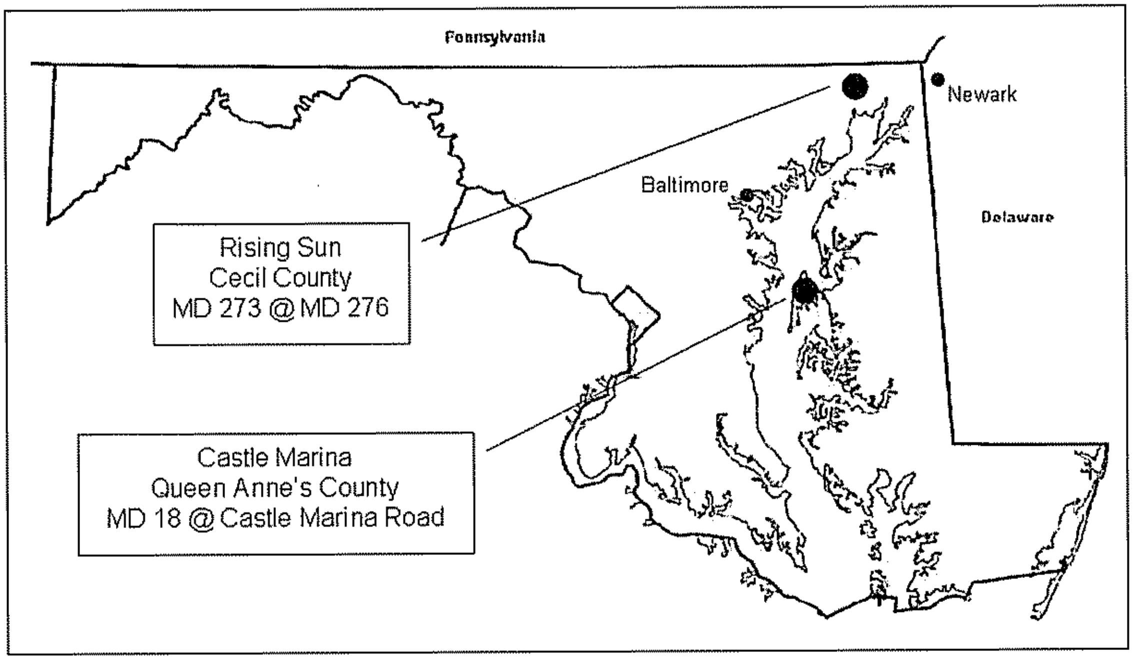


Figure 3.1 Study sites.

Figure 3.2 **Typical set-up of video recording equipment at study sites. (Cecil County roundabout shown).**

3.2.3 Data Reduction

The digital videotapes of the two locations were converted to high-quality Quicktime movies so that they could be reviewed on a computer with ease. The movies include timestamps accurate to HH:MM:SS:FF, where FF are frames, 30 frames/second. Quicktime has excellent play and pause capability, which was essential for obtaining accurate gap and follow-up times. Data extracted from the videotapes consisted of rejected lags and gaps, accepted lags and gaps, and follow-up times. The lag was determined as the difference between the time at which an entering vehicle arrived at the front of the queue and the time at which the next circulating vehicle passed this location. The gap is defined as the difference in time between the passages of two consecutive circulating vehicles at a point in front of the entering queue. The follow-up time was determined as the time difference between the passage of an entering vehicle into the roundabout and the arrival of the subsequent entering vehicle to the front of the queue, recorded when a queue of at least three entering vehicles existed. The effect of circulating vehicles exiting the roundabout at the subject approach, on entering vehicles is not within the scope of this study and so was ignored. Figure 3.3 shows an example of one frame of the Quicktime movie for the Cecil County roundabout.

Figure 3.3 Sample frame of Quicktime movie for Cecil County roundabout.

3.2.4 Data Analysis

The use of gap acceptance parameters entails the assumption that drivers reject all gaps shorter than the critical gap, and accept all those longer than the critical gap. Each driver can reject numerous gaps but accept only one. The gap-acceptance process at roundabouts is different than that at conventional intersections. Long gaps at roundabouts are not meaningful because entering vehicles are not required to consider them when making the decision whether or not to accept a gap [30]. Polus and Shmueli [30] developed a model for estimating the gap size above which gaps are not relevant in the gap-acceptance analysis for roundabouts. They concluded that gaps longer than a certain threshold value (e.g., half of the peripheral length of the circle) are not relevant in the acceptance process. The authors developed the following equation for estimating the relevant gap based upon the radius of the path and the operating speed of the circulating vehicles.

$$G_t = \frac{\pi R}{S}$$

where:

G_t = threshold gap for vehicles at roundabout (s);

R = radius of the path of vehicles around the central island (m); and

S = operating speed around the circle (m/s).

The average operating speed of circulating vehicles at both study sites was estimated from the videotapes to be approximately 26 mph and therefore, according to the above equation, the relevant gap is 8.2 seconds. That is, gaps larger than 8.2 seconds are assumed accepted by all entering vehicles and are therefore not relevant in determining the critical gap.

The critical gaps for each of the study sites were determined following Drew's method for accepted and rejected gap times [31]. With this method, accepted and rejected are collected and two cumulative distribution curves constructed. One curve represents the number of accepted gaps shorter than *t* and the other represents the number of rejected gaps longer than *t*. The critical gap is taken as the point of intersection of these two lines. Figures 3.4 and 3.5 show this method applied to each of the study sites. The critical gaps found for the Cecil County and Queen Anne's County roundabouts are 3.85 and 3.91 seconds, respectively. These values are slightly below the range of 4.1 to 4.6 seconds indicated in the HCM 2000. Data extracted from the videotapes consisted of 20 accepted and 161 rejected gaps for the Rising Sun roundabout, and 29 accepted and 158 rejected gaps for the Castle Marina roundabout.

Follow-up time is the time interval between the departure of the first vehicle in the queue and the arrival of the subsequent vehicle at the yield line under continuous queue conditions. The overall follow-up time was found by determining the median value of all follow-up times collected for each site. These values were 1.9 seconds for Cecil County (standard deviation of 0.89 seconds) and 2.1 seconds for Queen Anne's County (standard deviation of 0.66 seconds). These values are slightly below those the range of 2.6 to 3.1 seconds found in the HCM 2000. Follow-up time data extracted from the videotapes consisted of 82 times for the Rising Sun roundabout and 114 times for the Castle Marina roundabout.

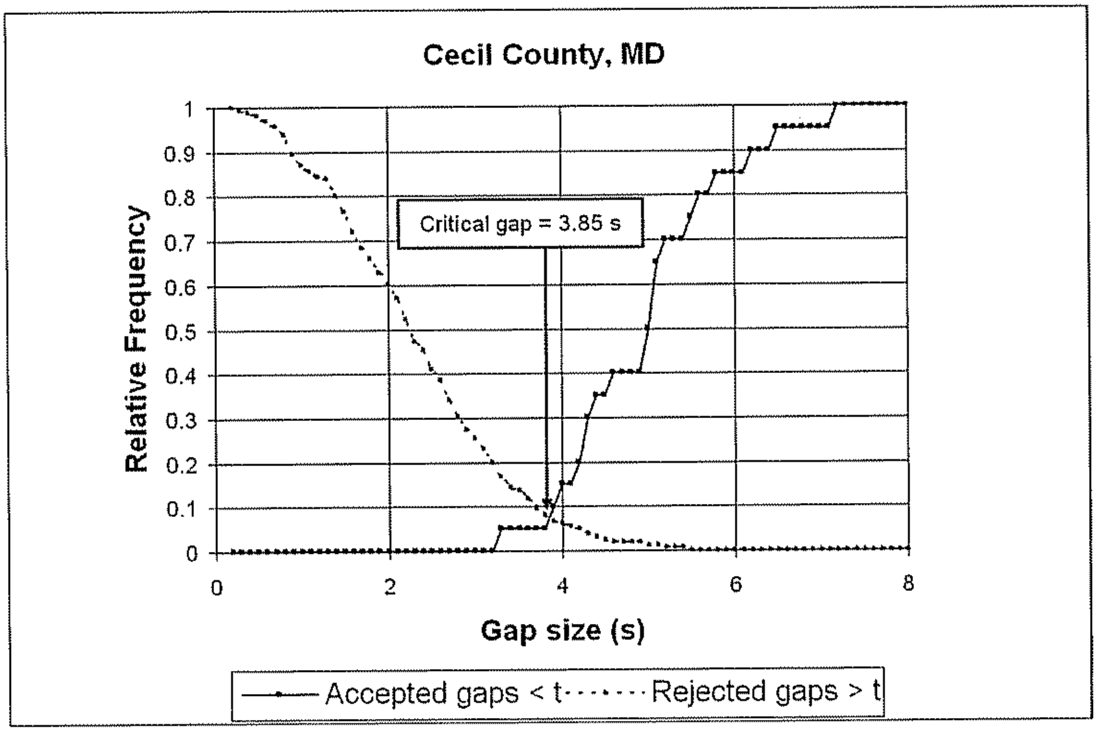


Figure 3.4 Determination of critical gap for Cecil County roundabout.

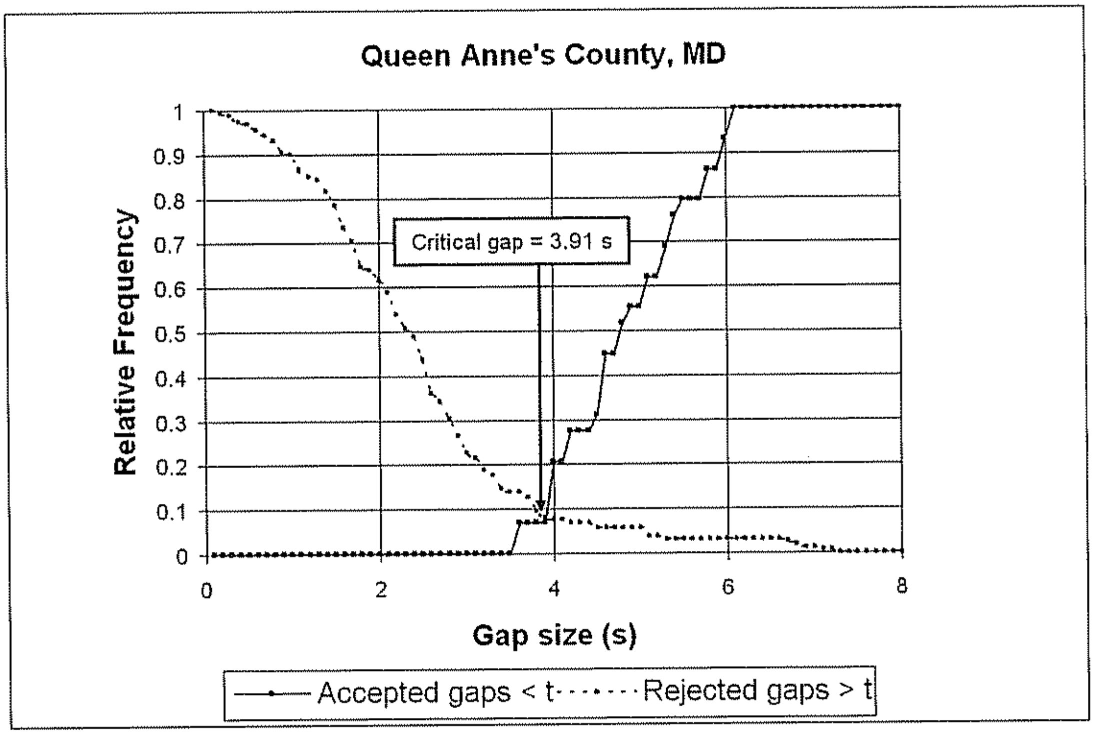


Figure 3.5 Determination of critical gap for Queen Anne's County roundabout.

3.3 Test Scenarios of aaSIDRA Software Analysis

SIDRA software analyses were run to compare three intersection types: AWSC, single-lane roundabout, and actuated signal. According to the FHWA Roundabout Guide, roundabouts that are proposed as alternatives to stop control would typically have single-lane approaches [6]. All approaching and departing lanes are 12 feet wide, and the terrain is assumed to be level (zero percent grade). Gap acceptance parameters used for roundabout analysis were a critical gap of 3.9 seconds and a follow-up time of 2.0 seconds, which were the average of those values determined for the two study sites.

The analyses varied volume ratio between the intersecting roads, turning percentages, heavy vehicle percentages and ratio between the roads, and roundabout diameter.

The volume ratios used were 1.00 and 1.33. When greater ratios were attempted for the AWSC intersection, the software issued the following warning, "*AWSC capacity based on HCM 1994—Some data outside valid range.*" Various restrictions apply to the applicability of the AWSC capacity model as stated in the HCM 1994. The method is not valid when approach volumes or turning proportions exceed certain limits, and this is most likely the reason for the warning. Since these ratios created problems for AWSC analysis, they were not used analyzing the other intersection types.

The FHWA Roundabout Guide, in its own analyses of turning percentages, assumed 10 percent right turns in all cases, and 0 to 40 percent left turns, which exceeds the normal expectation for left turn proportions [6]. Along this line of thought, the (left, through, right) percentages used in the analysis runs were (10, 80, 10), (20, 70, 10), and (30, 60, 10). These percentages were the same among the four approaches to the intersection.

Both the percentage of heavy vehicles (HV) and the ratio of heavy vehicles between the intersecting roads were varied. A ratio of 1.0 was tested for "lower" values of 10 percent HV on both roads and for "higher" values of 20 percent HV on both roads. Likewise, a ratio of 2.0 was tested for "lower" values of 10 percent HV on one road and 5 percent HV on the other, and for "higher" values of 20 percent HV on one road and 10 percent HV on the other.

In addition to these parameters, the roundabout analyses varied the inscribed diameter. The inscribed diameter is the length between the outside edges of the circulatory roadway—that is, island diameter plus twice the circulating roadway width. According to the FHWA Roundabout Guide [6], urban single-lane roundabouts typically have inscribed diameters ranging between 100 and 130 feet. With an 18-foot circulating roadway width, the inscribed diameters tested were 80, 100, and 120 feet (island diameters of 44, 64, and 84 feet, respectively).

When varying one particular parameter, all others were held constant at a designated default value. These defaults were: volume ratio of 1.0; turning percentages of 10 percent left turns, 80 percent through, and 10 percent right turns; and the lower heavy vehicle ratio of 1.0 (i.e., 10 percent heavy vehicles on both roads). The default roundabout inscribed diameter was 100 feet.

These variations are summarized below. Default values are indicated in bold.

- Road A / Road B volume ratio
    - **1.00**

- 1.33

- Turning percentages (left, through, right)

Note: same on both roads

  - **(10,80,10)**
  - (20,70,10)
  - (30,60,10)

- Heavy vehicles (Road A, Road B)

  - **(10,10)**
  - (20,20)
  - (10,5)
  - (20,10)

- Roundabout inscribed diameter (feet)

Note: value in parentheses is island diameter, assuming an 18-ft circulatory roadway

  - 80 (44)
  - **100 (64)**
  - 120 (84)

3.4 Results of aaSIDRA Software Analysis

All results obtained from the SIDRA software are included as Appendix A.

In a comparison of intersection control types, Sisiopiku and Oh [21] found signalized intersection performance superior to the performances of other intersection types when traffic demand was "heavy," though no numerical values are indicated for these demand volumes. The SIDRA data obtained for this study showed that for all

MOEs, the roundabout provided better operational performance (i.e., greater capacity, lower delay, etc.) than the signal up to a certain total intersection demand volume at which point the signal began to perform better than the roundabout. This crossover point was determined to be 2400 vph for the degree of saturation, 2400 vph for the effective intersection capacity, 2500 vph for the 95% queue length, 2500 vph for the average delay, 2540 vph for CO_2 emissions, 2540 vph for HC emissions, 1900 vph for CO emissions, and 2070 vph NO_X emissions. Therefore, the average roundabout-signal crossover volume was 2356 vph (total intersection demand).

The focus of the SIDRA analysis was a comparison of the roundabout and AWSC intersection performances for each of the test scenarios. The results of this comparison support the statement made in the FHWA Roundabout Guide, that roundabouts always offer better performance for vehicles than AWSC, given the same traffic conditions and right-of-way limitations [6]. Compared to the AWSC intersection, the roundabout provided a 190 percent increase in effective intersection capacity, a 65 percent decrease in degree of saturation, a 41 percent decrease in queue length, a 49 percent decrease in delay, an 11 percent decrease in CO_2 emissions, a 17 percent decrease in HC emissions, an 18 percent decrease in CO emissions, and a 12 percent decrease in NO_X emissions. Table 3.1 summarizes these overall percentage changes for the roundabout versus AWSC performances. Tables 3.2 and 3.3 present more detailed data on the changes for each MOE scenario for both intersection types.

Table 3.1 Change in MOE for roundabout compared to AWSC intersection.

MOE	Roundabout vs. AWSC Performance
Capacity	190% increase
Degree of Saturation	65% decrease
Queue Length	41% decrease
Delay	49% decrease
CO_2 Emissions	11% decrease
HC Emissions	17% decrease
CO Emissions	18% decrease
NO_X Emissions	12% decrease

Table 3.2 Percentage change for each operations MOE scenario for AWSC and roundabout intersections.

			Eff. Intn. Capacity		Degree Saturation		Queue Length		Average Delay	
Condition	**From**	**To**	**AWSC**	**Rbt**	**AWSC**	**Rbt**	**AWSC**	**Rbt**	**AWSC**	**Rbt**
Volume Ratio	1.0	1.33	-2.1%	-8.5%	-10.4%	-4.1%	-13.5%	-7.5%	-4.4%	-2.0%
Turning Percentages	(10,80,10)	(20,70,10)	-11.0%	-1.9%	+12.3%	+1.7%	+22.3%	+1.5%	+15.6%	+8.1%
	(20,70,10)	(30,60,10)	-13.1%	-1.7%	+15.0%	+1.9%	+29.4%	+2.7%	+24.5%	+8.0%
Heavy Vehicle Percentages	(10,5)	(10,10)	-0.5%	-0.9%	+0.5%	+0.7%	+2.0%	+1.1%	+1.2%	+1.3%
	(20,10)	(20,20)	-1.8%	-1.9%	+1.7%	+2.0%	+2.9%	+3.3%	+2.6%	+2.8%
	(10,5)	(20,10)	-3.2%	-10.6%	+3.3%	+11.7%	+15.5%	+17.2%	+3.9%	+3.7%
	(10,10)	(20,20)	-4.5%	-11.6%	+4.5%	+13.1%	+16.6%	+19.9%	+5.4%	+5.1%

Table 3.3 Percentage change for each emissions MOE scenario for AWSC and roundabout intersections.

			CO_2		HC		CO		NO_X	
Condition	**From**	**To**	**AWSC**	**Rbt**	**AWSC**	**Rbt**	**AWSC**	**Rbt**	**AWSC**	**Rbt**
Volume Ratio	1.0	1.33	-12.7%	-12.6%	-12.8%	-13.2%	-12.6%	-13.1%	-12.6%	-12.8%
Turning Percentages	(10,80,10)	(20,70,10)	+1.2%	+0.9%	+2.1%	+1.5%	+0.6%	+1.8%	+0.3%	+0.9%
	(20,70,10)	(30,60,10)	+2.6%	+1.0%	+3.9%	+1.3%	+1.4%	+2.0%	+1.2%	+1.2%
Heavy Vehicle Percentages	(10,5)	(10,10)	+5.6%	+5.6%	+3.1%	+3.1%	+7.1%	+7.1%	+5.7%	+5.3%
	(20,10)	(20,20)	+9.6%	+9.9%	+5.7%	+5.5%	+11.9%	+12.1%	+9.9%	+9.3%
	(10,5)	(20,10)	+16.8%	+16.7%	+9.5%	+8.9%	+21.5%	+21.7%	+17.1%	+16.1%
	(10,10)	(20,20)	+21.3%	+21.5%	+12.3%	+11.4%	+26.9%	+27.4%	+21.8%	+20.5%
Roundabout Diam. (ft)	80	100	N/A	-0.8%	N/A	-2.0%	N/A	-3.3%	N/A	-1.6%
	100	120	N/A	-0.8%	N/A	-1.8%	N/A	-3.1%	N/A	-1.5%

When the volume ratio between the intersecting roads was increased from 1.0 to 1.33, effective intersection capacity was reduced but all other MOEs improved for both the roundabout and AWSC intersections. AWSC capacity decreased an average of 2.1 percent, while roundabout capacity decreased an average of 8.5 percent. Degree of saturation, queue length, delay for the AWSC were reduced 10.4, 13.5, and 4.4 percent, respectively. The change in volume ratio had less effect on roundabout performance, as these MOEs were reduced 4.1, 7.5, and 2 percent, respectively. Emissions were decreased by similar amounts for both intersection types by an average of 12.8 percent.

Changes in the proportion of left-turning vehicles had a greater effect on the AWSC performance than on the roundabout. In general, an increase in left-turning percentage led to a decrease in intersection capacity and decreases in all other MOEs. When left-turns were increased from 10 to 20 percent, capacity was reduced 11 percent, degree of saturation was increased 12.3 percent, queue length was increased 22.3 percent, and delay was increased 15.6 percent for the AWSC intersection. Corresponding changes for the roundabout were smaller: capacity was reduced 1.9 percent, degree of saturation was increased 1.7 percent, queue length was increased 1.5 percent, and delay was increased 8.1 percent. When left-turns were further increased, from 20 to 30 percent, greater increases occurred for the AWSC, while those for the roundabout remained relatively the same as before. Emission rates experienced similar patterns in change, being greater for the AWSC intersection, and increasing with increased left-turn proportion.

For both intersection types, capacity was reduced and all other MOEs were increased with the heavy vehicle scenarios in the following order: (10,5), (10,10), (20,10), (20,20). This inherently makes sense, as the scenarios consecutively increase in overall heavy vehicle volume, which would affect intersection performance in a similar manner. Decreases in capacity and increases in all other MOEs were similar between the two intersection types when the heavy vehicle ratio was decreased from 2.0 ("lower" (10,5) and "higher" (20,10)) to 1.0 ("lower" (10,10) and "higher" (20,20)). When heavy vehicle percentages were increased from the "lower" scenarios ((10,10) and (10,5)) to the "higher" scenarios ((20,20) and (20,5)), increases in queue length, delay and emissions were similar for both roundabout and AWSC intersection. Decreases in capacity and increases in degree of saturation, however, were greater for the roundabout than for the AWSC intersection.

Roundabout capacity, degree of saturation, queue length, and delay were not affected by changes in the range of diameters tested for this analysis. Reductions in emissions were observed, however, as the roundabout diameter was increased. The decreases in emissions were similar for both increases, from 80 to 100 feet and from 100 to 120 feet, with the average being 2 percent. All data for this MOE scenario is presented in Table 3.3.

It is important to remember that, although certain MOEs for the roundabout were affected more by changes in traffic conditions than those of the AWSC intersection as described above, overall the roundabout still provided superior performance than the AWSC intersection.

3.5 Summary of Chapter 3

The traffic intersection software used for this thesis is aaSIDRA (Signalized and unsignalized Intersection Design and Research Aid), also known as SIDRA, version 2.1. The software is capable of analyzing signalized intersections (actuated and fixed-time), unsignalized intersections (TWSC, AWSC, and yield-controlled), and roundabouts. Among the output provided by SIDRA are the following measures of effectiveness (MOEs) used in this study: effective intersection capacity, average delay, maximum 95% queue length, degree of saturation, and emissions rates of CO, HC, CO_2, and NO_X.

The SIDRA default roundabout critical gap and follow-up time values are not fixed and are estimated by the program as functions of the roundabout geometry, circulating flow, and entry lane flows. The roundabout analysis conducted in this study has been calibrated for local driver characteristics using critical gap and follow-up times determined from data collection at two local roundabouts. As no sites suitable for use in this study presently exist in Delaware, it was decided to select locations in Maryland. Following consultation with the Maryland State Highway Administration (SHA), two roundabouts were chosen for this study—one in Cecil County and the other in Queen Anne's County.

The critical gaps for each of the study sites were determined following Drew's method for accepted and rejected gap times. The critical gaps found for the Cecil County and Queen Anne's County roundabouts are 3.85 and 3.91 seconds, respectively. These values are slightly below the range of 4.1 to 4.6 seconds indicated in the HCM 2000. Critical gap data consisted of 20 accepted and 161 rejected gaps for the Rising Sun roundabout, and 29 accepted and 158 rejected gaps for the Castle Marina roundabout. The follow-up times found were 1.9 seconds for the Cecil County roundabout (standard deviation of 0.89 seconds) and 2.1 seconds for the Queen Anne's County roundabout (standard deviation of 0.66 seconds). These values are slightly below those the range of 2.6 to 3.1 seconds found in the HCM 2000. Follow-up time data consisted of 82 times for the Rising Sun roundabout and 114 times for the Castle Marina roundabout.

SIDRA software analyses were run to compare three intersection types: AWSC, single-lane roundabout, and actuated signal. Gap acceptance parameters used for roundabout analysis were a critical gap of 3.9 seconds and a follow-up time of 2.0 seconds, which were the average between those values found for the two study sites. The analyses varied volume ratio between the intersecting roads, turning percentages, heavy vehicle percentages and ratio between the roads, and roundabout diameter. The SIDRA results showed that for all MOEs, the roundabout provided better operational performance (i.e., greater capacity, lower delay, etc.) than the signal up to a certain total intersection demand volume at which point the signal began to perform better than the roundabout. The average roundabout-signal crossover volume was 2356 vph.

The focus of the SIDRA analysis, however, was a comparison of the roundabout and AWSC intersection performances for each of the test scenarios. The results of this comparison support the statement made in the FHWA Roundabout Guide [6], that roundabouts always offer better performance for vehicles than AWSC, given the same traffic conditions and right-of-way limitations. Compared to the AWSC intersection, the roundabout provided a 190 percent increase in effective intersection capacity, a 65 percent decrease in degree of saturation, a 41 percent decrease in queue length, a 49 percent decrease in delay, an 11 percent decrease in CO_2 emissions, a 17 percent decrease in HC emissions, an 18 percent decrease in CO emissions, and a 12 percent decrease in NO_X emissions.

Chapter 4

KNOWLEDGE-BASED EXPERT SYSTEMS

4.1 Definition of Knowledge-Based Expert Systems

An expert is an individual who possesses considerable knowledge in a particular field, acquired through training and experience, which allows him or her to effectively and efficiently find solutions to problems. For non-experts, access to these individuals is invaluable in getting advice and helping them make good decisions quickly. However, being human, experts are not available to help at all times or other situations arise where access to them is limited.

Knowledge-based expert systems (KBES), or expert systems, are computer systems designed to model the interaction one would have with a human expert. Expert systems embody the knowledge of experts and make it available 24 hours a day [33]. In addition, an expert system can logically explain the basis for its conclusions, something that other artificial intelligence programs cannot do [32]. With these other forms of artificial intelligence, users are simply provided with information and expected to understand and convert it to usable knowledge on their own. Expert systems, on the other hand, enable people to solve complex decision-making problems without training and without having to learn the underlying logic. By asking the user questions in order to obtain information, the expert system determines what additional information is needed and also avoids asking unnecessary or redundant questions. The system reaches a conclusion and provides the user with one or more recommendations with varying degrees of confidence, and explains the basis for these conclusions [37]. In short, an expert system is distinguished from another form of artificial intelligence in that:

- It must deal with realistically complex problems that typically require a considerable amount of knowledge and experience in order to solve;
- It must be both highly reliable and quick in decision-making in order to be a useful tool; and
- It must be capable of explaining and justifying its recommendations in order to convince the user that the reasoning is correct [32].

The principle difference between a knowledge-based expert system and a conventional computer program is its structure. In a conventional computer system, domain knowledge (i.e., specialized knowledge in a field) is intertwined with the software for controlling the application of that knowledge, whereas in a KBES the two roles are explicitly separated into two modules: the knowledge base (knowledge module) and the inference engine (control module). The separation of knowledge from its control is a valuable feature of expert systems, helping make it easier to understand what knowledge is being used and how it is being used [35]. Additionally, the separation allows new knowledge to be added with relative ease, whereas this would require immersing oneself into the programming of a conventional computer system [34].

The knowledge base contains specialized knowledge as provided by the expert and may be rich with diverse forms of knowledge including problem facts, rules, concepts, and relationships [35]. Modeled after the reasoning ability of a human expert, the inference engine is the expert system's knowledge processor, relating information stored in the knowledge base with user-provided information in order to draw conclusions. Information obtained from the user is stored in the system's working memory, which the inference engine matches with information in the knowledge base in order to infer new facts, which are then added to the working memory. This process continues until the inference engine reaches one or more conclusions [35]. The inference engine determines what additional data is needed to decide if a particular answer is appropriate and which answer is most likely, based on the rules of the knowledge base. The relationships between these expert system components are presented in Figure 4.1.

In developing an expert system, the decision-making knowledge and procedures used by the human expert are converted to logical representation that the computer system can process by defining "rules" that the inference engine analyzes and combines to solve a larger problem. A large part of building an expert system is in identifying each of the steps in the expert's decision process and making it a heuristic rule. While the heuristics for a decision-making process can be described in a number of ways, the most effective and efficient is the IF-THEN rule [37]. IF-THEN rules logically relate information contained in the IF part to other information contained in the THEN part; when the IF part is found to be true, the statements in the THEN part are also considered to be true [35]. For example: IF the car will not start, THEN the problem may be in the electrical system.

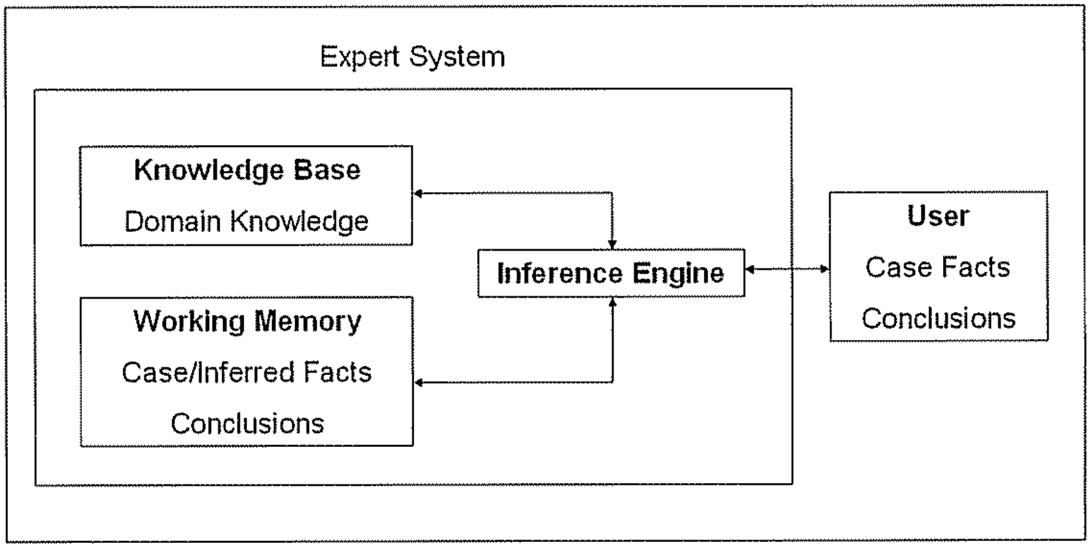


Figure 4.1 Expert system problem solving [35].

The IF-THEN rules of an expert system are very different from the simple IF-THEN commands in a computer language such as C++, all because of the inference engine. Rules are not the same as lines of code, but are facts that are automatically combined in various ways by the inference engine, making the expert system approach "far more powerful, effective, and maintainable for knowledge delivery than traditional programming techniques" [37].

Expert systems vary in the type of strategy used in reaching a conclusion, and two important types of these strategies are referred to as "forward chaining" and "backward chaining". In the data-driven (forward chaining) strategy, the expert system begins with a set of known information provided by the user, which is stored in the working memory. Using rules from the knowledge base with premises that match the known facts, the inference engine derives new facts and then adds these to the working memory. This process continues until either a goal is met or until no more rules exist having premises that match the facts in the working memory. Forward chaining is a good technique to use with problems where information is first gathered and from which logical conclusions must then be inferred, such as in planning, monitoring, control, and interpretation. A drawback to a forward chaining strategy is its inability to recognize the relative importance of information, and so it spends equal amounts of time gathering both useful and trivial information [35].

In the goal-driven (backward chaining) strategy, the expert system begins with a hypothesis that must either be established or refuted and then proceeds to gather the necessary information [34]. The inference engine initially checks only rules that directly lead to the goal, but moves on to other rules with THEN statements containing the desired goal. The system then checks if the premises of these rules are contained in the working memory and if they are not, these then become new goals. Eventually the system reaches a premise that is not supported by any rule and at this point the user is asked to supply this information. Backward chaining is similar to hypothesis testing in human problem solving, as it remains focused on a given goal and by asking a series of related questions [35]. It is a good technique to use for diagnostics, prescription, and de-bugging. A disadvantage is that the backward chaining strategy will continue to follow the same line of reasoning even if it should switch to another [35].

4.2 History of Knowledge-Based Expert Systems

Artificial intelligence (AI) is a field in computer science that studies the development of computer systems capable of having human-like intelligence, such as competent reasoning in decision-making. The AI field first emerged in the late 1950s in an attempt to make computers more useful for humans as well as to better understand human intelligence [35]. Early AI work mainly consisted of programs for playing chess and checkers, but in 1960 the General Problem Solver (GPS) was developed. GPS was a problem-solving technique capable of solving a variety of problems from games to symbolic integration. In defining a problem in terms of "states" representing the various stages of problem solving, it was the first technique attempting to separate the knowledge of the problem from the problem solving methods [35]. Among the problems associated with GPS, however, was the realization that its computer time and memory requirements were impractical for solving complex problems.

Considered by some to be the first real expert system, DENDRAL was first developed in 1965 at Stanford University for identifying the molecular structure of unknown substances. Stanford's researchers, seeing that chemists first used heuristics to eliminate unnecessary possibilities and create a more manageable amount of data, replicated this strategy in their program. This resulted in a computer program that could quickly identify compounds just as reliably as a human chemist. The pioneering aspect of DENDRAL was in showing other AI researchers that "intelligent behavior is dependent not so much on the methods of reasoning as on the knowledge one has to reason with" [35].

Also developed at Stanford University and called the "Grandfather of Expert Systems" by some, MYCIN diagnoses and treats infectious blood diseases. It was one of the first expert systems to use IF-THEN rules as well as backward chaining and was also first to use certainty factors, which assign numerical values indicating the confidence placed on an answer. Another distinguishing feature is the complete separation of its rule base from its inference program. Discarding the MYCIN knowledge base creates empty MYCIN or EMYCIN, upon which modern expert system shells (discussed below) are based [33].

Other notable expert systems include:

- MACSYMA: for simplifying algebraic expressions; like DENDRAL, it demonstrated the superiority of domain-specific knowledge over general problem-solving methods [38];
- PROSPECTOR: for helping geologists locate valuable ore deposits; built on the technology of MYCIN [33]; and
- HEARSAY II: for understanding spoken language, with a vocabulary of 1000 words and a simple grammar [38].

Expert system shells are expert systems with empty knowledge bases. They are commercially available for use in a variety of fields for functions such as:

regulatory compliance, product selection/recommendation, customer/product support, background monitoring, and smart questionnaires [37]. The expert system shell selected for use in this thesis is Exsys CORVID, version 3.2.1, which is discussed in the following section.

4.3 Exsys CORVID Knowledge Automation Expert System Software

CORVID was created by Exsys, Inc., the first company that made practical expert system development available for the PC in the early 1980s [37].

The CORVID inference engine combines rules with a goal-driven (backward chaining) strategy, though it also supports the forward chaining approach to logic. CORVID is based on Microsoft's Visual Basic (VB), which is not a true goal-driven programming language, but provides many goal-based features. This simplification provides a goal-oriented structure with which the developer can easily build systems using methods and properties of *variables*. Variables are the building blocks that are used to build expert systems with CORVID. There are seven types of variables, which share some characteristics, but each one has a special functionality and capability. Variables are used to define the logic in the logic blocks (discussed below), to hold user data during a session, and to define the goals of how the system will run [37].

Previous Exsys tools used tree logic diagrams and individual IF-THEN rules that often required multiple trees and rules to collectively provide a decision-making step, which created difficulty in organizing logic. CORVID introduces the concept of *logic blocks* in managing logic. Logic blocks are combinations of rules and trees and a unique way of defining, organizing, and structuring rules into logically related blocks. Rules within a logic block may be defined by tree diagrams or stated as individual rules. Logic blocks facilitate a development environment that is easy to learn and use because the underlying knowledge representation is still in IF-THEN rules. With logic blocks, rules can be used as a group and maintenance of complex systems and changes in logic become much easier to do [37].

Another useful feature of CORVID is the use of *confidence factors*, which enable the expert system to make multiple recommendations with varying degrees of confidence. This better emulates interaction with a human expert, since oftentimes in the real world more than one solution is possible for a problem. Confidence factors allow the system to rank the recommendations in order and present them to the user to make the final call.

4.4 Justification for Using a Knowledge-Based Expert System

The use of a knowledge-based expert system applies well to the process of evaluating an AWSC intersection for its feasibility in being converted to a roundabout.

The evaluation is a process that a knowledge-based expert system can guide the user through efficiently. Since roundabouts are still a relatively new form of intersection control in the United States, many traffic engineers and planners most likely lack adequate experience with their design and implementation and would therefore be required to read through numerous guides on their own or wait for assistance from other more experienced engineers. While this strategy works, it can also end up costing considerable time and money. Developing an expert system capable of helping to determine if an intersection is feasible for conversion to a roundabout is like having a human expert right there to assist the engineer at any time of the day. This allows the engineer to begin work on other aspects of the project, including, as past projects have shown, the lengthy process of increasing public approval.

4.5 Summary of Chapter 4

Knowledge-based expert systems (KBES), or expert systems, are computer systems designed to model the interaction one would have with a human expert. Expert systems embody the knowledge of experts and make it available 24 hours a day. Other forms of artificial intelligence simply provide users information and the users are then expected to understand and convert it to usable knowledge on their own. In contrast, expert systems enable people to solve complex decision-making problems without training and without having to learn the underlying logic.

The principle difference between a knowledge-based expert system and a conventional computer program is its structure. In a conventional computer system, domain knowledge (i.e., specialized knowledge in a field) is intertwined with the software for controlling the application of that knowledge, whereas in a KBES the two roles are explicitly separated into two modules: the knowledge base (knowledge module) and the inference engine (control module).

In developing an expert system, the decision-making knowledge and procedures used by the human expert are converted to logical representation that the computer system can process by defining "rules" that the inference engine analyzes and combines to solve a larger problem. A large part of building an expert system is in identifying each of the steps in the expert's decision process and making it a heuristic rule.

Expert systems vary in the type of strategy used in reaching a conclusion, and two important types of strategies are called forward chaining and backward chaining. Forward chaining is a good technique to use with problems where information is first gathered and from which logical conclusions must then be inferred, such as in planning, monitoring, control, and interpretation. Backward chaining is similar to hypothesis testing in human problem solving by remaining focused on a given goal and asking a series of related questions. It is a good technique to use for diagnostics, prescription, and de-bugging.

The artificial intelligence field first emerged in the late 1950s in an attempt to make computers more useful for humans as well as to better understand human intelligence. Notable early systems include DENDRAL for identifying the molecular structure of unknown substances, MYCIN for diagnosing and treating infectious blood diseases, MACSYMA for simplifying algebraic expressions, PROSPECTOR for locating ore deposits, and HEARSAY II for understanding spoken language. These examples show how expert systems can and have been applied to a variety of fields of study.

Expert system shells are expert systems with empty knowledge bases. They are commercially available for a variety of uses such as: regulatory compliance, product selection/recommendation, customer/product support, background monitoring, and smart questionnaires. The expert system shell selected for use in this thesis is Exsys CORVID.

The CORVID inference engine combines rules with a goal-driven (backward chaining) strategy, though it also supports the forward chaining approach to logic. CORVID provides a goal-oriented structure with which the developer can easily build systems using methods and properties of variables. Variables are the building blocks that are used to build expert systems with this software. CORVID introduces the concept of logic blocks in managing logic. Logic blocks are combinations of rules and trees and a unique way of defining, organizing, and structuring rules into logically related blocks. With logic blocks, rules can be used as a group and maintenance of complex systems and changes in logic become much easier to do. Another useful feature of CORVID is the use of confidence factors, which enable the expert system to make multiple recommendations with varying degrees of confidence. This better emulates interaction with a human expert, since oftentimes in the real world more than one solution is possible for a problem. The user is provided with a selection of possible solutions to the problem, from which he or she makes the final decision, using his or her best judgment.

Chapter 5

DEVELOPMENT AND ANALYSIS OF THE RATING SYSTEM

The purpose of the rating system is to evaluate an existing all-way stop-controlled intersection for its potential success if converted to a roundabout. The goal in building the system is to create a final product that is able to achieve several goals: to assess the intersection in a logical and accurate manner, to be user-friendly, and to clearly present the results of the analysis. As previously indicated, the expert system will be built using Exsys CORVID, version 3.2.1.

In reaching a conclusion, an expert system should function, as a human expert would think. How, then, would the human expert for this situation—that is, an engineer with adequate study of and experience with modern roundabouts—approach this problem? The task at hand raises an array of questions, some of which are concerned with the nature of the traffic; others relate to the physical features of intersection itself; and still others question a variety of issues regarding the surrounding community and public. For example: What is the current volume demand at the intersection? What will it be in the future? What are some other important characteristics of this traffic? How much space is available at the intersection? Is the public specifically interested in improving the appearance of the intersection and/or community? Is safety a major concern at the intersection? These are but a few of the questions that need to be asked when assessing an intersection for what form of traffic control will best work there. The expert system developed for this thesis addresses all of these questions and more in an attempt to replicate the procedure an experienced engineer would follow in order to rate the intersection.

5.1 Development of the Rating System

The first step in building the expert system is creating all of variables to be used by the system. This entails identifying the questions to be asked of the user and all possible answers to these questions, as well as creating variables to hold values that are calculated by the system during the analysis. The complete list of variables is included in Appendix C.

The next, and most time-consuming, step in creating the system is building the logic blocks. Exsys CORVID facilitates this process by allowing rules to be separated and organized into logic blocks of related rules, so that the developer does not have one large assortment of rules to sort through. Rules in CORVID are built within the logic blocks using variables to add nodes.

The first series of questions that the user is asked determine if the intersection would operate better as a signal or as a roundabout. The system does this by considering traffic characteristics (heavy vehicle and left-turning percentages) as well as projected future demand volume, while assuming the intersection configuration remains as it presently is. The basis for this decision is the data obtained from the SIDRA traffic analysis software, which are presented in Tables 5.1, 5.2, and 5.3. Results form the software analyses showed that the AWSC intersection always performed worse (lower capacity, greater delay, etc.) than the other two intersection types. Thus, when faced with improving an existing AWCS intersection, the decision must be made between converting to a roundabout or to a signalized intersection.

The values presented in Table 5.1 indicate total intersection demand volumes (vph) up to which the roundabout intersection performed better than the signalized intersection for each MOE considered. When total intersection demand volumes exceeded these values, the signalized intersection performed better than the roundabout. For many scenarios, the roundabout had a shorter queue length than the signal for all volumes tested; this is denoted in the table with dashed marks. Note that Table 5.1 presents data corresponding to volume ratio, turning percentage, and heavy vehicle ratio scenarios that were not initially tested with the SIDRA software. The analyses discussed previously in Chapter 3 used default values in order to simplify the analysis. However, it was later decided to include all the scenarios in order to obtain a more complete database of values for the rating system. The values in Tables 5.2 and 5.3 are based upon those in Table 5.1 and are the average volume for each scenario, excluding that for queue length, which in many cases did not exist. Table 5.2 shows averages not including those for emissions, while Table 5.3 shows averages including those for emissions.

The questions that the system asks the user are listed below, as well as discussions on the possible answers that the user may enter.

1) *Is the AWSC intersection currently experiencing operational problems during peak hours or throughout the day?* The user indicates yes or no. If no, there are still other reasons that merit consideration for the intersection to be converted to a roundabout, such as safety. In that case, the system still reports to the user which intersection type would perform better in the future, for informational purposes.

2) *Has a study been conducted to determine if the intersection volumes warrant signalization according to the MUTCD?* The user indicates yes or no.

3) *Do the volumes at the intersection warrant signalization according to the MUTCD? Do not answer if a study has not been conducted.* The user indicates yes or no. The system recognizes that three possible sets of answers exist for these two questions: yes/yes, yes/no, and no (in which case the second question is unnecessary), and takes these into consideration when assessing the intersection

4) *Enter the design year for the intersection.* The user types in the design year. This is needed to calculate the projected future demand volume.

5) *Enter the current year.* The user types in the current year. This is needed to calculate the projected future demand volume.

6) *What is the intersection demand during peak hours (total of all four approach volumes)?* The user types in the demand volume. This is needed to calculate the projected future demand volume.

7) *What is the expected growth rate for the demand volume (percentage per year)?* The user types in the expected growth rate. This is needed to calculate the projected future demand volume.

8) *Would you like the analysis to be based solely on operational performance (capacity, V/C, average delay) or would you also like to include emissions?* The user indicates yes or no. The answer to these questions directs the system to the appropriate maximum

roundabout total intersection control value. The projected future demand is compared to the value; if the future demand is below this value, a roundabout will most likely perform better than a signal, vice versa if the future demand is above this value.

9) *What is the ratio between the volumes of the two intersecting roads? Choose the closer value.* The user chooses between ratios of 1:1 and 3:4.

10) *What is the average left-turning percentage of vehicles at the intersection? Choose the closest value.* The user chooses between 10, 20, and 30 percent.

11) *What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value.* The user chooses between ratios of 1:1 and 2:1.

12) *What is the value of the greater of these two percentages? Choose the closer value.* The user chooses between 10 and 20 percent.

Table 5.1 Maximum roundabout total intersection demand (vph) for all MOEs.

	Volume Ratio 1.0											
	(10,80,10)				(20,70,10)				(30,60,10)			
	(10,5)	(10,10)	(20,10)	(20,20)	(10,5)	(10,10)	(20,10)	(20,20)	(10,5)	(10,10)	(20,10)	(20,20)
V/C	2500	2400	2250	2150	2380	2350	2040	2100	2300	2250	2050	2020
Capacity	2500	2450	2300	2150	2380	2350	2170	2100	2300	2250	2050	2020
Queue	2700	---	2500	---	2580	---	2315	---	2470	---	---	---
Delay	2620	2550	2390	2230	2500	2400	2250	2140	2380	2300	2125	2040
CO_2	2680	2600	2420	2290	2540	2460	2350	2190	2420	2350	2180	2100
HC	2660	2590	2420	2280	2540	2440	2300	2180	2420	2360	2190	2100
CO	2100	2100	1800	1500	2000	2000	1600	1000	1900	1800	1500	1300
No_X	2500	2500	2100	1900	2400	2300	1800	1100	2200	2100	1600	1500
	Volume Ratio 1.33											
	(10,80,10)				(20,70,10)				(30,60,10)			
	(10,5)	(10,10)	(20,10)	(20,20)	(10,5)	(10,10)	(20,10)	(20,20)	(10,5)	(10,10)	(20,10)	(20,20)
V/C	2480	2800	2280	2200	2380	2320	2150	2050	2240	2170	1980	1960
Capacity	2480	2800	2280	2190	2380	2320	2160	2050	2260	2180	1980	1980
Queue	---	---	2450	---	---	2510	2300	---	2420	---	2140	2060
Delay	2620	2900	2380	2240	2470	2400	2220	2110	2320	2260	2100	1980
CO_2	2800	2900	2400	2300	2540	2460	2380	2160	2380	2320	2140	2020
HC	2800	2980	2400	2350	2530	2460	2380	2160	2380	2320	2140	2020
CO	2100	2400	1900	1700	2010	1900	1920	1750	1920	1750	1575	1490
No_X	2500	2800	2200	1750	2400	2300	2000	1750	2180	1920	1750	1650

Table 5.2 Average maximum roundabout total intersection demand (vph) used in rating system, not including emissions.

V/C, CAPACITY, DELAY			
VOLUME RATIO	LEFT TURN %	HEAVY VEHICLES	MAX INTERSECTION DEMAND
1	10	10,5	2540
		10,10	2467
		20,10	2313
		20,20	2177
	20	10,5	2420
		10,10	2367
		20,10	2153
		20,20	2113
	30	10,5	2327
		10,10	2267
		20,10	2075
		20,20	2027
1.33	10	10,5	2527
		10,10	2833
		20,10	2313
		20,20	2210
	20	10,5	2410
		10,10	2347
		20,10	2177
		20,20	2070
	30	10,5	2273
		10,10	2203
		20,10	2020
		20,20	1973

Table 5.3 Average maximum roundabout total intersection demand (vph) used in rating system, including emissions.

V/C, CAPACITY, DELAY, EMISSIONS			
VOLUME RATIO	LEFT TURN %	HEAVY VEHICLES	MAX INTERSECTION DEMAND
1	10	10,5	2509
		10,10	2456
		20,10	2240
		20,20	2071
	20	10,5	2391
		10,10	2329
		20,10	2073
		20,20	1830
	30	10,5	2274
		10,10	2201
		20,10	1956
		20,20	1869
1.33	10	10,5	2540
		10,10	2797
		20,10	2263
		20,20	2104
	20	10,5	2387
		10,10	2309
		20,10	2173
		20,20	2004
	30	10,5	2240
		10,10	2131
		20,10	1952
		20,20	1871

After the system determines the projected future demand and compares this against the appropriate value from Tables 5.2 or 5.3, it proceeds to ask the user for information concerning the area surrounding the intersection:

13) *Has the public expressed an interest in enhancing the community's appearance?* The user indicates yes or no. If yes, a roundabout provides a good opportunity for doing so, and if no, this could be used in support in increasing public approval of the project. The user is advised that efforts to enhance the aesthetics, such as landscaping and sculptures, would increase costs for installation and maintenance.

14) *If this intersection were converted to a roundabout, would it be the first roundabout in the area?* The user indicates yes or no. If yes, this may cause some residents who area unfamiliar with roundabouts to be initially opposed to it just for this reason alone. Significant effort should be made towards public education on the benefits of roundabouts and how to properly use them. If no, residents may still have negative opinions.

15) *Is it possible to purchase additional right-of-way at the intersection, if necessary?* The user indicates yes or no. If not, and if a roundabout is applicable to the intersection, this would leave no choice but to choose a signal, if the existing area of the intersection cannot accommodate a roundabout of the appropriate size. The user is referred to the FHWA Roundabout Guide,

Appendix B [6] for guidance on initial roundabout space requirements.

16) *Is the intersection located along a transit route?* The user indicates yes or no. This question is closely related to the previous one; if yes, a roundabout must be designed to accommodate buses as well as any other expected large vehicles.

17) *Is this intersection located in the vicinity of a railroad crossing?* The user indicates yes or no. While locating any intersection near an at-grade intersection is generally discouraged, rail transit has been successfully incorporated into the design of roundabouts. If yes, the user is referred to the FHWA Roundabout Guide, Section 8.2 [6] for specific guidance on how this could be done.

18) *Are there signalized intersections in close proximity to the existing AWSC intersection?* The user indicates yes or no. If yes, the user is advised on possible effects the roundabout may have on these intersections, and vice versa. The user is referred to the FHWA Roundabout Guide, Section 8.5 [6] for further discussion.

19) *Is there a significant amount of pedestrian and/or bicyclist traffic at any time during the day?* The user indicates yes or no. If yes, the roundabout should be properly designed for this traffic. The user is referred to the FHWA Roundabout Guide, Sections 5.3.3, 6.3.7, and 5.3.4 [6] for further discussion and guidance.

Finally, the system asks the user a series of questions regarding the safety of the intersection. These questions determine whether or not the roundabout is highly recommended, if it has already been identified as being a better choice for the intersection than the signal.

20) *Is there a history of frequent and/or severe accidents at the intersection?* The user indicates yes or no.

21) *Is there a history of left-turn head-on and/or right-angle collisions at the intersection?* The user indicates yes or no.

22) *Have accidents been caused as a result of drivers failing to properly obey the stop control?* The user indicates yes or no. If the answers to one or more of these questions are yes, the case for a roundabout is stronger, due to the significant improvement in safety that they offer. If the system has determined that a roundabout would operate better than a signal, and the user has indicated a history of accidents at the intersection, the system will highly recommend a roundabout, along with a short explanation of the benefits in safety which are associated with roundabouts.

The highlight of using an expert system in determining the best possible choice for traffic control at the intersection is the ability to explain to the user the reasons for doing so. The results of the system and the final recommendation to the user are presented using the default CORVID results screen, through which the user may scroll. The system first reports its recommended form of intersection control for the intersection, i.e., roundabout or signal. If a roundabout is the recommended choice, the system also reports if it is highly recommended.

The remainder of the report is comprised of comments in response to the various topics addressed in the questions of the system, as well as references to specific sections of the FHWA Roundabout Guide [6] that the user could consult for more discussion and guidance. Figure 5.1 shows a sample results screen. All logic blocks for the rating system are included in Appendix C.

The final step in creating the system is writing the command block. Command blocks control how a system operates, what actions to take, and in what order to perform these actions. They direct the system how to use the logic blocks; that is, what variable or variables to derive values for, and when and how to display the results. A single command block is sufficient for most simply expert systems. For this system, one command block comprised of three commands is all that is necessary to run the system. The first command instructs the system to display the title screen, the second instructs it to derive results for the variable *Display_Results*, and the last instructs it to display the results.

5.2 Analysis of the Rating System

The true assessment of the rating system's performance is made by applying it to a variety of AWSC intersections. This allows one to determine if the system makes decisions in a logical manner and shows how useful it would be for application to real traffic engineering problems. For this validation process, traffic data and other information were obtained for three intersections from the Delaware Department of Transportation (DelDOT). All intersections are located in New Castle County, south of the C&D Canal and north of Middletown, DE. These intersections are listed below and shown in Figure 5.2.

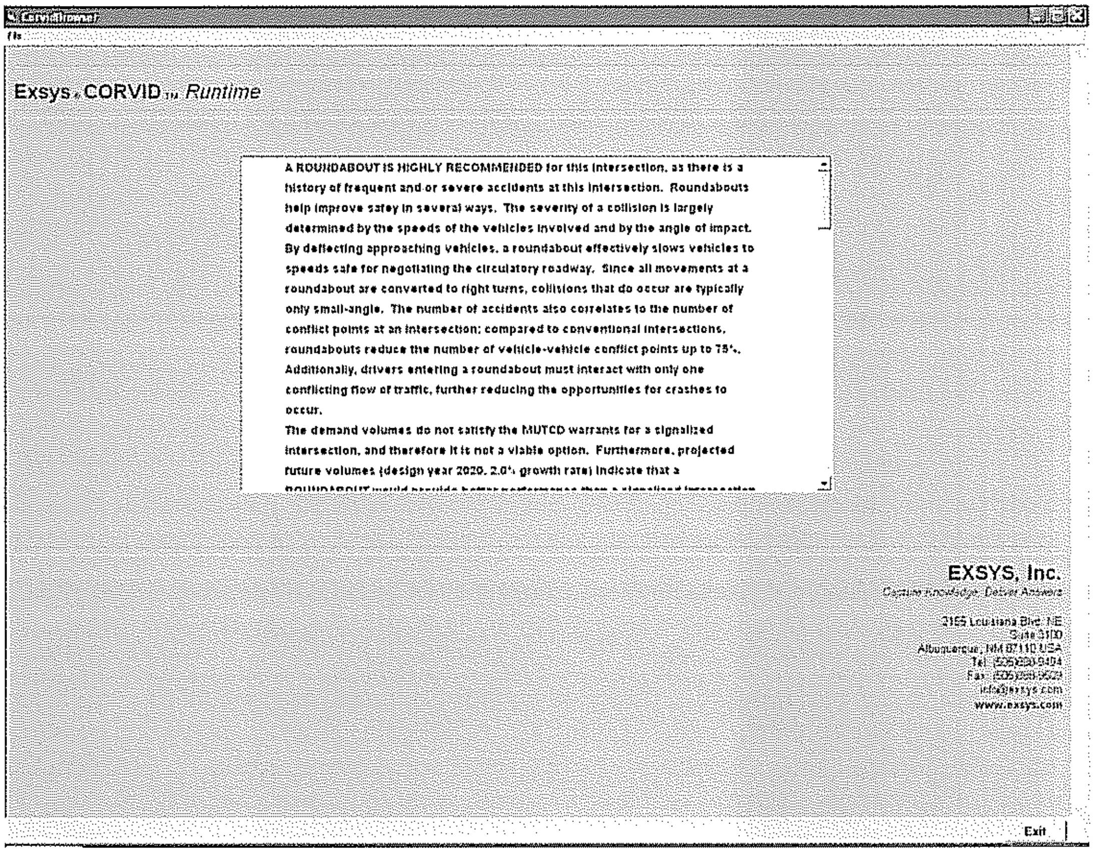


Figure 5.1 Sample results screen of rating system.

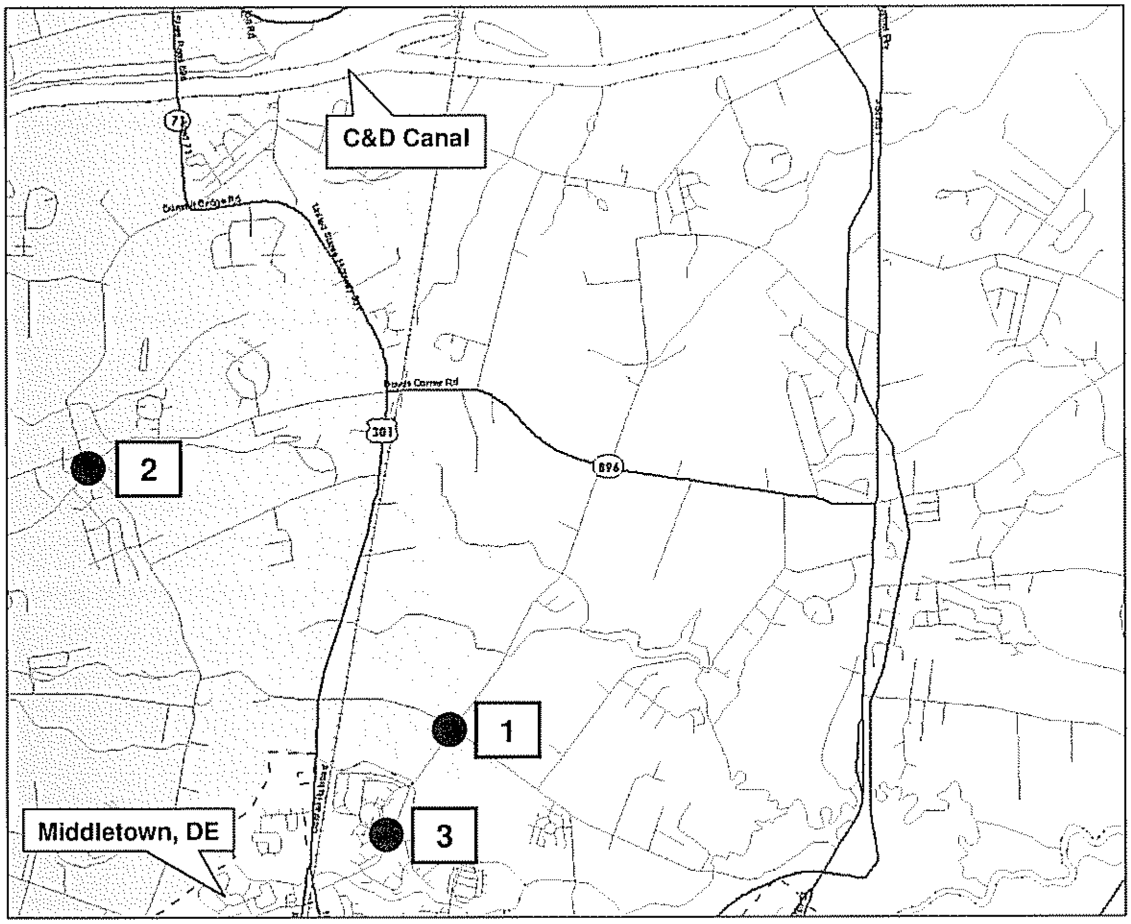


Figure 5.2 Locations of intersections used to validate the rating system [39].

1. Cedar Lane Road and Marl Pit Road;
2. Choptank Road and Churchtown Road;
3. Cedar Lane Road and Whittington Way.

5.2.1 Intersection Data

Data consisting of traffic counts (2005), heavy vehicle percentages, and expected volume growth rates were provided for both the morning and evening peak hours at each of the six intersections. The greater of the two peak hour volumes at each intersection was chosen for use in the rating system, which was the evening peak hour for all locations. Volume ratios, heavy vehicle ratios, and average left turning percentages were also calculated from these data. Other information was provided for some of the intersections, such as safety issues or planned improvements. Any other information needed to run the rating system, such as proximity of railroad crossings or amount of pedestrian/bicyclist traffic, was assumed using the best judgment possible.

Responses to all questions of the rating system are presented in Table 5.4. Some of the responses are based on numerical (volume and heavy vehicle) data provided by DelDOT. For questions requiring non-numerical answers (i.e., yes or no answer), engineering judgment was used to provide reasonable answers. Question numbers shown in the table were previously identified in Section 5.1. Note that while the actual volume ratio for intersection 3 is 5:1, higher than either of the choices the user is given, the closer of the two, 4:3, was selected.

Table 5.4 Responses to questions of the rating system.

Question		Intersection		
		1	2	3
1	Current operational problems	Yes	Yes	Yes
2	MUTCD signal study conducted	No	Yes	No
3	Signal warranted	---	No	---
4	Design year	2030	2030	2030
5	Current year	2005	2005	2005
6	Total peak volume demand	768	581	537
7	Expected growth rate (%/year)	2.2	2.5	1.6
8	Include emissions in analysis	Emissions	Emissions	Emissions
9	Volume ratio	4:3	1:1	4:3
10	Average left-turning percentage	20	20	20
11	Heavy vehicle ratio	1:1	1:1	2:1
12	Greater heavy vehicle percentage	10	10	10
13	Public interest in aesthetics	Yes	Yes	Yes
14	First roundabout in area	Yes	Yes	Yes
15	Additional right-of-way	Yes	Yes	Yes
16	Along transit route	No	No	No
17	Nearby railroad crossing	Yes	No	No
18	Nearby signalized intersection	Yes	No	Yes
19	Pedestrian/bicyclist traffic	No	No	Yes
20	Accident history	No	Yes	No
21	Right-angle collisions	No	No	No
22	Drivers do not obey stop control	No	No	No

5.2.2 Discussion of Rating System Results

Cedar Lane Road and Marl Pit Road: The rating system recommends a roundabout over a signal for this intersection. The 2030 projected demand indicates that a roundabout will provide better performance than a signal, based on the predetermined roundabout-signal crossover volume for volume ratio 3:4, 20 percent left turns, and heavy vehicles (10,10). No other information was provided for this location, and so some user responses were assumed. For example, since there are not many roundabouts in Delaware, it was assumed that if one were constructed, it would be the first for this community. The results address this by advising the user of various methods to help the local population become familiar with roundabouts as well as to decrease public opposition to a proposed roundabout, which oftentimes is a major obstacle for engineers to overcome. Since the location is relatively close to a town, there may be signalized intersections nearby, though the exact distance is not known. The results warn of possible effects that a roundabout and nearby signal may have on one another. If the effects from any nearby signal are significant, this may change the suitability of a roundabout to this location, despite the advantages over a signal that the rating system indicates a roundabout would offer. In this case, the installation of a signal may be the only option for improving operations at this intersection.

Choptank Road and Churchtown Road: The rating system highly recommends a roundabout over a signal for this intersection. The 2030 projected demand indicates that a roundabout will provide better performance than a signal, based on the predetermined roundabout-signal crossover volume for volume ratio 1:1, 20 percent left turns, and heavy vehicles (10,10). The roundabout is also recommended due to safety concerns indicated by the user at this location. Information provided by DelDOT indicated that a small hill on one of the approaches creates sight line constraints at the existing intersection. The proven improvements in safety that roundabouts provide, coupled with the operational benefits over a signalized intersection, lead the rating system to highly recommend a roundabout for this location. As it is, DelDOT is planning to construct a roundabout at this intersection in Fall 2008. This further validates the rating system recommendation.

Cedar Lane Road and Whittington Way: The rating system recommends a roundabout over a signal for this intersection. The 2030 projected demand indicates that a roundabout will provide better performance than a signal, based on the predetermined roundabout-signal crossover volume for volume ratio 3:4, 20 percent left turns, and heavy vehicles (10,5). However, the actual volume ratio at this location is close to 5:1, though the closest option provided by the system is a ratio of 3:4. This unbalanced traffic flow may significantly affect the successful implementation of a roundabout at this location. The roundabout-signal crossover volume that the rating system used for this intersection was based on a volume ratio of 3:4. If, however, the SIDRA analyses had included large ratios such as 5:1, it is very likely that the rating system's recommendation would have been different. No other information was provided for this location, and so some user responses were assumed. For example, since the location is within the limits of a town, it was assumed that local residents would be interested in improving the community's appearance, and so the rating system results suggest ways that a roundabout can be used for this purpose. It was assumed that significant pedestrian and/or bicyclist traffic exists at this intersection, and so the results advise the user of considerations for this traffic and provide reference to the FHWA Roundabout Guide [6] for further guidance on how to properly do this. Being within town limits also increases the probability that signalized intersections exist nearby, and so this was assumed as well. The rating system results warn of the possible effects that a roundabout and nearby signals may have on each other, particularly if the signals are part of a coordinated signal system. This is an important consideration that may ultimately affect the possibility of a roundabout performing well at this location.

The ability to purchase additional right-of-way was assumed for all intersections, which may very well not be true for one or more of them. In this case, despite the rating system's recommendation of a roundabout, a signal would be the only option for improving operations at the intersection. As previously noted in Section 2.3, intersection characteristics that have been identified as unfavorable to roundabouts include locations where topographic or site constraints limit the ability to provide appropriate geometry; in other words, locations where there is no space available for a roundabout of appropriate diameter.

Accident data was not obtained for these intersections, which may have added more weight to the recommendation of a roundabout at one or more locations. If accidents are frequent and/or consist of right-angle collisions, the case for a roundabout is made stronger, thanks to modern roundabout design and operational characteristics that help reduce both collision frequency and severity.

5.3 Summary of Chapter 5

The purpose of this rating system is to evaluate an existing all-way stop-controlled intersection for its potential success if converted to a roundabout. The goal in building the rating system is to create a user-friendly product that is able to logically and accurately assess the intersection and clearly present the results.

The first series of questions that the user is asked determine if the intersection would operate better as a signal or as a roundabout. The system does this by comparing projected future volumes with the data obtained from the SIDRA traffic analysis software, which are presented in Table 5.1. The values presented in Table 5.1 indicate total intersection demand volumes (vph) up to which the roundabout intersection performed better than the signalized intersection for each MOE considered. When total intersection demand volumes exceeded these values, the signalized intersection performed better than the roundabout. The system then proceeds to ask the user for information concerning the area surrounding the intersection as well as the safety of the intersection. These questions determine whether or not the roundabout is highly recommended, if it has already been identified as being a better choice for the intersection than the signal.

The highlight of using an expert system in determining the best possible choice for traffic control at the intersection is the ability to explain to the user the reasons for doing so. The results of the system and the final recommendation to the user are presented using the default CORVID results screen, through which the user may scroll.

In order to determine if the system makes decisions in a logical manner and, therefore, how useful it would be for application to real traffic engineering problems, the system was validated using real intersection data. Traffic data and other information were obtained for three intersections. Responses to all questions of the rating system corresponding to these intersections are presented in Table 5.4 and discussed in Section 5.2.2.

Chapter 6

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

This thesis has succeeded in accomplishing the following objectives, which were previously stated in Chapter 1:

- A literature review of past studies of roundabout operational and safety performance, comparisons of roundabouts with other forms of intersection control, and existing federal and state roundabout guides;
- The collection of local driver gap acceptance data at local roundabout sites;
- The determination of local driver critical gap and follow-up times from this data;
- A comparative analysis of an all-way stop-controlled intersection, a roundabout, and a signalized intersection to note behaviors and patterns in response to the variation of several traffic parameters; and
- The development of an expert system designed to rate an all-way stop-controlled intersection for its potential in being converted to a roundabout, incorporating the results of the comparative analysis and findings and recommendations in existing roundabout guides.

6.2 Conclusions

6.2.1 Results of Data Collection and SIDRA Software Analysis

Local driver gap acceptance was observed and recorded at two Maryland roundabout locations. Reduction of this data found critical gap times of 3.85 seconds for the Cecil County roundabout and 3.91 seconds for the Queen Anne's County roundabout. These values are slightly below the range of 4.1 to 4.6 seconds indicated in the HCM 2000. Reduction of the data also found follow-up times of 1.9 seconds for the Cecil County roundabout and 2.1 seconds for the Queen Anne's County roundabout. These values are slightly below those the range of 2.6 to 3.1 seconds found in the HCM 2000.

The comparative analysis of AWSC, roundabout, and signalized intersections was completed using SIDRA traffic analysis software. Gap acceptance parameters used in the analysis were calibrated for local conditions by using a 3.9 second critical gap and a 2.0 second follow-up time for drivers at the roundabout. Results from this comparative analysis are in agreement with other documents, which state that roundabouts always offer better performance for vehicles (greater capacity, less delay, etc.) than AWSC intersections, given the same traffic conditions and right-of-way limitations. It was also observed that the roundabout performed better than the signal up to a certain volume, after which the signal then performed better than the roundabout. The average value of this roundabout-signal crossover volume (the total of all four approach volumes) is 2356 vph.

In general, the effective intersection capacity for all intersection types decreased as the percentage of left-turning vehicles increased. Increases in the proportion of left-turning vehicles also had a greater effect on the performance of the

AWSC intersection than on the roundabout. For both intersection types, capacity was reduced and all other MOEs were increased with the heavy vehicle scenarios in the following order: (10,5), (10,10), (20,10), (20,20). Roundabout capacity, degree of saturation, queue length, and delay were not affected by changes in the range of diameters tested for this analysis.

The following tables were developed from the results from the SIDRA analysis. The values indicate total intersection demand (vph) below which a roundabout performs better than a signal, and above which a signal performs better than a roundabout. Knowing the volume ratio, average turning percentages, and heavy vehicle percentages for the intersection, the appropriate roundabout-signal crossover volume can be found. These tables were then used in developing the expert system, which bases its evaluation of the best form of intersection control on this data, in addition to user-provided information.

Table 6.1 Average maximum roundabout total intersection demand (vph) used in rating system, not including emissions.

V/C, CAPACITY, DELAY			
VOLUME RATIO	LEFT TURN %	HEAVY VEHICLES	MAX INTERSECTION DEMAND
1	10	10,5	2540
		10,10	2467
		20,10	2313
		20,20	2177
	20	10,5	2420
		10,10	2367
		20,10	2153
		20,20	2113
	30	10,5	2327
		10,10	2267
		20,10	2075
		20,20	2027
1.33	10	10,5	2527
		10,10	2833
		20,10	2313
		20,20	2210
	20	10,5	2410
		10,10	2347
		20,10	2177
		20,20	2070
	30	10,5	2273
		10,10	2203
		20,10	2020
		20,20	1973

Table 6.2 **Average maximum roundabout total intersection demand (vph) used in rating system, including emissions.**

V/C, CAPACITY, DELAY, EMISSIONS			
VOLUME RATIO	LEFT TURN %	HEAVY VEHICLES	MAX INTERSECTION DEMAND
1	10	10,5	2509
		10,10	2456
		20,10	2240
		20,20	2071
	20	10,5	2391
		10,10	2329
		20,10	2073
		20,20	1830
	30	10,5	2274
		10,10	2201
		20,10	1956
		20,20	1869
1.33	10	10,5	2540
		10,10	2797
		20,10	2263
		20,20	2104
	20	10,5	2387
		10,10	2309
		20,10	2173
		20,20	2004
	30	10,5	2240
		10,10	2131
		20,10	1952
		20,20	1871

6.2.2 Advantages of the Rating System

Since roundabouts are still a relatively new form of intersection control in the United States, the task of determining whether or not a roundabout is a feasible alternative to a signal at an existing AWSC intersection is a challenging one for many traffic engineers. The development of the rating system offers several advantages for inexperienced engineers.

- *The system makes expert knowledge available at anytime.* An individual with considerable knowledge in the implementation of roundabouts is a valuable resource for younger or inexperienced traffic engineers. Rather than spending time by waiting for a human expert to be available to help, an engineer may access the rating system at any time that suits him or her. The system offers guidance in decision-making, points out related issues and considerations that the inexperienced engineer may overlook, and helps make good decisions quickly. The system also identifies specific sections of the FHWA Roundabout Guide [6] that the user may refer to for additional guidance.
- *The system is fast and useful.* Engineers are occupied with numerous tasks when working on a traffic improvement project. By using this automated tool in the decision-making process, more time may be spent on other pressing engineering work to meet project deadlines. If all necessary data is readily available when using the rating system, results will be obtained in a matter of minutes. Additionally, the system can quickly indicate to the engineer if a roundabout or signal is likely to perform better based

on future volumes and on the various MOEs considered. This saves the engineer time by helping direct further study of the intersection.

- *The system is user-friendly.* Running the system is easy even for first-time users. Questions are short and easy to understand. The system recommendation and suggestions are clearly presented to the user in the results screen, which the user may scroll through to read.
- *The final decision belongs to the user.* The system makes a recommendation as to whether a roundabout or a signal would be a good choice to which to convert the AWSC intersection. However, the results always indicate that the final decision is ultimately up to the user and that he or she must use good engineering judgment in making the final choice. Multiple solutions oftentimes exist for traffic engineering problems; the task, then, is to decide which of these is best. The developed rating system simply recommends the better choice between roundabout and signal, based on operational measures of effectiveness, and provides suggestions on a number of relevant issues that the engineer should take into consideration before making the final decision.

6.2.2 Disadvantages of the Rating System

The limited applicability of the rating system is perhaps its largest shortcoming. In the interest of time and in order to simplify the software analysis, defaults for each type of varied parameter were chosen. Additionally, the only intersection configuration that the analysis considered was a perpendicular crossing of two roads. This avoided creating an immensely large number of software analyses to run, but ultimately limited the developed expert system, which is based on these analyses. For example, the user is asked to describe traffic demand at the intersection by choosing between 10, 20, and 30 percent left-turning vehicles. But what if the percentage is less than these values or lies between two of these values? Furthermore, the software analysis assumed identical conditions among all four approaches at the intersection. But what if there are 20 percent left-turning vehicles on one approach, 10 percent on another, and so on? This may be a major drawback for some users, who would like the system to be more flexible in allowing a larger variety of traffic and geometric conditions.

The rating system bases its recommendation of roundabout or signal on the roundabout-signal crossover volume determined by the software analyses. A roundabout is recommended if the projected future volume falls below this value and a signal is recommended if the volume falls above this value. But what about a situation where the projected volume is "borderline"? This is a close call; perhaps either intersection type would work in this case. The rating system, however, will make just one decision, regardless of how close or far the projected volume is from the roundabout-signal crossover volume. This is another shortcoming of the system, as it could be improved in order to be more sensitive to such "borderline" situations. Also, the validation process using real intersection data brought up the issue of locations with highly unbalanced traffic flows. For such locations, the rating system may not be completely accurate, as all roundabout-signal crossover volumes are based on analyses using volume ratios of either 1:1 or 3:4.

As previously stated, it is difficult to provide a clear-cut, yes-or-no answer in determining if a roundabout is suitable for a particular location, as numerous considerations have an affect on this issue. The same can be said of the developed rating system, and this may be frustrating for some users who would prefer to be given a direct and definite answer. These users may therefore consider this to be a disadvantage of the rating system.

6.3 Recommendations

Many factors must be considered when evaluating an existing AWSC intersection for possible conversion to a roundabout. While the demand volume is a good initial indication in assessing the intersection, there are many more considerations affecting this decision. If the total intersection demand is below 2300 vph, then a roundabout may be appropriate for the location; if it is close to or above this value, then a signal is likely to be the better choice. Additionally, if the intersection has a history of accidents, particularly right-angle collisions, then the case for a roundabout is made stronger. Factors that may hinder the success of a roundabout include spatial restrictions and the proximity of signalized intersections and railroads. Likewise, intersections where there is a large imbalance between the two roads are better served by a signal than a roundabout. The expert system developed for this thesis is a good starting point for the evaluation, but more in-depth analyses should be conducted using software such as SIDRA for all alternatives being considered for the intersection. Such an analysis would allow comparisons to be made in greater detail, for each MOE of importance. Additionally, a cost and benefit analysis should be conducted to determine if a roundabout is a cost effective option for the location. Referenced throughout this thesis, the FHWA Roundabout Guide [6] should always be consulted for issues associated with installing the roundabout.

There has been a considerable lack of research in the applicability of modern roundabouts to existing intersections and in comparative studies of modern roundabouts with other forms of intersection control in the United States. This may be due to the relatively little use they have had in the country. However, growing interest in the use of modern roundabouts in recent years warrants increased research on these topics. Studies could focus on the comparison of roundabouts with just one type of intersection control in order to allow for a more detailed analysis. Studies could also include one of each type, so as to cover a greater range of situations.

Future research could also address a different or a larger set of variations in the parameters used in this thesis: volume ratio, heavy vehicle percentage and ratio, turning percentages, and roundabout diameter. Future analyses could also become more complicated by assuming differences in these parameters between individual approaches at an intersection. This expansion of parameters applies to analyses done with traffic analysis software, as well as to other expert systems. More variations in parameters during the initial analysis allow for a more specific expert system that is capable of evaluating a greater variety of intersections.

Another suggestion for future work is the inclusion of two-way stop-controlled intersections in the analysis and rating system, in addition to AWSC intersections. This would make a developed system more powerful and useful to traffic engineers by being applicable to an even wider variety of intersections.

Appendix A

TABLES OF SIDRA SOFTWARE ANALYSIS RESULTS FOR AWSC, ROUNDABOUT, AND SIGNALIZED INTERSECTIONS FOR ALL TEST SCENARIOS

Volume ratio 1:1

AWSC. Turning (10,80,10). 10% HV.

Volume (vph) Per Approach A	Per Approach B	Road A L	Road A T	Road A R	Road B L	Road B T	Road B R	SIDRA Results: Degree of Saturation	Eff. Intn. Cap. (vph)	Queue (ft)	Avg. Delay (s/veh)	Emissions (kg/h) CO_2	HC	CO	Nox
25	25	3	20	3	3	20	3	0.060	1943	5	12.6	22.6	0.033	1.35	0.046
50	50	5	40	5	5	40	5	0.109	1980	10	12.8	42.1	0.062	2.52	0.087
75	75	8	60	8	8	60	8	0.161	2007	15	13.0	63.2	0.094	3.78	0.130
100	100	10	80	10	10	80	10	0.208	1997	20	13.3	81.2	0.120	4.86	0.167
125	125	13	100	13	13	100	13	0.263	2010	27	13.7	103.3	0.153	6.18	0.212
150	150	15	120	15	15	120	15	0.320	1988	34	14.2	124.8	0.186	7.46	0.256
175	175	18	140	18	18	140	18	0.373	1997	41	14.7	146.4	0.218	8.75	0.300
200	200	20	160	20	20	160	20	0.420	2008	49	15.3	166.6	0.248	9.95	0.341
225	225	23	180	23	23	180	23	0.473	2011	58	16.0	188.6	0.282	11.26	0.385
250	250	25	200	25	25	200	25	0.529	1995	69	16.9	210.4	0.315	12.53	0.428
275	275	28	220	28	28	220	28	0.580	2007	81	18.0	233.3	0.351	13.88	0.473
300	300	30	240	30	30	240	30	0.625	2010	93	19.2	253.3	0.382	15.05	0.513
325	325	33	260	33	33	260	33	0.680	2006	111	20.9	277.8	0.421	16.46	0.559

Volume ratio 4:3

AWSC. Turning (10,80,10). 10% HV.

Volume (vph) Per Approach A	Per Approach B	Road A L	Road A T	Road A R	Road B L	Road B T	Road B R	SIDRA Results: Degree of Saturation	Eff. Intn. Cap. (vph)	Queue (ft)	Avg. Delay (s/veh)	Emissions (kg/h) CO_2	HC	CO	Nox
25	19	3	20	3	2	15	2	0.054	1901	5	12.7	19.9	0.029	1.19	0.041
50	38	5	40	5	4	30	4	0.098	1948	9	12.7	37.0	0.055	2.22	0.076
75	56	8	60	8	6	45	6	0.146	1958	14	12.9	55.7	0.083	3.34	0.115
100	75	10	80	10	8	60	8	0.189	1961	18	13.1	72.2	0.107	4.32	0.148
125	94	13	100	13	9	75	9	0.236	1955	23	13.4	90.3	0.134	5.41	0.185
150	113	15	120	15	11	90	11	0.281	1958	29	13.8	107.7	0.160	6.44	0.221
175	131	18	140	18	13	105	13	0.328	1963	35	14.1	126.3	0.188	7.56	0.259
200	150	20	160	20	15	120	15	0.377	1963	42	14.7	145.6	0.217	8.70	0.298
225	169	23	180	23	17	135	17	0.423	1967	49	15.1	164.1	0.245	9.80	0.336
250	188	25	200	25	19	150	19	0.474	1951	57	15.8	182.9	0.273	10.92	0.373
275	206	28	220	28	21	165	21	0.517	1964	66	16.5	201.9	0.302	12.04	0.411
300	225	30	240	30	23	180	23	0.564	1959	76	17.3	220.3	0.331	13.12	0.448
325	244	33	260	33	24	195	24	0.609	1967	88	18.4	240.6	0.362	14.31	0.488
350	263	35	280	35	26	210	26	0.661	1952	103	19.7	260.9	0.394	15.49	0.527
375	281	38	300	38	28	225	28	0.706	1962	121	21.4	283.0	0.430	16.76	0.569

Turning (10,80,10)

AWSC. Volume ratio 1:1. 10% HV.

Volume (vph) Per Approach A	Per Approach B	Road A L	Road A T	Road A R	Road B L	Road B T	Road B R	SIDRA Results: Degree of Saturation	Eff. Intn. Cap. (vph)	Queue (ft)	Avg. Delay (s/veh)	Emissions (kg/h) CO_2	HC	CO	Nox
25	25	3	20	3	3	20	3	0.060	1943	5	12.6	22.6	0.033	1.35	0.046
50	50	5	40	5	5	40	5	0.109	1980	10	12.8	42.1	0.062	2.52	0.087
75	75	8	60	8	8	60	8	0.161	2007	15	13.0	63.2	0.094	3.78	0.130
100	100	10	80	10	10	80	10	0.208	1997	20	13.3	81.2	0.120	4.86	0.167
125	125	13	100	13	13	100	13	0.263	2010	27	13.7	103.3	0.153	6.18	0.212
150	150	15	120	15	15	120	15	0.320	1988	34	14.2	124.8	0.186	7.46	0.256
175	175	18	140	18	18	140	18	0.373	1997	41	14.7	146.4	0.218	8.75	0.300
200	200	20	160	20	20	160	20	0.420	2008	49	15.3	166.6	0.248	9.95	0.341
225	225	23	180	23	23	180	23	0.473	2011	58	16.0	188.6	0.282	11.26	0.385
250	250	25	200	25	25	200	25	0.529	1995	69	16.9	210.4	0.315	12.53	0.428
275	275	28	220	28	28	220	28	0.580	2007	81	18.0	233.3	0.351	13.88	0.473
300	300	30	240	30	30	240	30	0.625	2010	93	19.2	253.3	0.382	15.05	0.513
325	325	33	260	33	33	260	33	0.680	2006	111	20.9	277.8	0.421	16.46	0.559

Turning (20,70,10)

AWSC. Volume ratio 1:1. 10% HV.

Volume (vph) Per Approach A	Per Approach B	Road A L	Road A T	Road A R	Road B L	Road B T	Road B R	SIDRA Results: Degree of Saturation	Eff. Intn. Cap. (vph)	Queue (ft)	Avg. Delay (s/veh)	Emissions (kg/h) CO_2	HC	CO	Nox
25	25	5	18	3	5	18	3	0.065	1798	6	13.3	22.7	0.034	1.35	0.046
50	50	10	35	5	10	35	5	0.116	1822	11	13.5	41.5	0.061	2.48	0.085
75	75	15	53	8	15	53	8	0.181	1791	18	14.1	63.5	0.094	3.79	0.130
100	100	20	70	10	20	70	10	0.238	1747	24	14.7	81.8	0.122	4.68	0.167
125	125	25	88	13	25	88	13	0.302	1746	32	15.3	104.2	0.155	6.21	0.213
150	150	30	105	15	30	105	15	0.352	1786	39	15.7	124.2	0.185	7.40	0.253
175	175	35	123	18	35	123	18	0.422	1762	49	16.6	147.8	0.221	8.79	0.301
200	200	40	140	20	40	140	20	0.477	1768	59	17.5	168.5	0.253	10.01	0.342
225	225	45	158	23	45	158	23	0.545	1753	72	18.8	192.2	0.290	11.39	0.389
250	250	50	175	25	50	175	25	0.589	1788	84	19.8	212.8	0.322	12.59	0.429
275	275	55	193	28	55	193	28	0.652	1784	103	22.0	238.2	0.362	14.03	0.478
300	300	60	210	30	60	210	30	0.710	1775	124	24.6	261.4	0.400	15.33	0.520
325	325	65	228	33	65	228	33	0.774	1772	156	28.8	291.2	0.450	16.95	0.573

Turning (30,60,10) AWSC. Volume ratio 1:1. 10% HV.

Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay	Emissions (kg/h)			
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	No_x
25	25	8	15	3	8	15	3	0.073	1582	7	14.6	22.8	0.034	1.36	0.047
50	50	15	30	5	15	30	5	0.137	1552	13	15.1	41.8	0.062	2.49	0.085
75	75	23	45	8	23	45	8	0.205	1560	21	15.5	64.0	0.095	3.60	0.130
100	100	30	60	10	30	60	10	0.270	1539	29	16.4	82.5	0.123	4.90	0.168
125	125	38	75	13	38	75	13	0.345	1531	39	17.4	105.3	0.158	6.23	0.213
150	150	45	90	15	45	90	15	0.412	1535	49	18.3	126.7	0.190	7.49	0.256
175	175	53	105	18	53	105	18	0.487	1519	61	19.5	149.3	0.225	8.80	0.301
200	200	60	120	20	60	120	20	0.553	1527	74	21.0	171.6	0.260	10.09	0.344
225	225	68	135	23	68	135	23	0.615	1541	91	23.0	194.8	0.297	11.41	0.389
250	250	75	150	25	75	150	25	0.683	1546	114	25.9	220.4	0.338	12.84	0.436
275	275	83	165	28	83	165	28	0.757	1539	145	30.5	248.9	0.386	14.37	0.486
300	300	90	180	30	90	180	30	0.816	1544	182	36.3	277.5	0.437	15.84	0.534
325	325	98	195	33	98	195	33	0.895	1533	253	48.6	320.7	0.517	17.92	0.599

Road A HV=10%, Road B HV=10% AWSC. Volume ratio 1:1. Turning (10,80,10).

Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay	Emissions (kg/h)			
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	No_x
25	25	3	20	3	3	20	3	0.060	1943	5	12.6	22.6	0.033	1.35	0.046
50	50	5	40	5	5	40	5	0.109	1980	10	12.8	42.1	0.062	2.52	0.087
75	75	8	60	8	8	60	8	0.161	2007	15	13.0	63.2	0.094	3.78	0.130
100	100	10	80	10	10	80	10	0.208	1997	20	13.3	81.2	0.120	4.86	0.167
125	125	13	100	13	13	100	13	0.263	2010	27	13.7	103.3	0.153	6.18	0.212
150	150	15	120	15	15	120	15	0.320	1988	34	14.2	124.8	0.186	7.46	0.256
175	175	18	140	18	18	140	18	0.373	1997	41	14.7	145.4	0.218	8.75	0.300
200	200	20	160	20	20	160	20	0.420	2008	49	15.3	166.6	0.248	9.95	0.341
225	225	23	180	23	23	180	23	0.473	2011	58	16.0	188.6	0.282	11.26	0.385
250	250	25	200	25	25	200	25	0.529	1995	69	16.9	210.4	0.315	12.53	0.428
275	275	28	220	28	28	220	28	0.580	2007	81	18.0	233.3	0.351	13.88	0.473
300	300	30	240	30	30	240	30	0.625	2010	93	19.2	253.3	0.382	15.05	0.513
325	325	33	260	33	33	260	33	0.660	2006	111	20.9	277.8	0.421	16.46	0.559

Road A HV=20%, Road B HV=20% AWSC. Volume ratio 1:1. Turning (10,80,10).

Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay	Emissions (kg/h)			
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	No_x
25	25	3	20	3	3	20	3	0.062	1885	6	12.9	27.4	0.037	1.71	0.057
50	50	5	40	5	5	40	5	0.109	1914	11	13.0	49.1	0.067	3.08	0.101
75	75	8	60	8	8	60	8	0.173	1895	18	13.5	77.6	0.106	4.66	0.160
100	100	10	80	10	10	80	10	0.217	1914	23	13.8	98.6	0.135	6.17	0.203
125	125	13	100	13	13	100	13	0.280	1900	31	14.3	126.4	0.174	7.91	0.260
150	150	15	120	15	15	120	15	0.329	1918	38	14.7	150.5	0.207	9.41	0.310
175	175	18	140	18	18	140	18	0.388	1908	47	15.4	176.8	0.244	11.05	0.363
200	200	20	160	20	20	160	20	0.440	1919	57	16.0	202.3	0.279	12.64	0.415
225	225	23	180	23	23	180	23	0.500	1904	68	16.9	229.3	0.317	14.31	0.470
250	250	25	200	25	25	200	25	0.546	1918	79	17.9	253.6	0.352	15.82	0.519
275	275	28	220	28	28	220	28	0.612	1901	95	19.4	283.8	0.396	17.68	0.579
300	300	30	240	30	30	240	30	0.660	1910	112	20.9	309.7	0.434	19.26	0.630
325	325	33	260	33	33	260	33	0.719	1915	137	23.6	342.7	0.483	21.25	0.693

Road A HV=10%, Road B HV=5% AWSC. Volume ratio 1:1. Turning (10,80,10).

Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay	Emissions (kg/h)			
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	No_x
25	25	3	20	3	3	20	3	0.059	1958	5	12.6	21.4	0.032	1.26	0.044
50	50	5	40	5	5	40	5	0.109	1980	10	12.7	39.8	0.060	2.35	0.082
75	75	8	60	8	8	60	8	0.161	2007	15	12.9	59.8	0.091	3.53	0.123
100	100	10	80	10	10	80	10	0.209	2012	20	13.2	77.6	0.118	4.58	0.159
125	125	13	100	13	13	100	13	0.264	2006	26	13.6	98.2	0.149	5.79	0.201
150	150	15	120	15	15	120	15	0.315	2014	33	14.0	117.8	0.179	6.94	0.241
175	175	18	140	18	18	140	18	0.368	2016	40	14.5	138.3	0.211	8.14	0.283
200	200	20	160	20	20	160	20	0.420	2005	47	15.1	157.3	0.240	9.26	0.321
225	225	23	180	23	23	180	23	0.471	2016	56	15.8	178.2	0.273	10.48	0.363
250	250	25	200	25	25	200	25	0.520	2027	67	16.6	198.7	0.305	11.66	0.404
275	275	28	220	28	28	220	28	0.577	2014	79	17.7	220.4	0.339	12.91	0.447
300	300	30	240	30	30	240	30	0.622	2029	92	18.9	241.0	0.372	14.09	0.487
325	325	33	260	33	33	260	33	0.660	2015	109	20.6	264.2	0.410	15.40	0.531

Road A HV=20%, Road B HV=10% AWSC. Volume ratio 1:1. Turning (10,80,10).

Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of Saturation	Eff. Intn. Cap. (vph)	Ouene (ft)	Avg. Delay (s/veh)	Emissions (kg/h)			
A	B	L	T	R	L	T	R					CO_2	HC	CO	Hox
25	25	3	20	3	3	20	3	0.061	1914	6	12.8	25.0	0.035	1.53	0.051
50	50	5	40	5	5	40	5	0.109	1943	11	12.9	45.6	0.065	2.60	0.094
75	75	8	60	8	8	60	8	0.168	1943	17	13.3	70.4	0.100	4.32	0.145
100	100	10	80	10	10	80	10	0.213	1955	23	13.5	89.9	0.128	5.52	0.185
125	125	13	100	13	13	100	13	0.275	1931	30	14.0	114.8	0.163	7.05	0.236
150	150	15	120	15	15	120	15	0.327	1942	37	14.5	137.6	0.196	8.44	0.283
175	175	18	140	18	18	140	18	0.360	1953	46	15.0	161.6	0.231	9.90	0.332
200	200	20	160	20	20	160	20	0.432	1955	55	15.6	184.4	0.264	11.29	0.378
225	225	23	180	23	23	180	23	0.490	1944	66	16.5	208.9	0.300	12.78	0.427
250	250	25	200	25	25	200	25	0.542	1942	77	17.4	231.9	0.334	14.17	0.473
275	275	28	220	28	28	220	28	0.600	1940	92	18.7	258.5	0.373	15.77	0.526
300	300	30	240	30	30	240	30	0.646	1948	107	20.0	281.4	0.408	17.15	0.571
325	325	33	260	33	33	260	33	0.702	1951	129	22.2	310.0	0.452	18.84	0.626

Volume ratio 1:1 Roundabout. Turning (10,80,10). 10% HV. Inscribed d=100 ft. (island d=64 ft., circulating rd. w=18 ft.)

Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of Saturation	Eff. Intn. Cap. (vph)	Ouene (ft)	Avg. Delay (s/veh)	Emissions (kg/h)			
A	B	L	T	R	L	T	R					CO_2	HC	CO	Hox
25	25	3	20	3	3	20	3	0.018	6444	3	7.3	20.2	0.028	1.05	0.040
50	50	5	40	5	5	40	5	0.033	6456	6	7.2	37.7	0.052	1.98	0.075
75	75	8	60	8	8	60	8	0.051	6364	9	7.4	56.8	0.078	3.01	0.113
100	100	10	80	10	10	80	10	0.067	6228	12	7.4	73.1	0.101	3.89	0.146
125	125	13	100	13	13	100	13	0.087	6044	16	7.6	93.2	0.129	4.99	0.187
150	150	15	120	15	15	120	15	0.109	5840	21	7.7	112.7	0.156	6.06	0.226
175	175	18	140	18	18	140	18	0.130	5708	26	7.8	132.2	0.184	7.15	0.266
200	200	20	160	20	20	160	20	0.151	5576	31	7.9	150.5	0.209	8.17	0.303
225	225	23	180	23	23	180	23	0.175	5432	36	8.1	170.3	0.238	9.30	0.344
250	250	25	200	25	25	200	25	0.201	5248	43	8.3	189.6	0.265	10.40	0.384
275	275	28	220	28	28	220	28	0.228	5104	51	8.5	209.7	0.294	11.57	0.426
300	300	30	240	30	30	240	30	0.253	4960	58	8.6	226.9	0.319	12.57	0.461
325	325	33	260	33	33	260	33	0.283	4812	67	8.9	247.3	0.348	13.78	0.504
350	350	35	280	35	35	280	35	0.317	4640	77	9.1	267.9	0.378	15.00	0.547
375	375	38	300	38	38	300	38	0.354	4472	89	9.4	289.4	0.409	16.29	0.592
400	400	40	320	40	40	320	40	0.389	4328	101	9.6	308.7	0.437	17.47	0.633
425	425	43	340	43	43	340	43	0.434	4148	117	10.0	331.4	0.471	18.86	0.682
450	450	45	360	45	45	360	45	0.475	3996	132	10.3	351.1	0.500	20.09	0.724
475	475	48	380	48	48	380	48	0.522	3832	160	11.2	371.3	0.530	21.37	0.767
500	500	50	400	50	50	400	50	0.571	3676	193	12.3	391.7	0.561	22.66	0.811
525	525	53	420	53	53	420	53	0.635	3488	241	14.1	420.5	0.609	24.72	0.873
550	550	55	440	55	55	440	55	0.694	3336	291	16.2	446.7	0.653	26.46	0.926
575	575	58	460	58	58	460	58	0.758	3156	358	19.3	476.9	0.706	28.23	0.981
600	600	60	480	60	60	480	60	0.825	3064	453	24.4	513.1	0.772	30.32	1.042
625	625	63	500	63	63	500	63	0.905	2920	642	36.0	574.0	0.893	33.75	1.136
650	650	65	520	65	65	520	65	0.981	2796	971	59.9	673.9	1.107	39.04	1.271

Volume ratio 4:3 — Roundabout. Turning (10,80,10). 10% HV. Inscribed d=100 ft. (Island d=64 ft., circulating rd. w=18 ft.)

Volume (vph) Per Approach A	Per Approach B	Road A L	Road A T	Road A R	Road B L	Road B T	Road B R	SIDRA Results: Degree of Saturation	Eff. Intn. Cap. (vph)	Queue (ft)	Avg. Delay (s/veh)	Emissions (kg/h) CO_2	HC	CO	NO_x
25	19	3	20	3	2	15	2	0.018	5701	3	7.2	17.8	0.024	0.92	0.035
50	38	5	40	5	4	30	4	0.033	5739	5	7.2	33.1	0.045	1.74	0.066
75	56	8	60	8	6	45	6	0.050	5713	9	7.3	50.1	0.069	2.64	0.100
100	75	10	80	10	8	60	8	0.065	5660	11	7.4	64.9	0.089	3.44	0.130
125	94	13	100	13	9	75	9	0.085	5450	15	7.5	81.3	0.112	4.33	0.163
150	113	15	120	15	11	90	11	0.105	5234	20	7.5	97.1	0.134	5.20	0.195
175	131	18	140	18	13	105	13	0.125	5152	24	7.7	114.1	0.158	6.14	0.229
200	150	20	160	20	15	120	15	0.144	5127	28	7.8	131.5	0.182	7.10	0.265
225	169	23	180	23	17	135	17	0.166	5016	34	7.9	148.2	0.205	8.05	0.299
250	188	25	200	25	19	150	19	0.189	4886	40	8.0	165.1	0.230	9.00	0.333
275	206	28	220	28	21	165	21	0.213	4776	46	8.2	182.1	0.254	9.97	0.368
300	225	30	240	30	23	180	23	0.234	4711	52	8.3	198.4	0.278	10.91	0.402
325	244	33	260	33	24	195	24	0.260	4613	59	8.5	215.9	0.303	11.92	0.438
350	263	35	280	35	26	210	26	0.288	4476	67	8.7	233.7	0.327	12.93	0.474
375	281	38	300	38	28	225	28	0.318	4358	77	8.9	251.3	0.354	14.00	0.512
400	300	40	320	40	30	240	30	0.346	4249	85	9.1	267.3	0.377	14.96	0.546
425	319	43	340	43	32	255	32	0.381	4124	97	9.3	286.3	0.405	16.11	0.586
450	338	45	360	45	34	270	34	0.412	4034	108	9.5	304.3	0.431	17.19	0.624
475	356	48	380	48	36	285	36	0.446	3931	120	9.8	321.9	0.457	18.27	0.661
500	375	50	400	50	38	300	38	0.481	3831	134	10.1	339.5	0.483	19.36	0.699
525	394	53	420	53	39	315	39	0.523	3697	155	10.5	357.8	0.510	20.50	0.738
550	413	55	440	55	41	330	41	0.563	3597	183	11.3	376.8	0.537	21.66	0.778
575	431	58	460	58	43	345	43	0.609	3484	217	12.5	396.6	0.569	22.98	0.821
600	450	60	480	60	45	360	45	0.657	3370	257	13.8	418.9	0.605	24.54	0.869
625	469	63	500	63	47	375	47	0.712	3243	309	15.8	444.2	0.649	26.29	0.921
650	488	65	520	65	49	390	49	0.761	3150	364	18.1	467.9	0.689	27.71	0.965
675	506	68	540	68	51	405	51	0.813	3062	440	21.8	497.2	0.742	29.41	1.016
700	525	70	560	70	53	420	53	0.866	2960	549	28.0	535.1	0.814	31.58	1.078
725	544	73	580	73	54	435	54	0.929	2875	754	40.3	594.0	0.935	34.85	1.165
750	563	75	600	75	56	450	56	0.995	2774	1092	64.8	693.9	1.151	40.06	1.296

Turning (10,80,10) — Roundabout. Volume ratio 1:1. 10% HV. Inscribed d=100 ft. (Island d=64 ft., circulating rd. w=18 ft.)

Volume (vph) Per Approach A	Per Approach B	Road A L	Road A T	Road A R	Road B L	Road B T	Road B R	SIDRA Results: Degree of Saturation	Eff. Intn. Cap. (vph)	Queue (ft)	Avg. Delay (s/veh)	Emissions (kg/h) CO_2	HC	CO	NO_x
25	25	3	20	3	3	20	3	0.018	6444	3	7.3	20.2	0.028	1.05	0.040
50	50	5	40	5	5	40	5	0.033	6456	6	7.2	37.7	0.052	1.98	0.075
75	75	8	60	8	8	60	8	0.051	6364	9	7.4	56.8	0.078	3.01	0.113
100	100	10	80	10	10	80	10	0.067	6228	12	7.4	73.1	0.101	3.69	0.146
125	125	13	100	13	13	100	13	0.087	6044	16	7.6	93.2	0.129	4.99	0.187
150	150	15	120	15	16	120	15	0.109	5840	21	7.7	112.7	0.156	6.06	0.226
175	175	18	140	18	18	140	18	0.130	5708	26	7.8	132.2	0.184	7.15	0.266
200	200	20	160	20	20	160	20	0.151	5576	31	7.9	150.5	0.209	8.17	0.303
225	225	23	180	23	23	180	23	0.175	5432	36	8.1	170.3	0.238	9.30	0.344
250	250	25	200	25	25	200	25	0.201	5248	43	8.3	189.5	0.265	10.40	0.384
275	275	28	220	28	28	220	28	0.228	5104	51	8.5	209.7	0.294	11.57	0.426
300	300	30	240	30	30	240	30	0.253	4960	58	8.6	226.9	0.319	12.57	0.461
325	325	33	260	33	33	260	33	0.283	4812	67	8.9	247.3	0.348	13.78	0.504
350	350	35	280	35	35	280	35	0.317	4640	77	9.1	267.9	0.378	15.00	0.547
375	375	38	300	38	38	300	38	0.354	4472	89	9.4	289.4	0.409	16.29	0.592
400	400	40	320	40	40	320	40	0.389	4328	101	9.6	308.7	0.437	17.47	0.633
425	425	43	340	43	43	340	43	0.434	4148	117	10.0	331.4	0.471	18.86	0.682
450	450	45	360	45	45	360	45	0.475	3996	132	10.3	351.1	0.500	20.09	0.724
475	475	48	380	48	48	380	48	0.522	3832	160	11.2	371.3	0.530	21.37	0.767
500	500	50	400	50	50	400	50	0.571	3676	193	12.3	391.7	0.561	22.66	0.811
525	525	53	420	53	53	420	53	0.635	3488	241	14.1	420.6	0.609	24.72	0.873
550	550	55	440	55	55	440	55	0.694	3336	291	16.2	446.7	0.653	26.46	0.926
575	575	58	460	58	58	460	58	0.758	3196	358	19.3	476.9	0.705	28.23	0.981
600	600	60	480	60	60	480	60	0.825	3064	453	24.4	513.1	0.772	30.32	1.042
625	625	63	500	63	63	500	63	0.905	2920	642	36.0	574.0	0.893	33.75	1.136
650	650	65	520	65	65	520	65	0.981	2796	971	59.9	673.9	1.107	39.04	1.271

Turning (20,70,10) Roundabout. Volume ratio 1:1. 10% HV. Inscribed d=100 ft. (Island d=64 ft., circulating rd. w=18 ft.)

Volume (vph)															
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay	Emissions (kg/h)			
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	No_x
25	25	5	18	3	5	18	3	0.018	6432	3	7.7	20.4	0.028	1.07	0.040
50	50	10	35	5	10	35	5	0.033	6412	6	7.8	37.4	0.054	1.98	0.074
75	75	15	53	8	15	53	8	0.052	6244	9	7.9	57.4	0.079	3.07	0.115
100	100	20	70	10	20	70	10	0.067	6168	12	8.0	73.9	0.102	3.97	0.148
125	125	25	88	13	25	88	13	0.088	5976	16	8.2	94.1	0.131	5.09	0.189
150	150	30	105	15	30	105	15	0.109	5784	21	8.3	112.4	0.157	6.10	0.226
175	175	35	123	18	35	123	18	0.133	5612	26	8.4	133.6	0.187	7.29	0.269
200	200	40	140	20	40	140	20	0.154	5464	31	8.6	152.0	0.213	8.34	0.307
225	225	45	158	23	45	158	23	0.181	5288	38	8.8	172.8	0.242	9.52	0.350
250	250	50	175	25	50	175	25	0.205	5132	44	9.0	190.7	0.268	10.56	0.387
275	275	55	193	28	55	193	28	0.235	4960	52	9.2	211.7	0.298	11.78	0.430
300	300	60	210	30	60	210	30	0.262	4802	60	9.4	229.9	0.325	12.65	0.468
325	325	65	228	33	65	228	33	0.292	4628	71	9.7	251.3	0.355	14.12	0.513
350	350	70	245	35	70	245	35	0.330	4456	81	10.0	270.6	0.384	15.27	0.553
375	375	75	263	38	75	263	38	0.370	4284	94	10.3	292.2	0.415	16.68	0.599
400	400	80	280	40	80	280	40	0.406	4136	107	10.6	311.0	0.443	17.73	0.638
425	425	85	298	43	85	298	43	0.455	3944	124	11.0	333.9	0.477	19.14	0.687
450	450	90	315	45	90	315	45	0.501	3780	148	11.8	353.2	0.506	20.35	0.728
475	475	95	333	48	95	333	48	0.556	3596	183	13.1	375.8	0.540	21.76	0.776
500	500	100	350	50	100	350	50	0.617	3416	226	14.8 .	402.7	0.585	23.68	0.833
525	525	105	368	53	105	368	53	0.684	3240	281	17.2	431.0	0.633	25.49	0.889
550	550	110	385	55	110	385	55	0.750	3092	348	20.6	460.8	0.684	27.21	0.943
575	575	115	403	58	115	403	58	0.820	2956	443	26.0	497.5	0.752	29.30	1.004
600	600	120	420	60	120	420	60	0.898	2816	614	37.3	553.1	0.863	32.37	1.089
625	625	125	438	63	125	438	63	0.985	2676	983	65.6	665.0	1.103	38.13	1.236

Turning (30,60,10) Roundabout. Volume ratio 1:1. 10% HV. Inscribed d=100 ft. (Island d=64 ft., circulating rd. w=18 ft.)

Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay	Emissions (kg/h)			
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	No_x
25	25	8	15	3	8	15	3	0.018	6416	3	8.4	20.6	0.029	1.10	0.041
50	50	15	30	5	15	30	5	0.033	6360	6	8.4	37.8	0.052	2.03	0.075
75	75	23	45	8	23	45	8	0.052	6272	9	8.5	58.0	0.081	3.13	0.116
100	100	30	60	10	30	60	10	0.068	6108	12	8.6	74.7	0.104	4.05	0.150
125	125	38	75	13	38	75	13	0.089	5900	17	8.8	95.1	0.133	5.19	0.191
150	150	45	90	15	45	90	15	0.111	5704	21	8.9	114.2	0.160	6.29	0.230
175	175	53	105	18	53	105	18	0.134	5508	27	9.1	134.2	0.188	7.40	0.271
200	200	60	120	20	60	120	20	0.158	5352	32	9.3	153.5	0.216	8.50	0.310
225	225	68	135	23	68	135	23	0.183	5184	39	9.5	173.0	0.244	9.62	0.351
250	250	75	150	25	75	150	25	0.212	4960	46	9.7	193.4	0.273	10.60	0.392
275	275	83	165	28	83	165	28	0.242	4812	55	10.0	213.9	0.303	12.00	0.435
300	300	90	180	30	90	180	30	0.271	4648	63	10.2	232.2	0.329	13.08	0.473
325	325	98	195	33	98	195	33	0.308	4460	74	10.5	253.7	0.361	14.37	0.518
350	350	105	210	35	105	210	35	0.344	4280	85	10.8	273.2	0.389	15.53	0.559
375	375	113	225	38	113	225	38	0.387	4092	100	11.2	295.1	0.421	16.86	0.605
400	400	120	240	40	120	240	40	0.430	3920	114	11.6	314.8	0.450	18.07	0.646
425	425	128	255	43	128	255	43	0.482	3728	137	12.3	337.3	0.484	19.45	0.694
450	450	135	270	45	135	270	45	0.533	3556	168	13.6	358.3	0.516	20.74	0.737
475	475	143	285	48	143	285	48	0.595	3360	210	15.3	384.3	0.559	22.57	0.792
500	500	150	300	50	150	300	50	0.662	3176	262	17.7	411.3	0.605	24.29	0.846
525	525	158	315	53	158	315	53	0.735	3016	330	21.3	443.0	0.660	26.11	0.903
550	550	165	330	55	165	330	55	0.806	2872	421	26.8	478.3	0.725	28.09	0.962
575	575	173	345	58	173	345	58	0.890	2724	590	38.6	534.7	0.837	31.15	1.046
600	600	180	360	60	180	360	60	0.978	2584	936	66.3	640.1	1.062	36.48	1.184

Road A HV=10%, Road B HV=10% Roundabout. Turning (10,80,10). Volume ratio 1:1. Inscribed d=100 ft. (island d=64 ft., circulating rd. w=18 ft.)

Volume (vph)								SIDRA Results								
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay	Emissions (kg/h)				
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	Nox
25	25	3	20	3	3	20	3	0.018	6444	3	7.3	20.2	0.028	1.05	0.040
50	50	5	40	5	5	40	5	0.033	6456	6	7.2	37.7	0.052	1.98	0.075
75	75	8	60	8	8	60	8	0.051	6364	9	7.4	55.8	0.078	3.01	0.113
100	100	10	80	10	10	80	10	0.067	6228	12	7.4	73.1	0.101	3.89	0.146
125	125	13	100	13	13	100	13	0.087	6044	16	7.6	93.2	0.129	4.99	0.187
150	150	15	120	15	15	120	15	0.109	5840	21	7.7	112.7	0.156	6.06	0.226
175	175	18	140	18	18	140	18	0.130	5708	26	7.8	132.2	0.184	7.15	0.266
200	200	20	160	20	20	160	20	0.151	5576	31	7.9	150.5	0.209	8.17	0.303
225	225	23	180	23	23	180	23	0.175	5432	36	8.1	170.3	0.238	9.30	0.344
250	250	25	200	25	25	200	25	0.201	5248	43	8.3	189.5	0.265	10.40	0.384
275	275	28	220	28	28	220	28	0.228	5104	51	8.5	209.7	0.294	11.57	0.426
300	300	30	240	30	30	240	30	0.253	4960	58	8.6	226.9	0.319	12.57	0.461
325	325	33	260	33	33	260	33	0.283	4812	67	8.9	247.3	0.348	13.78	0.504
350	350	35	280	35	35	280	35	0.317	4640	77	9.1	267.9	0.378	15.00	0.547
375	375	38	300	38	38	300	38	0.354	4472	89	9.4	289.4	0.409	16.29	0.592
400	400	40	320	40	40	320	40	0.389	4328	101	9.6	308.7	0.437	17.47	0.633
425	425	43	340	43	43	340	43	0.434	4148	117	10.0	331.4	0.471	18.66	0.682
450	450	45	360	45	45	360	45	0.475	3996	132	10.3	351.1	0.500	20.09	0.724
475	475	48	380	48	48	380	48	0.522	3832	160	11.2	371.3	0.530	21.37	0.767
500	500	50	400	50	50	400	50	0.571	3676	193	12.3	391.7	0.561	22.66	0.811
525	525	53	420	53	53	420	53	0.635	3488	241	14.1	420.5	0.609	24.72	0.873
550	550	55	440	55	55	440	55	0.694	3336	291	16.2	446.7	0.653	26.46	0.926
575	575	58	460	58	58	460	58	0.758	3196	358	19.3	476.9	0.706	28.23	0.981
600	600	60	480	60	60	480	60	0.825	3064	453	24.4	513.1	0.772	30.32	1.042
625	625	63	500	63	63	500	63	0.905	2920	642	36.0	574.0	0.893	33.75	1.136
650	650	65	520	65	65	520	65	0.981	2796	971	59.9	673.9	1.107	39.04	1.271

Road A HV=20%, Road B HV=20% Roundabout. Turning (10,80,10). Volume ratio 1:1. Inscribed d=100 ft. (island d=64 ft., circulating rd. w=18 ft.)

Volume (vph)								SIDRA Results								
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay	Emissions (kg/h)				
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	Nox
25	25	3	20	3	3	20	3	0.019	6036	3	7.4	24.5	0.031	1.33	0.048
50	50	5	40	5	5	40	5	0.035	5944	6	7.4	44.0	0.055	2.41	0.086
75	75	8	60	8	8	60	8	0.058	5680	11	7.6	69.9	0.088	3.86	0.137
100	100	10	80	10	10	80	10	0.075	5544	14	7.7	88.9	0.112	4.94	0.176
125	125	13	100	13	13	100	13	0.099	5364	20	7.9	114.2	0.145	6.40	0.226
150	150	15	120	15	15	120	15	0.121	5240	25	8.0	136.1	0.173	7.67	0.271
175	175	18	140	18	18	140	18	0.147	5048	31	8.2	160.1	0.204	9.08	0.319
200	200	20	160	20	20	160	20	0.172	4896	38	8.4	183.2	0.234	10.45	0.367
225	225	23	180	23	23	180	23	0.202	4716	46	8.6	207.5	0.266	11.91	0.417
250	250	25	200	25	25	200	25	0.229	4576	53	8.8	229.2	0.295	13.22	0.462
275	275	28	220	28	28	220	28	0.264	4408	64	9.1	255.7	0.330	14.84	0.517
300	300	30	240	30	30	240	30	0.296	4252	74	9.3	277.8	0.360	16.22	0.563
325	325	33	260	33	33	260	33	0.337	4084	87	9.7	304.7	0.396	17.90	0.620
350	350	35	280	35	35	280	35	0.373	3936	99	10.0	326.2	0.426	19.27	0.666
375	375	38	300	38	38	300	38	0.420	3768	116	10.4	353.6	0.462	21.03	0.724
400	400	40	320	40	40	320	40	0.464	3620	132	10.8	376.6	0.493	22.53	0.774
425	425	43	340	43	43	340	43	0.522	3436	168	12.0	404.0	0.531	24.33	0.833
450	450	45	360	45	45	360	45	0.576	3284	204	13.3	431.5	0.572	26.31	0.894
475	475	48	380	48	48	380	48	0.645	3100	256	15.4	464.3	0.624	28.70	0.966
500	500	50	400	50	50	400	50	0.715	2948	320	18.3	498.6	0.678	30.97	1.035
525	525	53	420	53	53	420	53	0.787	2816	404	22.7	537.3	0.742	33.38	1.108
550	550	55	440	55	55	440	55	0.867	2676	547	31.2	589.3	0.836	36.58	1.199
575	575	58	460	58	58	460	58	0.953	2544	825	51.0	679.2	1.014	41.92	1.342

Road A HV=10%, Road B HV=5%

Roundabout. Turning (10,80,10). Volume ratio 1:1. Inscribed d=100 ft. (island d=64 ft., circulating rd. w=18 ft.)

Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay		Emissions (kg/h)		
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	No_x
25	25	3	20	3	3	20	3	0.018	6452	3	7.2	19.1	0.027	0.99	0.038
50	50	5	40	5	5	40	5	0.033	6468	6	7.2	35.7	0.050	1.85	0.071
75	75	8	60	8	8	60	8	0.051	6384	9	7.3	53.8	0.076	2.81	0.108
100	100	10	80	10	10	80	10	0.067	6312	12	7.4	69.9	0.099	3.66	0.140
125	125	13	100	13	13	100	13	0.087	6103	16	7.5	88.5	0.126	4.67	0.178
150	150	15	120	15	15	120	15	0.108	5862	21	7.6	106.3	0.151	5.63	0.214
175	175	18	140	18	18	140	18	0.129	5737	25	7.7	124.8	0.178	6.65	0.252
200	200	20	160	20	20	160	20	0.150	5611	30	7.8	142.0	0.203	7.60	0.287
225	225	23	180	23	23	180	23	0.173	5476	36	8.0	160.8	0.230	8.65	0.326
250	250	25	200	25	25	200	25	0.199	5302	43	8.1	179.0	0.256	9.66	0.363
275	275	28	220	28	28	220	28	0.225	5163	50	8.3	198.0	0.284	10.75	0.403
300	300	30	240	30	30	240	30	0.249	5060	57	8.5	215.6	0.310	11.75	0.439
325	325	33	260	33	33	260	33	0.279	4914	65	8.7	234.9	0.339	12.87	0.479
350	350	35	280	35	35	280	35	0.311	4734	75	8.9	253.6	0.366	13.96	0.518
375	375	38	300	38	38	300	38	0.347	4568	87	9.2	273.6	0.396	15.14	0.560
400	400	40	320	40	40	320	40	0.380	4428	98	9.4	291.8	0.423	16.22	0.599
425	425	43	340	43	43	340	43	0.423	4247	113	9.7	312.5	0.455	17.47	0.643
450	450	45	360	45	45	360	45	0.462	4107	127	10.0	331.1	0.483	18.60	0.682
475	475	48	380	48	48	380	48	0.506	3964	149	10.5	351.4	0.514	19.85	0.725
500	500	50	400	50	50	400	50	0.552	3811	179	11.5	370.5	0.543	21.05	0.766
525	525	53	420	53	53	420	53	0.611	3628	221	12.9	393.6	0.580	22.54	0.816
550	550	55	440	55	55	440	65	0.667	3472	267	14.6	418.2	0.622	24.31	0.868
575	575	58	460	58	58	460	68	0.727	3332	324	17.0	445.2	0.669	25.95	0.919
600	600	60	480	60	60	480	60	0.790	3197	400	20.4	474.3	0.721	27.61	0.970
625	625	63	500	63	63	500	63	0.864	3053	534	27.0	516.3	0.802	29.97	1.038
650	650	65	520	65	65	520	65	0.933	2934	746	39.4	575.8	0.926	33.19	1.123
675	675	68	540	68	68	540	68	1.010	2818	1167	67.4	691.0	1.177	39.04	1.270

Road A HV=20%, Road B HV=10%

Roundabout. Turning (10,80,10). Volume ratio 1:1. Inscribed d=100 ft. (island d=64 ft., circulating rd. w=18 ft.)

Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay		Emissions (kg/h)		
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	No_x
25	25	3	20	3	3	20	3	0.019	6052	3	7.3	22.3	0.029	1.19	0.044
50	50	5	40	5	5	40	5	0.035	6087	6	7.3	40.8	0.053	2.19	0.081
75	75	8	60	8	8	60	8	0.057	5689	11	7.5	63.3	0.083	3.43	0.125
100	100	10	80	10	10	80	10	0.074	5600	14	7.6	81.0	0.107	4.41	0.161
125	125	13	100	13	13	100	13	0.098	5408	19	7.7	103.7	0.137	5.69	0.207
150	150	15	120	15	15	120	15	0.119	5333	24	7.8	124.4	0.165	6.86	0.248
175	175	18	140	18	18	140	18	0.144	5154	30	8.0	143.1	0.194	8.11	0.293
200	200	20	160	20	20	160	20	0.169	5000	36	8.1	166.8	0.222	9.30	0.336
225	225	23	180	23	23	180	23	0.197	4828	44	8.3	188.9	0.252	10.60	0.380
250	250	25	200	25	25	200	25	0.223	4718	51	8.5	209.3	0.280	11.80	0.423
275	275	28	220	28	28	220	28	0.256	4544	61	8.8	232.6	0.312	13.19	0.471
300	300	30	240	30	30	240	30	0.286	4393	70	9.0	252.3	0.339	14.38	0.512
325	325	33	260	33	33	260	33	0.324	4225	82	9.2	275.9	0.373	15.82	0.561
350	350	35	280	35	35	280	35	0.357	4114	93	9.5	296.9	0.401	17.12	0.606
375	375	38	300	38	38	300	38	0.401	3952	108	9.8	321.4	0.435	18.64	0.658
400	400	40	320	40	40	320	40	0.440	3821	123	10.1	342.5	0.465	19.97	0.703
425	425	43	340	43	43	340	43	0.492	3652	147	10.7	367.5	0.501	21.56	0.756
450	450	45	360	45	45	360	45	0.539	3515	178	11.6	389.6	0.532	22.99	0.804
475	475	48	380	48	48	380	48	0.599	3340	220	13.0	415.2	0.571	24.77	0.860
500	500	50	400	50	50	400	50	0.661	3182	271	14.8	444.0	0.617	26.66	0.923
525	525	53	420	53	53	420	53	0.728	3044	334	17.4	476.3	0.670	28.98	0.988
550	550	55	440	55	55	440	55	0.797	2909	422	21.2	509.7	0.727	31.00	1.049
575	575	58	460	58	59	460	58	0.869	2788	557	28.0	554.5	0.809	33.70	1.127
600	600	60	480	60	60	480	60	0.949	2666	827	43.0	627.6	0.953	37.98	1.242
625	625	63	500	63	63	500	63	1.030	2562	1315	71.0	747.8	1.203	44.67	1.416

Inscribed d=80 ft (island d=44 ft., circulating rd. w=18 ft.) Roundabout. Volume ratio 1:1. Turning (10,80,10). 10% HV.

Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay	Emissions (kg/h)			
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	NO_x
25	25	3	20	3	3	20	3	0.018	6444	3	7.9	20.5	0.029	1.12	0.041
50	50	5	40	5	5	40	5	0.033	6456	6	7.9	38.3	0.053	2.10	0.077
75	75	8	60	8	8	60	8	0.051	6364	9	8.0	57.6	0.081	3.18	0.117
100	100	10	80	10	10	80	10	0.067	6228	12	8.1	74.2	0.106	4.11	0.151
125	125	13	100	13	13	100	13	0.087	6044	16	8.2	94.4	0.133	5.26	0.192
150	150	15	120	15	15	120	15	0.109	5840	21	8.3	114.1	0.160	6.37	0.232
175	175	18	140	18	18	140	18	0.130	5708	26	8.5	133.8	0.189	7.50	0.273
200	200	20	160	20	20	160	20	0.151	5576	31	8.6	152.2	0.215	8.56	0.311
225	225	23	180	23	23	180	23	0.175	5432	36	8.8	172.1	0.243	9.71	0.352
250	250	25	200	25	25	200	25	0.201	5248	43	8.9	191.4	0.271	10.84	0.392
275	275	28	220	28	28	220	28	0.228	5104	51	9.1	211.6	0.300	12.02	0.434
300	300	30	240	30	30	240	30	0.253	4960	58	9.3	228.9	0.325	13.05	0.470
325	325	33	260	33	33	260	33	0.283	4812	67	9.5	249.3	0.355	14.26	0.513
350	350	35	280	35	35	280	35	0.317	4640	77	9.8	269.8	0.385	15.49	0.556
375	375	38	300	38	38	300	38	0.354	4472	89	10.0	291.3	0.416	16.78	0.601
400	400	40	320	40	40	320	40	0.389	4328	101	10.3	310.5	0.444	17.95	0.641
425	425	43	340	43	43	340	43	0.434	4148	117	10.6	333.1	0.478	19.33	0.689
450	450	45	360	45	45	360	45	0.475	3996	132	10.9	352.7	0.507	20.55	0.731
475	475	48	380	48	48	380	48	0.522	3832	160	11.9	372.7	0.537	21.79	0.773
500	500	50	400	50	50	400	50	0.571	3676	193	13.0	394.3	0.570	23.21	0.819
525	525	53	420	53	53	420	53	0.635	3488	241	14.8	422.8	0.618	25.19	0.879
550	550	55	440	55	55	440	55	0.694	3336	291	16.8	448.4	0.661	26.60	0.929
575	575	58	460	58	58	460	58	0.758	3196	358	20.0	478.8	0.714	28.58	0.985
600	600	60	480	60	60	480	60	0.825	3064	453	25.1	515.0	0.780	30.69	1.047
625	625	63	500	63	63	500	63	0.905	2920	642	36.7	576.0	0.902	34.14	1.140
650	650	65	520	65	65	520	65	0.981	2796	971	60.6	676.0	1.116	39.44	1.275

Inscribed d=100 ft (island d=64 ft., circulating rd. w=18 ft.) Roundabout. Volume ratio 1:1. Turning (10,80,10). 10% HV.

Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay	Emissions (kg/h)			
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	NO_x
25	25	3	20	3	3	20	3	0.018	6444	3	7.3	20.2	0.028	1.05	0.040
50	50	5	40	5	5	40	5	0.033	6456	6	7.2	37.7	0.052	1.90	0.075
75	75	8	60	8	8	60	8	0.051	6364	9	7.4	56.8	0.078	3.01	0.113
100	100	10	80	10	10	80	10	0.067	6228	12	7.4	73.1	0.101	3.89	0.146
125	125	13	100	13	13	100	13	0.087	6044	16	7.6	93.2	0.129	4.99	0.187
150	150	15	120	15	15	120	15	0.109	5840	21	7.7	112.7	0.156	6.06	0.226
175	175	18	140	18	18	140	18	0.130	5708	26	7.8	132.2	0.184	7.15	0.266
200	200	20	160	20	20	160	20	0.151	5576	31	7.9	150.5	0.209	8.17	0.303
225	225	23	180	23	23	180	23	0.175	5432	36	8.1	170.3	0.238	9.30	0.344
250	250	25	200	25	25	200	25	0.201	5248	43	8.3	189.5	0.265	10.40	0.384
275	275	28	220	28	28	220	28	0.228	5104	51	8.5	209.7	0.294	11.57	0.426
300	300	30	240	30	30	240	30	0.253	4960	58	8.6	226.9	0.319	12.57	0.461
325	325	33	260	33	33	260	33	0.283	4812	67	8.9	247.3	0.348	13.78	0.504
350	350	35	280	35	35	280	35	0.317	4640	77	9.1	267.9	0.378	15.00	0.547
375	375	38	300	38	38	300	38	0.354	4472	89	9.4	289.4	0.409	16.29	0.592
400	400	40	320	40	40	320	40	0.389	4328	101	9.6	308.7	0.437	17.47	0.633
425	425	43	340	43	43	340	43	0.434	4148	117	10.0	331.4	0.471	18.66	0.682
450	450	45	360	45	45	360	45	0.475	3996	132	10.3	351.1	0.500	20.09	0.724
475	475	48	380	48	48	380	48	0.522	3832	160	11.2	371.3	0.530	21.37	0.767
500	500	50	400	50	50	400	50	0.571	3676	193	12.3	391.7	0.561	22.66	0.811
525	525	53	420	53	53	420	53	0.635	3488	241	14.1	420.5	0.609	24.72	0.873
550	550	55	440	55	55	440	55	0.694	3336	291	16.2	446.7	0.653	26.46	0.926
575	575	58	460	58	58	460	58	0.758	3196	358	19.3	476.9	0.706	28.23	0.981
600	600	60	480	60	60	480	60	0.825	3064	453	24.4	513.1	0.772	30.32	1.042
625	625	63	500	63	63	500	63	0.905	2920	642	36.0	574.0	0.893	33.75	1.136
650	650	65	520	65	65	520	65	0.981	2796	971	59.9	673.9	1.107	39.04	1.271

Inscribed d=120 ft (island d=84 ft., circulating rd. w=18 ft.) **Roundabout. Volume ratio 1:1. Turning (10,80,10). 10% HV.**

Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay		Emissions (kg/h)		
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	No_x
25	25	3	20	3	3	20	3	0.018	6444	3	6.6	19.9	0.027	0.99	0.039
50	50	5	40	5	5	40	5	0.033	6456	6	6.6	37.1	0.050	1.66	0.073
75	75	8	60	8	8	60	8	0.051	6364	9	6.7	56.8	0.076	2.84	0.110
100	100	10	80	10	10	80	10	0.067	6228	12	6.8	72.2	0.098	3.68	0.142
125	125	13	100	13	13	100	13	0.087	6044	16	6.9	92.0	0.125	4.74	0.182
150	150	15	120	15	15	120	15	0.109	5840	21	7.0	111.3	0.152	5.77	0.221
175	175	18	140	18	18	140	18	0.130	5708	26	7.2	130.8	0.179	6.83	0.260
200	200	20	160	20	20	160	20	0.151	5576	31	7.3	148.9	0.205	7.82	0.297
225	225	23	180	23	23	180	23	0.175	5432	36	7.5	168.6	0.232	8.92	0.337
250	250	25	200	25	25	200	25	0.201	5248	43	7.6	187.8	0.259	10.00	0.376
275	275	28	220	28	28	220	28	0.228	5104	51	7.8	207.9	0.288	11.15	0.418
300	300	30	240	30	30	240	30	0.253	4960	58	8.0	225.1	0.313	12.15	0.454
325	325	33	260	33	33	260	33	0.283	4812	67	8.2	245.5	0.345	13.35	0.496
350	350	35	280	35	35	280	35	0.317	4640	77	8.5	266.1	0.372	14.56	0.539
375	375	38	300	38	38	300	38	0.354	4472	89	8.7	287.7	0.403	15.86	0.585
400	400	40	320	40	40	320	40	0.389	4328	101	9.0	307.1	0.431	17.05	0.626
425	425	43	340	43	43	340	43	0.434	4148	117	9.3	330.0	0.465	18.46	0.675
450	450	45	360	45	45	360	45	0.475	3996	132	9.6	349.8	0.494	19.71	0.718
475	475	48	380	48	48	380	48	0.522	3832	160	10.6	370.1	0.525	21.02	0.762
500	500	50	400	50	50	400	50	0.571	3676	193	11.7	390.8	0.556	22.35	0.807
525	525	53	420	53	53	420	53	0.635	3468	241	13.5	418.3	0.601	24.28	0.866
550	550	55	440	55	55	440	55	0.694	3336	291	15.5	445.3	0.647	26.21	0.923
575	575	58	460	58	58	460	58	0.758	3196	358	18.7	475.5	0.699	27.97	0.978
600	600	60	480	60	60	480	60	0.825	3064	453	23.8	511.7	0.766	30.05	1.039
625	625	63	500	63	63	500	63	0.905	2920	642	35.4	572.4	0.887	33.47	1.133
650	650	65	520	65	65	520	65	0.981	2796	971	59.3	672.3	1.100	38.75	1.267

Volume ratio 1:1 **Signal. Turning (10,80,10). 10% HV.**

Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay		Emissions (kg/h)		
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	No_x
25	25	3	20	3	3	20	3	0.055	2123	6	5.4	20.5	0.028	1.05	0.040
50	50	5	40	5	5	40	5	0.103	2098	12	5.3	38.2	0.053	1.95	0.075
75	75	8	60	8	8	60	8	0.152	2127	18	5.4	57.4	0.079	2.98	0.114
100	100	10	80	10	10	80	10	0.189	2196	21	5.3	74.1	0.103	3.68	0.147
125	125	13	100	13	13	100	13	0.260	2112	30	5.6	94.3	0.131	4.97	0.188
150	150	15	120	15	15	120	15	0.292	2176	34	5.7	114.5	0.160	6.15	0.230
175	175	18	140	18	18	140	18	0.341	2183	43	6.4	134.8	0.189	7.28	0.271
200	200	20	160	20	20	160	20	0.385	2194	54	7.0	153.6	0.217	8.35	0.309
225	225	23	180	23	23	180	23	0.454	2097	68	7.5	173.8	0.246	9.47	0.349
250	250	25	200	25	25	200	25	0.508	2078	80	8.1	194.1	0.275	10.65	0.391
275	275	28	220	28	28	220	28	0.489	2381	108	9.2	214.8	0.305	11.53	0.427
300	300	30	240	30	30	240	30	0.497	2526	133	10.3	233.1	0.332	12.37	0.460
325	325	33	260	33	33	260	33	0.531	2571	164	11.4	255.2	0.365	13.49	0.501
350	350	35	280	35	35	280	35	0.625	2357	147	11.4	277.9	0.401	15.28	0.555
375	375	38	300	38	38	300	38	0.566	2705	226	13.7	302.4	0.438	15.94	0.589
400	400	40	320	40	40	320	40	0.628	2683	258	14.9	324.8	0.473	17.16	0.631
425	425	43	340	43	43	340	43	0.637	2828	305	16.5	352.1	0.517	18.51	0.679
450	450	45	360	45	45	360	45	0.696	2731	330	17.6	375.0	0.554	19.89	0.724
475	475	48	380	48	48	380	48	0.713	2804	376	19.2	399.3	0.593	21.12	0.768
500	500	50	400	50	50	400	50	0.761	2759	425	20.9	425.0	0.636	22.52	0.814
525	525	53	420	53	53	420	53	0.776	2856	471	23.1	456.1	0.689	24.15	0.869
550	550	55	440	55	55	440	55	0.806	2872	537	25.7	485.9	0.741	25.63	0.918
575	576	58	460	58	58	460	58	0.844	2871	618	28.9	519.3	0.800	27.33	0.973
600	600	60	480	60	60	480	60	0.842	3001	764	34.7	563.6	0.884	29.07	1.032
625	625	63	500	63	63	500	63	0.875	3022	1004	43.6	626.9	1.007	31.65	1.113
650	650	65	520	65	65	520	65	0.910	3016	1126	47.4	663.2	1.077	33.73	1.176
675	675	68	540	68	68	540	68	0.954	2981	1264	56.0	720.8	1.193	37.07	1.267
700	700	70	560	70	70	560	70	0.965	3051	1343	61.5	769.3	1.289	39.85	1.345
725	725	73	580	73	73	580	73	0.993	3079	1491	73.9	848.6	1.452	44.15	1.462
750	750	75	600	75	75	600	75	1.024	3081	1546	75.4	866.4	1.479	46.41	1.521

Volume ratio 4:3		Signal. Turning (10,80,10). 10% HV.														
Volume (vph)								SIDRA Results								
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay	Emissions (kg/h)				
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	Nox
25	25	3	20	3	3	20	3	0.050	2054	6	5.4	18.0	0.025	0.92	0.035
50	50	5	40	5	5	40	5	0.091	2098	10	5.3	33.5	0.046	1.71	0.066
75	75	8	60	8	8	60	8	0.134	2129	16	5.4	50.6	0.070	2.61	0.100
100	100	10	80	10	10	80	10	0.172	2148	21	5.4	65.7	0.091	3.41	0.130
125	125	13	100	13	13	100	13	0.218	2117	27	5.4	82.3	0.114	4.30	0.163
150	150	15	120	15	15	120	15	0.292	1883	34	5.6	98.7	0.138	5.25	0.197
175	175	18	140	18	18	140	18	0.341	1891	43	5.9	116.2	0.162	6.23	0.233
200	200	20	160	20	20	160	20	0.384	1926	52	6.5	134.4	0.189	7.25	0.269
225	225	23	180	23	23	180	23	0.393	2118	61	7.0	151.3	0.213	8.15	0.303
250	250	25	200	25	25	200	25	0.439	2105	72	7.4	168.9	0.239	9.16	0.339
275	275	28	220	28	28	220	28	0.483	2103	83	7.8	186.5	0.265	10.19	0.375
300	300	30	240	30	30	240	30	0.520	2122	93	8.3	203.9	0.290	11.19	0.410
325	325	33	260	33	33	260	33	0.590	2030	114	9.2	222.8	0.319	12.26	0.448
350	350	35	280	35	35	280	35	0.590	2166	126	9.7	240.6	0.345	13.24	0.483
375	375	38	300	38	38	300	38	0.544	2548	187	11.4	260.1	0.373	13.73	0.510
400	400	40	320	40	40	320	40	0.551	2668	220	12.6	278.1	0.401	14.56	0.541
425	425	43	340	43	43	340	43	0.590	2660	243	13.2	298.9	0.432	15.75	0.582
450	450	45	360	45	45	360	45	0.638	2607	275	14.2	319.7	0.465	16.89	0.622
475	475	48	380	48	48	380	48	0.642	2731	337	16.3	342.4	0.502	17.66	0.658
500	500	50	400	50	50	400	50	0.675	2728	351	16.9	361.9	0.533	19.06	0.698
525	525	53	420	53	53	420	53	0.756	2559	329	16.7	381.2	0.563	20.65	0.745
550	550	55	440	55	55	440	55	0.739	2740	438	19.5	407.7	0.608	21.49	0.780
575	575	58	460	58	58	460	58	0.804	2639	441	16.3	430.1	0.645	23.07	0.829
600	600	60	480	60	60	480	60	0.809	2736	499	22.0	454.3	0.686	24.21	0.869
625	625	63	500	63	63	500	63	0.822	2809	613	25.7	485.2	0.743	25.55	0.916
650	650	65	520	65	65	520	65	0.848	2827	706	28.5	515.7	0.796	26.96	0.961
675	675	68	540	68	68	540	68	0.863	2883	785	31.6	546.7	0.853	28.53	1.012
700	700	70	560	70	70	560	70	0.855	3019	914	36.6	583.8	0.922	29.89	1.060
725	725	73	580	73	73	580	73	0.896	2981	1115	42.9	633.8	1.021	32.30	1.131
750	750	75	600	75	75	600	75	0.944	2925	1281	49.5	683.9	1.122	35.11	1.209
775	775	78	620	78	78	620	78	1.000	2855	1290	54.1	715.7	1.181	37.69	1.278
800	800	80	640	80	80	640	80	1.051	2802	1565	71.1	798.0	1.354	41.72	1.388

Turning (10,80,10)		Signal. Volume ratio 1:1. 10% HV.														
Volume (vph)								SIDRA Results								
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay	Emissions (kg/h)				
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	Nox
25	25	3	20	3	3	20	3	0.055	2123	6	5.4	20.5	0.028	1.05	0.040
50	50	5	40	5	5	40	5	0.103	2098	12	5.3	38.2	0.053	1.95	0.075
75	75	8	60	8	8	60	8	0.152	2127	18	5.4	57.4	0.079	2.98	0.114
100	100	10	80	10	10	80	10	0.189	2196	21	5.3	74.1	0.103	3.80	0.147
125	125	13	100	13	13	100	13	0.250	2112	30	5.6	94.3	0.131	4.97	0.188
150	150	15	120	15	15	120	15	0.292	2176	34	5.7	114.5	0.160	6.15	0.230
175	175	18	140	18	18	140	18	0.341	2183	43	6.4	134.8	0.189	7.28	0.271
200	200	20	160	20	20	160	20	0.385	2194	54	7.0	153.6	0.217	8.35	0.309
225	225	23	180	23	23	180	23	0.454	2097	68	7.5	173.8	0.246	9.47	0.349
250	250	25	200	25	25	200	25	0.508	2078	80	8.1	194.1	0.275	10.65	0.391
275	275	28	220	28	28	220	28	0.469	2381	108	9.2	214.8	0.305	11.53	0.427
300	300	30	240	30	30	240	30	0.497	2526	133	10.3	233.1	0.332	12.37	0.460
325	325	33	260	33	33	260	33	0.631	2571	164	11.4	255.2	0.365	13.49	0.501
350	350	35	280	35	35	280	35	0.625	2357	147	11.4	277.9	0.401	15.28	0.555
375	375	38	300	38	38	300	38	0.586	2705	226	13.7	302.4	0.438	15.94	0.589
400	400	40	320	40	40	320	40	0.628	2683	258	14.9	324.8	0.473	17.16	0.631
425	425	43	340	43	43	340	43	0.637	2828	305	16.5	352.1	0.517	18.51	0.679
450	450	45	360	45	45	360	45	0.696	2731	330	17.6	375.0	0.554	19.89	0.724
475	475	48	380	48	48	380	48	0.713	2804	376	19.2	399.3	0.593	21.12	0.768
500	500	50	400	50	50	400	50	0.761	2759	425	20.9	425.0	0.636	22.52	0.814
525	525	53	420	53	53	420	53	0.776	2856	471	23.1	456.1	0.689	24.15	0.869
550	550	55	440	55	55	440	55	0.806	2872	537	25.7	485.9	0.741	25.63	0.918
575	575	58	460	58	58	460	58	0.844	2871	618	28.9	519.3	0.800	27.33	0.973
600	600	60	480	60	60	480	60	0.842	3001	764	34.7	563.6	0.884	29.07	1.032
625	625	63	500	63	63	500	63	0.875	3022	1004	43.6	625.9	1.007	31.65	1.113
650	650	65	520	65	65	520	65	0.910	3016	1126	47.4	663.2	1.077	33.73	1.176
675	675	68	540	68	68	540	68	0.954	2981	1264	56.0	720.8	1.193	37.07	1.267
700	700	70	560	70	70	560	70	0.965	3051	1343	61.6	769.3	1.289	39.85	1.345
725	725	73	580	73	73	580	73	0.993	3079	1491	73.9	848.6	1.452	44.15	1.462
750	750	75	600	75	75	600	75	1.024	3081	1546	75.4	866.4	1.479	46.41	1.521

Turning (20,70,10) Signal. Volume ratio 1:1. 10% HV.

Volume (vph) Per Approach A	Per Approach B	Road A L	Road A T	Road A R	Road B L	Road B T	Road B R	SIDRA Results Degree of Saturation	Eff. Intn. Cap. (vph)	Queue (ft)	Avg. Delay (s/veh)	CO_2	Emissions (kg/h) HC	CO	Nox
25	25	5	18	3	5	18	3	0.055	2114	6	6.1	20.7	0.029	1.08	0.041
50	50	10	35	5	10	35	5	0.099	2152	10	6.1	37.8	0.053	1.99	0.075
75	75	15	53	8	15	53	8	0.149	2171	16	6.2	58.0	0.081	3.08	0.116
100	100	20	70	10	20	70	10	0.190	2184	21	6.2	74.7	0.104	3.99	0.149
125	125	25	88	13	25	88	13	0.251	2102	30	6.5	95.0	0.133	5.10	0.190
150	150	30	105	15	30	105	15	0.288	2178	34	6.6	113.8	0.160	6.20	0.229
175	175	35	123	18	35	123	18	0.353	2105	47	7.3	135.2	0.191	7.30	0.272
200	200	40	140	20	40	140	20	0.387	2182	52	8.0	164.7	0.220	8.51	0.312
225	225	45	158	23	45	158	23	0.461	2075	69	8.5	175.8	0.250	9.69	0.355
250	250	50	175	25	50	175	25	0.514	2048	80	9.0	194.6	0.270	10.80	0.393
275	275	55	193	28	55	193	28	0.492	2368	108	10.2	216.5	0.310	11.78	0.432
300	300	60	210	30	60	210	30	0.534	2362	134	11.0	236.1	0.339	12.78	0.469
325	325	65	228	33	65	228	33	0.520	2597	165	12.3	258.7	0.373	13.85	0.510
350	350	70	245	35	70	245	35	0.576	2558	193	13.4	280.1	0.406	15.03	0.550
375	375	75	263	38	75	263	38	0.579	2733	239	15.1	305.9	0.447	16.22	0.595
400	400	80	280	40	80	280	40	0.625	2689	261	15.8	327.0	0.480	17.46	0.636
425	425	85	298	43	85	298	43	0.654	2745	315	18.0	355.2	0.526	18.68	0.686
450	450	90	315	45	90	315	45	0.690	2741	341	18.9	377.0	0.561	20.08	0.727
475	475	95	333	48	95	333	48	0.721	2774	382	20.4	403.4	0.604	21.50	0.775
500	500	100	350	50	100	350	50	0.759	2777	436	23.0	433.3	0.655	23.08	0.827
525	525	105	368	53	105	368	53	0.792	2799	508	25.4	463.0	0.706	24.53	0.877
550	550	110	385	55	110	385	55	0.839	2766	609	29.7	498.7	0.774	26.22	0.932
575	575	115	403	58	115	403	58	0.855	2837	710	34.1	538.6	0.845	28.05	0.992
600	600	120	420	60	120	420	60	0.864	2927	907	41.4	588.9	0.943	29.96	1.055
625	625	125	438	63	125	438	63	0.940	2805	1125	41.7	645.6	1.055	33.12	1.144
650	650	130	455	65	130	455	65	0.984	2784	1334	60.4	703.7	1.172	36.12	1.229
675	675	135	473	68	135	473	68	1.009	2818	1201	59.5	721.7	1.196	38.00	1.283
700	700	140	490	70	140	490	70	1.074	2745	1489	82.9	830.5	1.429	43.22	1.423
725	725	145	508	73	145	508	73	1.089	2603	1568	93.1	898.3	1.560	46.68	1.520
750	750	150	525	75	150	525	75	1.157	2729	1958	127.3	1053.8	1.905	53.29	1.699

Turning (30,60,10) Signal. Volume ratio 1:1. 10% HV.

Volume (vph) Per Approach A	Per Approach B	Road A L	Road A T	Road A R	Road B L	Road B T	Road B R	SIDRA Results Degree of Saturation	Eff. Intn. Cap. (vph)	Queue (ft)	Avg. Delay (s/veh)	CO_2	Emissions (kg/h) HC	CO	Nox
25	25	8	15	3	8	15	3	0.056	2105	6	7.1	20.9	0.029	1.12	0.042
50	50	15	30	5	15	30	5	0.099	2148	11	7.1	38.1	0.053	2.04	0.076
75	75	23	45	8	23	45	8	0.148	2184	16	7.1	58.5	0.082	3.17	0.117
100	100	30	60	10	30	60	10	0.194	2139	23	7.3	75.2	0.106	4.07	0.151
125	125	38	75	13	38	75	13	0.242	2181	27	7.3	95.9	0.136	5.26	0.193
150	150	45	90	15	45	90	15	0.302	2089	37	7.7	115.1	0.163	6.35	0.233
175	175	53	105	18	53	105	18	0.360	2058	47	8.2	135.5	0.193	7.50	0.274
200	200	60	120	20	60	120	20	0.389	2170	52	8.5	155.5	0.222	8.67	0.315
225	225	68	135	23	68	135	23	0.432	2196	72	9.6	175.5	0.251	9.71	0.353
250	250	75	150	25	75	150	25	0.464	2276	90	10.3	196.6	0.282	10.86	0.395
275	275	83	165	28	83	165	28	0.500	2329	110	11.2	217.7	0.313	11.98	0.436
300	300	90	180	30	90	180	30	0.541	2330	135	11.9	236.6	0.341	12.97	0.472
325	325	98	195	33	98	195	33	0.531	2583	170	13.5	261.5	0.380	14.16	0.516
350	350	105	210	35	105	210	35	0.578	2549	195	14.4	282.8	0.413	15.31	0.556
375	375	113	225	38	113	225	38	0.600	2641	258	16.6	310.1	0.457	16.60	0.602
400	400	120	240	40	120	240	40	0.630	2672	290	17.7	332.6	0.493	17.80	0.644
425	425	128	255	43	128	255	43	0.659	2725	336	19.6	359.7	0.537	19.21	0.693
450	450	135	270	45	135	270	45	0.689	2751	375	20.9	383.9	0.577	20.49	0.737
475	475	143	285	48	143	285	48	0.743	2692	415	23.2	411.4	0.623	21.97	0.786
500	500	150	300	50	150	300	50	0.781	2694	464	25.1	438.4	0.669	23.40	0.834
525	525	158	315	53	158	315	53	0.800	2770	550	28.6	473.3	0.730	25.02	0.889
550	550	165	330	55	165	330	55	0.841	2755	677	33.3	510.2	0.798	26.59	0.942
575	575	173	345	58	173	345	58	0.861	2812	881	41.7	565.5	0.907	28.76	1.012
600	600	180	360	60	180	360	60	0.920	2748	1035	48.0	609.7	0.992	31.26	1.085
625	625	188	375	63	188	375	63	0.975	2703	1245	58.6	669.3	1.111	34.36	1.172
650	650	195	390	65	195	390	65	1.049	2613	1366	72.2	733.7	1.242	37.93	1.270
675	675	203	405	68	203	405	68	1.067	2664	1473	80.4	791.6	1.358	40.96	1.356
700	700	210	420	70	210	420	70	1.139	2584	1839	111.2	924.3	1.644	46.70	1.512
725	725	218	435	73	218	435	73	1.199	2552	2158	140.6	1061.4	1.944	52.61	1.675
750	750	225	450	75	225	450	75	1.241	2544	2416	158.1	1142.4	2.107	56.26	1.777

Road A HV=10%, Road B HV=10% Signal. Volume ratio 1:1. Turning (10,80,10).

Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay		Emissions (kg/h)		
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	NO_x
25	25	3	20	3	3	20	3	0.055	2123	6	5.4	20.5	0.028	1.05	0.040
50	50	5	40	5	5	40	5	0.103	2038	12	5.3	38.2	0.053	1.95	0.075
75	75	8	60	8	8	60	8	0.152	2127	18	5.4	57.4	0.079	2.98	0.114
100	100	10	80	10	10	80	10	0.189	2196	21	5.3	74.1	0.103	3.88	0.147
125	125	13	100	13	13	100	13	0.250	2112	30	5.6	94.3	0.131	4.97	0.188
150	150	15	120	15	15	120	15	0.292	2176	34	5.7	114.5	0.160	6.15	0.230
175	175	18	140	18	18	140	18	0.341	2183	43	6.4	134.8	0.189	7.28	0.271
200	200	20	160	20	20	160	20	0.385	2194	54	7.0	153.6	0.217	8.35	0.309
225	225	23	180	23	23	180	23	0.454	2097	68	7.5	173.8	0.246	9.47	0.349
250	250	25	200	25	25	200	25	0.508	2078	80	8.1	194.1	0.275	10.65	0.391
275	275	28	220	28	28	220	28	0.489	2381	108	9.2	214.8	0.305	11.53	0.427
300	300	30	240	30	30	240	30	0.497	2526	133	10.3	233.1	0.332	12.37	0.460
325	325	33	260	33	33	260	33	0.531	2571	164	11.4	255.2	0.365	13.49	0.501
350	350	35	280	35	35	280	35	0.625	2357	147	11.4	277.9	0.401	15.28	0.555
375	375	38	300	38	38	300	38	0.586	2705	226	13.7	302.4	0.438	15.94	0.589
400	400	40	320	40	40	320	40	0.628	2683	258	14.9	324.8	0.473	17.16	0.631
425	425	43	340	43	43	340	43	0.637	2828	305	16.5	352.1	0.517	18.51	0.679
450	450	45	360	45	45	360	45	0.696	2731	330	17.6	375.0	0.554	19.89	0.724
475	475	48	380	48	48	380	48	0.713	2804	376	19.2	399.3	0.593	21.12	0.768
500	500	50	400	50	50	400	50	0.761	2759	425	20.9	425.0	0.636	22.52	0.814
525	525	53	420	53	53	420	53	0.776	2856	471	23.1	456.1	0.689	24.15	0.869
550	550	55	440	55	55	440	55	0.806	2872	537	25.7	485.9	0.741	25.63	0.918
575	575	58	460	58	58	460	58	0.844	2871	618	28.9	519.3	0.800	27.33	0.973
600	600	60	480	60	60	480	60	0.842	3001	764	34.7	563.6	0.884	29.07	1.032
625	625	63	500	63	63	500	63	0.875	3022	1004	43.6	625.9	1.007	31.65	1.113
650	650	65	520	65	65	520	65	0.910	3016	1126	47.4	663.2	1.077	33.73	1.176
675	675	68	540	68	68	540	68	0.954	2981	1264	56.0	720.8	1.193	37.07	1.267
700	700	70	560	70	70	560	70	0.965	3051	1343	61.5	769.3	1.289	39.85	1.345
725	725	73	580	73	73	580	73	0.993	3079	1491	73.9	840.6	1.452	44.15	1.462
750	750	75	600	75	75	600	75	1.024	3081	1546	75.4	866.4	1.479	46.41	1.521

Road A HV=20%, Road B HV=20% Signal. Volume ratio 1:1. Turning (10,80,10).

Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay		Emissions (kg/h)		
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	NO_x
25	25	3	20	3	3	20	3	0.058	2014	6	5.5	24.8	0.031	1.32	0.048
50	50	5	40	5	5	40	5	0.103	2019	11	5.1	44.4	0.056	2.37	0.086
75	75	8	60	8	8	60	8	0.171	1916	20	5.6	70.4	0.089	3.80	0.137
100	100	10	80	10	10	80	10	0.208	2003	23	5.4	89.8	0.114	4.92	0.176
125	125	13	100	13	13	100	13	0.266	2002	30	5.7	115.6	0.140	6.43	0.228
150	150	15	120	15	15	120	15	0.326	1937	42	6.4	137.8	0.177	7.67	0.271
175	175	18	140	18	18	140	18	0.387	1913	54	7.3	162.6	0.210	9.13	0.321
200	200	20	160	20	20	160	20	0.443	1904	66	7.7	186.4	0.242	10.56	0.369
225	225	23	180	23	23	180	23	0.501	1900	79	8.3	211.7	0.276	12.09	0.421
250	250	25	200	25	25	200	25	0.477	2197	100	9.3	233.5	0.304	13.09	0.459
275	275	28	220	28	28	220	28	0.505	2304	134	10.6	261.5	0.343	14.52	0.510
300	300	30	240	30	30	240	30	0.595	2118	126	10.8	285.5	0.377	16.43	0.567
325	325	33	260	33	33	260	33	0.553	2489	201	13.0	313.7	0.415	17.24	0.605
350	350	35	280	35	35	280	35	0.590	2490	229	14.1	337.7	0.449	18.69	0.651
375	375	38	300	38	38	300	38	0.625	2534	278	16.0	370.0	0.497	20.31	0.709
400	400	40	320	40	40	320	40	0.646	2600	311	17.0	395.4	0.534	21.77	0.757
425	425	43	340	43	43	340	43	0.716	2502	370	19.2	428.5	0.584	23.67	0.819
450	450	45	360	45	45	360	45	0.718	2635	395	20.6	457.6	0.629	25.36	0.874
475	475	48	380	48	48	380	48	0.762	2604	457	23.0	490.6	0.680	27.25	0.935
500	500	50	400	50	50	400	50	0.808	2608	536	26.7	529.9	0.745	29.37	1.002
525	525	53	420	53	53	420	53	0.813	2724	593	28.9	564.8	0.800	31.20	1.062
550	550	55	440	55	55	440	55	0.854	2716	766	36.2	619.4	0.898	33.83	1.143
575	575	58	460	58	58	460	58	0.865	2802	982	43.2	674.7	0.998	36.06	1.216
600	600	60	480	60	60	480	60	0.917	2762	1152	50.2	731.3	1.101	39.53	1.316
625	625	63	500	63	63	500	63	0.964	2732	1309	59.2	795.9	1.224	43.57	1.427
650	650	65	520	65	65	520	65	0.988	2774	1444	69.2	870.5	1.367	48.10	1.553
675	675	68	540	68	68	540	68	1.011	2814	1485	73.2	914.5	1.444	51.49	1.646
700	700	70	560	70	70	560	70	1.042	2832	1376	73.0	921.4	1.440	53.95	1.712
725	725	73	580	73	73	580	73	1.057	2684	1484	66.9	1005.0	1.604	58.44	1.837
750	750	75	600	75	75	600	75	1.119	2821	1833	121.9	1178.4	1.960	66.68	2.063

Road A HV=10%, Road B HV=5% Signal. Volume ratio 1:1. Turning (10,80,10).

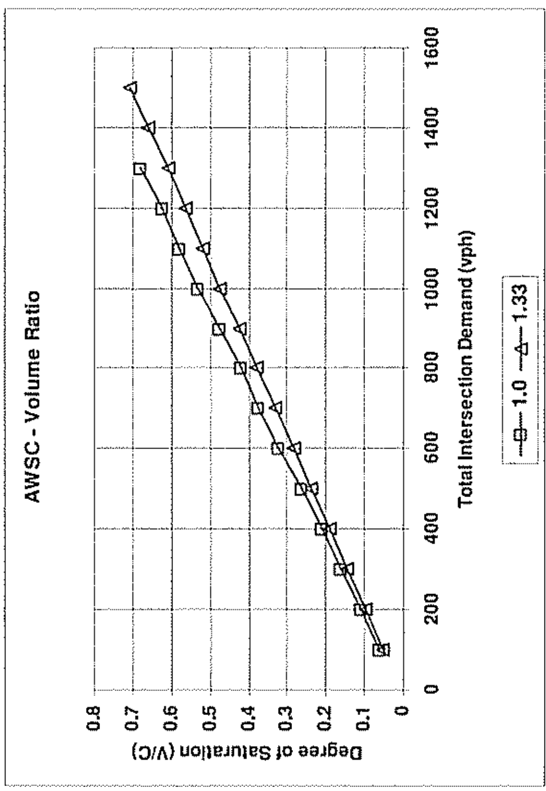
Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay		Emissions (kg/h)		
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	No_x
25	25	3	20	3	3	20	3	0.055	2123	6	5.4	19.5	0.028	0.99	0.039
50	50	5	40	5	5	40	5	0.100	2161	11	5.3	36.2	0.051	1.83	0.072
75	75	8	60	8	8	60	8	0.148	2191	17	5.4	54.4	0.077	2.78	0.108
100	100	10	80	10	10	80	10	0.189	2218	21	5.3	70.9	0.101	3.67	0.142
125	125	13	100	13	13	100	13	0.424	2194	29	5.6	89.6	0.128	4.66	0.180
150	150	15	120	15	15	120	15	0.288	2203	35	5.7	107.8	0.154	5.66	0.217
175	175	18	140	18	18	140	18	0.333	2231	43	6.3	126.9	0.182	6.72	0.255
200	200	20	160	20	20	160	20	0.384	2191	52	6.9	146.2	0.210	7.77	0.293
225	225	23	180	23	23	180	23	0.433	2194	63	7.4	164.2	0.238	8.80	0.331
250	250	25	200	25	25	200	25	0.485	2175	75	7.9	183.3	0.266	9.89	0.370
275	275	28	220	28	28	220	28	0.471	2467	101	9.0	203.0	0.296	10.78	0.406
300	300	30	240	30	30	240	30	0.545	2316	101	9.2	222.4	0.326	12.09	0.449
325	325	33	260	33	33	260	33	0.510	2646	153	10.9	242.6	0.356	12.69	0.479
350	350	35	280	35	35	280	35	0.598	2464	143	11.0	263.1	0.388	14.23	0.527
375	375	38	300	38	38	300	38	0.631	2512	167	11.9	285.0	0.423	15.41	0.569
400	400	40	320	40	40	320	40	0.611	2758	252	14.3	307.7	0.459	15.99	0.599
425	425	43	340	43	43	340	43	0.676	2656	220	14.0	328.1	0.490	17.60	0.649
450	450	45	360	45	45	360	45	0.698	2718	262	15.5	351.1	0.529	18.79	0.690
475	475	48	380	48	48	380	48	0.701	2658	367	18.5	379.4	0.577	19.74	0.730
500	500	50	400	50	50	400	50	0.730	2884	407	20.0	403.4	0.618	21.01	0.773
525	525	53	420	53	53	420	53	0.754	2941	453	22.0	431.0	0.665	22.45	0.822
550	550	55	440	55	55	440	55	0.778	2974	499	23.6	455.8	0.707	23.73	0.866
575	575	58	460	58	58	460	58	0.806	3006	566	26.7	487.5	0.765	25.29	0.918
600	600	60	480	60	60	480	60	0.845	2990	672	30.1	522.0	0.828	26.66	0.970
625	625	63	500	63	63	500	63	0.864	3052	915	38.0	576.8	0.937	28.78	1.036
650	650	65	520	65	65	520	65	0.881	3106	1050	44.8	624.0	1.031	30.91	1.101
675	675	68	540	68	68	540	68	0.921	3090	1138	50.6	671.6	1.126	33.65	1.178
700	700	70	560	70	70	560	70	0.935	3149	1235	56.3	719.8	1.223	36.38	1.254
725	725	73	580	73	73	580	73	0.965	3169	1366	65.6	784.3	1.355	39.77	1.349
750	750	75	600	75	75	600	75	0.999	3162	1546	80.5	868.7	1.536	44.23	1.465

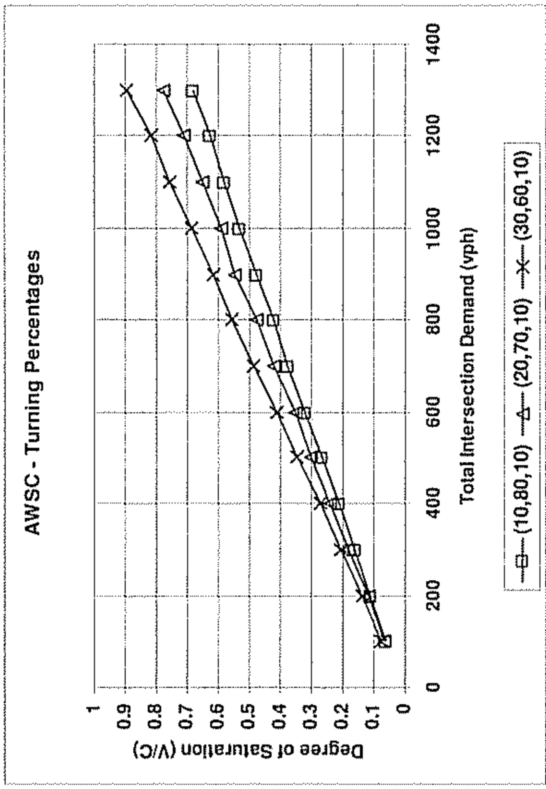
Road A HV=20%, Road B HV=10% Signal. Volume ratio 1:1. Turning (10,80,10).

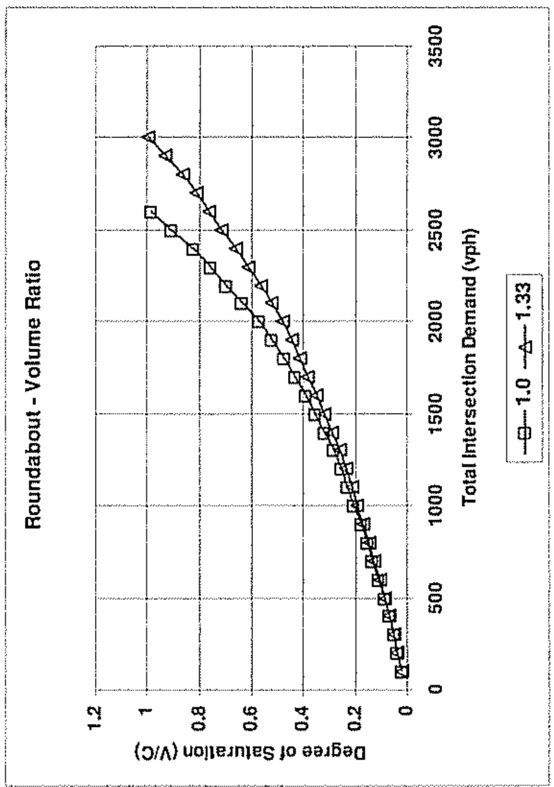
Volume (vph)								SIDRA Results							
Per Approach		Road A			Road B			Degree of	Eff. Intn. Cap.	Queue	Avg. Delay		Emissions (kg/h)		
A	B	L	T	R	L	T	R	Saturation	(vph)	(ft)	(s/veh)	CO_2	HC	CO	No_x
25	25	3	20	3	3	20	3	0.058	2014	6	5.4	22.7	0.030	1.19	0.044
50	50	5	40	5	5	40	5	0.103	2059	12	5.3	41.2	0.054	2.15	0.080
75	75	8	60	8	8	60	8	0.152	2141	18	5.5	63.9	0.084	3.38	0.125
100	100	10	80	10	10	80	10	0.208	2003	23	5.4	82.0	0.109	4.40	0.161
125	125	13	100	13	13	100	13	0.250	2120	30	5.7	104.7	0.139	5.66	0.207
150	150	15	120	15	15	120	15	0.302	2096	38	6.0	125.9	0.168	6.87	0.249
175	175	18	140	18	18	140	18	0.354	2098	49	7.0	148.5	0.199	8.16	0.295
200	200	20	160	20	20	160	20	0.402	2101	59	7.4	169.8	0.229	9.39	0.338
225	225	23	180	23	23	180	23	0.454	2097	71	7.9	192.7	0.261	10.74	0.384
250	250	25	200	25	25	200	25	0.507	2075	82	8.3	214.0	0.291	12.02	0.428
275	275	28	220	28	28	220	28	0.500	2329	121	9.6	237.8	0.323	13.06	0.469
300	300	30	240	30	30	240	30	0.560	2167	114	10.0	259.3	0.355	14.62	0.517
325	325	33	260	33	33	260	33	0.543	2524	191	12.3	285.1	0.391	15.39	0.554
350	350	35	280	35	35	280	35	0.566	2598	225	13.4	308.3	0.425	16.56	0.596
375	375	38	300	38	38	300	38	0.601	2635	249	14.6	335.3	0.466	18.12	0.648
400	400	40	320	40	40	320	40	0.663	2539	225	14.2	355.9	0.498	19.89	0.702
425	425	43	340	43	43	340	43	0.670	2680	342	17.7	390.1	0.550	21.09	0.749
450	450	45	360	45	45	360	45	0.702	2700	382	19.1	416.3	0.591	22.54	0.797
475	475	48	380	48	48	380	48	0.731	2735	415	20.7	444.2	0.635	24.15	0.850
500	500	50	400	50	50	400	50	0.775	2715	483	23.2	476.7	0.689	25.92	0.907
525	525	53	420	53	53	420	53	0.805	2752	551	26.1	511.6	0.747	27.75	0.967
550	550	55	440	55	55	440	55	0.837	2770	644	29.6	547.6	0.809	29.56	1.026
575	575	58	460	58	58	460	58	0.851	2850	807	35.3	593.7	0.892	31.54	1.091
600	600	60	480	60	60	480	60	0.862	2934	951	41.0	641.1	0.979	33.71	1.159
625	625	63	500	63	63	500	63	0.902	2923	1157	49.7	706.9	1.107	37.16	1.259
650	650	65	520	65	65	520	65	0.940	2916	1268	55.9	762.6	1.212	40.49	1.359
675	675	68	540	68	68	540	68	0.977	2910	1445	68.7	842.0	1.372	45.13	1.479
700	700	70	560	70	70	560	70	1.014	2908	1343	67.2	851.3	1.378	47.06	1.533
725	725	73	580	73	73	580	73	1.047	2914	1492	82.5	938.8	1.555	51.87	1.663
750	750	75	600	75	75	600	75	1.084	2912	1672	89.3	976.9	1.618	55.04	1.750

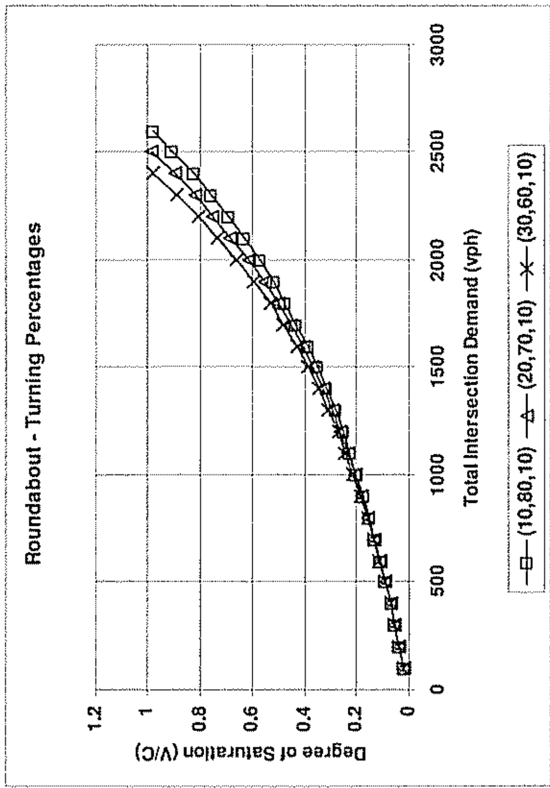
APPENDIX B

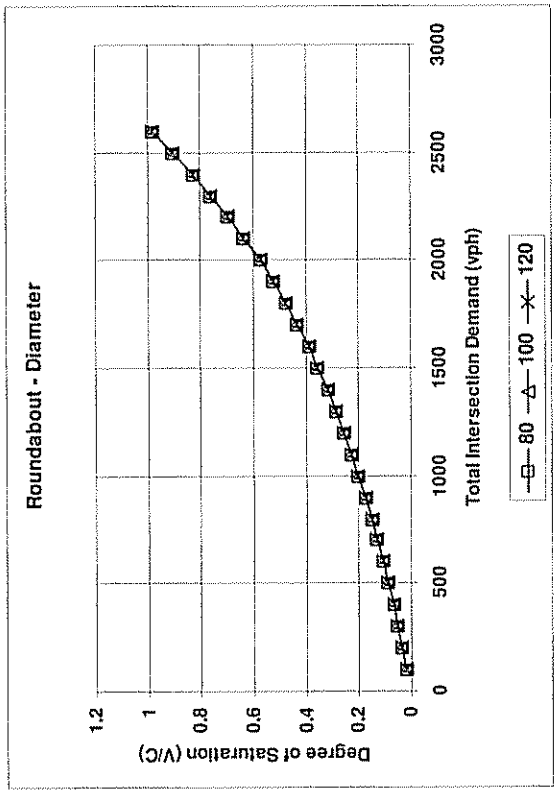
GRAPHS OF SIDRA SOFTWARE ANALYSIS RESULTS FOR AWSC AND ROUNDABOUT INTERSECTIONS SHOWING CHANGES IN EACH MOE AS EACH TEST PARAMETER WAS VARIED

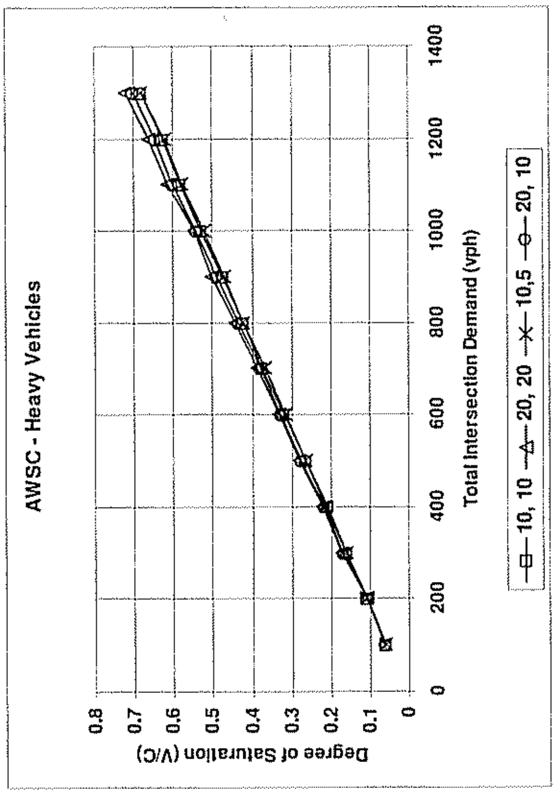

AWSC - Volume Ratio
Degree of Saturation (V/C)
Total Intersection Demand (vph)
1.0
1.33

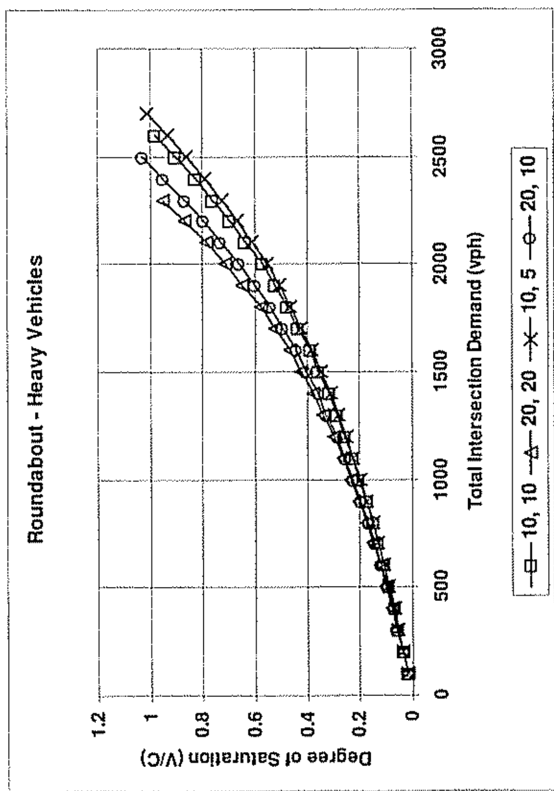

AWSC - Turning Percentages
Degree of Saturation (V/C)
Total Intersection Demand (vph)
(10,80,10)
(20,70,10)
(30,60,10)

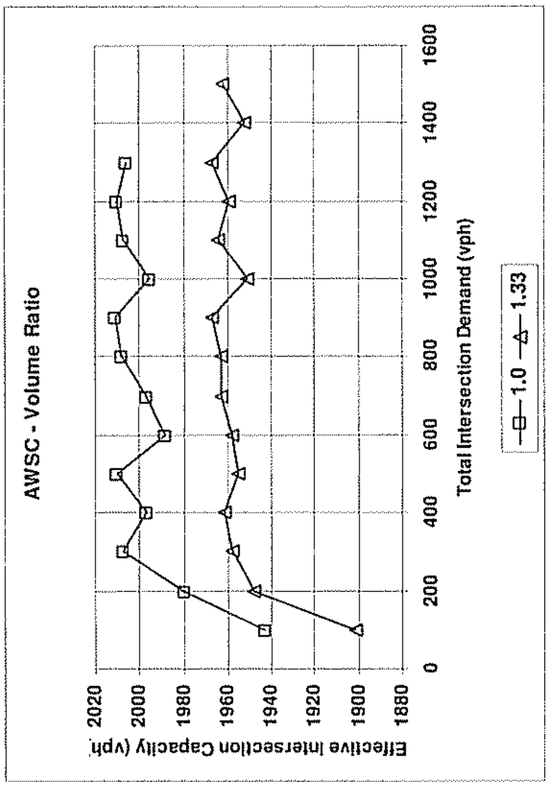

Roundabout - Volume Ratio
Degree of Saturation (V/C)
Total Intersection Demand (vph)
1.0
1.33

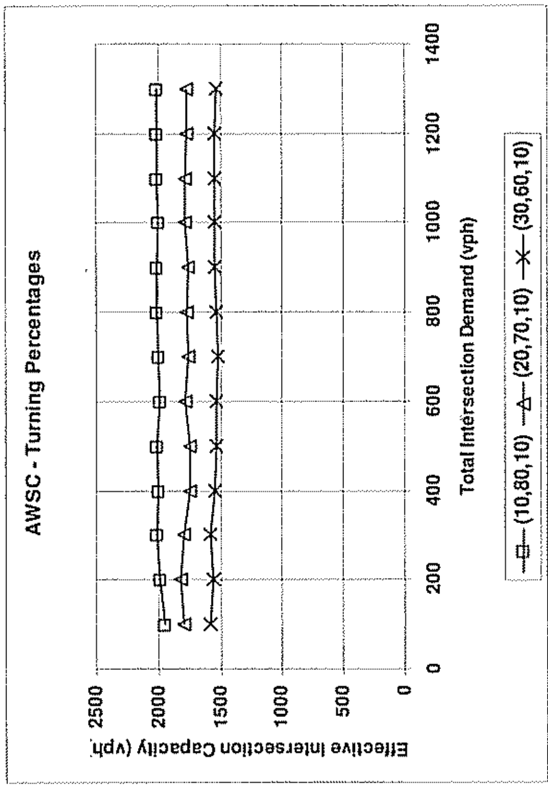

Roundabout - Turning Percentages
Degree of Saturation (V/C)
Total Intersection Demand (vph)
(10,80,10)
(20,70,10)
(30,60,10)

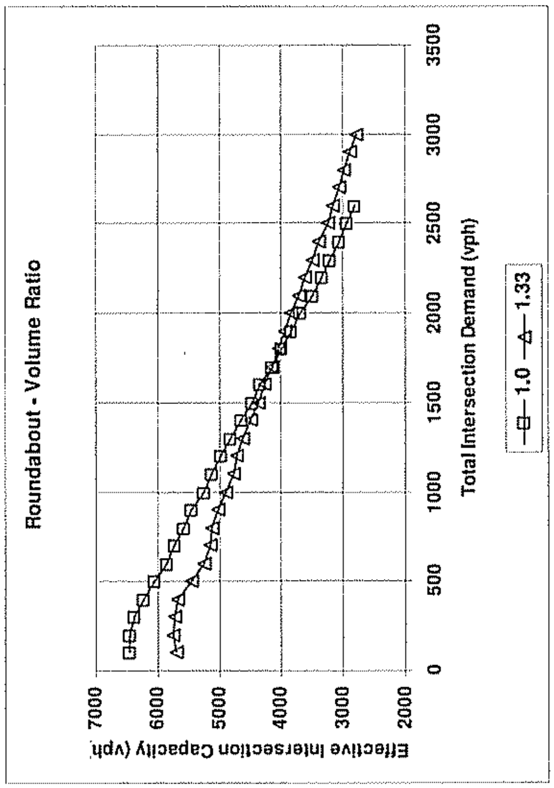

Roundabout - Diameter
Degree of Saturation (V/C)
1.2
1
0.8
0.6
0.4
0.2
0
0
500
1000
1500
2000
2500
3000
Total Intersection Demand (vph)
80
100
120

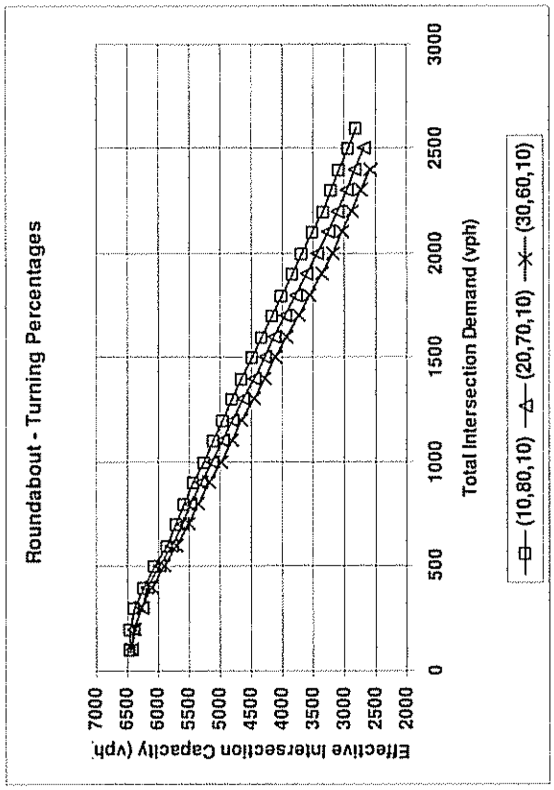

AWSC - Heavy Vehicles
Degree of Saturation (V/C)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
1400
Total Intersection Demand (vph)
10, 10
20, 20
10,5
20, 10

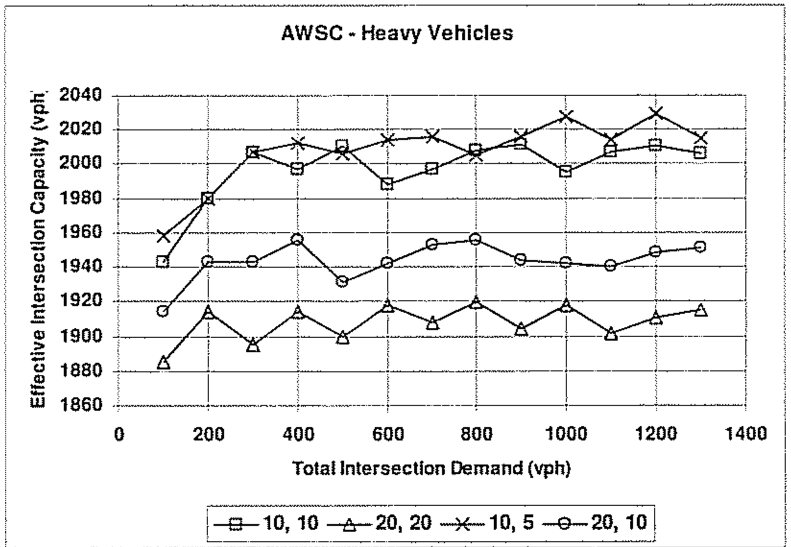

Roundabout - Heavy Vehicles
Degree of Saturation (V/C)
1.2
1
0.8
0.6
0.4
0.2
0
0
500
1000
1500
2000
2500
3000
Total Intersection Demand (vph)
10, 10
20, 20
10, 5
20, 10

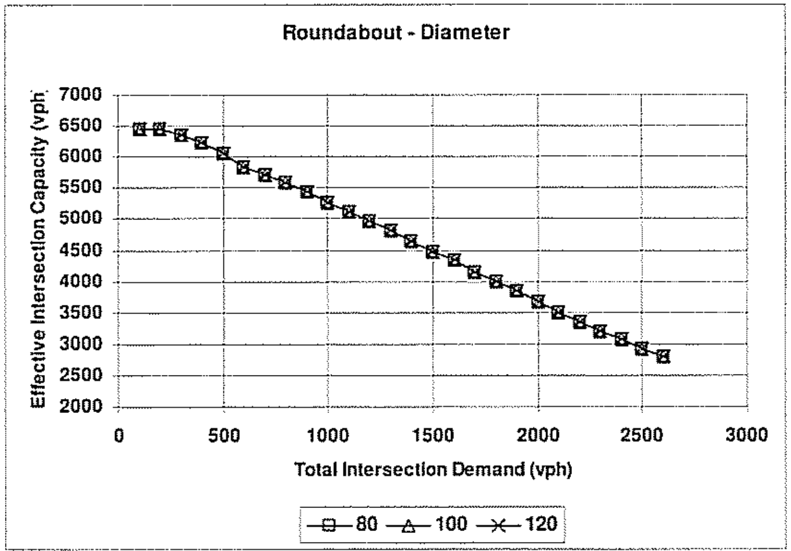

AWSC - Volume Ratio
Effective Intersection Capacity (vph)
2020
2000
1980
1960
1940
1920
1900
1880
0
200
400
600
800
1000
1200
1400
1600
Total Intersection Demand (vph)
1.0
1.33

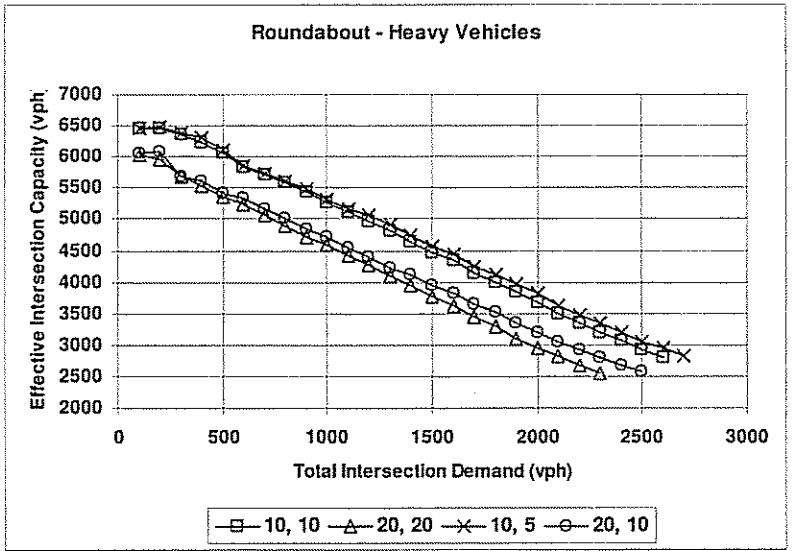

AWSC - Turning Percentages
Effective Intersection Capacity (vph)
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
1400
Total Intersection Demand (vph)
(10,80,10)
(20,70,10)
(30,60,10)

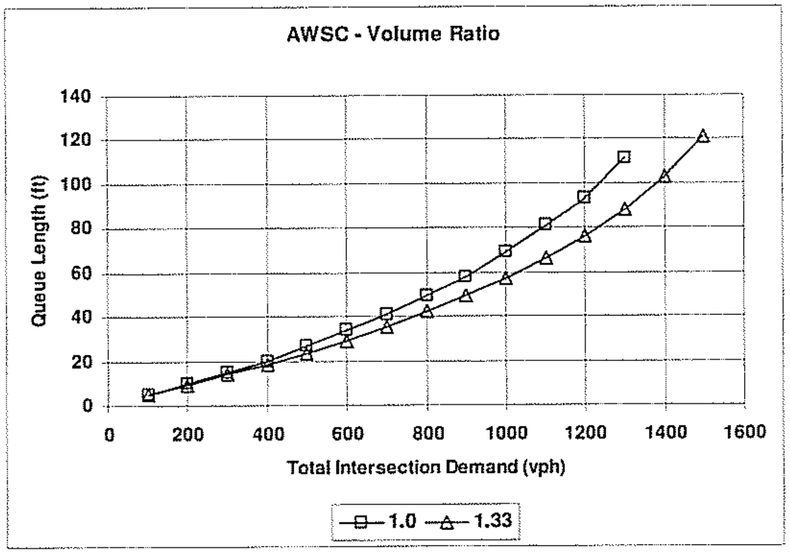

Roundabout - Volume Ratio
Effective Intersection Capacity (vph)
7000
6000
5000
4000
3000
2000
0
500
1000
1500
2000
2500
3000
3500
Total Intersection Demand (vph)
1.0
1.33

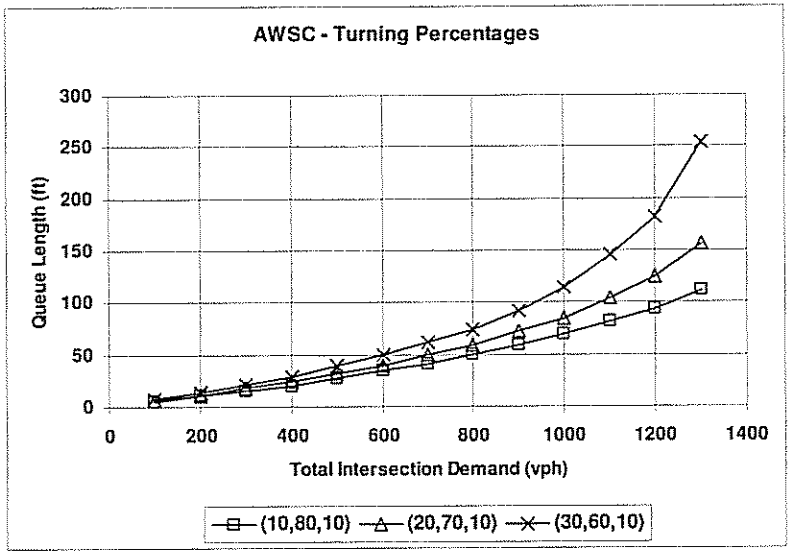

Roundabout - Turning Percentages
Effective Intersection Capacity (vph)
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
0
500
1000
1500
2000
2500
3000
Total Intersection Demand (vph)
(10,80,10)
(20,70,10)
(30,60,10)

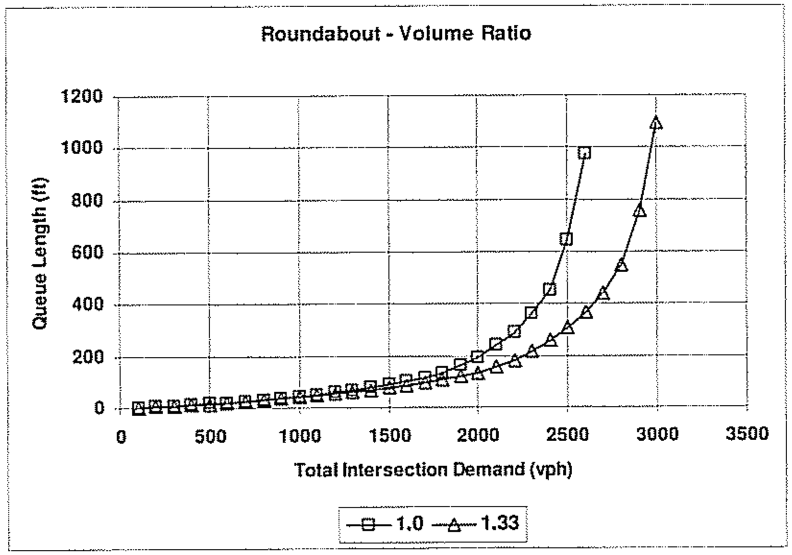

AWSC - Heavy Vehicles
Effective Intersection Capacity (vph)
2040
2020
2000
1980
1960
1940
1920
1900
1880
1860
0
200
400
600
800
1000
1200
1400
Total Intersection Demand (vph)
10, 10
20, 20
10, 5
20, 10

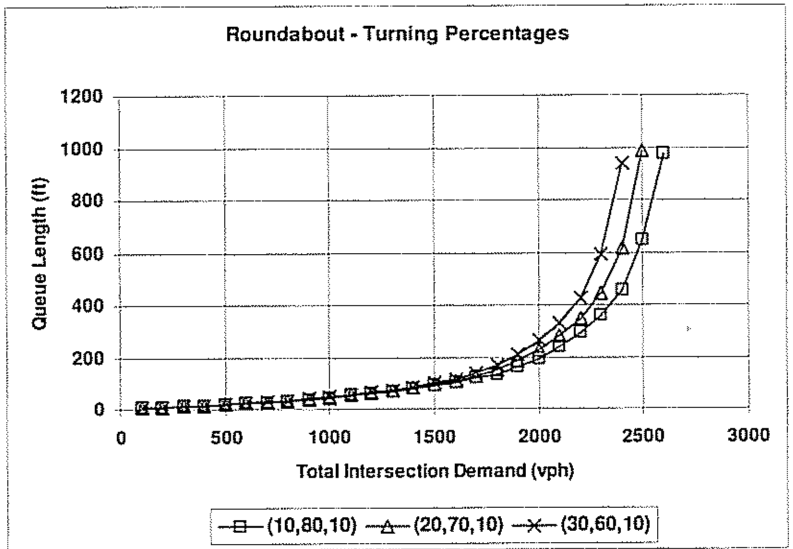

Roundabout - Diameter
Effective Intersection Capacity (vph)
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
0
500
1000
1500
2000
2500
3000
Total Intersection Demand (vph)
80
100
120

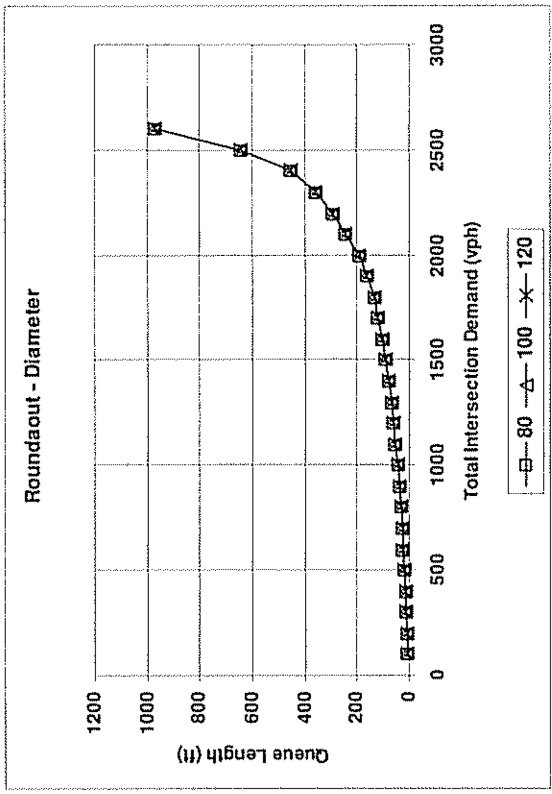

Roundabout - Heavy Vehicles
Effective Intersection Capacity (vph)
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
0
500
1000
1500
2000
2500
3000
Total Intersection Demand (vph)
10, 10
20, 20
10, 5
20, 10

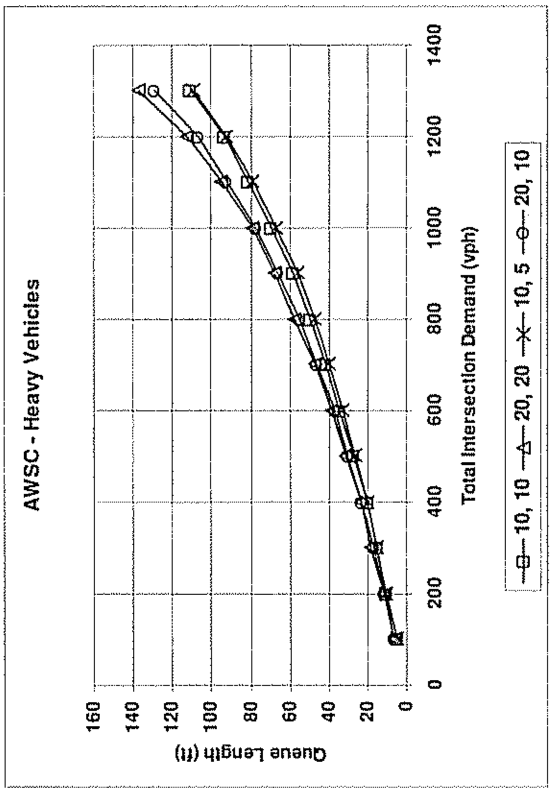

AWSC - Volume Ratio
Queue Length (ft)
140
120
100
80
60
40
20
0
0
200
400
600
800
1000
1200
1400
1600
Total Intersection Demand (vph)
1.0
1.33

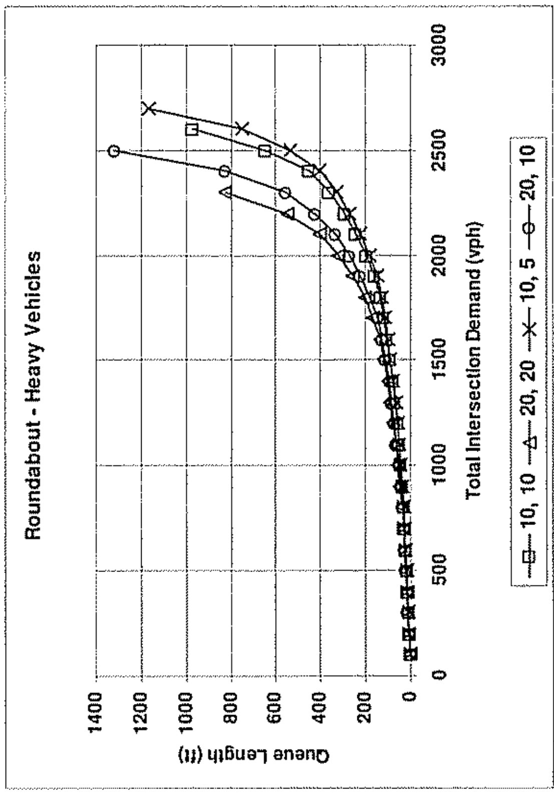

AWSC - Turning Percentages
Queue Length (ft)
300
250
200
150
100
50
0
0
200
400
600
800
1000
1200
1400
Total Intersection Demand (vph)
(10,80,10)
(20,70,10)
(30,60,10)

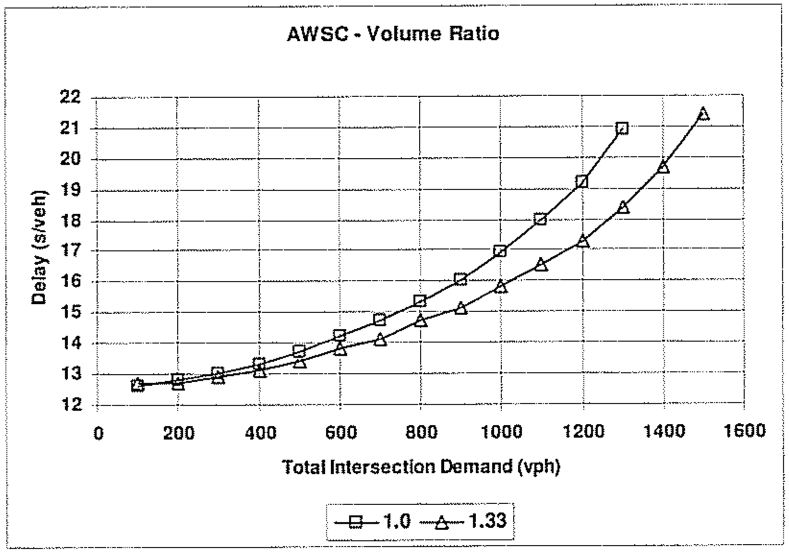

Roundabout - Volume Ratio
Queue Length (ft)
1200
1000
800
600
400
200
0
0
500
1000
1500
2000
2500
3000
3500
Total Intersection Demand (vph)
1.0
1.33

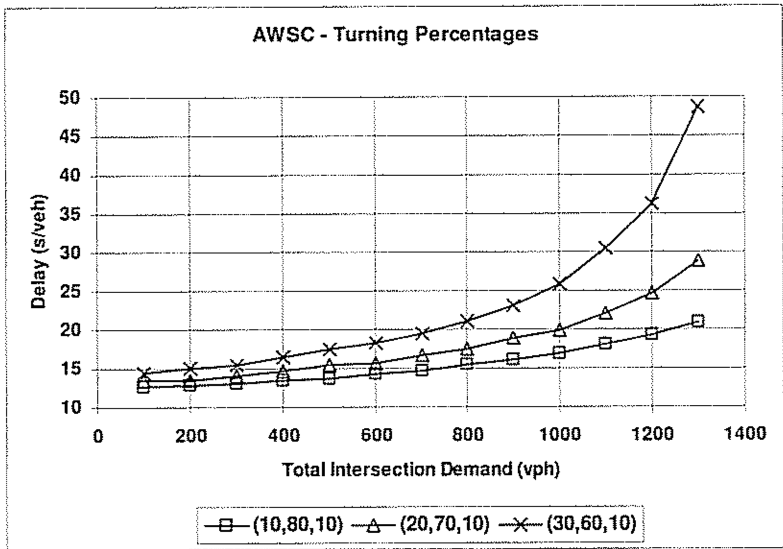

Roundabout - Turning Percentages
Queue Length (ft)
1200
1000
800
600
400
200
0
0
500
1000
1500
2000
2500
3000
Total Intersection Demand (vph)
(10,80,10)
(20,70,10)
(30,60,10)

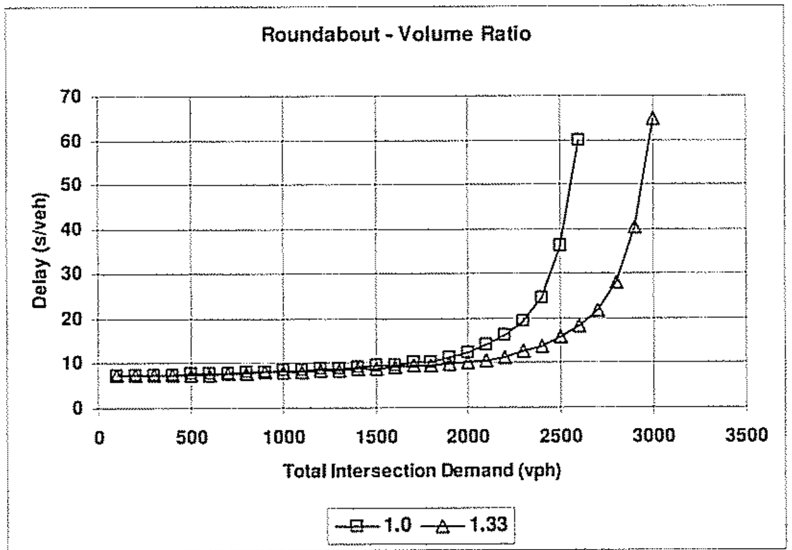

Roundaout - Diameter
Queue Length (ft)
Total Intersection Demand (vph)
80
100
120

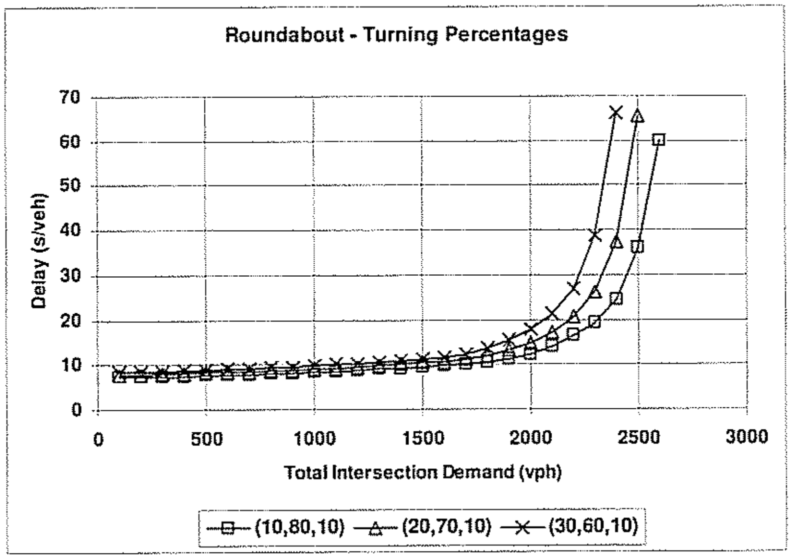

AWSC - Heavy Vehicles
Queue Length (ft)
Total Intersection Demand (vph)
10, 10
20, 20
10, 5
20, 10

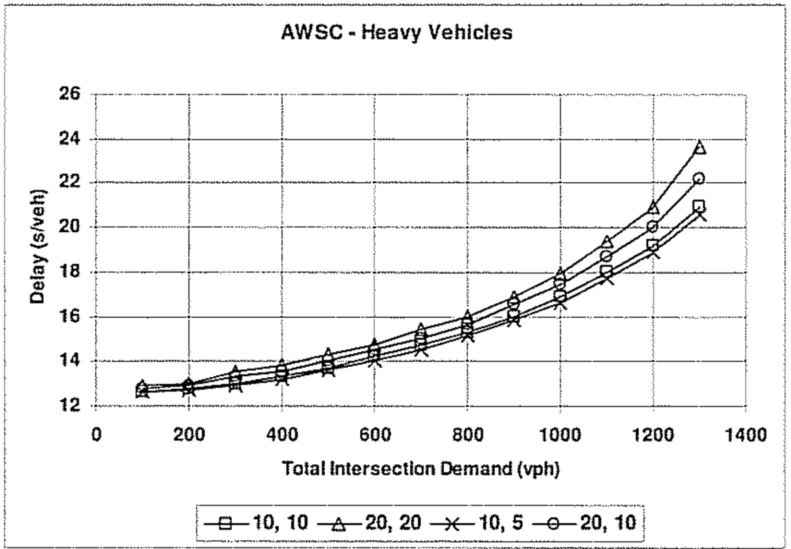

Roundabout - Heavy Vehicles
Queue Length (ft)
Total Intersection Demand (vph)
10, 10
20, 20
10, 5
20, 10

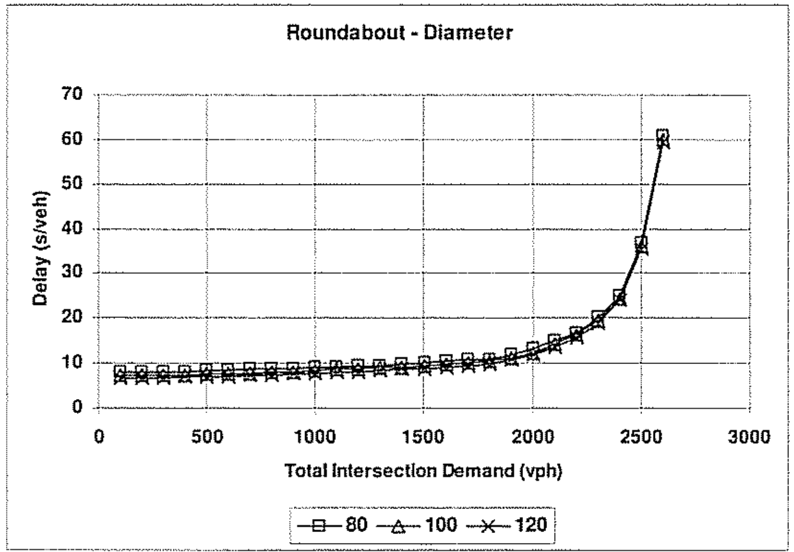

AWSC - Volume Ratio
Delay (s/veh)
Total Intersection Demand (vph)
1.0
1.33

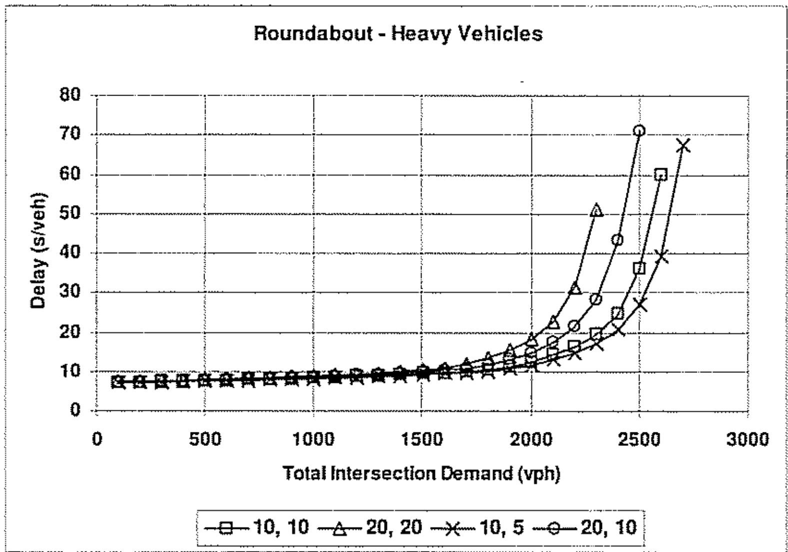

AWSC - Turning Percentages
Delay (s/veh)
Total Intersection Demand (vph)
(10,80,10)
(20,70,10)
(30,60,10)

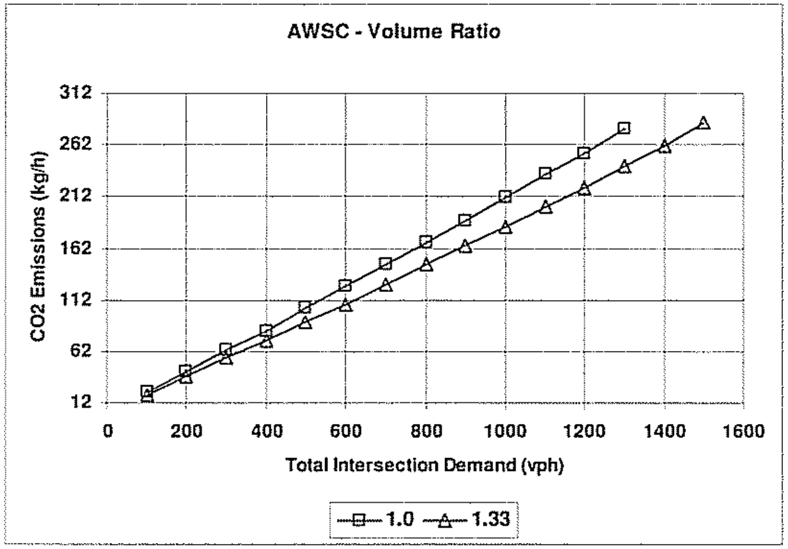

Roundabout - Volume Ratio
Delay (s/veh)
Total Intersection Demand (vph)
1.0
1.33

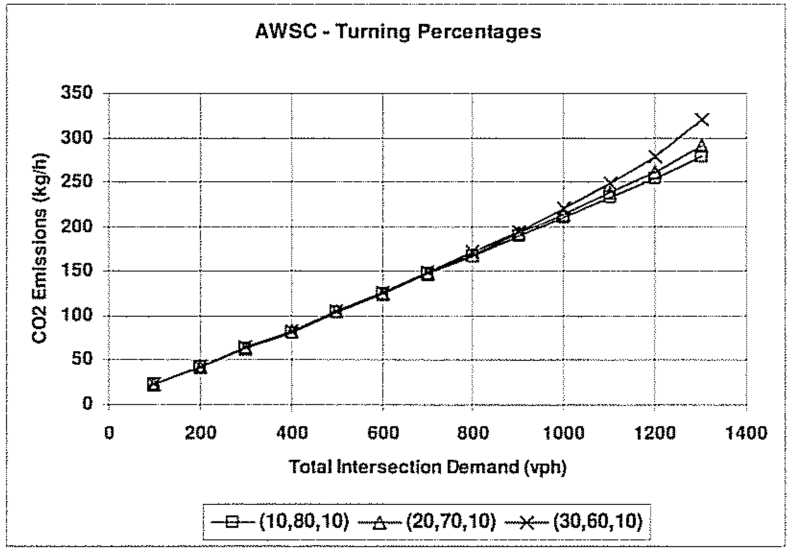

Roundabout - Turning Percentages
Delay (s/veh)
Total Intersection Demand (vph)
(10,80,10)
(20,70,10)
(30,60,10)

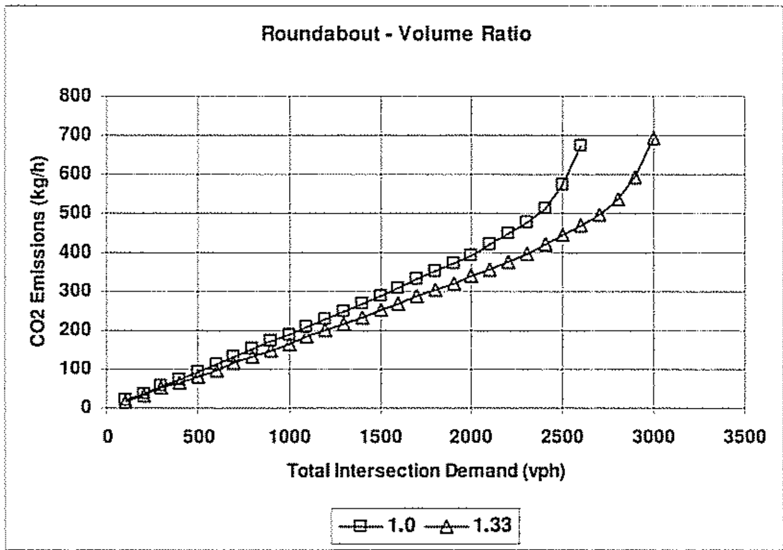

AWSC - Heavy Vehicles
Delay (s/veh)
26
24
22
20
18
16
14
12
0
200
400
600
800
1000
1200
1400
Total Intersection Demand (vph)
10, 10
20, 20
10, 5
20, 10

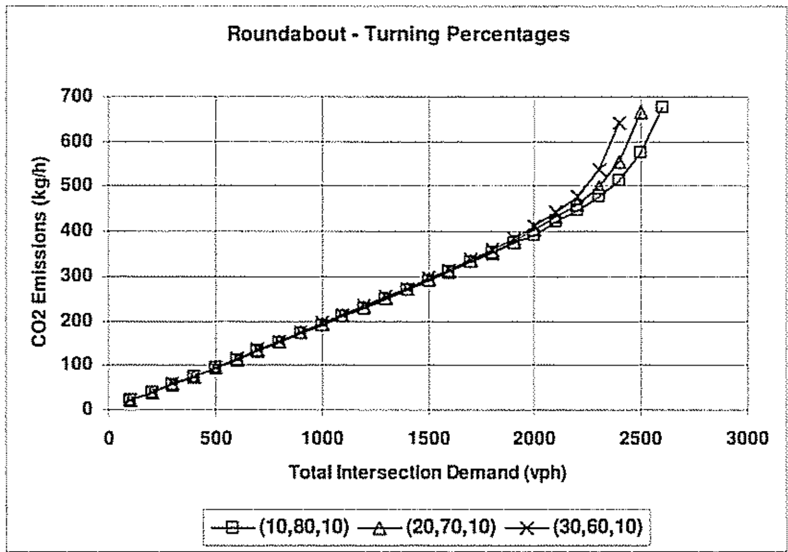

Roundabout - Diameter
Delay (s/veh)
70
60
50
40
30
20
10
0
0
500
1000
1500
2000
2500
3000
Total Intersection Demand (vph)
80
100
120

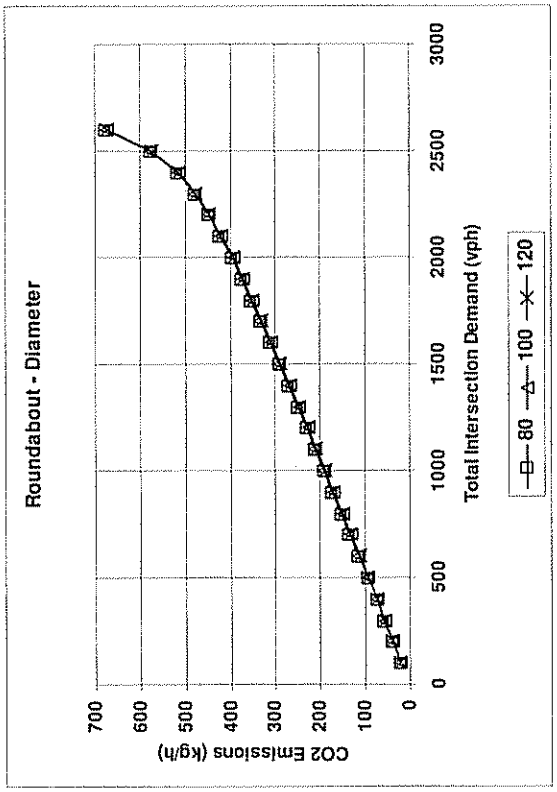

Roundabout - Heavy Vehicles
Delay (s/veh)
80
70
60
50
40
30
20
10
0
0
500
1000
1500
2000
2500
3000
Total Intersection Demand (vph)
10, 10
20, 20
10, 5
20, 10

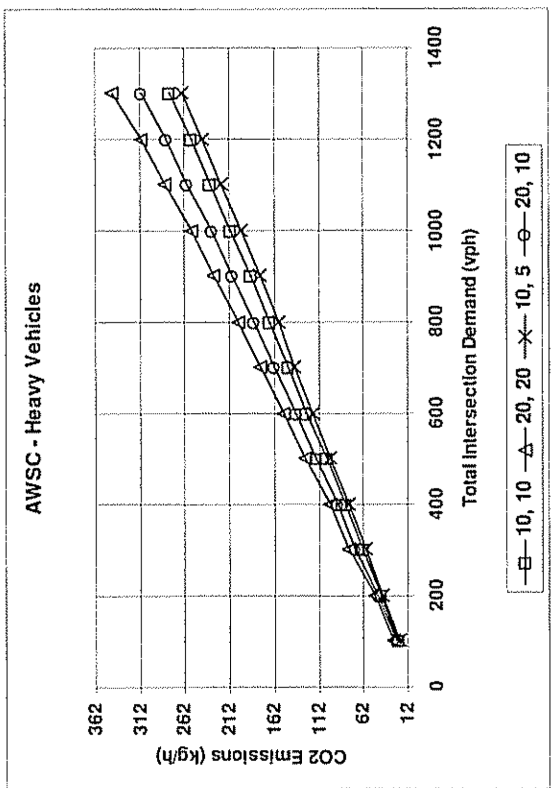

AWSC - Volume Ratio
CO2 Emissions (kg/h)
312
262
212
162
112
62
12
0
200
400
600
800
1000
1200
1400
1600
Total Intersection Demand (vph)
1.0
1.33

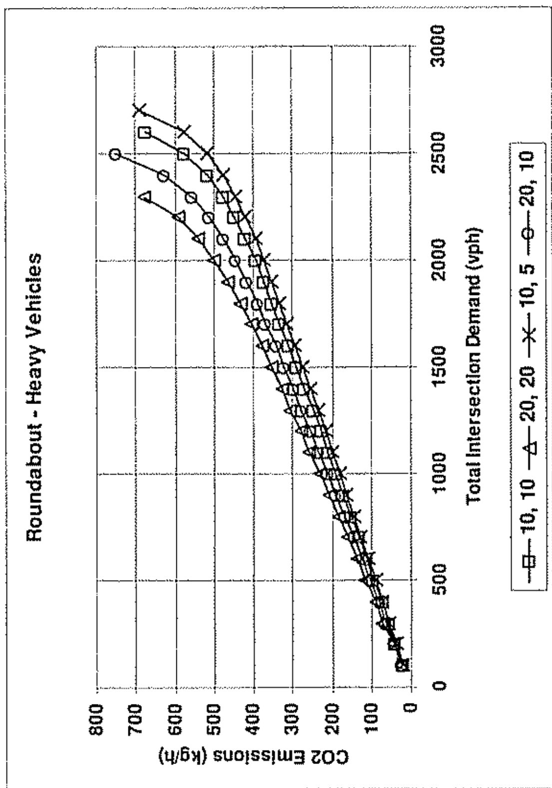

AWSC - Turning Percentages
CO2 Emissions (kg/h)
350
300
250
200
150
100
50
0
0
200
400
600
800
1000
1200
1400
Total Intersection Demand (vph)
(10,80,10)
(20,70,10)
(30,60,10)

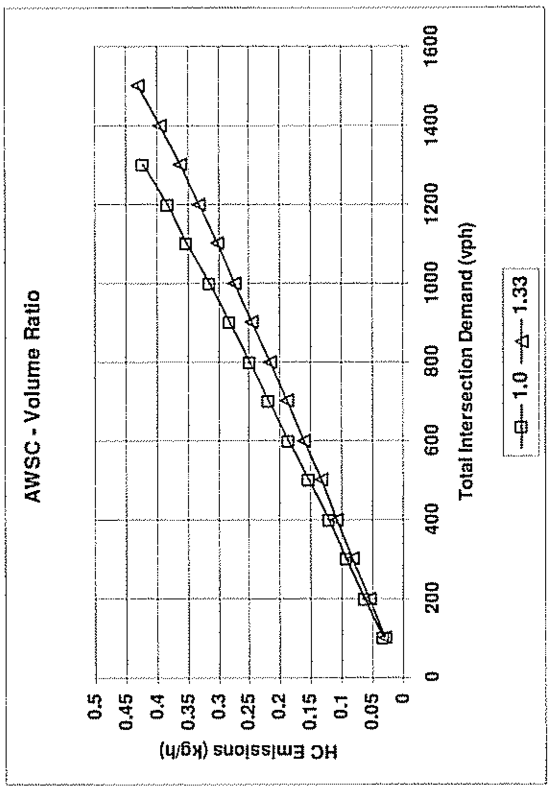

Roundabout - Volume Ratio
CO2 Emissions (kg/h)
800
700
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
3500
Total Intersection Demand (vph)
1.0
1.33

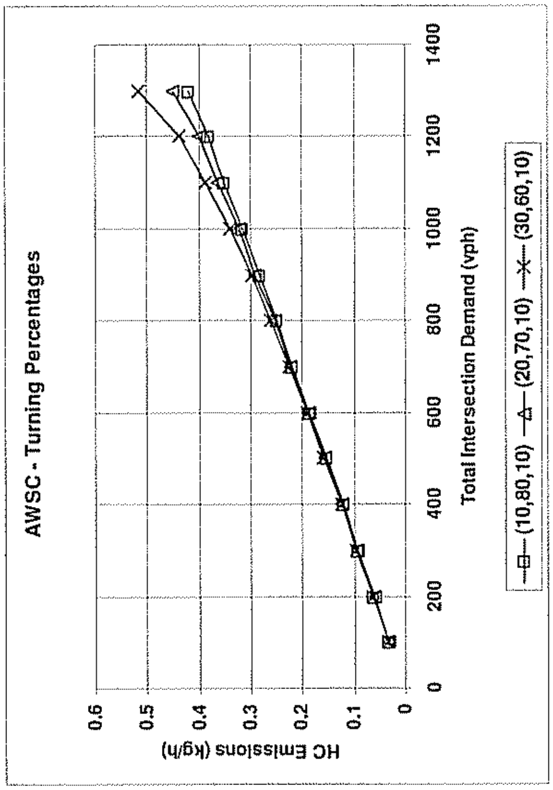

Roundabout - Turning Percentages
CO2 Emissions (kg/h)
700
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
Total Intersection Demand (vph)
(10,80,10)
(20,70,10)
(30,60,10)

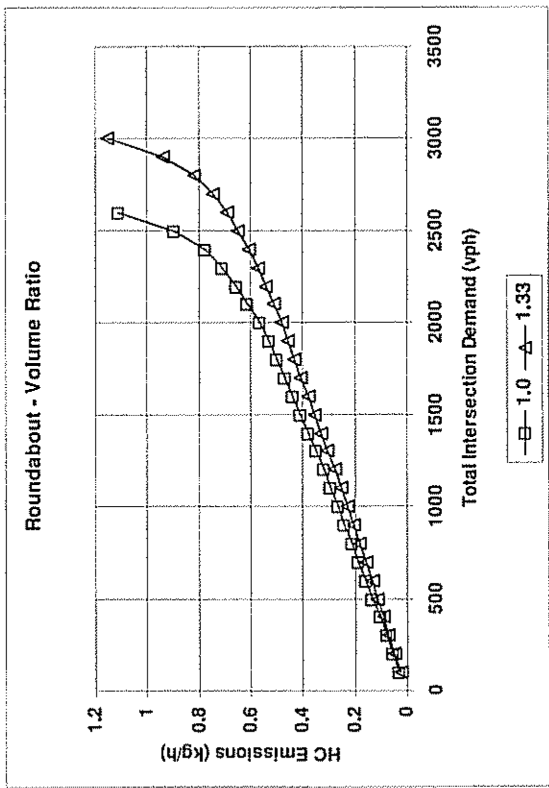

Roundabout - Diameter
CO2 Emissions (kg/h)
700
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
Total Intersection Demand (vph)
80
100
120

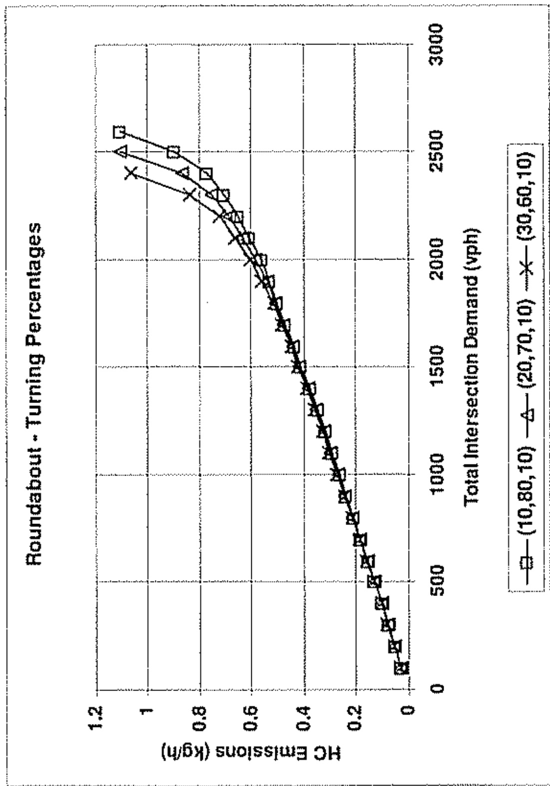

AWSC - Heavy Vehicles
CO2 Emissions (kg/h)
362
312
262
212
162
112
62
12
0
200
400
600
800
1000
1200
1400
Total Intersection Demand (vph)
10, 10
20, 20
10, 5
20, 10

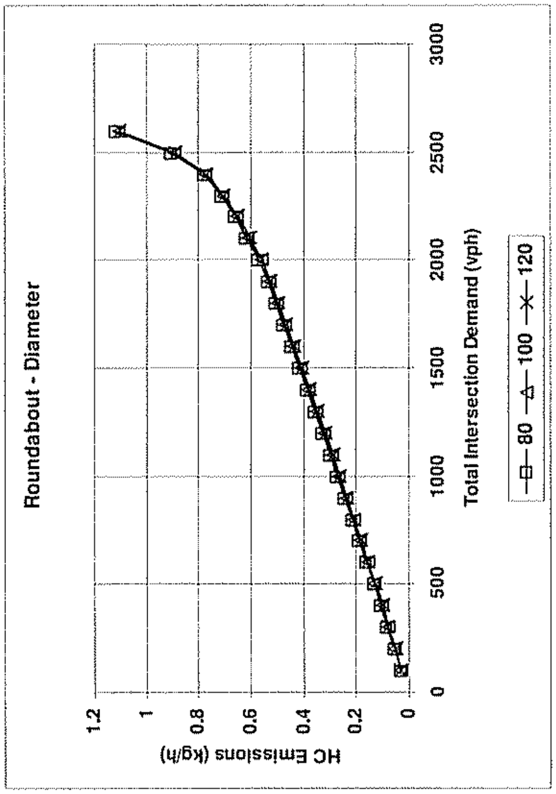

Roundabout - Heavy Vehicles
CO2 Emissions (kg/h)
800
700
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
Total Intersection Demand (vph)
10, 10
20, 20
10, 5
20, 10

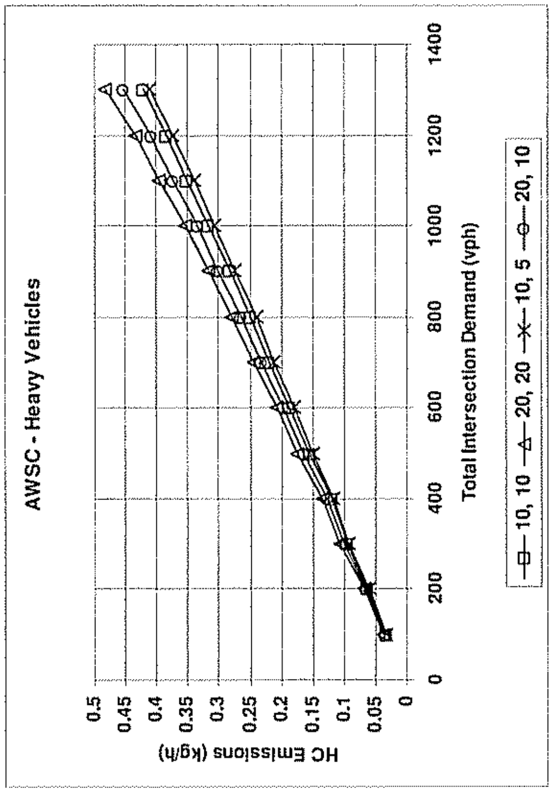

AWSC - Volume Ratio
HC Emissions (kg/h)
Total Intersection Demand (vph)
1.0
1.33

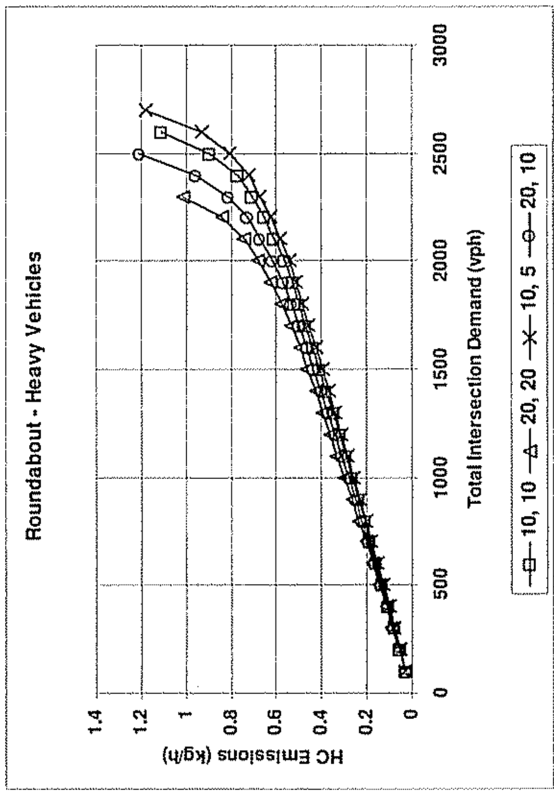

AWSC - Turning Percentages
HC Emissions (kg/h)
Total Intersection Demand (vph)
(10,80,10)
(20,70,10)
(30,60,10)

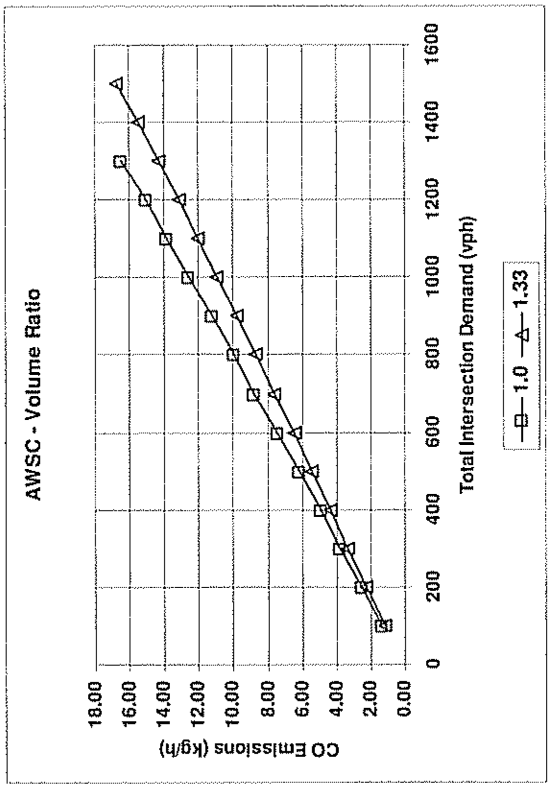

Roundabout - Volume Ratio
HC Emissions (kg/h)
Total Intersection Demand (vph)
1.0
1.33

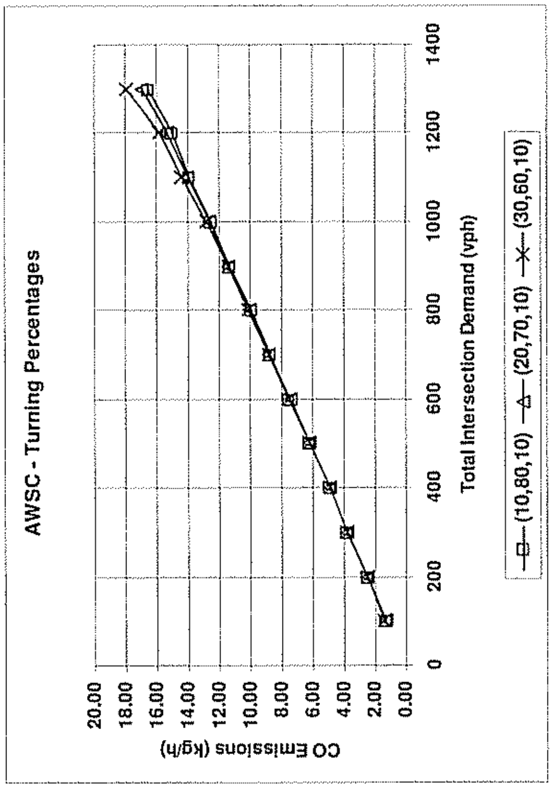

Roundabout - Turning Percentages
HC Emissions (kg/h)
Total Intersection Demand (vph)
(10,80,10)
(20,70,10)
(30,60,10)

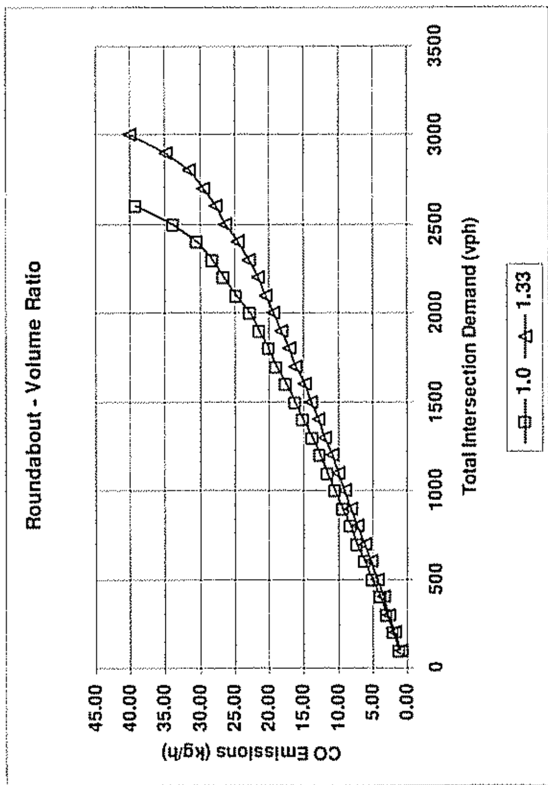

Roundabout - Diameter
HC Emissions (kg/h)
Total Intersection Demand (vph)
80
100
120

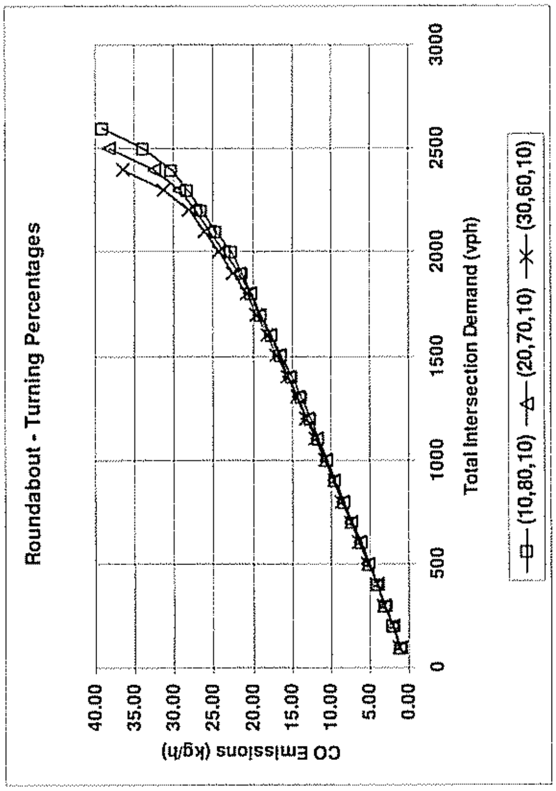

AWSC - Heavy Vehicles
HC Emissions (kg/h)
Total Intersection Demand (vph)
10, 10
20, 20
10, 5
20, 10

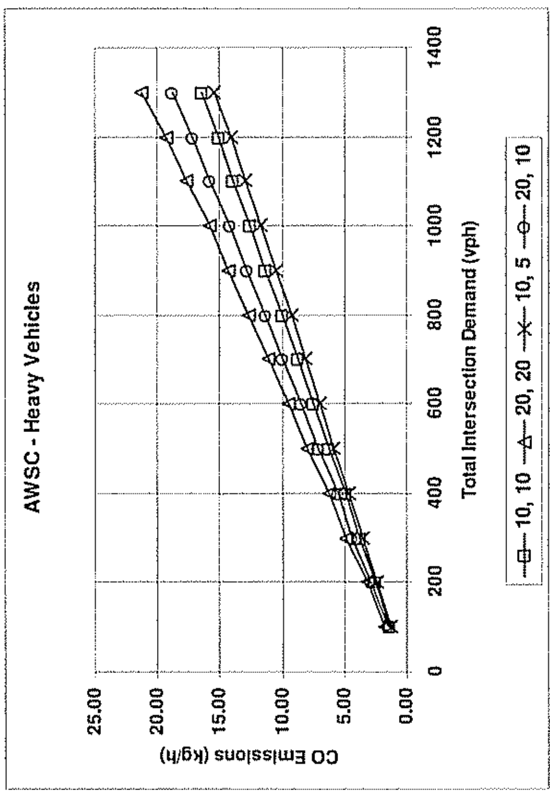

Roundabout - Heavy Vehicles
HC Emissions (kg/h)
Total Intersection Demand (vph)
10, 10
20, 20
10, 5
20, 10

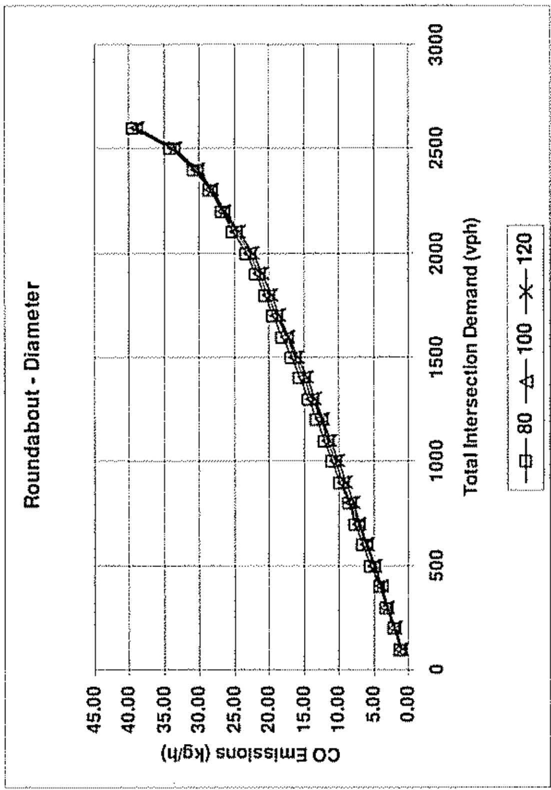

AWSC - Volume Ratio
CO Emissions (kg/h)
Total Intersection Demand (vph)
1.0
1.33

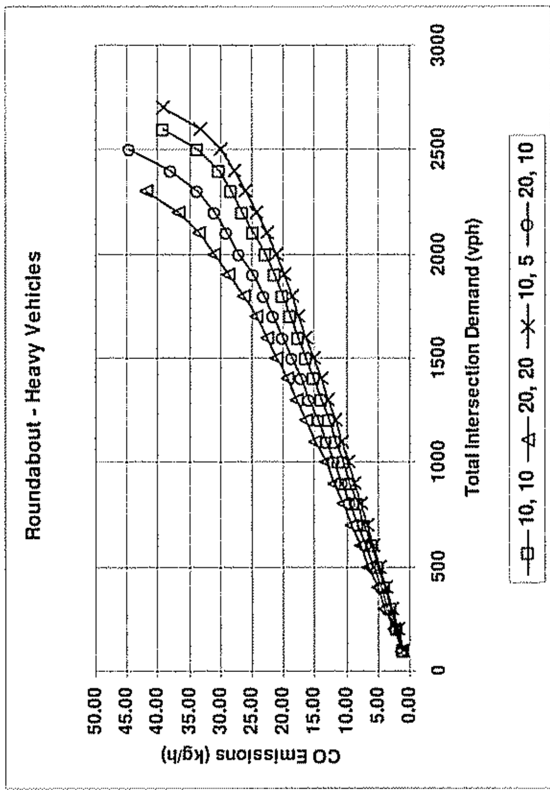

AWSC - Turning Percentages
CO Emissions (kg/h)
Total Intersection Demand (vph)
(10,80,10)
(20,70,10)
(30,60,10)

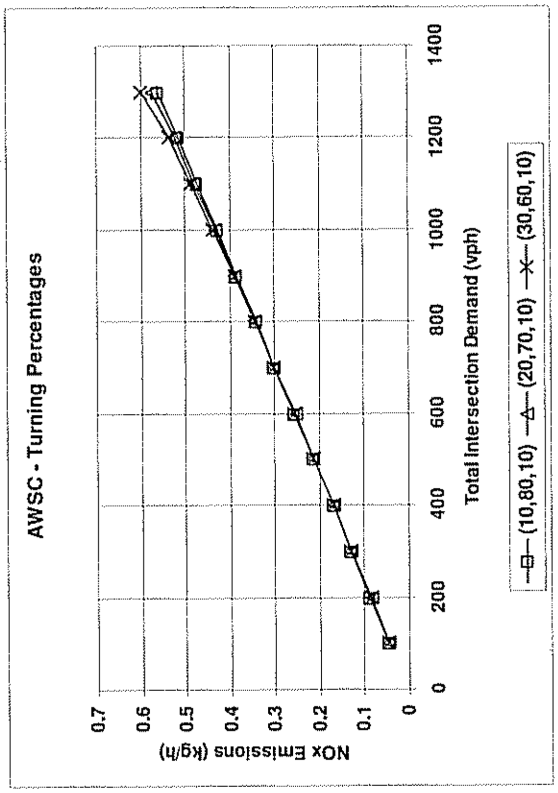

Roundabout - Volume Ratio
CO Emissions (kg/h)
Total Intersection Demand (vph)
1.0
1.33

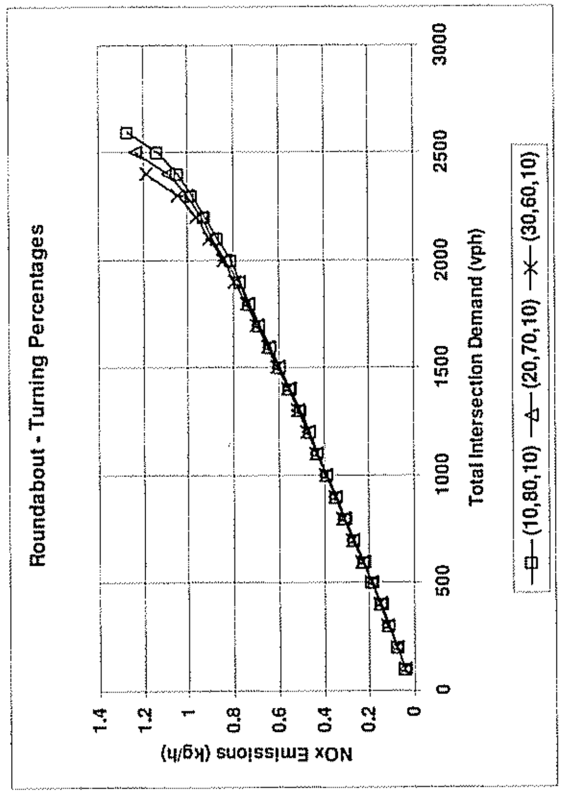

Roundabout - Turning Percentages
CO Emissions (kg/h)
Total Intersection Demand (vph)
(10,80,10)
(20,70,10)
(30,60,10)

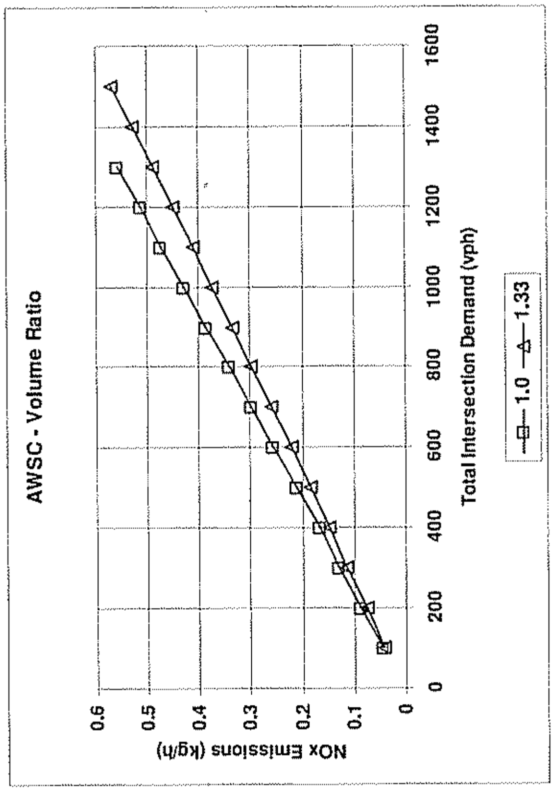

AWSC - Heavy Vehicles
CO Emissions (kg/h)
Total Intersection Demand (vph)
10, 10
20, 20
10, 5
20, 10

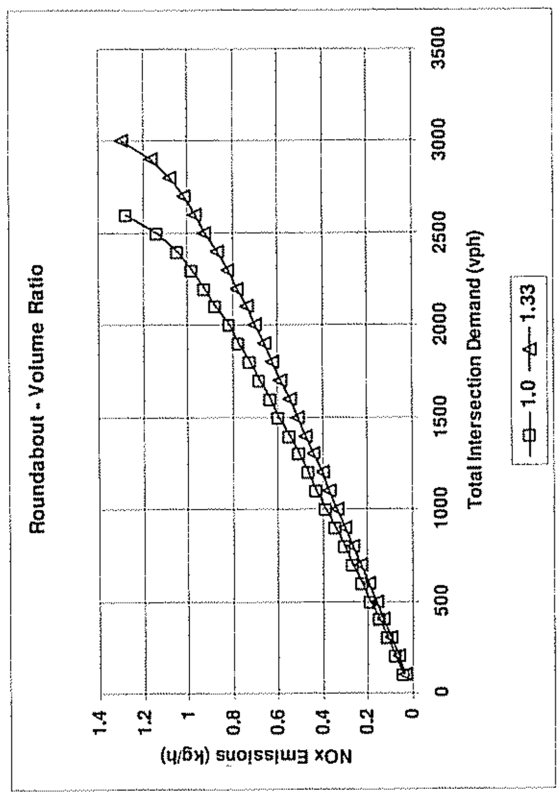

Roundabout - Diameter
CO Emissions (kg/h)
Total Intersection Demand (vph)
80
100
120

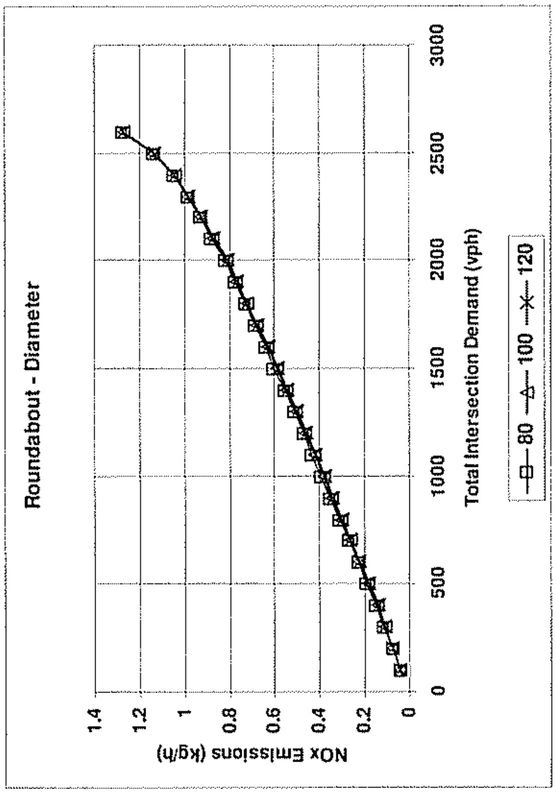

Roundabout - Heavy Vehicles
CO Emissions (kg/h)
Total Intersection Demand (vph)
10, 10
20, 20
10, 5
20, 10

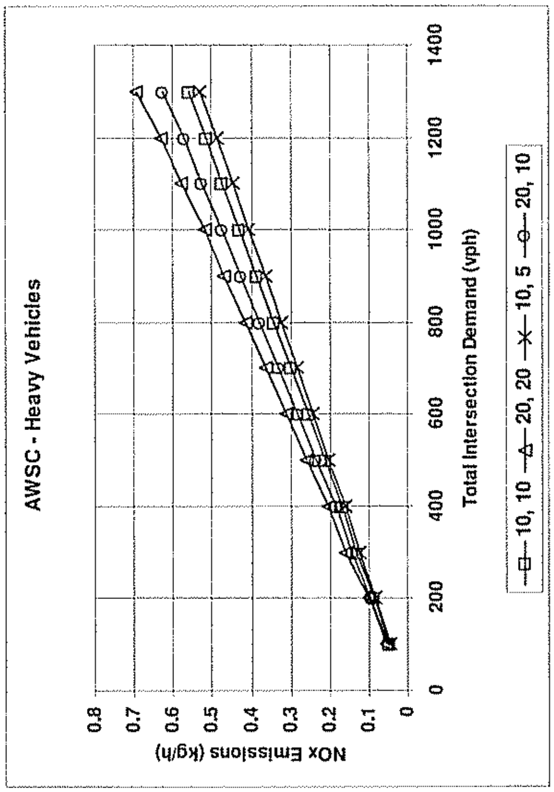

AWSC - Turning Percentages
NOx Emissions (kg/h)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
1400
Total Intersection Demand (vph)
(10,80,10)
(20,70,10)
(30,60,10)

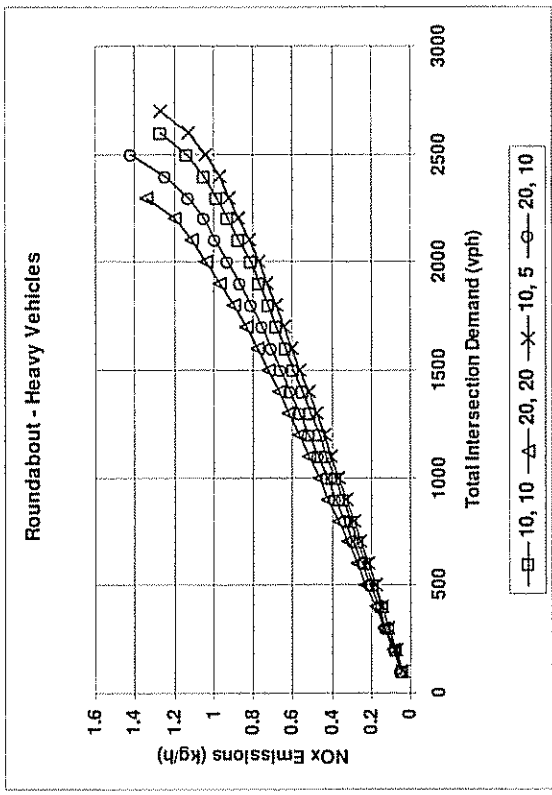

Roundabout - Turning Percentages
NOx Emissions (kg/h)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
500
1000
1500
2000
2500
3000
Total Intersection Demand (vph)
(10,80,10)
(20,70,10)
(30,60,10)


AWSC - Volume Ratio
NOx Emissions (kg/h)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
1400
1600
Total Intersection Demand (vph)
1.0
1.33


Roundabout - Volume Ratio
NOx Emissions (kg/h)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
500
1000
1500
2000
2500
3000
3500
Total Intersection Demand (vph)
1.0
1.33


Roundabout - Diameter
NOx Emissions (kg/h)
Total Intersection Demand (vph)
80
100
120


AWSC - Heavy Vehicles
NOx Emissions (kg/h)
Total Intersection Demand (vph)
10, 10
20, 20
10, 5
20, 10


Roundabout - Heavy Vehicles
NOx Emissions (kg/h)
Total Intersection Demand (vph)
10, 10
20, 20
10, 5
20, 10

APPENDIX C

VARIABLES AND LOGIC BLOCKS FOR THE ROUNDABOUT RATING SYSTEM

VARIABLES

Accident_History
Static List Variable
Prompt: Is there a history of frequent and/or severe accidents at the intersection?
Static List Values: Yes, No

Aesthetics
Static List Variable
Prompt: Has the public expressed an interest in enhancing the community's appearance?
Static List Values: Yes, No

Buy_ROW
Static List Variable
Prompt: Is it possible to purchase additional right-of-way at the intersection, if necessary?
Static List Values: Yes, No

Collision_Types
Static List Variable
Prompt: Is there a history of left-turn head-on and/or right-angle collisions at the intersection?
Static List Values: Yes, No

Current_Problems
Static List Variable
Prompt: Is the intersection currently experiencing operational problems during peak hours or throughout the day?
Static List Values: Yes, No

Current_Volume
Numeric Variable
Prompt: What is the intersection demand during peak hours (total all four approach volumes)?

Current_Year
Numeric Variable
Prompt: Enter the current year.

Design_Year
Numeric Variable
Prompt: Enter the design year for the intersection.

Display_Results
Collection Variable

Driver_Fail_to_Stop
Static List Variable
Prompt: Have accidents been caused as a result of drivers failing to properly obey the stop control?
Static List Values: Yes, No

First_Roundabout
Static List Variable
Prompt: If this intersection were converted to a roundabout, would it be the first roundabout in the area?
Static List Values: Yes, No

Future_Volume
Numeric Variable

Growth_Rate
Numeric Variable

Prompt: What is the expected growth rate for the demand volume (percentage per year)?

HV_Greater

Static List Variable

Prompt: What is the value of the greater of these two percentages? Choose the closer value.

Static List Values: 10, 20

HV_Ratio

Static List Variable

Prompt: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value.

Static List Values: 1:1, 2:1

Include_Emissions

Static List Variable

Prompt: Would you like the analysis to be based solely on operational performance (capacity, delay, V/C), or would you also like to include emissions?

Static List Values: Operational_Performance_Only, Include_Emissions

LT

Static List Variable

Prompt: What is the average left turning percentage of vehicles at the intersection? Choose the closest value.

Static List Values: 10, 20, 30

MUTCD_Signal_Warranted

Static List Variable

Prompt: Do the volumes at the intersection warrant signalization according to the MUTCD? Do not answer if a study has not been conducted.

Static List Values: Yes, No

MUTCD_Study

Static List Variable

Prompt: Has a study been conducted to determine if the intersection volumes warrant signalization according to the MUTCD?

Static List Values: Yes, No

Nearby_Signals

Static List Variable

Prompt: Are there signalized intersections in close proximity to the existing AWSC intersection?

Static List Values: Yes, No

No_Accident_History

Confidence Variable

Ped_Bike

Static List Variable

Prompt: Is there a significant amount of pedestrian and/or bicyclist traffic at any time during the day?

Static List Values: Yes, No

Railroad

Static List Variable

Prompt: Is this intersection located in the vicinity of a railroad crossing?

Static List Values: Yes, No

Rbt_high

Confidence Variable

Rbt_rec

Confidence Variable

RbtSignal_Intn_V
Numeric Variable
Signal_rec
Confidence Variable
Transit_Route
Static List Variable
Prompt: Is the intersection located along a transit route?
Static List Values: Yes, No
Volume_Ratio
Static List Variable
Prompt: What is the ratio between the volumes of the two intersecting roads? Choose the closer value
Static List Values: 1:1, 3:4

LOGIC BLOCKS

Block: Roundabout Comments

IF: [Rbt_rec]>[Signal_rec]
THEN: [Display_Results.ADD_UNIQUE] The analysis and comments are provided as an aid in determining the feasibility of converting an AWSC intersection to a roundabout while keeping the same configuration (i.e., no added lanes). A definite yes-or-no answer can never be given, as various factors create pros and cons for multiple alternatives, of which just two are considered in this analysis. The final decision, therefore, is left to the planning individuals who must use practical logic and engineering judgment in making the best choice. For further discussion and guidance, see the FHWA Roundabout Guide, Publication No. FHWA-RD-00-067

IF: [Rbt_rec]>[Signal_rec]
AND: Has the public expressed an interest in enhancing the community's appearance? Yes
THEN: [Display_Results.ADD] A roundabout would provide a good opportunity for improving the appearance of both the intersection and the community, in which the public has expressed interest, as well as being an attractive trademark of the community. The central island, splitter islands, and perimeter of the roundabout would provide space for landscaping. Some communities have also placed sculptures or fountains in the central island as well. Note that such additions to the aesthetics of the intersection will increase installation costs of the roundabout, and landscaping will also require regular maintenance.
>>> [Display_Results.ADD_UNIQUE] The analysis and comments are provided as an aid in determining the feasibility of converting an AWSC intersection to a roundabout while keeping the same configuration (i.e., no added lanes). A definite yes-or-no answer can never be given, as various factors create pros and cons for multiple alternatives, of which just two are considered in this analysis. The final decision, therefore, is left to the planning individuals who must use practical logic and engineering judgment in making the best choice. For further discussion and guidance, see the FHWA Roundabout Guide, Publication No. FHWA-RD-00-067

IF: [Rbt_rec]>[Signal_rec]
AND: Has the public expressed an interest in enhancing the community's appearance? No
THEN: [Display_Results.ADD] While the public has not specifically expressed an interest in improving the aesthetics of the intersection and/or community, a roundabout would be a good opportunity for creating an attractive trademark for the community. The central island, splitter islands, and perimeter of the roundabout provide space for landscaping. Some communities have placed fountains or sculptures in the central island as well. Note that such enhancements to aesthetics will increase installation costs of the roundabout. Additionally, costs would be involved in the regular maintenance of the lanscaping.
>>> [Display_Results.ADD_UNIQUE] The analysis and comments are provided as an aid in determining the feasibility of converting an AWSC intersection to a roundabout while keeping the same configuration (i.e., no added lanes). A definite yes-or-no answer can never be given, as various factors create pros and cons for multiple alternatives, of which just two are considered in this analysis. The final decision, therefore, is left to the planning individuals who must use practical logic and engineering judgment in making the best choice. For further discussion and guidance, see the FHWA Roundabout Guide, Publication No. FHWA-RD-00-067

IF: [Rbt_rec]>[Signal_rec]
AND: If this intersection were converted to a roundabout, would it be the first roundabout in the area? Yes

THEN: [Display_Results.ADD] Since this would be the first roundabout in the area, many residents unfamiliar with roundabouts may be initially opposed to the proposal. Oftentimes, lack of proper knowledge causes the public to become one of the biggest challenges facing a proposed roundabout project. However, experience has shown that once drivers become accustomed to this new form of traffic control, public acceptance noticeably increases. To ease this introduction to the roundabout, significant effort should be put into educating the public on the benefits that it offers compared to a signal, in terms of improved operations (capacity, delay, etc.), aesthetics, and safety; reduced vehicular emissions levels; and lowered costs. Public workshops and informational brochures could also be used to discuss the proposed roundabout as well as to explain proper driver behavior at roundabouts.

>>> [Display_Results.ADD_UNIQUE] The analysis and comments are provided as an aid in determining the feasibility of converting an AWSC intersection to a roundabout while keeping the same configuration (i.e., no added lanes). A definite yes-or-no answer can never be given, as various factors create pros and cons for multiple alternatives, of which just two are considered in this analysis. The final decision, therefore, is left to the planning individuals who must use practical logic and engineering judgment in making the best choice. For further discussion and guidance, see the FHWA Roundabout Guide, Publication No. FHWA-RD-00-067

IF: [Rbt_rec]>[Signal_rec]

AND: If this intersection were converted to a roundabout, would it be the first roundabout in the area? No

THEN: [Display_Results.ADD] This will not be the first roundabut in the area. However, many residents may still be somewhat unfamiliar with modern roundabouts. Oftentimes, lack of proper knowledge causes the public to become one of the biggest challenges facing a proposed roundabout project. Experience has shown, however, that once drivers become accustomed to this new form of traffic control, public acceptance noticeably increases. To ease this introduction to the roundabout, effort should be put into educating the public on the benefits it offers compared to a signal, in terms of improved operations (capacity, delay, etc.), aesthetics, and safety; reduced vehicular emissions levels; and lowered costs. Public workshops and informational brochures could also be used to discuss the propsed roundabout as well as to explain proper driver behavior at roundabouts.

>>> [Display_Results.ADD_UNIQUE] The analysis and comments are provided as an aid in determining the feasibility of converting an AWSC intersection to a roundabout while keeping the same configuration (i.e., no added lanes). A definite yes-or-no answer can never be given, as various factors create pros and cons for multiple alternatives, of which just two are considered in this analysis. The final decision, therefore, is left to the planning individuals who must use practical logic and engineering judgment in making the best choice. For further discussion and guidance, see the FHWA Roundabout Guide, Publication No. FHWA-RD-00-067

IF: [Rbt_rec]>[Signal_rec]

AND: Is it possible to purchase additional right-of-way at the intersection, if necessary? Yes

THEN: [Display_Results.ADD] Typical inscribed diameters (including circulatory roadway) for urban single-lane roundabouts range between 100 and 130 feet, assuming 90-degree entries and no more than four approach legs. The roundabout should be designed to provide sight distance in three critical types of locations: approach sight distance, sight distance on circulatory roadway, and sight distance to crosswalk on exit (see FHWA Roundabout Guide, Section 6.3.9). If the existing area of the intersection cannot accomodate a roundabout of the appropriate diameter, additional right-of-way will have to be purchased, which will increase costs. See the FHWA Roundabout Guide, Appendix B, for guidance on initial roundabout space requirements.

>>> [Display_Results.ADD_UNIQUE] The analysis and comments are provided as an aid in determining the feasibility of converting an AWSC intersection to a roundabout while keeping the same

configuration (i.e., no added lanes). A definite yes-or-no answer can never be given, as various factors create pros and cons for multiple alternatives, of which just two are considered in this analysis. The final decision, therefore, is left to the planning individuals who must use practical logic and engineering judgment in making the best choice. For further discussion and guidance, see the FHWA Roundabout Guide, Publication No. FHWA-RD-00-067

IF: [Rbt_rec]>[Signal_rec]
AND: Is it possible to purchase additional right-of-way at the intersection, if necessary? Yes
AND: Is the intersection located along a transit route? Yes
THEN: [Display_Results.ADD] The intersection is located along a transit route, and therefore design of the roundabout must ensure that buses as well as any other expected large vehicles (trucks, emergency vehicles) can easily traverse the circulatory roadway. It is also important that nearby bus stops be located so as to minimize the probability of vehicle back-ups into the roundabout.
>>> [Display_Results.ADD] Typical inscribed diameters (including circulatory roadway) for urban single-lane roundabouts range between 100 and 130 feet, assuming 90-degree entries and no more than four approach legs. The roundabout should be designed to provide sight distance in three critical types of locations: approach sight distance, sight distance on circulatory roadway, and sight distance to crosswalk on exit (see FHWA Roundabout Guide, Section 6.3.9). If the existing area of the intersection cannot accomodate a roundabout of the appropriate diameter, additional right-of-way will have to be purchased, which will increase costs. See the FHWA Roundabout Guide, Appendix B, for guidance on initial roundabout space requirements.
>>> [Display_Results.ADD_UNIQUE] The analysis and comments are provided as an aid in determining the feasibility of converting an AWSC intersection to a roundabout while keeping the same configuration (i.e., no added lanes). A definite yes-or-no answer can never be given, as various factors create pros and cons for multiple alternatives, of which just two are considered in this analysis. The final decision, therefore, is left to the planning individuals who must use practical logic and engineering judgment in making the best choice. For further discussion and guidance, see the FHWA Roundabout Guide, Publication No. FHWA-RD-00-067

IF: [Rbt_rec]>[Signal_rec]
AND: Is it possible to purchase additional right-of-way at the intersection, if necessary? Yes
AND: Is the intersection located along a transit route? No
THEN: [Display_Results.ADD] The intersection is not located along a transit route. However, design of the roundabout must ensure that any expected large vehicles (trucks, schoolbuses, emergency vehicles) can easily traverse the circulatory roadway.
>>> [Display_Results.ADD] Typical inscribed diameters (including circulatory roadway) for urban single-lane roundabouts range between 100 and 130 feet, assuming 90-degree entries and no more than four approach legs. The roundabout should be designed to provide sight distance in three critical types of locations: approach sight distance, sight distance on circulatory roadway, and sight distance to crosswalk on exit (see FHWA Roundabout Guide, Section 6.3.9). If the existing area of the intersection cannot accomodate a roundabout of the appropriate diameter, additional right-of-way will have to be purchased, which will increase costs. See the FHWA Roundabout Guide, Appendix B, for guidance on initial roundabout space requirements.
>>> [Display_Results.ADD_UNIQUE] The analysis and comments are provided as an aid in determining the feasibility of converting an AWSC intersection to a roundabout while keeping the same configuration (i.e., no added lanes). A definite yes-or-no answer can never be given, as various factors create pros and cons for multiple alternatives, of which just two are considered in this analysis. The final decision, therefore, is left to the planning individuals who must use practical logic and engineering judgment in making the best choice. For further discussion and guidance, see the FHWA Roundabout Guide, Publication No. FHWA-RD-00-067

IF: [Rbt_rec]>[Signal_rec]
AND: Is it possible to purchase additional right-of-way at the intersection, if necessary? No
THEN: [Display_Results.ADD] Typical inscribed diameters (including circulatory roadway) for urban single-lane roundabouts range between 100 and 130 feet, assuming 90-degree entries and no more than four approach legs. The roundabout should be designed to provide sight distance in three critical types of locations: approach sight distance, sight distance on the circulatory roadway, and sight distance to crosswalk on exit (see FHWA Roundabout Guide, Section 6.3.9). If the existing area of the intersection cannot accomodate a roundabout of sufficient inscribed diameter, additional right-of-way would have to be purchased, however this is not possible. In this case, despite the better operational performance a roundabout would provide, a signal is the only option. See the FHWA Roundabout Guide, Appendix B, for guidance on initial roundabout space requirements.
\>>> [Display_Results.ADD_UNIQUE] The analysis and comments are provided as an aid in determining the feasibility of converting an AWSC intersection to a roundabout while keeping the same configuration (i.e., no added lanes). A definite yes-or-no answer can never be given, as various factors create pros and cons for multiple alternatives, of which just two are considered in this analysis. The final decision, therefore, is left to the planning individuals who must use practical logic and engineering judgment in making the best choice. For further discussion and guidance, see the FHWA Roundabout Guide, Publication No. FHWA-RD-00-067

IF: [Rbt_rec]>[Signal_rec]
AND: Is it possible to purchase additional right-of-way at the intersection, if necessary? No
AND: Is the intersection located along a transit route? Yes
THEN: [Display_Results.ADD] The intersection is located along a transit route, and therefore, if the appropriately-sized roundabout can be accomodated within the existing intersection, its design must ensure that buses as well as any other expected large vehicles (trucks, emergency vehicles) can easily traverse the circulatory roadway. It is also important that nearby bus stops be located so as to minimize the probability of vehicle back-ups into the circulatory roadway.
\>>> [Display_Results.ADD] Typical inscribed diameters (including circulatory roadway) for urban single-lane roundabouts range between 100 and 130 feet, assuming 90-degree entries and no more than four approach legs. The roundabout should be designed to provide sight distance in three critical types of locations: approach sight distance, sight distance on the circulatory roadway, and sight distance to crosswalk on exit (see FHWA Roundabout Guide, Section 6.3.9). If the existing area of the intersection cannot accomodate a roundabout of sufficient inscribed diameter, additional right-of-way would have to be purchased, however this is not possible. In this case, despite the better operational performance a roundabout would provide, a signal is the only option. See the FHWA Roundabout Guide, Appendix B, for guidance on initial roundabout space requirements.
\>>> [Display_Results.ADD_UNIQUE] The analysis and comments are provided as an aid in determining the feasibility of converting an AWSC intersection to a roundabout while keeping the same configuration (i.e., no added lanes). A definite yes-or-no answer can never be given, as various factors create pros and cons for multiple alternatives, of which just two are considered in this analysis. The final decision, therefore, is left to the planning individuals who must use practical logic and engineering judgment in making the best choice. For further discussion and guidance, see the FHWA Roundabout Guide, Publication No. FHWA-RD-00-067

IF: [Rbt_rec]>[Signal_rec]
AND: Is it possible to purchase additional right-of-way at the intersection, if necessary? No
AND: Is the intersection located along a transit route? No
THEN: [Display_Results.ADD] The intersection is not located along a transit route. However, if the appropriately-sized roundabout can be accomodated within the existing intersection, its design must

ensure that any expected large vehicles (trucks, schoolbuses, emergency vehicles) can easily traverse the circulatory roadway.

>>> [Display_Results.ADD] Typical inscribed diameters (including circulatory roadway) for urban single-lane roundabouts range between 100 and 130 feet, assuming 90-degree entries and no more than four approach legs. The roundabout should be designed to provide sight distance in three critical types of locations: approach sight distance, sight distance on the circulatory roadway, and sight distance to crosswalk on exit (see FHWA Roundabout Guide, Section 6.3.9). If the existing area of the intersection cannot accomodate a roundabout of sufficient inscribed diameter, additional right-of-way would have to be purchased, however this is not possible. In this case, despite the better operational performance a roundabout would provide, a signal is the only option. See the FHWA Roundabout Guide, Appendix B, for guidance on initial roundabout space requirements.

>>> [Display_Results.ADD_UNIQUE] The analysis and comments are provided as an aid in determining the feasibility of converting an AWSC intersection to a roundabout while keeping the same configuration (i.e., no added lanes). A definite yes-or-no answer can never be given, as various factors create pros and cons for multiple alternatives, of which just two are considered in this analysis. The final decision, therefore, is left to the planning individuals who must use practical logic and engineering judgment in making the best choice. For further discussion and guidance, see the FHWA Roundabout Guide, Publication No. FHWA-RD-00-067

IF: [Rbt_rec]>[Signal_rec]

AND: Is this intersection located in the vicinity of a railroad crossing? Yes

THEN: [Display_Results.ADD] Locating any intersection near an at-grade railroad crossing is generally discouraged. However, rail transit has been successfully incorporated into the design of roundabouts in two ways: through the central island, or across one leg. During train passage, the roundabout either completely closes or operates only partially. See the FHWA Roundabout Guide, Section 8.2, for further discussion of at-grade rail crossings.

>>> [Display_Results.ADD_UNIQUE] The analysis and comments are provided as an aid in determining the feasibility of converting an AWSC intersection to a roundabout while keeping the same configuration (i.e., no added lanes). A definite yes-or-no answer can never be given, as various factors create pros and cons for multiple alternatives, of which just two are considered in this analysis. The final decision, therefore, is left to the planning individuals who must use practical logic and engineering judgment in making the best choice. For further discussion and guidance, see the FHWA Roundabout Guide, Publication No. FHWA-RD-00-067

IF: [Rbt_rec]>[Signal_rec]

AND: Are there signalized intersections in close proximity to the existing AWSC intersection? Yes

THEN: [Display_Results.ADD] The performance of a roundabout is affected by its proximity to signalized intersections. Roundabouts become more efficient when servicing platoons of vehicles rather than isolated, individual vehicles. However, since platoons tend to disperse as they travel along a road, the further the signal is, the fewer the closely-spaced platoons entering the roundabout. Consideration should be given to the probability of queues from adjacent signals backing up into the roundabout. Since traffic leaving a roundabout tends to be more random than that from other types of intersection control, it is an important consideration if the intersection is located within a coordinated signal network, as it would be difficult to maintain the required closely-spaced platoons. It may be beneficial to divide the signal system into sub-systems separated by the roundabout in order to minimize overall system delay. See the FHWA Roundabout Guide, Section 8.5 for further discussion of this issue.

>>> [Display_Results.ADD_UNIQUE] The analysis and comments are provided as an aid in determining the feasibility of converting an AWSC intersection to a roundabout while keeping the same configuration (i.e., no added lanes). A definite yes-or-no answer can never be given, as various factors

create pros and cons for multiple alternatives, of which just two are considered in this analysis. The final decision, therefore, is left to the planning individuals who must use practical logic and engineering judgment in making the best choice. For further discussion and guidance, see the FHWA Roundabout Guide, Publication No. FHWA-RD-00-067

IF: [Rbt_rec]>[Signal_rec]
AND: Is a there a significant amount of pedestrian and/or bicyclist traffic at any time during the day? Yes
THEN: [Display_Results.ADD] The roundabout should be designed to discourage pedestrians from using the central island (e.g., with landscaping buffers). Consideration should be given for elderly and disabled pedestrians, who may have difficulty crossing. See the FHWA Roundabout Guide, Sections 5.3.3 and 6.3.7 for discussions on safety and geometric design for pedestrians. For single-lane roundabouts, bicyclists have the option of either using the circulatory roadway and mixing with traffic or using the perimeter of the roundabout like a pedestrian. Bicycle lanes should never be used within the circulatory roadway. See the FHWA Roundabout Guide, Section 5.3.4 for discussion on bicyclist safety in roundabouts.
>>> [Display_Results.ADD_UNIQUE] The analysis and comments are provided as an aid in determining the feasibility of converting an AWSC intersection to a roundabout while keeping the same configuration (i.e., no added lanes). A definite yes-or-no answer can never be given, as various factors create pros and cons for multiple alternatives, of which just two are considered in this analysis. The final decision, therefore, is left to the planning individuals who must use practical logic and engineering judgment in making the best choice. For further discussion and guidance, see the FHWA Roundabout Guide, Publication No. FHWA-RD-00-067

IF: [Signal_rec]>[Rbt_rec]
THEN: [Display_Results.ADD_UNIQUE] The preceding analysis and comments are provided as an aid in determining the feasibility of converting an AWSC intersection to a roundabout while keeping the same configuration (i.e., no added lanes). A definite yes-or-no answer can never be given, as various factors create pros and cons for multiple alternatives, of which just two are considered in this analysis. The final decision, therefore, is left to the planning individuals who must use practical logic and engineering judgment in making the best choice.

Block: Rbt-Signal Intn Demand

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 10
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2456

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1

AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 10
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2071

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 10
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2509

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 10
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2240

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 20
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2329

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 20
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 1830

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 20
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2391

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 20
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2073

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 30
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2201

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 30
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 1869

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1

AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 30
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2274

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 30
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 1956

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 10
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2797

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 10
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2104

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 10
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2540

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 10
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2263

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 20
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2309

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 20
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2004

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 20
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2387

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4

AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 20
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2173

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 30
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2131

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 30
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 1871

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 30
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2240

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Include Emissions
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 30
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 1952

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 10
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2467

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 10
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2177

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 10
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2540

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 10
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2313

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1

AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 20
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2367

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 20
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2113

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 20
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2420

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 20
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2153

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 30
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2267

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 30
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2027

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 30
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2327

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 1:1
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 30
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2075

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 10
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2833

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4

AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 10
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2210

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 10
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2527

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 10
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2313

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 20
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2347

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 20
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2070

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 20
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2410

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 20
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2177

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 30
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2203

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 30
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 1:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 1973

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4

AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 30
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 10
THEN: [RbtSignal_Intn_V] = 2273

IF: Would you like the analysis to be based solely on operational performance (capacity, delay, queue, V/C), or would you also like to include emissions? Operational Performance Only
AND: What is the ratio between the volumes of the two intersecting roads? Choose the closer value. 3:4
AND: What is the average left turning percentage of vehicles at the intersection? Choose the closest value. 30
AND: What is the ratio between the heavy vehicle percentages of the two intersecting roads? Choose the closer value. 2:1
AND: What is the value of the greater of these two percentages? Choose the closer value. 20
THEN: [RbtSignal_Intn_V] = 2020

Block: Future Demand

IF: [Design_Year]>=[Current_Year]
THEN: [Future_Volume] = [Current_Volume]*(1+([Growth_Rate]/100))^([Design_Year]-[Current_Year])

Block: Signal or Roundabout

IF: Is the AWSC intersection currently experiencing operational problems during peak hours or throughout the day? Yes
AND: Has a study been conducted to determine if the intersection volumes warrant signalization according to the MUTCD? Yes
AND: Do the volumes at the intersection warrant signalization according to the MUTCD? Do not answer if a study has not been conducted. Yes
AND: [Future_Volume]>=[RbtSignal_Intn_V]
THEN: [Display_Results.ADDFIRST] A SIGNALIZED INTERSECTION IS RECOMMENDED. Projected future volumes (design year [[Design_Year.FORMAT ####]], [[Growth_Rate.VALUE]]% growth rate) indicate that it would provide superior performance to that of a roundabout, based on the selected MOEs. Furthermore, present volumes already warrant signalization according to the MUTCD.
Signal recommended: Confidence = 10
Roundabout recommended: Confidence = -10

IF: Is the AWSC intersection currently experiencing operational problems during peak hours or throughout the day? Yes
AND: Has a study been conducted to determine if the intersection volumes warrant signalization according to the MUTCD? Yes
AND: Do the volumes at the intersection warrant signalization according to the MUTCD? Do not answer if a study has not been conducted. Yes
AND: [Future_Volume]<[RbtSignal_Intn_V]
THEN: [Display_Results.ADDFIRST] A ROUNDABOUT IS RECOMMENDED. While present volumes warrant signalization according to the MUTCD, projected future volumes (design year

[[Design_Year.FORMAT ####]], [[Growth_Rate.VALUE]]% growth rate) indicate that it would provide superior performance than a signalized intersection, based on the selected MOEs.

Signal recommended: Confidence = -10

Roundabout recommended: Confidence = 10

IF: Is the AWSC intersection currently experiencing operational problems during peak hours or throughout the day? Yes

AND: Has a study been conducted to determine if the intersection volumes warrant signalization according to the MUTCD? Yes

AND: Do the volumes at the intersection warrant signalization according to the MUTCD? Do not answer if a study has not been conducted. No

AND: [Future_Volume]>=[RbtSignal_Intn_V]

THEN: [Display_Results.ADDFIRST] A SIGNALIZED INTERSECTION IS RECOMMENDED. Projected future volumes (design year [[Design_Year.FORMAT ####]], [[Growth_Rate.VALUE]]% growth rate) indicate that it would provide better performance than a roundabout, based on the selected MOEs. However, a study should be done in order to determine if these future volumes will warrant signalization according to the MUTCD, as present volumes do not.

Signal recommended: Confidence = 10

Roundabout recommended: Confidence = -10

IF: Is the AWSC intersection currently experiencing operational problems during peak hours or throughout the day? Yes

AND: Has a study been conducted to determine if the intersection volumes warrant signalization according to the MUTCD? Yes

AND: Do the volumes at the intersection warrant signalization according to the MUTCD? Do not answer if a study has not been conducted. No

AND: [Future_Volume]<[RbtSignal_Intn_V]

THEN: [Display_Results.ADDFIRST] A ROUNDABOUT IS RECOMMENDED. Projected future volumes (design year [[Design_Year.FORMAT ####]], [[Growth_Rate.VALUE]]% growth rate) indicate that it would provide better performance than a signalized intersection, based on the selected MOEs. However, a study should be done to determine if these future volumes will warrant signalization according to the MUTCD, as present volumes do not.

Signal recommended: Confidence = -10

Roundabout recommended: Confidence = 10

IF: Is the AWSC intersection currently experiencing operational problems during peak hours or throughout the day? Yes

AND: Has a study been conducted to determine if the intersection volumes warrant signalization according to the MUTCD? No

AND: [Future_Volume]>=[RbtSignal_Intn_V]

THEN: [Display_Results.ADDFIRST] A SIGNALIZED INTERSECTION IS RECOMMENDED. Projected future volumes (design year [[Design_Year.FORMAT ####]], [[Growth_Rate.VALUE]]% growth rate) indicate that it would perform better than a roundabout, based on the selected MOEs. However, it is also recommended that a study be done to determine if these volumes would warrant signalization according to the MUTCD.

Signal recommended: Confidence = 10

Roundabout recommended: Confidence = -10

IF: Is the AWSC intersection currently experiencing operational problems during peak hours or throughout the day? Yes

AND: Has a study been conducted to determine if the intersection volumes warrant signalization according to the MUTCD? No

AND: [Future_Volume]<[RbtSignal_Intn_V]

THEN: [Display_Results.ADDFIRST] A ROUNDABOUT IS RECOMMENDED. Projected future volumes (design year [[Design_Year.FORMAT ####]], [[Growth_Rate.VALUE]]% growth rate) indicate that it would perform better than a signal, based on the selected MOEs. However, a study should still be done to determine if these volumes would warrant signalization according to the MUTCD.

Signal recommended: Confidence = -10

Roundabout recommended: Confidence = 10

IF: Is the AWSC intersection currently experiencing operational problems during peak hours or throughout the day? No

AND: Has a study been conducted to determine if the intersection volumes warrant signalization according to the MUTCD? Yes

AND: Do the volumes at the intersection warrant signalization according to the MUTCD? Do not answer if a study has not been conducted. Yes

AND: [Future_Volume]>=[RbtSignal_Intn_V]

THEN: [Display_Results.ADDFIRST] A SIGNALIZED INTERSECTION IS RECOMMENDED. Projected future volumes (design year [[Design_Year.FORMAT ####]], [[Growth_Rate.VALUE]]% growth rate) indicate that it would provide superior performance to that of a roundabout, based on the selected MOEs. Furthermore, present volumes already warrant signalization according to the MUTCD.

Signal recommended: Confidence = 10

Roundabout recommended: Confidence = -10

IF: Is the AWSC intersection currently experiencing operational problems during peak hours or throughout the day? No

AND: Has a study been conducted to determine if the intersection volumes warrant signalization according to the MUTCD? Yes

AND: Do the volumes at the intersection warrant signalization according to the MUTCD? Do not answer if a study has not been conducted. Yes

AND: [Future_Volume]<[RbtSignal_Intn_V]

THEN: [Display_Results.ADDFIRST] A ROUNDABOUT IS RECOMMENDED. While present volumes warrant signalization according to the MUTCD, projected future volumes (design year [[Design_Year.FORMAT ####]], [[Growth_Rate.VALUE]]% growth rate) indicate that a roundabout would provide superior performance than a signalized intersection, based on the selected MOEs.

Signal recommended: Confidence = -10

Roundabout recommended: Confidence = 10

IF: Is the AWSC intersection currently experiencing operational problems during peak hours or throughout the day? No

AND: Has a study been conducted to determine if the intersection volumes warrant signalization according to the MUTCD? Yes

AND: Do the volumes at the intersection warrant signalization according to the MUTCD? Do not answer if a study has not been conducted. No

AND: [Future_Volume]>=[RbtSignal_Intn_V]

THEN: [Display_Results.ADDFIRST] A SIGNALIZED INTERSECTION IS RECOMMENDED based on projected future volumes (design year [[Design_Year.FORMAT ####]], [[Growth_Rate.VALUE]]% growth rate), which indicate that it would provide better performance than a roundabout, according to the selected MOEs. However, a study must be done to determine if these volumes will warrant signalization according to the MUTCD, since current volumes do not.

Signal recommended: Confidence = 10
Roundabout recommended: Confidence = -10

IF: Is the AWSC intersection currently experiencing operational problems during peak hours or throughout the day? No
AND: Has a study been conducted to determine if the intersection volumes warrant signalization according to the MUTCD? Yes
AND: Do the volumes at the intersection warrant signalization according to the MUTCD? Do not answer if a study has not been conducted. No
AND: [Future_Volume]<[RbtSignal_Intn_V]
THEN: [Display_Results.ADDFIRST] A ROUNDABOUT IS RECOMMENDED. Projected future volumes (design year [[Design_Year.FORMAT ####]], [[Growth_Rate.VALUE]]% growth rate) indicate that it would provide better performance than a signalized intersection, according to the selected MOEs. Furthermore, present volumes do not warrant signalization according to the MUTCD; however, a study should also be done to determine whether or not these future volumes would.

Signal recommended: Confidence = -10
Roundabout recommended: Confidence = 10

IF: Is the AWSC intersection currently experiencing operational problems during peak hours or throughout the day? No
AND: Has a study been conducted to determine if the intersection volumes warrant signalization according to the MUTCD? No
AND: [Future_Volume]>=[RbtSignal_Intn_V]
THEN: [Display_Results.ADDFIRST] A SIGNALIZED INTERSECTION IS RECOMMENDED, as projected future volumes (design year [[Design_Year.FORMAT ####]], [[Growth_Rate.VALUE]]% growth rate) indicate that it would perform better than a roundabout, based on the selected MOEs. However, a study should be done to determine if these volumes would warrant signalization according to the MUTCD.

Signal recommended: Confidence = 10
Roundabout recommended: Confidence = -10

IF: Is the AWSC intersection currently experiencing operational problems during peak hours or throughout the day? No
AND: Has a study been conducted to determine if the intersection volumes warrant signalization according to the MUTCD? No
AND: [Future_Volume]<[RbtSignal_Intn_V]
THEN: [Display_Results.ADDFIRST] A ROUNDABOUT IS RECOMMENDED, as projected future volumes (design year [[Design_Year.FORMAT ####]], [[Growth_Rate.VALUE]]% growth rate) indicate that it would perform better than a signal, based on the selected MOEs. Nevertheless, a study should still be done to determine whether or not these volumes would warrant signalization according to the MUTCD.

Signal recommended: Confidence = -10
Roundabout recommended: Confidence = 10

Block: Roundabout Highly Recommended

IF: [Rbt_rec]>[Signal_rec]
AND: Is there a history of frequent and/or severe accidents at the intersection? Yes

AND: Is there a history of left-turn head-on and/or right-angle collisions at the intersection? Yes
AND: Have accidents been caused as a result of drivers failing to properly obey the stop control? Yes
THEN: [Display_Results.ADDFIRST] A ROUNDABOUT IS HIGHLY RECOMMENDED for this intersection. There is a history of frequent and/or severe accidents at this intersection, and in particular, a history of left-turn head-on and/or right-angle collisions, which are typically the most severe of collision types. Accidents at this intersection have also been caused by drivers failing to properly obey the stop control. Roundabouts help improve safey in several ways. The severity of a collision is largely determined by the speeds of the vehicles involved and by the angle of impact. By deflecting approaching vehicles, a roundabout effectively slows vehicles to speeds safe for negotiating the circulatory roadway. Since all movements at a roundabout are converted to right turns, collisions that do occur are typically only small-angle. The number of accidents also correlates to the number of conflict points at an intersection; compared to conventional intersections, roundabouts reduce the number of vehicle-vehicle conflict points up to 75%. Additionally, drivers entering a roundabout must interact with only one conflicting flow of traffic, further reducing the opportunities for crashes to occur.
Roundabout highly recommended: Confidence = 10

IF: [Rbt_rec]>[Signal_rec]
AND: Is there a history of frequent and/or severe accidents at the intersection? Yes
AND: Is there a history of left-turn head-on and/or right-angle collisions at the intersection? Yes
AND: Have accidents been caused as a result of drivers failing to properly obey the stop control? No
THEN: [Display_Results.ADDFIRST] A ROUNDABOUT IS HIGHLY RECOMMENDED for this intersection. There is a history of frequent and/or severe accidents at this intersection, and in particular, a history of left-turn head-on and/or right-angle collisions, which are typically the most severe of collision types. Roundabouts help improve safey in several ways. The severity of a collision is largely determined by the speeds of the vehicles involved and by the angle of impact. By deflecting approaching vehicles, a roundabout effectively slows vehicles to speeds safe for negotiating the circulatory roadway. Since all movements at a roundabout are converted to right turns, collisions that do occur are typically only small-angle. The number of accidents also correlates to the number of conflict points at an intersection; compared to conventional intersections, roundabouts reduce the number of vehicle-vehicle conflict points up to 75%. Additionally, drivers entering a roundabout must interact with only one conflicting flow of traffic, further reducing the opportunities for crashes to occur.
Roundabout highly recommended: Confidence = 5

IF: [Rbt_rec]>[Signal_rec]
AND: Is there a history of frequent and/or severe accidents at the intersection? Yes
AND: Is there a history of left-turn head-on and/or right-angle collisions at the intersection? No
AND: Have accidents been caused as a result of drivers failing to properly obey the stop control? Yes
THEN: [Display_Results.ADDFIRST] A ROUNDABOUT IS HIGHLY RECOMMENDED for this intersection, as there is a history of frequent and/or severe accidents at this intersection. Furthermore, accidents at this intersection have been caused by drivers failing to properly obey the stop control. Roundabouts help improve safey in several ways. The severity of a collision is largely determined by the speeds of the vehicles involved and by the angle of impact. By deflecting approaching vehicles, a roundabout effectively slows vehicles to speeds safe for negotiating the circulatory roadway. Since all movements at a roundabout are converted to right turns, collisions that do occur are typically only small-angle. The number of accidents also correlates to the number of conflict points at an intersection; compared to conventional intersections, roundabouts reduce the

number of vehicle-vehicle conflict points up to 75%. Additionally, drivers entering a roundabout must interact with only one conflicting flow of traffic, further reducing the opportunities for crashes to occur.
Roundabout highly recommended: Confidence = 10

IF: [Rbt_rec]>[Signal_rec]
AND: Is there a history of frequent and/or severe accidents at the intersection? Yes
AND: Is there a history of left-turn head-on and/or right-angle collisions at the intersection? No
AND: Have accidents been caused as a result of drivers failing to properly obey the stop control? No
THEN: [Display_Results.ADDFIRST] A ROUNDABOUT IS HIGHLY RECOMMENDED for this intersection, as there is a history of frequent and/or severe accidents at this intersection. Roundabouts help improve safey in several ways. The severity of a collision is largely determined by the speeds of the vehicles involved and by the angle of impact. By deflecting approaching vehicles, a roundabout effectively slows vehicles to speeds safe for negotiating the circulatory roadway. Since all movements at a roundabout are converted to right turns, collisions that do occur are typically only small-angle. The number of accidents also correlates to the number of conflict points at an intersection; compared to conventional intersections, roundabouts reduce the number of vehicle-vehicle conflict points up to 75%. Additionally, drivers entering a roundabout must interact with only one conflicting flow of traffic, further reducing the opportunities for crashes to occur.
Roundabout highly recommended: Confidence = 5

IF: [Rbt_rec]>[Signal_rec]
AND: Is there a history of frequent and/or severe accidents at the intersection? No
THEN: [Display_Results.ADD] There is no history of accidents at this intersection.

IF: [Rbt_rec]<[Signal_rec]
AND: Is there a history of frequent and/or severe accidents at the intersection? Yes
AND: Is there a history of left-turn head-on and/or right-angle collisions at the intersection? Yes
AND: Have accidents been caused as a result of drivers failing to properly obey the stop control? Yes
THEN: [Display_Results.ADD] There is a history of frequent and/or severe accidents at this intersection, and in particular, a history of left-turn head-on and/or right-angle collisions, which are typically the most severe of collision types. Accidents at this intersection have also been caused by drivers failing to properly obey the stop control. While projected future demand volumes indicate that a signalized intersection may perform better than a roundabout according to the selected MOEs, consider how roundabouts help in improving safey: The severity of a collision is largely determined by the speeds of the vehicles involved and by the angle of impact. By deflecting approaching vehicles, a roundabout effectively slows vehicles to speeds safe for negotiating the circulatory roadway. Since all movements at a roundabout are converted to right turns, collisions that do occur are typically only small-angle. The number of accidents also correlates to the number of conflict points at an intersection; compared to conventional intersections, roundabouts reduce the number of vehicle-vehicle conflict points up to 75%. Additionally, drivers entering a roundabout must interact with only one conflicting flow of traffic, further reducing the opportunities for crashes to occur.

IF: [Rbt_rec]<[Signal_rec]
AND: Is there a history of frequent and/or severe accidents at the intersection? Yes
AND: Is there a history of left-turn head-on and/or right-angle collisions at the intersection? Yes
AND: Have accidents been caused as a result of drivers failing to properly obey the stop control? No

THEN: [Display_Results.ADD] There is a history of frequent and/or severe accidents at this intersection, and in particular, a history of left-turn head-on and/or right-angle collisions, which are typically the most severe of collision types. While projected future demand volumes indicate that a signalized intersection may perform better than a roundabout, consider how roundabouts help in improving safey: The severity of a collision is largely determined by the speeds of the vehicles involved and by the angle of impact. By deflecting approaching vehicles, a roundabout effectively slows vehicles to speeds safe for negotiating the circulatory roadway. Since all movements at a roundabout are converted to right turns, collisions that do occur are typically only small-angle. The number of accidents also correlates to the number of conflict points at an intersection; compared to conventional intersections, roundabouts reduce the number of vehicle-vehicle conflict points up to 75%. Additionally, drivers entering a roundabout must interact with only one conflicting flow of traffic, further reducing the opportunities for crashes to occur.

IF: [Rbt_rec]<[Signal_rec]
AND: Is there a history of frequent and/or severe accidents at the intersection? Yes
AND: Is there a history of left-turn head-on and/or right-angle collisions at the intersection? No
AND: Have accidents been caused as a result of drivers failing to properly obey the stop control? Yes
THEN: [Display_Results.ADD] There is a history of frequent and/or severe accidents at this intersection, some of which have been caused by drivers failing to properly obey the stop control. While projected future demand volumes indicate that a signalized intersection may perform better than a roundabout, consider how roundabouts help in improving safety: The severity of a collision is largely determined by the speeds of the vehicles involved and by the angle of impact. By deflecting approaching vehicles, a roundabout effectively slows vehicles to speeds safe for negotiating the circulatory roadway. Since all movements at a roundabout are converted to right turns, collisions that do occur are typically only small-angle. The number of accidents also correlates to the number of conflict points at an intersection; compared to conventional intersections, roundabouts reduce the number of vehicle-vehicle conflict points up to 75%. Additionally, drivers entering a roundabout must interact with only one conflicting flow of traffic, further reducing the opportunities for crashes to occur.

IF: [Rbt_rec]<[Signal_rec]
AND: Is there a history of frequent and/or severe accidents at the intersection? Yes
AND: Is there a history of left-turn head-on and/or right-angle collisions at the intersection? No
AND: Have accidents been caused as a result of drivers failing to properly obey the stop control? No
THEN: [Display_Results.ADD] There is a history of frequent and/or severe accidents at this intersection. While projected future demand volumes indicate that a signalized intersection may perform better than a roundabout, consider how roundabouts help in improving safety: The severity of a collision is largely determined by the speeds of the vehicles involved and by the angle of impact. By deflecting approaching vehicles, a roundabout effectively slows vehicles to speeds safe for negotiating the circulatory roadway. Since all movements at a roundabout are converted to right turns, collisions that do occur are typically only small-angle. The number of accidents also correlates to the number of conflict points at an intersection; compared to conventional intersections, roundabouts reduce the number of vehicle-vehicle conflict points up to 75%. Additionally, drivers entering a roundabout must interact with only one conflicting flow of traffic, further reducing the opportunities for crashes to occur.

IF: [Rbt_rec]<[Signal_rec]
AND: Is there a history of frequent and/or severe accidents at the intersection? No
THEN: [Display_Results.ADD] There is no history of accidents at this intersection.

Block: No Current Problems

IF: Is the AWSC intersection currently experiencing operational problems during peak hours or throughout the day? No
AND: [Rbt_rec] =10
THEN: [Display_Results.ADD] Whille the intersection is not currently experiencing operational problems, this analysis assumes that demand volumes increase in future years, at which point a roundabout would likely perform better than either all-way stop-control or a signal.

IF: Is the AWSC intersection currently experiencing operational problems during peak hours or throughout the day? No
AND: [Signal_rec]=10
THEN: [Display_Results.ADD] While the intersection is not currently experiencing operational problems, this analysis assumes that demand volumes increase in future years, at which point a signal would likely perform better than either all-way stop-control or a roundabout.

IF: Is the AWSC intersection currently experiencing operational problems during peak hours or throughout the day? No
AND: [Rbt_high]>0
THEN: [Display_Results.ADD] The intersection is not currently experiencing operational problems. However, concerns for safety may be enough to justify consideration for conversion to a different form of intersection control. This analysis also assumes that demand volumes increase in future years, at which point a roundabout would likely perform better than either all-way stop-control or a signal.

Block: Costs

IF: [Rbt_rec]>[Signal_rec]
THEN: [Display_Results.ADD] Costs associated with roundabouts include those for engineering and design, land acquisition, construction, operating, and maintenance. A roundabout eliminates the high installation and maintenance costs of signals; however, construction costs for a roundabout could cost more than those for a signal, depending on the amount of new pavement area needed. Costs and benefits for the roundabout should be considered while keeping in mind that its average service life (25 years) is over twice as long as that for a signal (10 years). The FHWA Roundabout Guide, Section 3.7, discusses estimating benefits and costs for an economic evaluation.

IF: [Signal_rec]>[Rbt_rec]
THEN: [Display_Results.ADD] Costs associated with signals include those for installation and periodic maintenance as well as signal timing updates. Roundabout eliminate the high installation and maintenance costs of signals, and have over twice as long a service life as signals (25 vs. 10 years). However, installing a roundabout can become more costly depending on the amount of new pavement area needed. If a signal can be installed without significant modifications to pavement area of curbs, a roundabout is likely to cost more than a signal.

References

1 Johnson, M.T. and W.A. Hange. "Modern roundabout intersections: when to use them? A comparison with signalized intersections." *Institute of Transportation Engineers (ITE) Annual Technical Conference*, Fort Lauderdale, FL, March 2003.

2 Roess, R.P., E.S. Prassas, and W.R. McShane. (2004). *Traffic engineering*, 3rd Edition, Pearson Prentice Hall, Upper Saddle River, NJ.

3 Wu, N. "Capacity at all-way stop-controlled and first-in-first-out intersections." *Fourth International Symposium on Highway Capacity,* Maui, HI, June 2000.

4 Federal Highway Administration (2003). *Manual on uniform traffic control devices for streets and highways.* Washington, D.C.: FHWA.

5 Jacquemart, G. (1998). *Synthesis of highway practice 264: Modern roundabout practice in the United States.* National Highway Research Program. Washington, D.C.: National Academy Press.

6 Federal Highway Administration. (2000). *Roundabouts: An informational guide.* Publication Number FHWA-RD-00-067. Washington, D.C.: FHWA.

7 Cottrell, B.H., Jr. (1997). "Using all-way stop-control for residential traffic management." *Transportation Research Record 1605*, 22-27.

8 Kyte, M. and G. List. (1999). "A capacity model for all-way stop-controlled intersections based on stream interactions." *Transportation Research Part A.* (33), 313-335.

9 Flannery, A., L. Elefteriadou, P. Koza, and J. McFadden. (1998). "Safety, delay, and capacity of single-lane roundabouts in the United States." *Transportation Research Record 1646*, 63-70.

10 Kyte, M., A. Flannery, M. Dixon, L. Rodegerdts, G. List, and M. Blogg. (2005). "Characteristics of modern roundabouts in the United States: A summary of the NCHRP 3-65 operations database." *Transportation Research Board 85th Annual Meeting*, Washington, D.C., January 2006.

11 Insurance Institute for Highway Safety. (2000). *Status Report*. **35**(5).

12 Insurance Institute for Highway Safety. (2001). *Status Report*. **36**(7).

13 Russell, E.R., S. Mandavilli, and M.J. Rys. (2005). *Operational performance of Kansas roundabouts: Phase II*. Report Number K-TRAN: KSU-02-4. Kansas Department of Transportation.

14 Retting, R.A., S. Mandavilli, E.R. Russell, and A.T. McCartt. "Traffic flow and public opinion: Newly installed roundabouts in New Hampshire, New York, and Washington." *Transportation Research Board 85th Annual Meeting*, Washington, D.C., January 2006.

15 U.S. Environmental Protection Agency. (2005). "Mobile source emissions: Past, present, and future." <http://www.epa.gov/otaq/invntory/overview/index.htm> (Accessed 30 January 2006)

16 Várhelyi, A. (2002). "The effects of small roundabouts on emissions and fuel consumption: a case study." *Transportation Research Part D*, (7), 65-71.

17 Mandavilli, S., E.R. Russell, and M.J. Rys. "Impact of modern roundabouts on vehicular emissions." *Proceedings of the 2003 Mid-Continent Transportation Research Symposium*, Ames, IA, August 2003.

18 Federal Highway Administration. (2006). *Priority, market-ready technologies and innovations: Roundabouts*. Publication Number FHWA-HRT-06-047. HRTC-01/01-06(1M)E. Washington, D.C.: FHWA.

19 Persaud, B.N., R.A. Retting, P.E. Garder, and D. Lord. (2001). "Safety effect of roundabout conversions in the United States: Empirical Bayes observational before-after study." *Transportation Research Record 1751*, 1-8.

20 Maryland Department of Transportation. (2004). *Maryland's roundabouts: Accident experience and economic evaluation*. State of Maryland Department of Transportation, State Highway Administration.

21 Sisiopiku, V.P. and H. Oh. (2001). "Evaluation of roundabout performance using SIDRA." *Journal of Transportation Engineering*, March/April, 143-150.

22 Maryland Department of Transportation. (1995). *Roundabout design guidelines*. State of Maryland Department of Transportation, State Highway Administration.

23 Florida Department of Transportation. (1996). *Florida roundabout guide*. Florida Department of Transportation.

24 Pennsylvania Department of Transportation. (2001). *Guide to roundabouts*. Publication Number 414. Pennsylvania Department of Transportation.

25 Washington State Department of Transportation. (2004). Roundabouts. *Design manual*. Chapter 915.

26 Kansas Department of Transportation. (2003). *Kansas roundabout guide: a supplement to FHWA's Roundabouts: an informational guide*. Kansas Department of Transportation.

27 Akcelik & Associates Pty Ltd. (2005). *aaSIDRA user guide*. Akcelik & Associates Pty Ltd., Greythorn, Victoria, Australia.

28 Kittelson & Associates, Inc. "Modern roundabouts: The website." <http:://roundabout.kittelson.com> (Accessed 25 January 2006).

29 Niederhauser, M. (mniederhauser@sha.state.md.us), (10 May 2005) "Re: Maryland Roundabouts," E-mail to E. Vlahos (evydv@ce.udel.edu).

30 Polus, A. and S. Shmueli. (1999). "Entry capacity at roundabouts and impact of waiting times." *Road & Transport Research*, **8** (3), 43-54.

31 Drew, D.R. (1968). *Traffic flow theory and control*. McGraw-Hill, New York.

32 Jackson, P. (1986). *Introduction to expert systems*. Addison-Wesley, Reading, Massachusetts.

33 Frenzel, L.E., Jr. (1987). *Understanding expert systems*. Howard W. Sams & Company, Indianapolis, Indiana.

34 Hopgood, A.A. (1993). *Knowledge-based systems for engineers and scientists*. CRC Press, Boca Raton, Florida.

35 Durkin, J. (1994). *Expert systems: Design and development*. Macmillan, New York.

36 Sell, P. (1985). *Expert systems: A practical introduction*. John Wiley & Sons, New York.

37 EXSYS Inc. (2004). *EXSYS CORVID knowledge automation expert system software user guide*. EXSYS Inc., Albuquerque, New Mexico.

38 Puppe, F. (1993). *Systematic introduction to expert systems: Knowledge representations and problem-solving methods*. Springer-Verlag, New York.

39 DuRoss, M. (Michael.DuRoss@state.de.us), (6 April 2006) "U of D-Evdokia.ppt," E-mail to E. Vlahos (evydv@ce.udel.edu).

Delaware Center for Transportation
University of Delaware
Newark, Delaware 19716