ROUNDABOUTS: AN ARIZONA CASE STUDY AND DESIGN GUIDELINES

Final Report 545

Prepared by:
Jim C. Lee and Brennan D. Kidd
Lee Engineering, L.L.C.
3033 N. 44th Street, Suite 375
Phoenix, Arizona 85018

Bruce Robinson and Wade Scarbrough
Kittelson & Associates, Inc.
610 SW Alder, Suite 700
Portland, Oregon 97205

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Arizona Department of Transportation
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Phoenix, Arizona 85007
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16. Abstract –

The roundabouts controlling traffic at the I-17/Happy Valley Road interchange represent Arizona's first application of modern roundabout traffic control in this manner. The construction of roundabouts at this interchange location served to alleviate past congestion and safety issues by reducing off-ramp queues and reducing speeds in the area of the I-17 off-ramp termini. The use of the roundabouts offered flexibility in addressing the complicated traffic interactions of the freeway on- and off-ramps, two-way frontage roads, and Happy Valley Road.

Based on this milestone and the overall unique application of roundabout design and function at this particular interchange, the I-17/Happy Valley Road roundabouts were studied to help identify possible improvements that could be incorporated at this location and into future Arizona Department of Transportation (ADOT) roundabout initiatives. The anticipated benefits of the improvements include, but are not limited to, more efficient traffic operations, reduced costs (on average), increased capacity, and improved safety (due to overall slower speeds through the roundabout). The main objectives of this research project include literature review of other state guidelines; evaluation of the roundabouts' design parameters and operation as they relate to capacity and safety; collecting public opinion; and guidelines development.

The deliverables of the research project include recommended improvements for the existing roundabouts involving geometric, striping, and signing modifications. Also, the research project culminates in Guidelines for the Selection, Evaluation, and Design of Roundabouts which provides details on the facets of roundabout use as it relates to Arizona.

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SI (MODERN METRIC) CONVERSION FACTORS*

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	Inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	Feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	Yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	Miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	square millimeters	mm^2	mm^2	Square millimeters	0.0016	square inches	in^2
ft^2	square feet	0.093	square meters	m^2	m^2	Square meters	10.764	square feet	ft^2
yd^2	square yards	0.836	square meters	m^2	m^2	Square meters	1.195	square yards	yd^2
ac	Acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	square kilometers	km^2	km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	Gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	cubic meters	m^3	m^3	Cubic meters	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	cubic meters	m^3	m^3	Cubic meters	1.308	cubic yards	yd^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.								
		MASS					**MASS**		
oz	Ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	Pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000lb)	0.907	megagrams (or "metric ton")	mg (or "t")	Mg	megagrams (or "metric ton")	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION					**ILLUMINATION**		
fc	foot candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2	cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS					**FORCE AND PRESSURE OR STRESS**		
lbf	Poundforce	4.45	newtons	N	N	newtons	0.225	poundforce	lbf
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway & Transportation Officials
aaSIDRA/SIDRA	Akcelik & Associates Signalized & Unsignalized Intersections Design and Research Aid (Traffic Modeling Software)
AC	Asphaltic Concrete
ACFC	Asphaltic Concrete Friction Course
ADAAG	Americans with Disabilities Act Accessibility Guidelines
ADOT	Arizona Department of Transportation
ARCADY	Assessment of Roundabout Capacity and Delay (Traffic Modeling Software)
ATR	Automatic Traffic Recorder
CAD	Computer Aided Drafting
COFA	Change Order, Force Account
EB	Eastbound
FHWA	Federal Highway Administration
GPS	Global Positioning Satellite
HCM	Highway Capacity Manual
HOV	High Occupancy Vehicle
KDOT	Kansas Department of Transportation
MEV	Million Entering Vehicles
MoDOT	Missouri Department of Transportation
MUTCD	Manual on Uniform Traffic Control Devices
MVD	Motor Vehicle Division (ADOT)
NB	Northbound
NYSDOT	New York State Department of Transportation
PennDOT	Pennsylvania Department of Transportation
RODEL	Roundabout Analysis Software
SB	Southbound
SU	Single-unit truck
TAC	Technical Advisory Committee
TUDI	Tight Urban Diamond Interchange
USAA	Large financial services company serving the U.S. military
V/C	Volume-to-Capacity Ratio
VISSIM	Microscopic Simulation Traffic Model Software
WB	Westbound
WB-50	Large semi-trailer combination design vehicle
WB-67	Interstate semi-trailer design vehicle
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

The roundabouts controlling traffic at the I-17/Happy Valley Road interchange represent Arizona's first application of modern roundabout traffic control in this manner. The construction of roundabouts at this interchange location served to alleviate past congestion and safety issues by reducing off-ramp queues and reducing speeds in the area of the I-17 off-ramp termini. The design, preparation for, and construction of the two roundabouts cost about one-third of the estimated cost to build a new overpass bridge and other interchange modifications necessary to accommodate a typical diamond interchange design. The use of the roundabouts also offered flexibility in addressing the complicated traffic interactions of the freeway on- and off-ramps, two-way frontage roads, and Happy Valley Road.

Based on this milestone and the overall unique application of roundabout design and function at this particular interchange, the I-17/Happy Valley Road roundabouts were studied to help identify possible improvements that could be incorporated at this location and into future Arizona Department of Transportation (ADOT) roundabout initiatives. The improvements set forth in this report will serve to further enhance the inherent benefits of roundabouts at this particular location as well as when compared to a typical traffic interchange. Such benefits include, but are not limited to, more efficient traffic operations, reduced costs (on average), increased capacity, and improved safety (due to overall slower speeds through the roundabout). The examination and conclusions drawn from the analysis of the roundabouts was also used to develop guidelines for selecting, evaluating, and designing future roundabouts in Arizona.

The research consisted of three main components, which have been presented as separate chapters in this report:

Chapter 1 – Literature Review
This Chapter summarizes current guidelines and policy documents prepared by other states concerning the analysis, design, and selection of roundabouts. Review of the documents reveals that some states are utilizing aspects of *Roundabouts: An Informational Guide* [1] published by the Federal Highway Administration (FHWA) as a base with supplements of some procedures and information borrowed from Australian or European methodologies. In particular, the Washington State guidelines are the most applicable to Arizona and serve as the model for the Arizona guidelines.

Chapter 2 – Operations & Design
The data collection effort is described and presented in this Chapter along with the geometric and operational evaluations. Data collection tasks include traffic volume counts, vehicle classification and speed determination, peak period turning movement counts, GPS-based speed/vehicle path information, conflict observations, reporting of collision history, and a public opinion survey. Capacity analyses of the existing conditions and traffic operations with proposed recommendations are conducted using FHWA methodologies and SIDRA, an Australian traffic modeling program. This Chapter concludes with recommendations to be implemented at the I-17/Happy Valley Road roundabouts in

order to enhance capacity, efficiency, safety, and driver understanding. These changes include a number of geometric adjustments to the entry, exit and circulatory roadway; approach realignment; pedestrian accommodations; changes to the striping design; improved signage; and removal of a yield control location.

Chapter 3 – Guidelines for the Selection, Evaluation, and Design of Roundabouts
Many characteristics of the I-17/Happy Valley Road interchange roundabouts were collected, reviewed and compared to state of the practice design measures in the United States to develop the most appropriate set of guidelines to serve future roundabout construction in Arizona. The Guidelines contained in this Chapter present key features of roundabouts, critical design aspects and approaches, site selection details, performance evaluation methods, and the design parameters for geometric layout and traffic guidance.

The results of the analyses regarding current traffic operations versus projected traffic operations with the implemented improvements show that the operational performance of the roundabouts will be enhanced considerably by implementing the recommended geometric, striping, and signing modifications. Based on the FHWA model results, the critical approach at the two roundabouts would operate at a volume-to-capacity ratio (V/C) of approximately 0.51 (compared against the current 0.97 V/C for the same approach). Thus, with the implementation of the recommended improvements presented in this report, the roundabouts should provide enough capacity at the ramp terminal intersections to accommodate continued growth for several more years.

However, the accommodation of the growth is limited due to the maximum exit capacity at a double-lane roundabout being about 2,400 vehicles per hour, while the maximum directional flow of the single-lane overpass is approximately 1,800-2,000 vehicles per hour. Therefore, with these recommended roundabout improvements, it is likely that the existing bridge width will become the next capacity constraint rather than the roundabouts. At the time when the traffic demand exceeds the capacity of the existing bridge, additional interchange improvements should be considered (including widening the bridge and/or providing a new fly-over ramp or loop ramp for the heavy northbound-to-westbound movement). Even so, the roundabout improvements detailed in this report should allow several more years of acceptable operation until a major interchange reconstruction is required.

It should be noted that the recommended improvements are primarily intended to enhance the capacity of the two roundabouts. The improvements may also reduce the overall number of property-damage crashes by removing some confusion and friction between adjacent traffic lanes. The crash prediction model results contained in the report confirm that, while the improvements may not lower the number of injury crashes, they should not increase the number either.

Below are some of the more notable findings drawn from this research project:

Need for Interchange Solution

- Prior to the roundabout construction, vehicle queues were consistently long at the northbound I-17 off-ramp approach, occasionally backing-up onto the I-17 main lanes of traffic.
- Funding was and is currently unavailable to increase the capacity of the two-lane Happy Valley Road bridge over I-17 or for removal/modification of the frontage road approach legs.
- Signalization of the interchange is not a feasible alternative primarily due to the Happy Valley bridge constraints and is further hindered by the complexity associated with two-way frontage road operations/interactions.

Traffic Volumes & Patterns

- Approximately 3,800 vehicles utilize the Happy Valley interchange in the peak demand hours and approximately 43,000 vehicles utilize the interchange on a daily basis.
- The heaviest movements are from eastbound Happy Valley Road to southbound I-17 in the morning and from I-17 northbound to westbound Happy Valley Road in the evening.
- The west roundabout accommodates approximately 46 percent more traffic than the east roundabout due to current travel patterns.
- Conflicts observed from videotaping and site visitation revealed some incidents caused by driver confusion with roundabout operations in general or the current roundabout lane striping (i.e., two approach lanes with one circulatory lane).

Public Opinion

- The project team received 1,898 responses from about 5,000 survey cards that were distributed via mailings and direct deliveries. The survey cards posed questions regarding the characteristics of the roundabouts as well as providing space for personal comments on experiences and opinions. Results indicate that the majority of people feel the roundabouts are less safe and more confusing than typical freeway interchanges. The most frequent personal comment identified the need for driver education in navigating the roundabouts.

Safety

- Review of the crash database at the roundabout locations indicates that the east roundabout has a crash rate of 0.64 and an injury rate of 0.11 per million entering vehicles (MEV). The west roundabout has a 1.16 and 0.36 per MEV crash and injury rate, respectively. For perspective, a previous ADOT research project calculated that Tight Urban Diamond Interchanges (TUDIs) had a crash rate of 1.79 per MEV based on the five local interchanges examined in the study.

1. INTRODUCTION

1.1 BACKGROUND

Modern roundabouts have been widely used in many countries for many years and during the past decade have begun to gain acceptance in the United States because they provide an effective means of traffic control. Roundabouts can offer a number of benefits over traditional signal or stop controlled intersections through their safety performance, reduced operation and maintenance costs, and operational enhancements. However, since roundabouts are relatively new to the United States landscape, guidelines and procedures for use and effective design are only now being formed by a handful of agencies.

Recently, the Arizona Department of Transportation (ADOT) constructed two roundabouts to control traffic flow through the I-17/Happy Valley Road traffic interchange in north Phoenix, their first implementation of this device. The roundabout serves a somewhat atypical roadway configuration in that it processes arterial traffic, interstate ramp movements, and a two-way frontage road on both sides of the interchange. Construction of the roundabouts was an interim measure to facilitate traffic movement at these locations, noting that the initial stop-controlled intersections were creating long vehicle queues and safety concerns at some approaches. Conversion of the interchange control to traffic signal operations was not feasible because the rapid, unforeseen growth of vehicular traffic in the area did not allow for enough time to allocate funds for the widening of the Happy Valley Road bridge over I-17. Traffic signal control at the interchange would work efficiently only if the two-lane bridge over I-17 were replaced and the frontage roads were relocated. These modifications to the interchange were estimated to cost approximately $10 million dollars, which at the time was well before the anticipated horizon year of fund attainment.

1.2 PROJECT PURPOSE

Since this is the first implementation of modern roundabouts in Arizona, ADOT does not have relevant research or local experience with their design, construction, or operation. To bridge this gap, Lee Engineering and Kittelson & Associates, Inc., were selected to research current roundabout operations and provide guidance for future roundabout designs. The research included investigating other state agency experiences and their resulting guidelines. Analysis of the existing roundabouts further enhanced these other agencies perspectives and approaches so that future roundabout implementation in Arizona can focus on safe and efficient roundabout design aspects.

The main objectives of this research project are to:

1. Conduct a literature search and state-of-the-practice review.
2. Evaluate the specific roundabouts' design parameters, assumptions, and design history based upon available information.
3. Collect critical data and conduct analysis of the roundabouts to evaluate their performance related to safety, cost, and efficiency. Identify increased safety and capacity opportunities.

4. Evaluate public perception and acceptance of modern roundabouts.
5. Develop formal roundabout selection warrants, design guidelines, and operating guidelines for ADOT to use for roundabout implementation within the Arizona Highway System.

1.3 SUMMARY OF TASKS PERFORMED

Through meetings and discussions with an ADOT Research Technical Advisory Committee (TAC), the investigative team collected and reviewed relevant literature and issues pertaining to the design and operation of roundabouts. The tasks below summarize the scope of this project:

1. Literature Search and State-of-the-Practice Review (Chapter 2) – This task reviewed relevant literature and surveyed practitioners regarding the operational and safety characteristics of roundabouts. The synthesis of this task with supplemental information from the operations analysis is the basis for the Guidelines for the Selection, Evaluation, and Design of Roundabouts presented in this report (Chapter 4).
2. Data Collection at the Existing Roundabouts (Chapter 3) – This task focused on the existing conditions of the roundabouts to determine their operational performance and design history. Data collection efforts included traffic counts, vehicular classification, movement identification, vehicle speeds, conflict analysis, heavy truck performance, public opinion sampling, design history, crash history, and cost information.
3. Analysis of the Collected Data (Chapter 3) – Information identified above has been analyzed through current state of the practice tools to determine the functionality of the roundabouts. The impacts to emergency service providers, pedestrian and bicycle traffic, public perceptions issues, and other performance indicators are also discussed in the Chapter.
4. Preparation of a Design and Operation Report (Chapter 3) – This Chapter of the report details the findings and analysis of the information collected in the above tasks. Results include detailed recommendations for improvements to optimize the long term safety and functionality of this facility.
5. Development of the Guidelines for the Selection, Evaluation, and Design of Roundabouts (Chapter 4) – These guidelines will describe interchange selection issues relevant to roundabout implementation. They will also help ADOT determine if roundabout traffic control is a viable option at a specific location.

1.4 HOW ADOT WILL USE THIS REPORT

The information contained within this report describes the current state of the practice in roundabout design guidelines within the United States. This report provides a framework for analyzing sites for the advisability and applicability of constructing roundabouts. As more information is gathered throughout the United States and from ADOT experience, this manual should be updated to reflect the issues and policies affecting their position. The data collection and analysis portion of this project will act as a guideline for ADOT to follow when evaluating roundabout performance in the future.

Within the state of Arizona, an old traffic circle is being converted to a roundabout in Bisbee, a roundabout design is being considered at the I-17/ SR74 (Carefree Highway) interchange, the I-17/Table Mesa Road interchange is a candidate for roundabout installation, and in the Prescott area a number of sites are being considered for roundabout construction. These guidelines will provide ADOT with a better under-standing of the issues and concerns of roundabout design and operation for use in the decision process.

2. LITERATURE REVIEW

2.1 INTRODUCTION

This Chapter summarizes current guidelines and policy documents prepared by other states for the analysis, design, and selection of roundabouts.

Based on a survey of practitioners conducted by the New York State Department of Transportation and the Kittelson & Associates, Inc., database of state-of-the-practice reference materials, the following states currently have, or are preparing, formal guidelines related to roundabouts:

- Maryland
- Florida
- New York (draft)
- Pennsylvania
- Washington
- Missouri
- Kansas (under development)

2.2 OTHER STATE GUIDELINES

The key features and highlights of each state's document are summarized below.

2.2.1 Maryland State Highway Administration

The Maryland Department of Transportation State Highway Administration produced a statewide roundabout guide in 1995 as an interim document prior to completion of the Federal Highway Administration's publication *Roundabouts: An Informational Guide* [1] (hereafter referred to as *FHWA Guide*). The text of the Maryland guidelines borrowed most of its information from the Austroads' *Traffic Engineering Practice Part 6: Roundabouts* [2]. The procedures and guidelines were largely the same as those in the Australian guide with all units converted to U.S. customary units and the diagrams inverted to right-side traffic flow. Where necessary, the design guidelines were slightly altered to conform to American Association of State Highway & Transportation Officials (AASHTO) and Manual on Uniform Traffic Control Devices (MUTCD) practices. Some added details were also included such as examples of landscaping designs, truck apron details, typical signing plans for state route and local street roundabouts, construction staging diagrams, and public education suggestions. The appendix included a sample benefit/cost analysis.

At this time, the Maryland State Highway Administration has adopted the *FHWA Guide* [1] as its standard. In addition, they have created several supplements with regards to signing and pavement marking guidance.

2.2.2 Florida Department of Transportation (FDOT)

The *Florida Roundabout Guide* [3] was developed by FDOT in March 1996 to assist district offices and local agencies in identifying appropriate sites for roundabouts and determining their preferred configuration and operational features. The most unique feature of the manual is its "roundabout justification" section. This section contains a discussion of intersection traffic control alternatives and presents a series of categories representing reasons to install a roundabout. An objective "justification procedure" is outlined to provide guidance in the decision to install a roundabout.

The *Florida Roundabout Guide* [3] compares intersection control alternatives (stop-control, two-phase signal, three-phase signal, and four-phase signal), and presents a graph that shows average delay as a function of volume. The performance analysis section is based upon the Australian methodology (gap-acceptance theory) and also encourages the use of the SIDRA program. Guidelines for geometric design are provided with key dimensions and concepts detailed individually for each design element. A useful figure in the geometric design section displays the recommended minimum dimensions for a typical single-lane roundabout. The manual also provides a number of guidelines for signing, pavement markings, lighting, and landscaping.

The outline of the *Florida Roundabout Guide* is as follows:

1. *Introduction*
    - Includes discussion of roundabout characteristics and suitable locations for roundabouts.
2. *Roundabout Justification*
    - Provides general guidance to aid in selecting of locations for roundabouts.
    - Outlines a step-by-step approach to document the evaluation and justification for a roundabout as the most appropriate form of traffic control.
3. *Roundabout Performance Analysis*
    - Describes the methodology for analyzing roundabout performance in terms of capacity and delays, based on the Australian formulas.
4. *Geometric Design of Roundabouts*
    - Establishes design concepts and standards for all major design elements.
5. *Operational Considerations*
    - Provides guidance on traffic design elements such as signing, marking, lighting, and landscaping.

2.2.3 New York State Department of Transportation (NYSDOT)

Guidelines for the State of New York are contained in the NYSDOT's *Highway Design Manual Chapter 26: Roundabouts* [4]. This chapter is still in draft form and is dated February 28, 2001. It is a total of 73 pages in length and largely based on the *FHWA Guide* [1]. Many of the figures and tables are taken directly from the *FHWA Guide*, although some have been modified slightly to reflect the standards of NYSDOT. The NYSDOT guidelines have also been influenced by British practice. The operation analysis techniques and many of the geometric parameters are based on the British standards.

The outline of the *NYSDOT Guide* [4] is summarized below along with notable specifications.

1. Introduction

- Discusses background information and defining features of roundabouts
- Summarizes advantages and disadvantages of roundabouts vs. other alternatives.
- Describes roundabout categories (same as *FHWA Guide* [1]).

2. Project Scoping

- Describes appropriate applications for roundabouts, general site requirements, system considerations, and public coordination issues.
- Provides general guidance for where roundabouts are advantageous.
- Specifies RODEL should be used for all capacity analysis.
- Provides typical diameters and services volumes for various site categories.
- Provides some guidance for 3-lane roundabouts.
- Discusses pedestrian and bicycle issues.

3. Preliminary Design: Geometric Standards

- Provides general design principles and dimension ranges for each geometric element, often specifying a "desirable" value.
- Includes discussion and values for *entry angle* and *effective flare length* (British-based parameters not included in the *FHWA Guide*).
- Requires a "Design Criteria Table" be prepared for each project summarizing the proposed dimensions of each major roundabout element.
- Presents methods for analyzing roundabout operations. RODEL is to be used for determining capacity, delay, and queue lengths.
- Presents and discusses safety analysis, including U.S. crash data, international crash data, and crash prediction models.

4. Detailed Design Stage

- Provides guidelines for traffic design elements (signing, pavement marking, and illumination), work zone traffic control, and landscaping. It generally replicates the guidelines in the *FHWA Guide* with a few minor modifications.
- Recommends no lane use striping in circulatory roadway (in general).
- Specifies using sharks teeth markings at yield lines.

5. Construction Stage

- States that the project Engineer in Charge must be alerted to any geometric changes made during construction to prevent adverse impacts on traffic circulation.

6. Monitoring

- Provides guidelines for monitoring roundabouts after construction in effort to better understand roundabout operations and improve design standards.

2.2.4 Pennsylvania Department of Transportation (PennDOT)

PennDOT's *Guide to Roundabouts* [5] is a freestanding document completed in May 2001. It is designed as a supplement to the *FHWA Guide* [1] to aid in determining whether a roundabout is a feasible alternative for a specific location. Unlike the other state guides, it does not provide specific guidelines or criteria for design elements. Its primary function is to assist transportation professionals in the planning and study phases of a project to reach a decision regarding the feasibility of installing a roundabout. The guide directs readers to the *FHWA Guide* for further design guidance.

The *PennDOT Guide* [5] begins with a general description of roundabouts and their benefits. The core of the guide is an eight-page questionnaire with an array of questions and insights to help determine whether a roundabout is the best form of traffic control at a given location. To complete the questionnaire, the analyst will be required to obtain a variety of information on the site. An operational analysis and conceptual geometric layout is generally required to answer the questions. The guide provides general insights and discussion throughout the questionnaire to help the analyst understand the probable implications of a roundabout at the subject site. The document also includes several appendices including a number of case studies.

The outline of the *PennDOT Guide* is summarized below.

1. Introduction

2. Roundabouts versus Traffic Circles

- Describes roundabout characteristics and distinguishing features from rotaries and neighborhood traffic circles.
- Identifies roundabout categories from *FHWA Guide* [1].

3. Benefits of Using Roundabouts
- Discusses safety, capacity, traffic calming, environmental and aesthetic benefits of roundabouts.

4. Where to Use Roundabouts
- Lists numerous situations where a roundabout could be beneficial.
- Provides the Roundabout Questionnaire, which is intended to help consider all issues and determine whether a roundabout is appropriate at a given site by requiring the analyst to collect a variety of information about the intersection.

5. Issues Associated with Roundabouts
- Discusses roundabout issues including pedestrians, bicyclists, educating the public, and maintenance.

6. Appendices
- Includes a glossary of terms, the description of roundabout categories (taken from *FHWA Guide*), and several case studies with completed questionnaires.

The *PennDOT Roundabout Guide* can be viewed at the following web address:

ftp://ftp.dot.state.pa.us/public/bureaus/design/GuideToRoundabouts.pdf

2.2.5 Washington State Department of Transportation (WSDOT)

WSDOT added a section (915) on roundabouts to their *Design Manual* [6] in late 2001. The guidelines are 29 pages in length and primarily based on the principles from the *FHWA Guide* [1]. The outline and notable features of the *WSDOT Guidelines* are as follows:

1. General
- Includes a discussion of locations recommended for roundabouts, locations not normally recommended, and locations not recommended.

2. References
- Lists significant reference documents.

3. Definitions
- Consists of approximately three pages of terms and definitions.

4. Roundabout Categories
- Identifies and describes the six categories from the *FHWA Guide* [1].

5. Capacity Analysis
- Briefly discusses two analysis methods and states that gap acceptance method is preferred.

6. Geometric Design
- Discusses design principles and establishes standard design criteria for each geometric element.

7. Pedestrians

- Discusses pedestrian issues and specifies pedestrian crossing dimensions.

8. Bicycles

- Discusses cyclist issues and design treatments.

9. Signing and Pavement Markings

- Presents standard roundabout signing and pavement markings through figures.

10. Illumination

- Discusses illumination principles and depicts light standard placement.

11. Access, Parking, and Transit Facilities

- Specifies policies and design principles for road approaches, parking, and transit stops.

12. Procedures

- Presents suggested steps for selecting a roundabout for intersection control.
- Identifies and discusses "justification categories" for when roundabouts could be considered.
- Lists the information required for submittal to WSDOT to gain approval of a roundabout on a state highway.

13. Documentation

- Lists the documents to be preserved in the project file.

The entire *WSDOT Guidelines* can be viewed at the following web address:

http://www.wsdot.wa.gov/fasc/engineeringpublications/desEnglish/915-E.pdf

2.2.6 Missouri Department of Transportation (MoDOT)

MoDOT incorporated the first phase of roundabout guidelines into its *Project Development Manual* [7] in early 2002. It is intended to serve as a policy-level document that defines an enforceable set of requirements. The guidelines apply only to single-lane roundabouts. The document specifies that multi-lane roundabouts may be considered but will require a design exception at this time. MoDOT is currently working on developing guidelines for multi-lane roundabouts.

The roundabout information consists of five pages of text plus eight figures. It begins with some introductory information, a procedure for selecting a roundabout as the preferred form of traffic control, and basic guidance on operational analysis. The majority of information is focused on geometric and traffic design elements, outlining fundamental principles and identifying dimensions of the primary roundabout features. In most cases, the principles and dimensions are based on the *FHWA Guide* [1]. In some cases modifications were made to reflect MoDOT's standards for intersection design. The document is divided into 17 sections as follows:

1. Introduction and Definitions
2. Justification Procedures
3. Operational/Capacity Analysis
4. Fundamental Design Principles
5. Design Speeds
6. Design Vehicle
7. Sight Distance
8. Central Island
9. Truck Apron
10. Circulatory Roadway
11. Splitter Islands
12. Approach Legs
13. Grades, Cross-Slopes, Superelevation
14. Bicyclists and Pedestrians
15. Signing and Pavement Marking
16. Landscaping, Lighting, and Drainage
17. Traffic Control During Construction

Some of the notable features of the MoDOT guidelines are as follows:

- *Justification Procedures*
  This section establishes a process for selecting a roundabout as the preferred form of traffic control. It includes three stages of evaluation. If a site fails at any of these three stages, a roundabout should not be considered. The three stages are:
  (1) Appropriateness – a table specifies conditions for which a roundabout *may* be appropriate, *may not* be appropriate, and *will not* be used.
  (2) Operational Feasibility – to determine whether a roundabout can provide acceptable levels of service.
  (3) Comparative Performance – to compare its performance to that of other potential forms of control.
- *Operational Analysis*
  The guide specifies that the Highway Capacity Manual procedure be used for initial analysis. SIDRA should be used for more detailed analysis. If simulation is used, VISSIM is the preferred model.
- *Approach Legs*
  This section provides some guidance when considering right-turn bypass lanes. It also suggests minimum spacing criteria between adjacent approach legs (a unique concept not developed in other guides).
- *Bicyclists*
  The MoDOT guidelines introduces a unique option for accommodating bicyclists: a "bicycle platform," which is a raised concrete strip immediately outside the curb (inside the landscape buffer and sidewalk) between the crosswalks of adjacent legs.

The MoDOT *Project Development Manual* [7] can be viewed at the following web address:

http://www.modot.state.mo.us/design/ppdm/ppdm.htm

2.2.7 Kansas Department of Transportation (KDOT)

KDOT is currently in the process of developing its own set of guidelines for roundabouts. This document is intended to be a supplement to the *FHWA Guide,* [1], and therefore, it is intended to have similar chapters addressing existing issues in more depth or adding discussion of any new issues.

Below are the proposed outline and the issues KDOT would like to address:

1. General

- Specific discussion of small traffic circles versus modern roundabouts in Kansas with specific examples and pictures.
- Discuss the importance of proper/consistent roundabout design and review by a roundabout expert.
- General list of "Do's and Don'ts."

2. Policy Considerations

- Guidance/training for law enforcement on roundabouts and how to code and record crashes.
- Clarification of legal views of an "intersection" (K.S.A. 8-1548).
- Legal issues – "Rules of the Road" in Kansas.
- Impacts of roundabouts for blind pedestrians (see attached notes from meeting with blind pedestrian).
- Educational efforts or programs to educate the public (this is a request to have a public education campaign that would travel across the state and educating the public).
- Public involvement guidelines.

3. Planning

- Appropriate use of one-lane versus two-lane roundabouts.
- Typical construction costs and a typical benefit-to-cost calculation that others can use as an example.
- Discussion on the use of roundabouts to increase safety and/or capacity at an intersection.

4. Operation

- Operational analysis and software (SIDRA vs. RODEL vs. others).
- Considerations for future growth.

5. Safety

- Latest Accident Reduction Factors for single and multi-lane roundabouts.
- Additional information regarding the safety of pedestrians and bicyclists in roundabouts.

- The need to design, sign and mark multi-lane roundabouts such that drivers will stay in their own lane through the roundabout (drivers will not want to cross the path of another vehicle in the roundabout).

6. Geometric Design

- Recommended curb face design for splitter islands and central islands (appropriateness of a stand-up curb versus lay-back curb).
- Recommended cross-section for truck apron including a typical slope of the face of the truck apron.
- The use of concrete joints in roundabout design and construction.
- Building roundabouts out of asphalt versus concrete (issues with trucks rutting the pavement).
- Typical construction staging for a roundabout project.
- Drainage considerations.
- Sidewalk considerations.

7. Traffic Design and Landscaping

- Typical signing for Kansas roundabouts.
- Signing and marking at multi-lane roundabouts in Kansas (markings or no markings). Is it a project per project consideration based on turning movements and volumes?
- Advance warning signs: are they needed in all instances or just when sight distance is limited?
- Use of Pedestrian Advance signs as well as Pedestrian Crossing signs at roundabouts. There is the issue of how much signing is too much signing (sign clutter).
- Lighting guidelines at Kansas roundabouts.
- Typical landscaping layouts used in the central island and splitter islands. Use of small trees? Sight distance considerations.

8. System Considerations:

- Recommended distance from other existing traffic control devices such as stop signs, traffic signals, railroad crossings and parking.
- Dealing with nearby intersections and business/residential entrances.
- Information on multiple roundabouts built in a series along a stretch of roadway.

2.3 CONCLUSIONS AND RECOMMENDATIONS

2.3.1 Conclusions

While only a few states have produced guidelines or policies specific to roundabouts at this time, those that have done so include several features and practices that could be beneficial to the state of Arizona. Based on this literature review, the following recommendations are made for the Arizona Roundabout Guidelines

- The document should be a supplement to the *FHWA Guide* [1] and not attempt to reproduce all the information in that guide.
- The Washington State guidelines should serve as a model document for the Arizona guidelines. This document highlights the key issues and design guidelines for all major roundabout components, and it refers to the *FHWA Guide* for more detailed discussion on some issues.
- For site selection guidelines, much of the information from the *Florida Roundabout Guide* [3], *PennDOT's Guide to Roundabouts* [5], and the MoDOT *Project Development Manual* [7] should be incorporated.
- A tabular summary of design speeds should be required for all roundabout designs submitted for review. This tabular summary should be similar to that shown in Figure 4-05.9 of the MoDOT guidelines.
- The supplemental guidelines for multi-lane roundabout design being developed for the KDOT guidelines should be incorporated, if possible.

2.3.2 Recommended Outline for Arizona Guidelines

The following outline is proposed for Arizona's roundabout guidelines:

1. General Information
- 1.1. Key Features
- 1.2. Categories
- 1.3. Overall Design & Evaluation Process
- 1.4. Site Selection Guidelines
- 1.5. Sites Where Roundabouts Are Typically Ideal
- 1.6. Sites Where Roundabouts Are Not Typically Ideal
- 1.7. Roundabouts at Interchanges

2. Roundabout Performance Analysis
- 2.1. FHWA Analysis Procedure (Show Capacity Graphs)
- 2.2. Other Models
- 2.3. SIDRA
- 2.4. RODEL/ARCADY
- 2.5. Simulation

3. Geometric Design
- 3.1. Fundamental Principles

- 3.1.1. Design Vehicle
- 3.1.2. Design Speeds
- 3.1.3. Speed Consistency
- 3.1.4. Approach Alignment
- 3.1.5. Multi-Lane Design Issues
- 3.1.6. Future Expansion (Single-Lane to Double-Lane)

3.2. Elements of Design

- 3.2.1. Inscribed Circle Diameter
- 3.2.2. Circulatory Roadway
- 3.2.3. Central Island
- 3.2.4. Typical Truck Apron Cross Section
- 3.2.5. Pedestrian Crossing Provisions
- 3.2.6. Entries
- 3.2.7. Exits
- 3.2.8. Splitter Islands
- 3.2.9. Bicycle Provisions
- 3.2.10. Right-Turn Bypass Lanes
- 3.2.11. Sight Distance
- 3.2.12. Refer to *FHWA Guide*
- 3.2.13. Grades and Superelevation

4. Traffic Design

4.1. Signing

4.2. Pavement Marking

4.3. Illumination

3. OPERATIONS & DESIGN

3.1 INTRODUCTION

3.1.1 Project Description

Recently, the Arizona Department of Transportation (ADOT) constructed two roundabouts to control traffic flow through the Happy Valley Road traffic interchange in north Phoenix, its first implementation of this device. The roundabouts serve a somewhat atypical roadway configuration in that they process arterial traffic, interstate ramp movements, and a two-way frontage road on both sides of the interchange. Construction of the roundabouts was an interim measure to facilitate traffic movements at these locations, noting that the initial stop-controlled intersections were creating long vehicle queues and safety concerns at some approaches. Conversion of the interchange control to traffic signal operations was not feasible because the rapid, unforeseen growth of vehicular traffic in the area did not allow for enough time to allocate funds for the widening of the Happy Valley Bridge over I-17. Traffic signal control at the interchange would work efficiently only if the two-lane bridge over I-17 were replaced and the frontage roads were relocated. These modifications to the interchange were estimated to cost approximately $10 million dollars, which at the time was well before the anticipated year of available funds.

Since this is the first implementation of modern roundabouts in Arizona, ADOT does not have relevant research or local experience with the design, construction, or operation of modern roundabouts. To bridge this gap, Lee Engineering and Kittelson & Associates, Inc. were selected to research the current roundabout operations and provide guidance for future roundabout designs. The research included investigating the experiences of state department of transportation agencies and their resulting guidelines. Analysis of the existing roundabouts further enhanced the perspectives and approaches gathered from other agencies so that future roundabout implementation in Arizona can focus on safe and efficient roundabout design aspects.

The main objectives of this chapter are to:

1. Evaluate the existing roundabouts' design parameters, assumptions, and design history based upon available information.
2. Present critical data collected at the roundabouts and the resulting analysis to evaluate their performance related to safety, cost, and efficiency. Identify increased safety and capacity opportunities.
3. Evaluate public perception and acceptance of modern roundabouts.

3.1.2 Construction Background

To understand the concerns and need for this project, review of the area and its existing and future conditions at the I-17/Happy Valley Road interchange were considered.

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Projections indicate that the USAA office development in the northeast quadrant of the east roundabout will grow from its current 1,500 employees to an office park setting of 12,000 to 15,000 employees at a near future date. The southeast quadrant is currently being considered for development, but detailed land usage intensity and construction timeframe are unknown at this time. However, preliminary indications suggest a rather intense commercial/residential development with Happy Valley Road serving as the primary entrance/exit route. The northwest quadrant of the west roundabout is home to the Skunk Creek Landfill operated by the City of Phoenix supporting daily trucking operations. The southwest quadrant is currently undeveloped. Given the current design of the interchange, the interior quadrants are not foreseen to accommodate development. Locally, a number of area housing projects are currently under construction and will lead to increased residential growth in the area. In addition, a number of trucking facilities are in close proximity and use this interchange regularly. The City of Phoenix has initiated a Design Concept Report for an interchange at I-17 and Jomax Road (one mile north of Happy Valley Road), that could allow for a reduction in future demand volumes by providing alternative I-17 access as well as allowing a conversion of the two-way frontage roads to one-way pairs. This traffic interchange has not been funded in the latest five-year plan.

Previously, the I-17/Happy Valley interchange was an unsignalized two-way stop-controlled intersection providing Happy Valley Road continuous vehicular movement. During peak hour traffic conditions, vehicles queued at the I-17 northbound off-ramp regularly backed up onto the freeway. These poor conditions were also compounded by delays caused by the number of turning vehicles, heavy truck traffic volumes associated with an adjacent landfill and local quarry operations, and overall growth associated with the entire Phoenix area.

Considerations to provide typical signalized intersection control were complicated by the two-lane Happy Valley Road bridge that spanned I-17 and the two-way frontage roads. Signalized intersection control could not perform as intended unless the bridge was widened and the frontage roads were separated from the interchange. Although I-17 is being planned for capacity increases, these improvements will not require the replacement of the bridge until the ultimate I-17 cross section (5 lanes + 1 HOV lane per direction) is provided (estimated at 10 to 15 year horizon). As an interim measure, a roundabout design was produced. The roundabouts are performing better than the stop-controlled conditions, but are nearing capacity in their single-lane circulating configuration due to the unforeseen increase in traffic volumes. Although there are mixed reviews about the roundabouts overall performance, ADOT has made minor improvements to the roundabout design. The following provides a history of the construction design and issues relating to the roundabouts:

1. When this intersection was being considered for improvement in 1997, the Maricopa Association of Governments traffic projections for the area were considered. Projected traffic volumes for year 2010 were used for the roundabout design criteria. By 2002, actual traffic volumes have exceeded the 2010 design estimates.

2. The design firm of Michael Baker, Jr. prepared the project plans and specifications for the interchanges.
3. Several change orders and letters of agreement were issued during the construction process to address the following issues: a) increased area landscaping; b) drainage pipe protection due to shallow depth; c) additional 10' x 14' approach guide signs; d) assistance to the City of Phoenix to improve area drainage problems near the east end of the project; e) milling and overlay of the interchange ramps; and f) the installation of a right-turn lane for westbound traffic on Happy Valley Road at the east roundabout.
4. Since construction completion in the Spring of 2001, the following location improvements have been implemented: a) sharks teeth striping for the yield bars; b) increased size of sharks teeth striping at yield bars; c) guide sign improvements; d) speed signs; e) freshened striping, and f) larger-sized yield signs.

3.1.3 Cost History

The following is a cost history account of the roundabout design collected through research and interviews of ADOT representatives.

An estimate was prepared during the preparation of the Final Project Assessment, in August 1998 (Project 017 MA 218 H 4628 01 L; Happy Valley Road/I-17 Traffic Interchange; Phoenix - Flagstaff Highway Interstate 17, by AGRA Infrastructure, Inc.). This estimate was based upon prices provided in ADOT construction costs tabulations from 1997, and assumed a structural section of asphaltic concrete friction course (ACFC), four inches of asphaltic concrete pavement and 10 inches of aggregate base. The right-of-way cost estimate was provided by ADOT.

Construction Cost	$1,518,000
Preliminary Engineering	151,800
Right-of-Way Acquisition	6,000
Total	$1,676,000

The estimate detailed the City of Phoenix participation in the project for $150,000, and ADOT's Project Cost estimate was reduced to $1,526,000. The itemized estimate included in the Assessment is included in **Appendix A**. The itemized estimate included $281,100 (30%) for Construction Engineering and Contingencies, which is double the typical percentage of 15%.

The Combined Estimate (Engineer's Estimate) for Contract #1999152 was prepared by the Contracts and Specifications Section of ADOT. ADOT's estimate for the project was $2,251,303 which does not include the costs of preliminary engineering, construction engineering, or right-of-way acquisition. Therefore, this estimate should only be compared to the Construction Cost ($1,518,000) shown in the Assessment Estimate indicated above. The detailed Combined Estimate is also included in **Appendix A**.

The bid by the successful contractor was $2,174,362.95, which was $76,940.05 below the Combined Estimate. However, as indicated in the COFA (Change Order, Force Account)

Log, for the project, included in **Appendix A**, final payments to the contractor were larger than the bid price and included:

Change Orders	$298,061.76
Letters of Agreement	$ 15,032.60
Quantity Omissions	$ 75,241.39

ADOT financial management records indicate the total costs charged to the project were $3,677,876.83, which includes location, design, right-of-way acquisition, utility relocation and construction. The Location cost component included the preparation of the Final Project Assessment.

Location	$ 34,069.55
Design	259,393.94
Right-of-Way Acq.	552,847.82
Utility Relocation	5,787.25
Construction	2,825,778.27
Total	$3,677,876.83

The Construction cost component consists of the amount paid to the contractor ($2,545,205.27) and the other construction costs ($280,573.00), which was primarily construction engineering and inspection costs of ADOT.

3.2 DATA COLLECTION

3.2.1 Introduction

Data was collected at the Happy Valley interchange to provide a benchmark for the performance level of the facility and determine its current design, safety, and operational characteristics. An aerial photograph of the roundabouts can be found in ***Figure 1***. The data collection effort helps assess when and at what intersections/ interchanges roundabout installations may be an effective alternative to traffic signal control, and possibly identify the volume horizons or design life before other control measures should be considered. Service level comparisons between signal controlled interchange and roundabout operation identified average delay, queue length, and design differences that offer a helpful perspective in the determination process between design applications. Data has been collected through procedures outlined in the FHWA publication *Roundabouts: An Informational Guide* [1] (*FHWA Guide*) and as agreed upon by the ADOT Technical Advisory Committee (TAC).

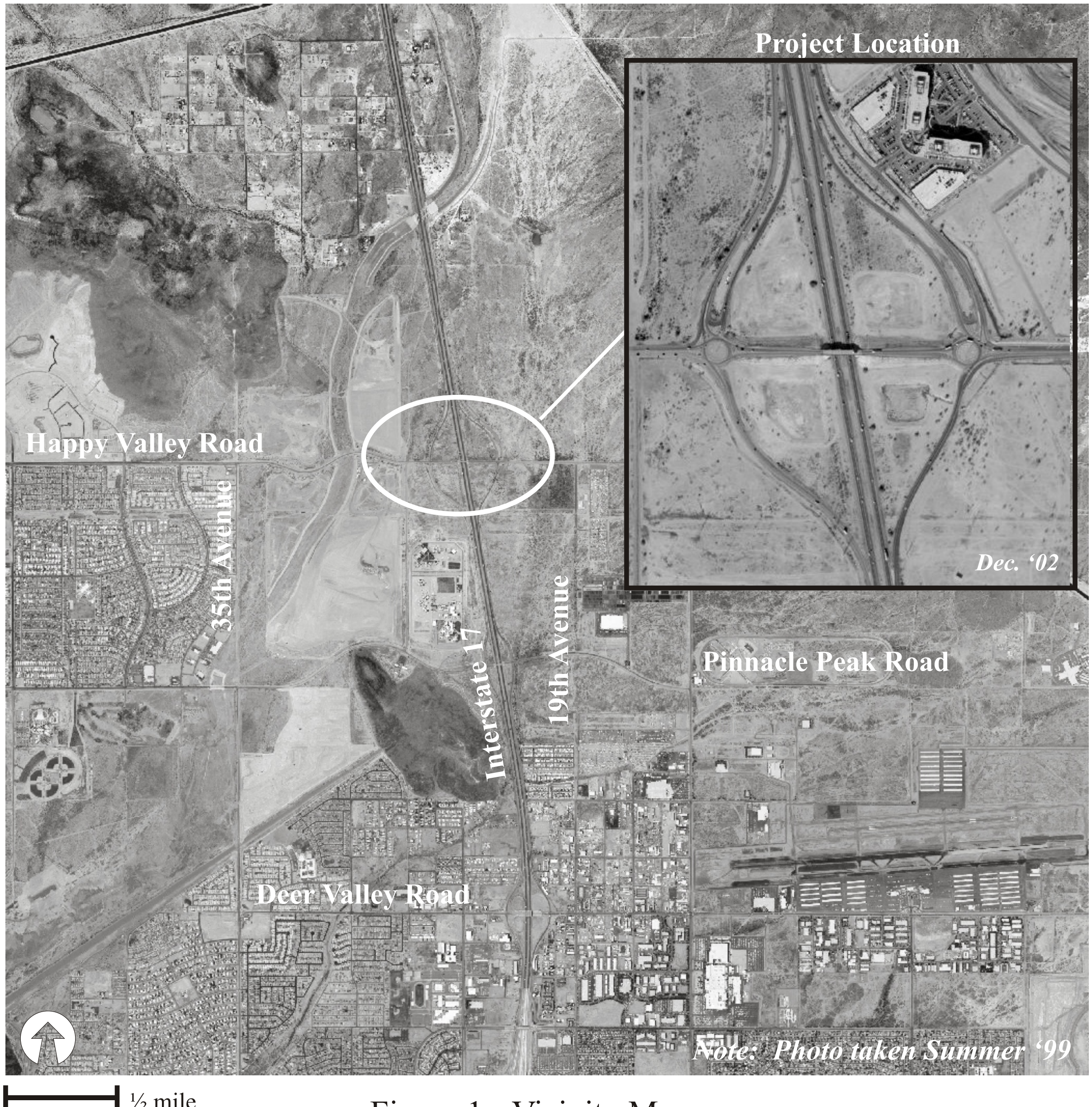

Figure 1 - Vicinity Map

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The following data was collected for use in the analysis:

- Volume counts at all approaches and at exclusive turn locations (Section 3.2.2)
- Vehicle classification and spot speed counts at each approach leg (Section 3.2.3)
- Peak period turning movement percentages (Section 3.2.4)
- GPS speed and vehicle path runs (Section 3.2.5)
- Videotaping of vehicle movements to help determine conflicts (Section 3.2.6)
- On-site vehicle observations of driver behavior and truck performance (Section 3.2.7)
- Pedestrian and bicycle activity (Section 3.2.8)
- Public opinion sampling (provided as its own Section 3.3)
- Collision history (presented as part of the Safety Analysis, Section 3.6.1)

3.2.2 Volume Counts

To determine the traffic volumes utilizing the two roundabouts and their associated exclusive right-turn lanes, a series of automatic traffic recorders (ATRs) were placed on the approach and exit legs of the roundabouts as well as on the circulatory roadway within the roundabouts. The ATRs were strategically placed so that all traffic movements could be directly or indirectly obtained for each approach and departure roadway. A total of 21 count locations were utilized to collect a minimum 48 hours of continuous raw axle pair data in 15-minute increments during typical weekday travel conditions. A map has been provided in ***Figures 2 and 3*** to show the relative ATR placement locations at each roundabout. The ATR machines and associated roadway tubes were placed on Monday (10/14/02) and retrieved on Thursday (10/17/02) to obtain volume data that coincided with vehicle turning movement observations being conducted during this same time period. Raw data captured by the ATR machines have been provided in **Appendix B**.

Observations conducted during this data collection effort identified construction activity present on Happy Valley Road east of the east roundabout. This construction work was confined to off-street areas (assumed to be final landscaping and sidewalk work) and not considered to have a detrimental effect on the volume data being collected. Final roadway striping in this area on Tuesday night (10/15/02) at approximately 11:30 PM shifted traffic from the westbound lanes to the eastbound lanes. This was evident from the westbound Happy Valley Road ATR at Location 4 (L4) which showed zero volume and the eastbound Happy Valley Road ATR which showed volume data approximately double that of the previous day. Results of the volume count data collection effort are provided in ***Figures 4 and 5*** displaying AM peak hour volumes, PM peak hour volumes and 24 hour volume counts as collected for Tuesday, 10/15/02.

LEGEND:

(L#, red) Machine Count Location Speed, Class, and Volume (4 locations)

(L#, yellow) Machine Count Location Volume Only (7 locations)

(F#, blue) Flow Count Location (6 locations)

NOTE:

F1 = L1-L2
F2 = L3-L2
F3 = L4-L5
F4 = L6-L5
F5 = L7-L8
F6 = L9-F5

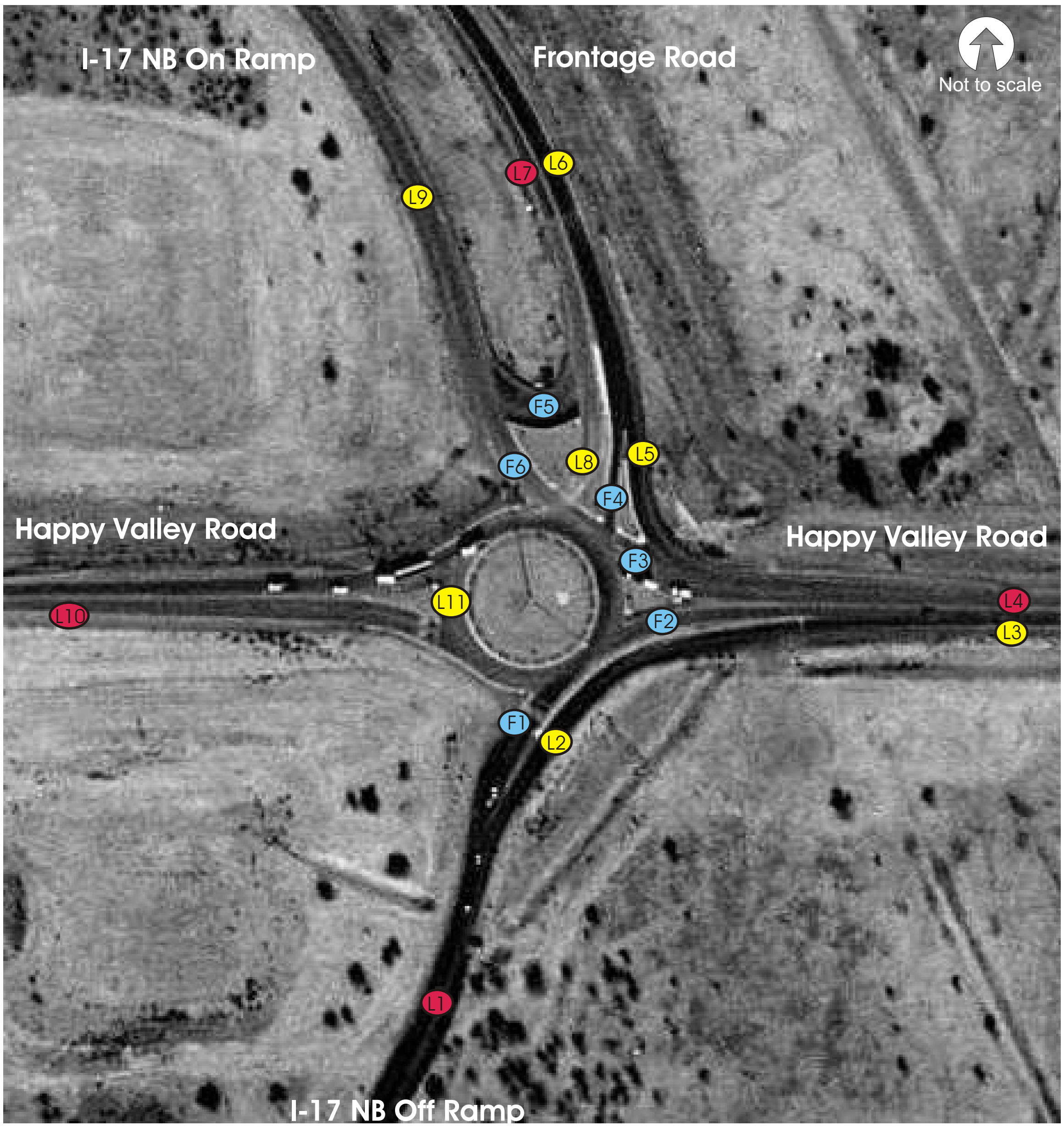

Figure 2 - Count Locations - East Roundabout

LEGEND:

L#	Machine Count Location Speed, Class, and Volume (4 locations)
L#	Machine Count Location Volume Only (7 locations)
F#	Flow Count Location (6 locations)

NOTE:

F7 = L13-L14
F8 = L12-F7
F9 = L15-L16
F10 = L17-L16
F11 = L18-L19
F12 = L20-L19

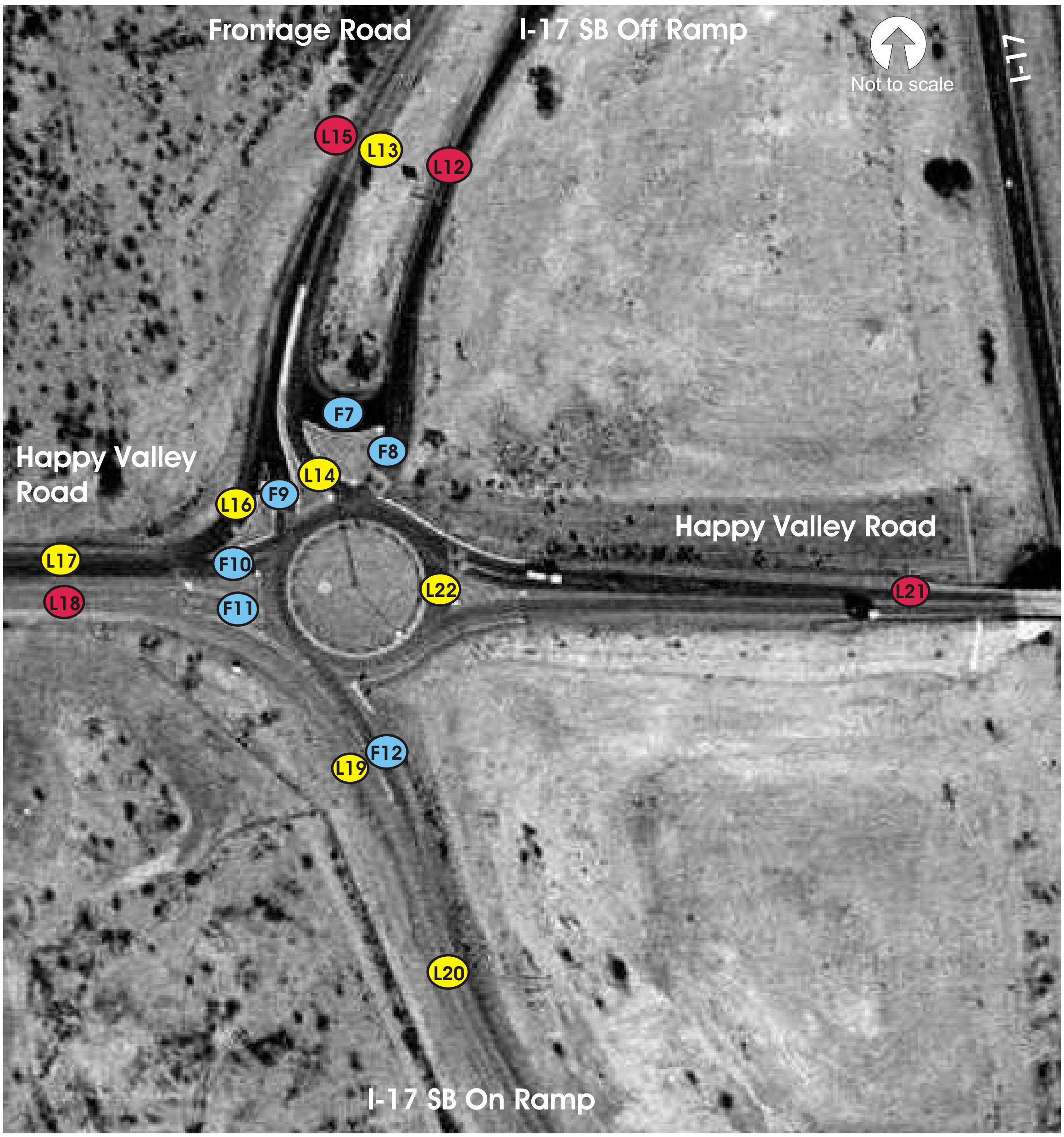

Figure 3 - Count Locations - West Roundabout

LEGEND:

XXX / XXX / XXX
- 24 Hour Counts
- PM Peak Hour (4:30 - 5:30)
- AM Peak Hour (6:45 - 7:45)

Counts from October 2002

L1 = 612 / 994 / 10023	L6 = 251 / 81 / 1171	F1 = 504 / 912 / 8483
L2 = 108 / 82 / 1540	L7 = 18 / 165 / 1014	F2 = 205 / 94 / 1993
L3 = 313 / 176 / 3533	L8 = 15 / 145 / 908	F3 = 271 / 353 / 3956
L4 = 282 / 361 / 4018	L9 = 172 / 159 / 1904	F4 = 240 / 73 / 1109
L5 = 11 / 8 / 62	L10 = 458 / 122 / 3099	F5 = 3 / 20 / 106
L6 = 251 / 81 / 1171	L11 = 3 / 3 / 70	F6 = 169 / 139 / 1798

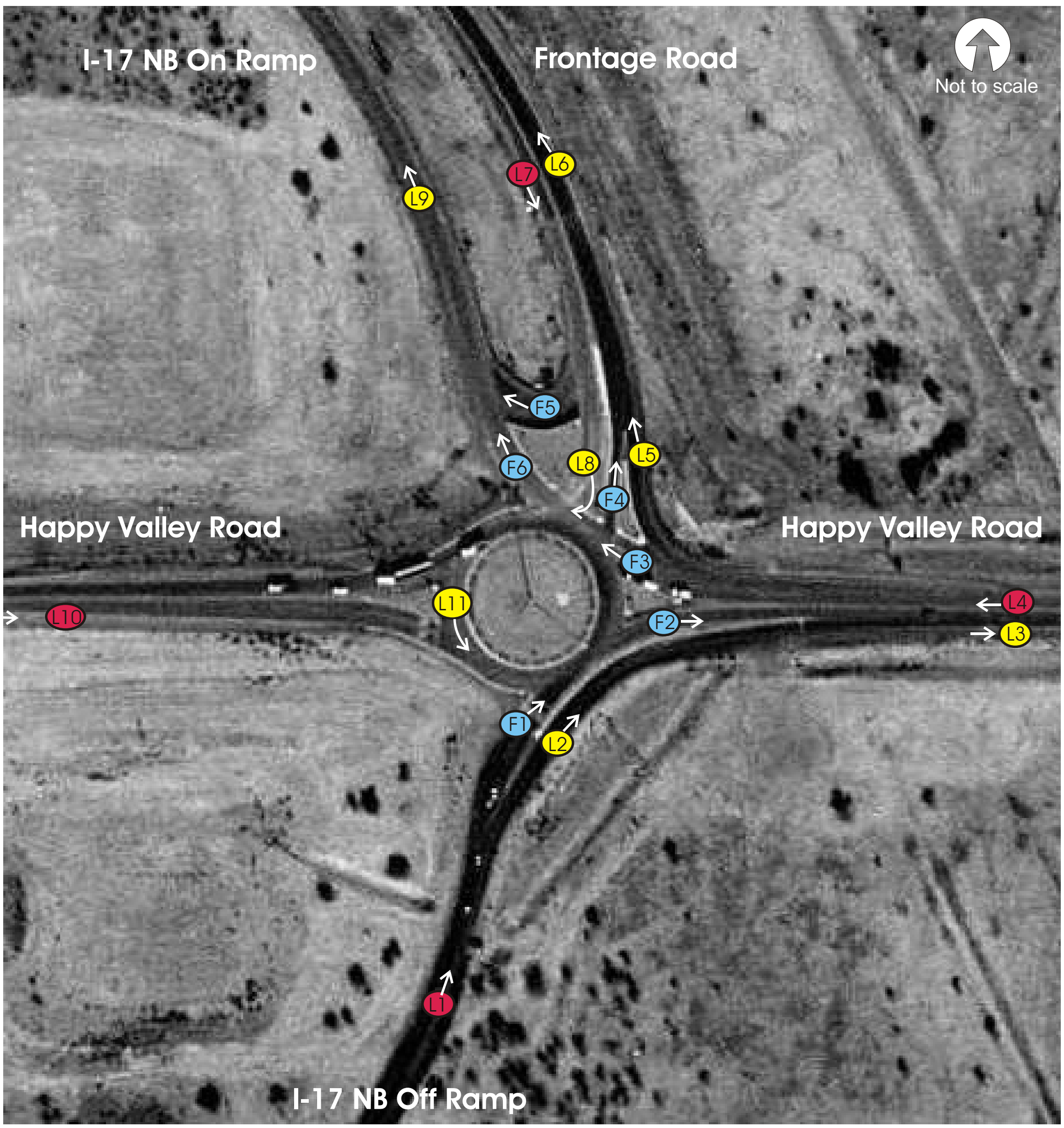

Figure 4 - AM & PM Peak Hour and 24 Hour Counts
East Roundabout

LEGEND:

XXX / XXX / XXX
- 24 Hour Counts
- PM Peak Hour (4:30 - 5:30)
- AM Peak Hour (6:45 - 7:45)

Counts from October 2002

L12	= 181 / 128 / 1885	L17	= 493 / 1033 / 9107	F7	= 5 / 5 / 20
L13	= 162 / 256 / 2825	L18	= 1455 / 439 / 10497	F8	= 176 / 123 / 1865
L14	= 157 / 250 / 2805	L19	= 1143 / 295 / 7758	F9	= 222 / 99 / 2093
L15	= 295 / 165 / 2818	L20	= 1457 / 671 / 12199	F10	= 420 / 967 / 8382
L16	= 73 / 66 / 725	L21	= 496 / 1321 / 11093	F11	= 312 / 145 / 2739
				F12	= 314 / 376 / 4441

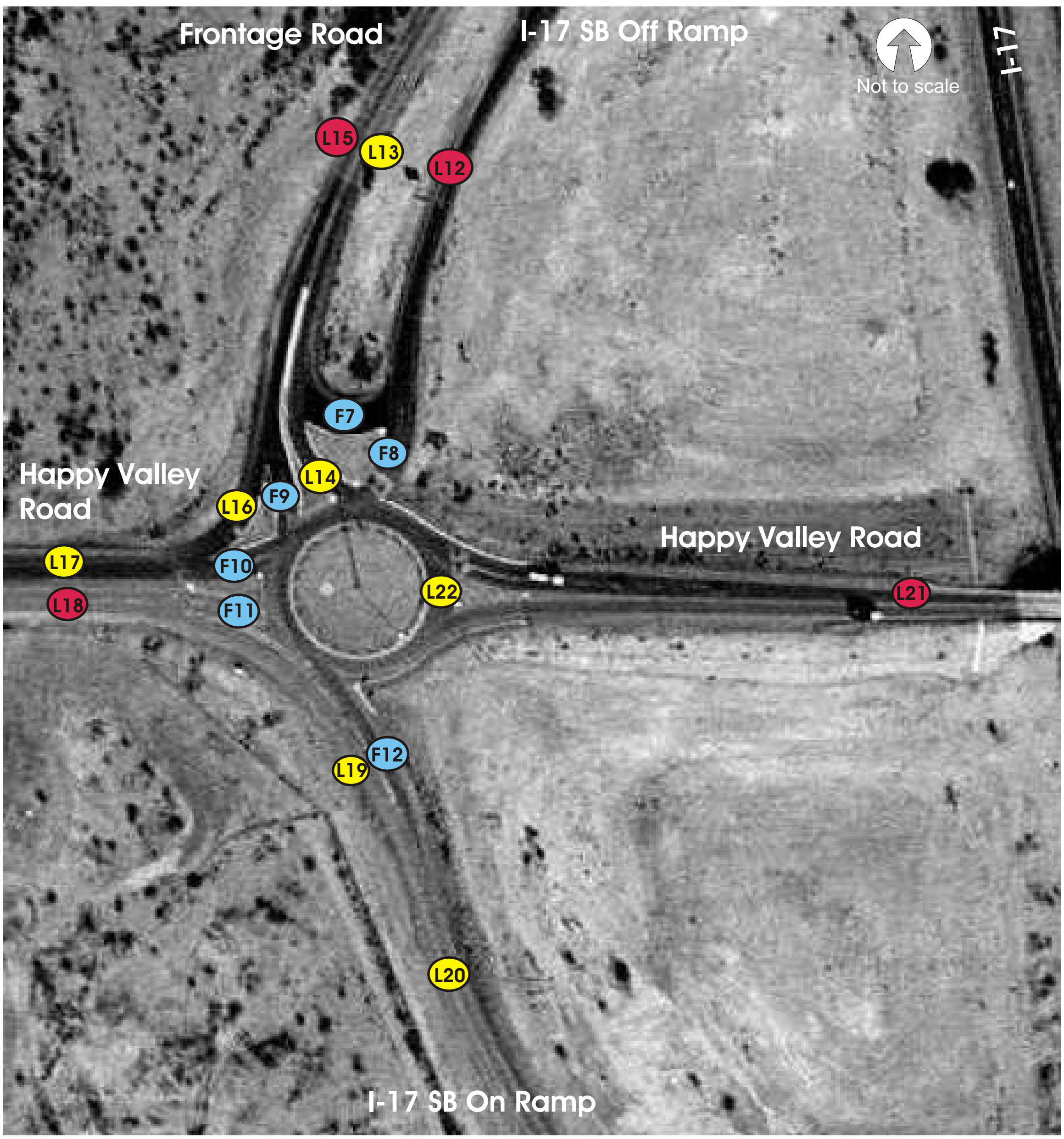

Figure 5 - AM & PM Peak Hour and 24 Hour Counts
West Roundabout

Review of these figures indicates that the system-wide peak hour for this network was from 6:45 AM to 7:45 AM in the morning and from 4:30 PM to 5:30 PM in the evening. Results also indicate that the west roundabout accommodates approximately 46 percent more traffic volume than the east roundabout. This can be confirmed by the high east-bound Happy Valley Road residential volume that utilizes the southbound I-17 on-ramp in the AM peak period rather than having to utilize the east roundabout to reach most employment centers. On their return trip, motorists must utilize both roundabouts if they exit from I-17 northbound and desire to travel west to most of the area's residential neighborhoods. Hence, the west roundabout receives the majority of traffic.

3.2.3 Vehicle Classification and Spot Speed Counts

In addition to the volume counts, vehicle classification and speed data was also obtained at the eight approach legs to the roundabouts by the ATR machines. At Location 21, the reinstalled machine data was used to identify truck percentage and spot speed information. ***Figure 6*** shows peak hour average speed and truck percentage observed by the ATR machines for Tuesday, 11/15/02.

Results of the speed and class information indicate the following:

- Average approach speed is higher than the posted speed limit at most of the locations, the exception being Location 18 (eastbound Happy Valley Road west of the west roundabout). The reduced speeds may be attributed to the serpentine- road geometry of Happy Valley Road west of the ATR placement, and/or the increased vehicle interactions in the area of this location (e.g., increased turning movements, start-up acceleration from landfill driveway and 29th Avenue).

- Vehicles travel at a lower speed between the two roundabouts than on other approach legs. This may be a result of a combination of: 1) vehicles exiting the first roundabout at reduced speeds (posted warning speed limit of 20 mph) and knowing that a second roundabout is forthcoming, 2) the positive incline that must be climbed by the vehicles to reach the apex of the bridge over I-17, 3) the limited sight distance drivers have before they ascend the bridge grade, and/or 4) speed-volume relationships influenced by capacity limitations of the overpass.

- A relatively large number of trucks were observed in the AM peak period traveling the road network. This can be attributed to an adjacent landfill located in the northwest quadrant of the west roundabout, a quarry operation located northeast of the east roundabout, other trucking operations located toward the east, and the overall construction activities associated with this area. By the PM peak period most of these operations are closed or have ended for the day resulting in decreased truck percentages.

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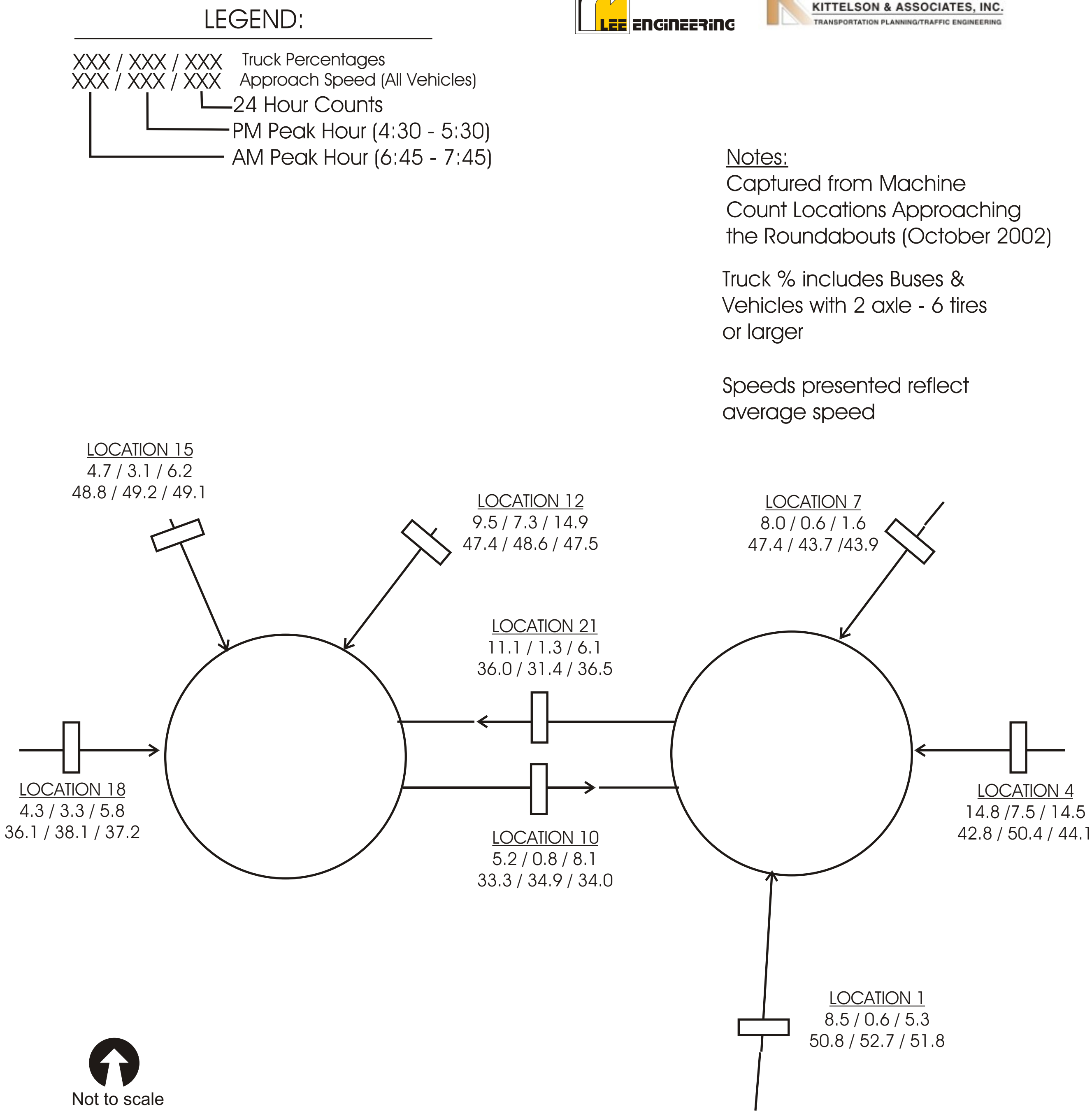


Figure 6 - Vehicle Speed and Truck Percentages

3.2.4 Peak Period Turning Movement Counts

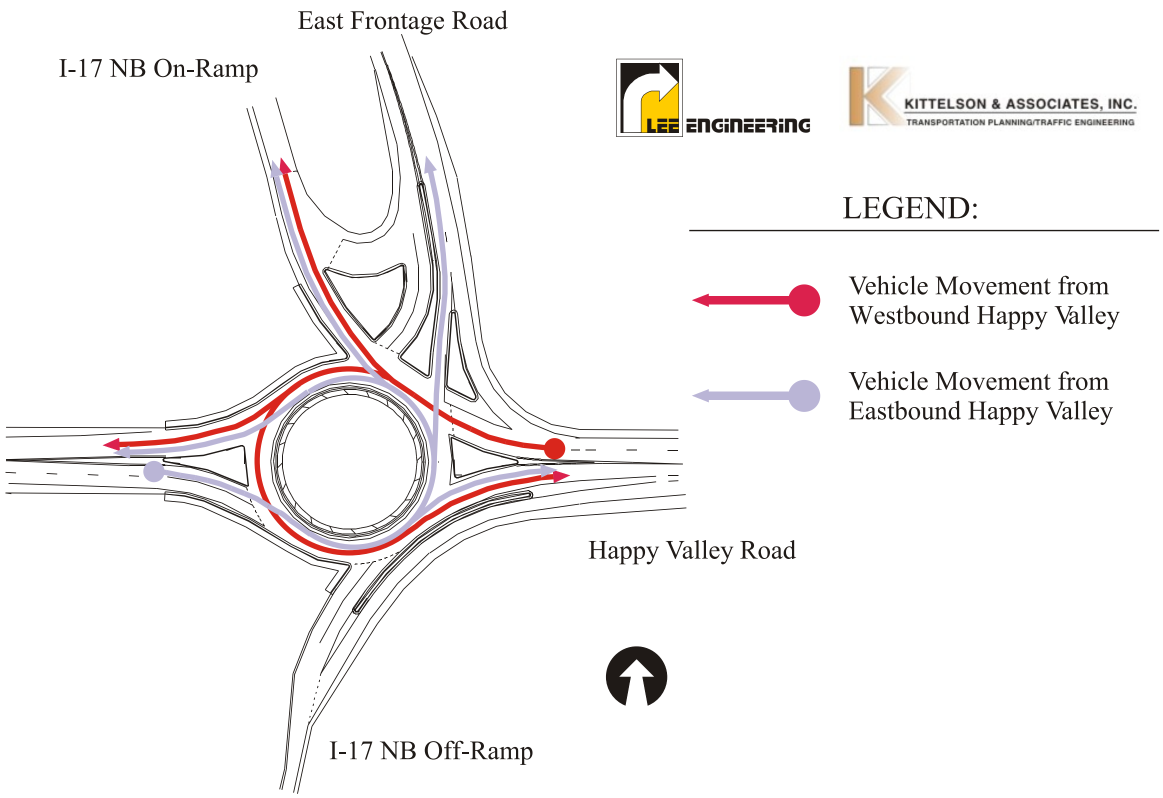
Simultaneous to the machine count data, observers traced vehicle movements through the roundabouts in the AM and PM peak periods. Each observer was responsible for collecting a random sampling of vehicles as they entered the roundabouts to determine their departure leg destination. Emphasis was placed on quality of the observations and not quantity for this effort (a majority of total entering vehicles were accounted for nevertheless). ***Figures 7 and 8*** show the particular paths each observer was responsible for, with the different shades indicating responsibility of a separate individual. ***Figures 9 through 16*** show the peak period turning movement percentages per roundabout as observed in the field and verified through the results of the ATR machine counts.

Corresponding with the volume data, the above figures show a high percentage of vehicles in the AM are destined for I-17 southbound, and in the PM, the majority of motorists are destined for westbound Happy Valley Road.

3.2.5 Speed and Vehicle Path Survey

To obtain a better representation of driving behavior of motorists approaching and continuing through the roundabouts, vehicles were followed by a test car using GPS equipment. A driver of the test vehicle attempted to follow random vehicles entering the roundabout network by mimicking the targeted vehicles speed and path. This method was not always possible due to the yield control entries into the roundabouts which allowed some target vehicles to enter the roundabout by accepting gaps in conflicting traffic that were too short to allow for the test car to follow.

Other inherent difficulties with the car-following method were the inability to anticipate and follow specific vehicles exiting the freeway and attempting to accelerate from a stop condition (e.g., if waiting on the freeway ramp shoulder or prior to following traffic on Happy Valley Road) to match the speed of a moving/passing target vehicle. These instances occurred rather frequently despite performing the data collection during the off-peak time period. Therefore, a portion of the data collection runs were conducted with different drivers operating the test car in order to provide a sampling of driver behavior when navigating through the roundabouts. Although these runs did not necessarily follow specific target vehicles, they do provide some representation of how various motorists react to and drive through the roundabouts.



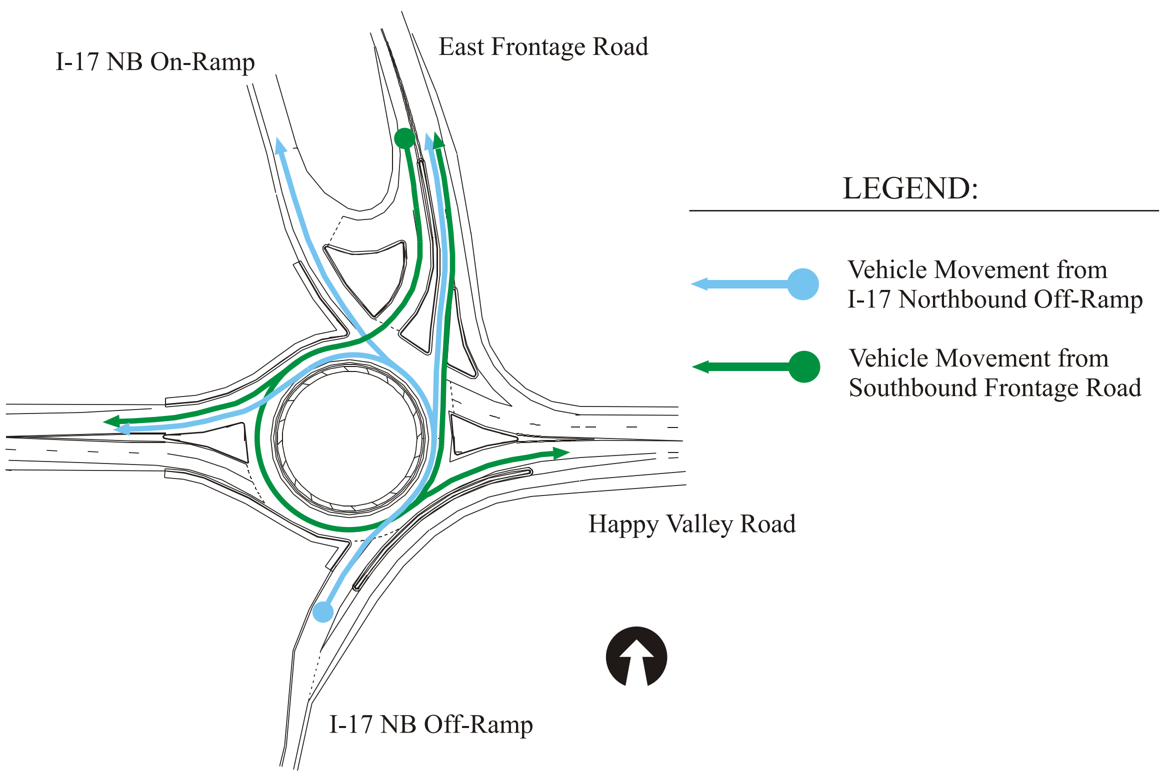
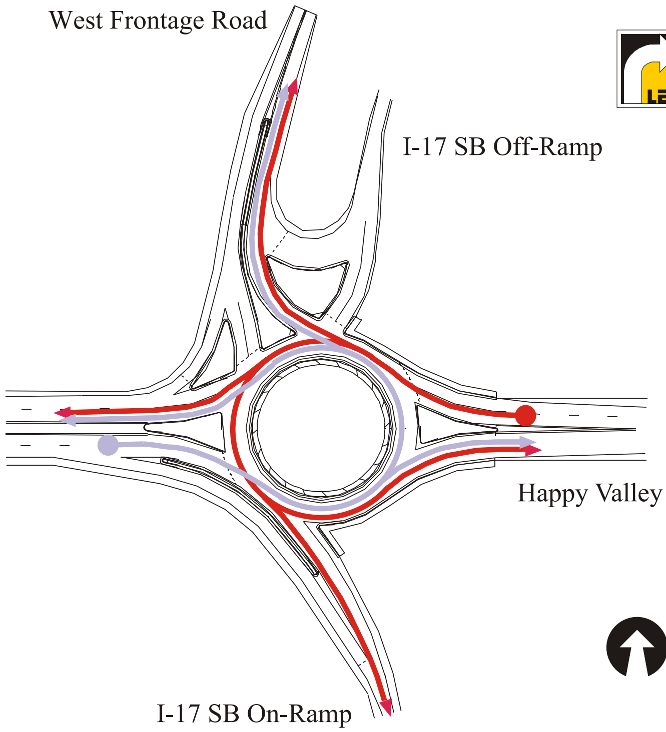


Figure 7 - Vehicle Trace Locations
East Roundabout, All Approaches



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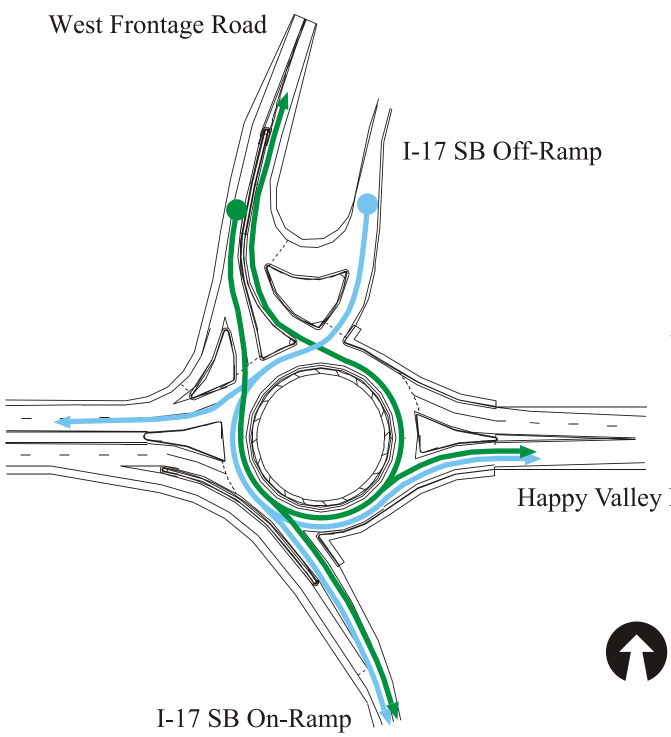
TRANSPORTATION PLANNING/TRAFFIC ENGINEERING

LEGEND:

- Vehicle Movement from Westbound Happy Valley
- Vehicle Movement from Eastbound Happy Valley



LEGEND:

- Vehicle Movement from I-17 Southbound Off-Ramp
- Vehicle Movement from Southbound Frontage Road

Figure 8 - Vehicle Trace Locations
West Roundabout, All Approaches

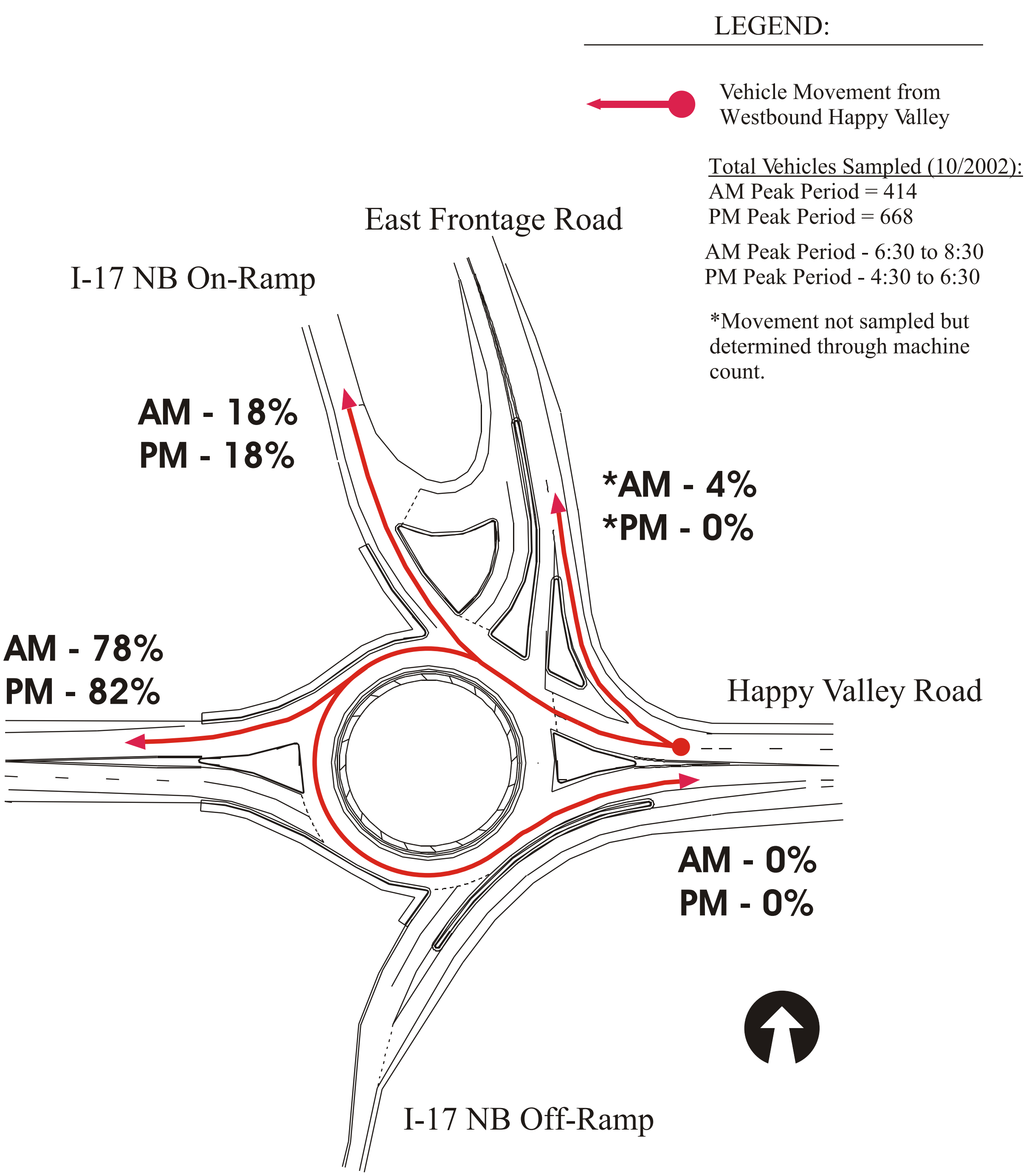


Figure 9 - AM & PM Peak Period Movement Percentages
East Roundabout, East Approach

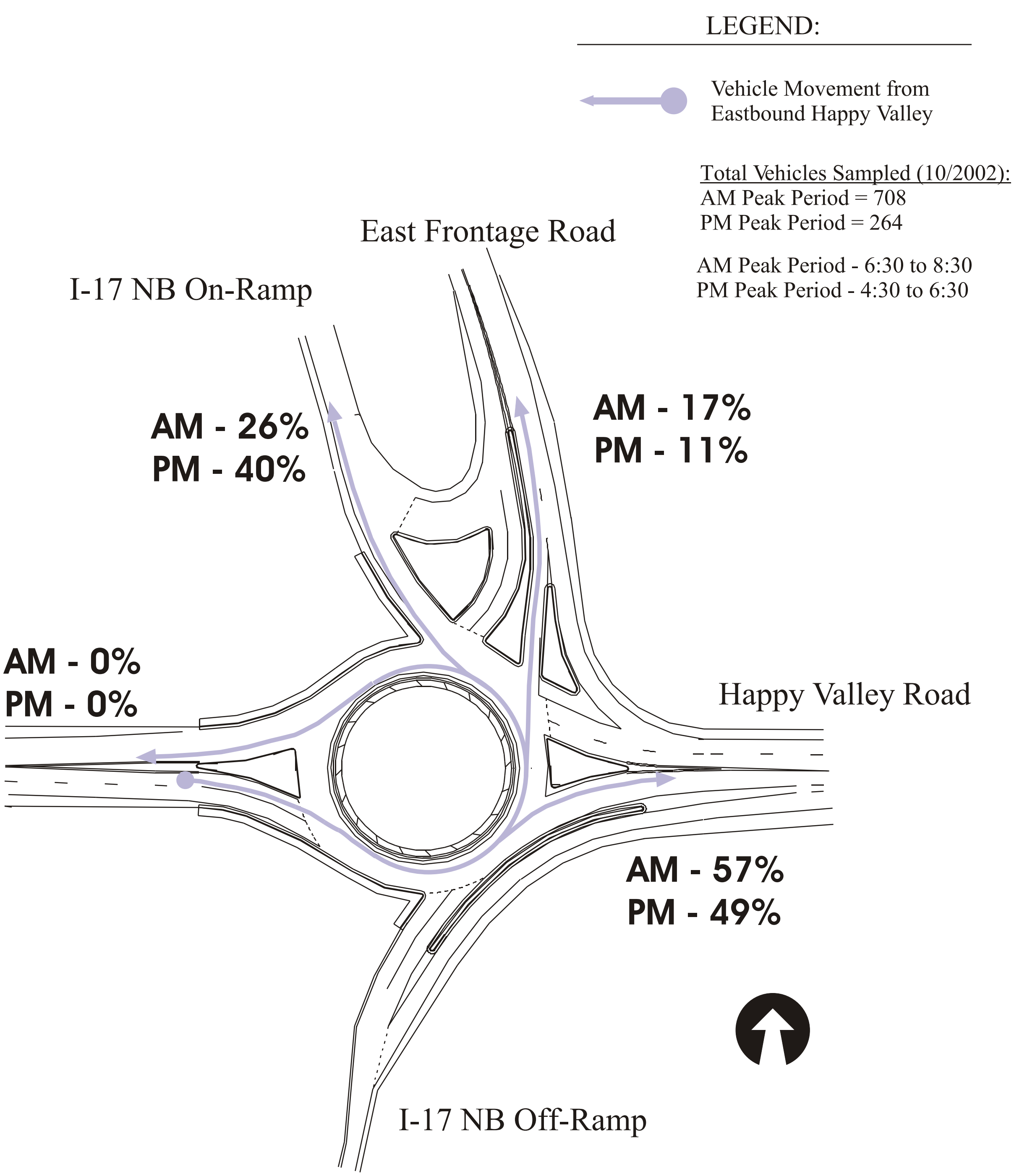


Figure 10 - AM & PM Peak Period Movement Percentages
East Roundabout, West Approach

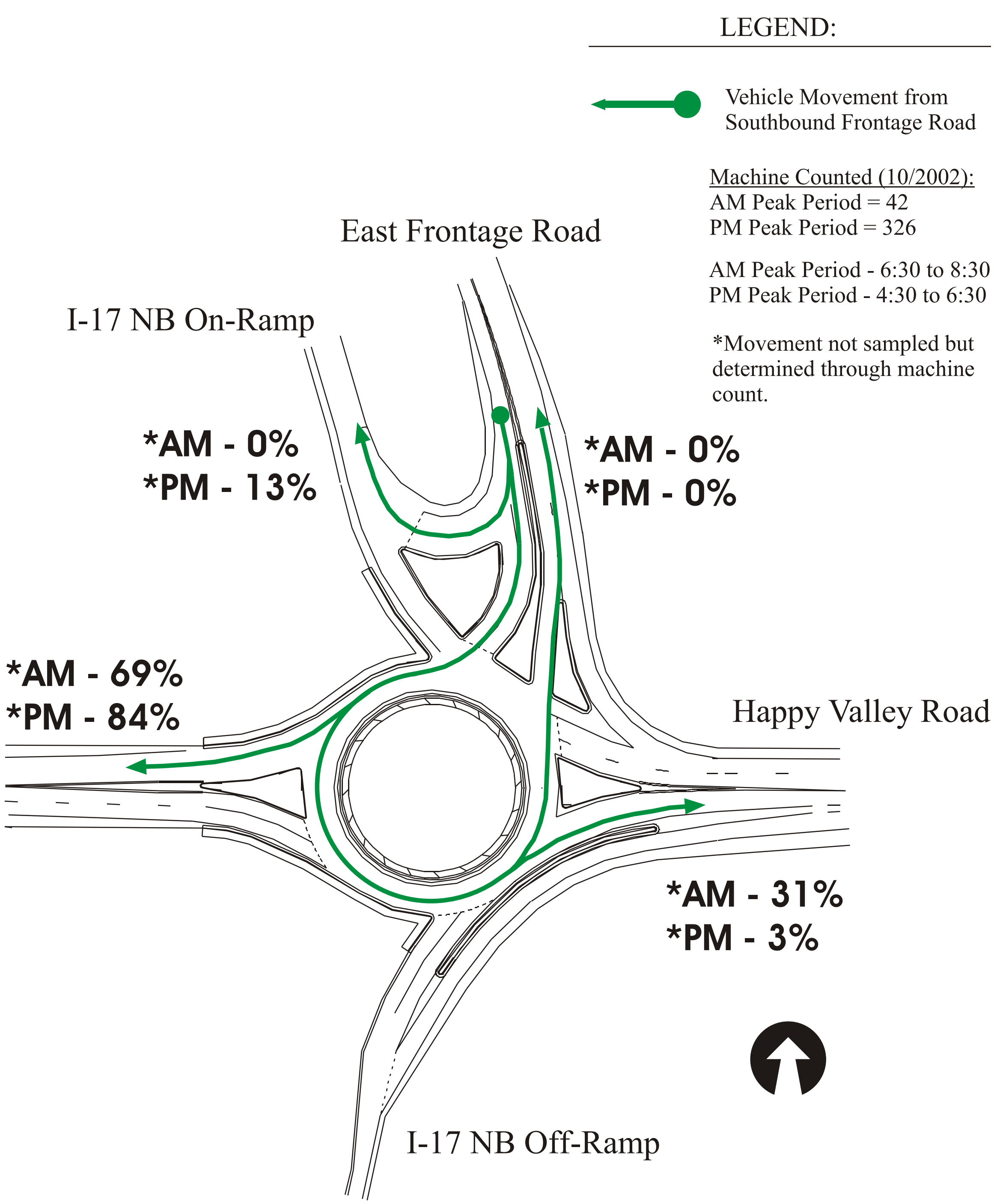


Figure 11 - AM & PM Peak Period Movement Percentages
East Roundabout, North Approach

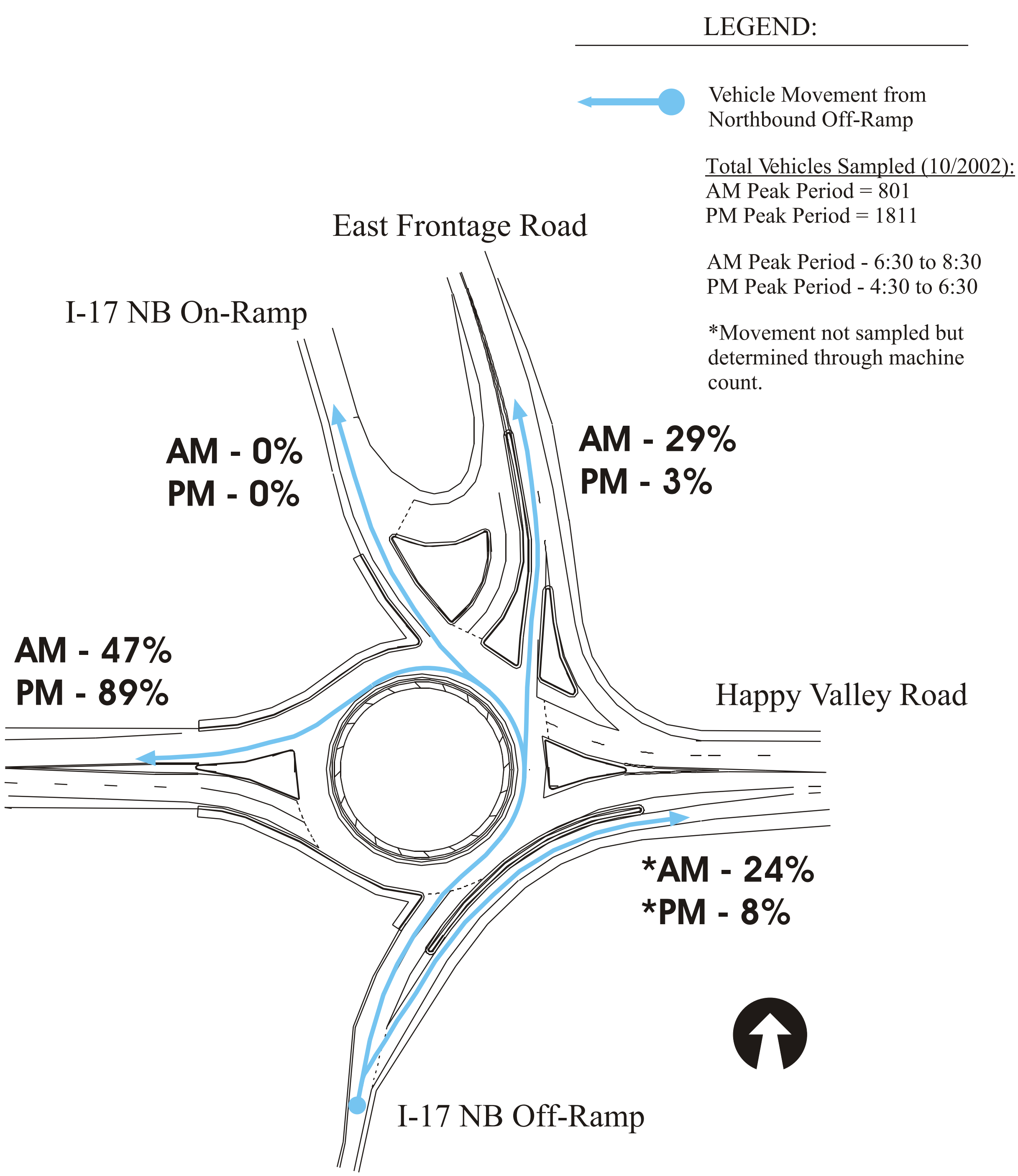


Figure 12 - AM & PM Peak Period Movement Percentages
East Roundabout, South Approach

LEGEND:

Vehicle Movement from
I-17 Southbound Off-Ramp

Total Vehicles Sampled (10/2002):
AM Peak Period = 304
PM Peak Period = 214

AM Peak Period - 6:30 to 8:30
PM Peak Period - 4:30 to 6:30

*Movement not sampled but determined through machine count.

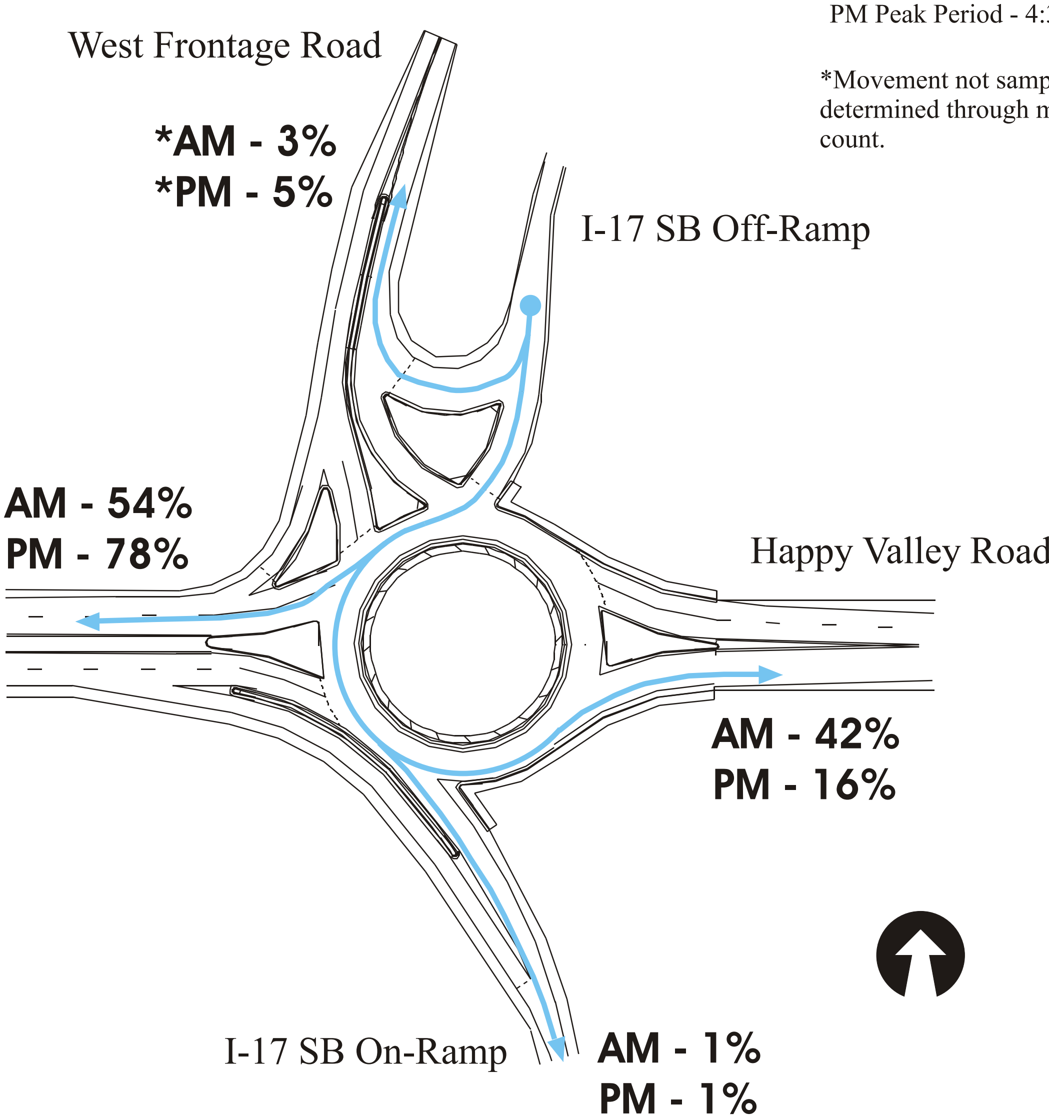


Figure 13 - AM & PM Peak Period Movement Percentages
West Roundabout, Northeast Approach

LEGEND:

Vehicle Movement from Westbound Happy Valley

Total Vehicles Sampled (10/2002):
AM Peak Period = 931
PM Peak Period = 2190

AM Peak Period - 6:30 to 8:30
PM Peak Period - 4:30 to 6:30

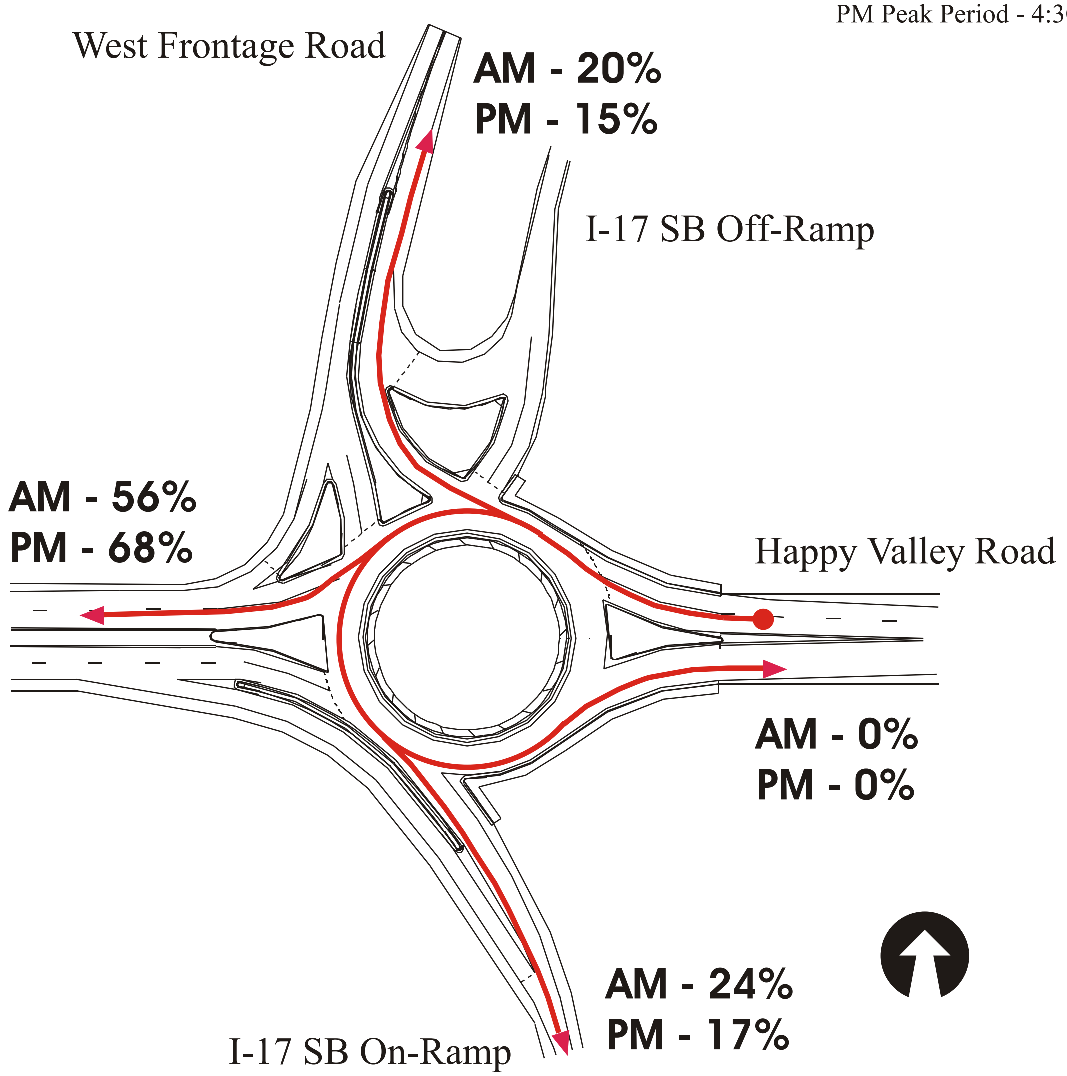


Figure 14 - AM & PM Peak Period Movement Percentages
West Roundabout, East Approach

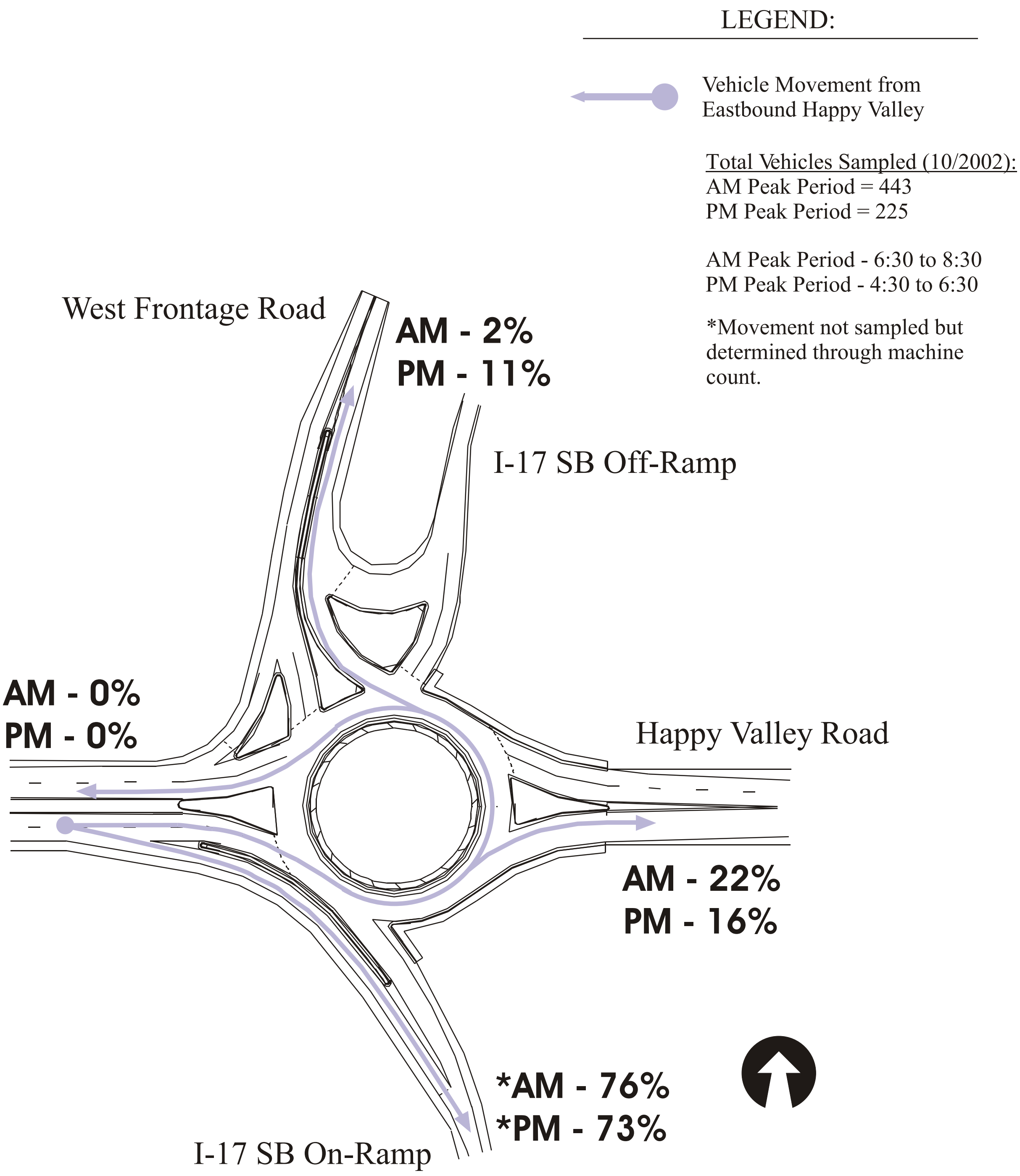


Figure 15 - AM & PM Peak Period Movement Percentages
West Roundabout, West Approach

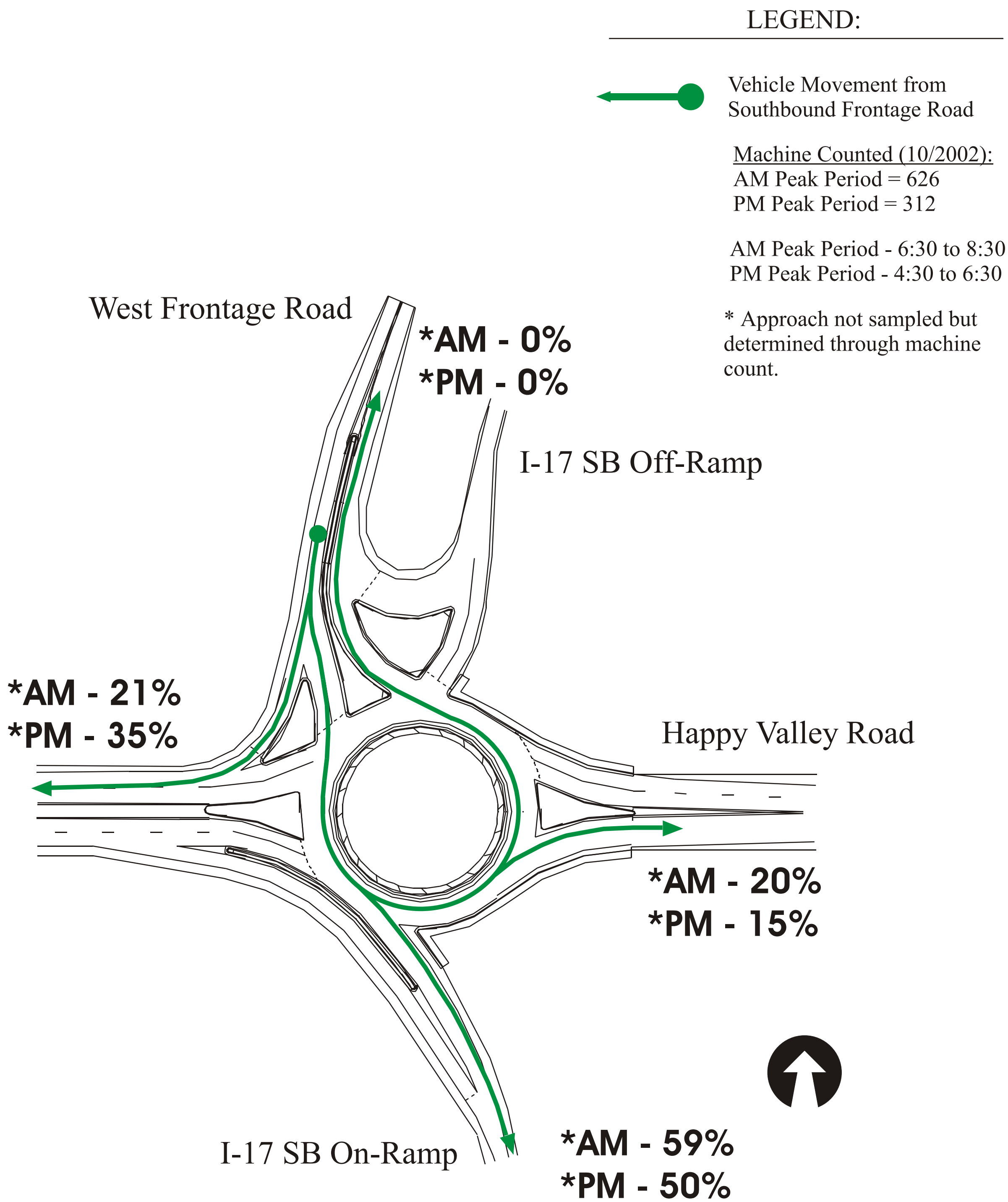


Figure 16 - AM & PM Peak Period Movement Percentages
West Roundabout, Northwest Approach

The collected speed and vehicle path information from each vehicle run was spatially plotted against one another to determine general path and average speed characteristics. The information obtained is representative of nearly free-flow conditions and allows a comparison of design parameters and actual conditions. A total of about 30 vehicle runs were conducted consisting of variety of routings through the roundabouts. ***Figures 17 and 18*** provide a representation of data point sets collected for all of the vehicle runs, which gives a general indication of vehicle paths through the roundabouts. Various data points, at one-second intervals, from multiple vehicle runs are shown simultaneously in the figures below. Specific routes were not sampled as often as other routes because of motorists' tendency to use particular routes.

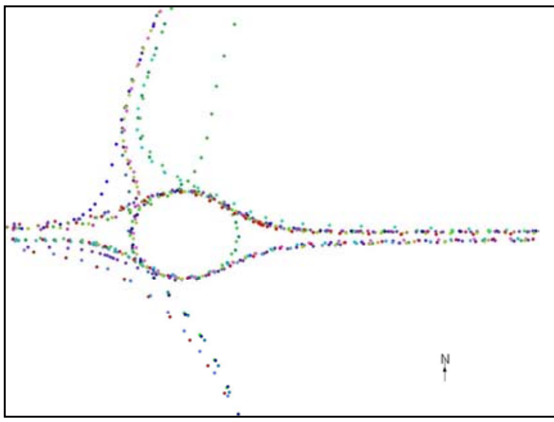


Figure 17
GPS Data Point Samples
(West Roundabout)

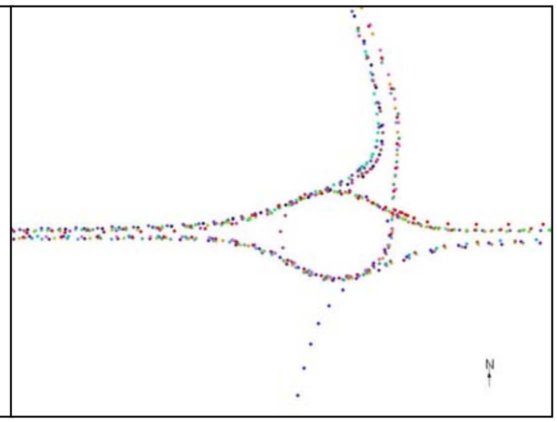


Figure 18
GPS Data Point Samples
(East Roundabout)

Detailed examinations of the data collected from the various vehicle runs yields average speeds at certain locations at and within the roundabouts. These location-specific speed samples and resulting averages are presented in Table 1. The speed values presented in the table can be compared against the fastest-path speed determinations (presented later in this report) with the following three exceptions: 1) since the average speeds presented in Table 1 are based on the various number of samples at a given location, they are not associated with any one particular path through the roundabout; 2) the collection of the speed samples were conducted at off-peak times, but these times were not necessarily representative of truly free-flow conditions; and 3) the vehicle runs were conducted within the confines of obeying roadway striping and pavement markings (not a pre-requisite of theoretical fastest path determinations). ***Figures 19 and 20*** show the same average speed values from Table 1 but with given geometric references (not all of the values shown in Table 1 are displayed in the figures).

Table 1 - GPS Speed Samples

East Roundabout

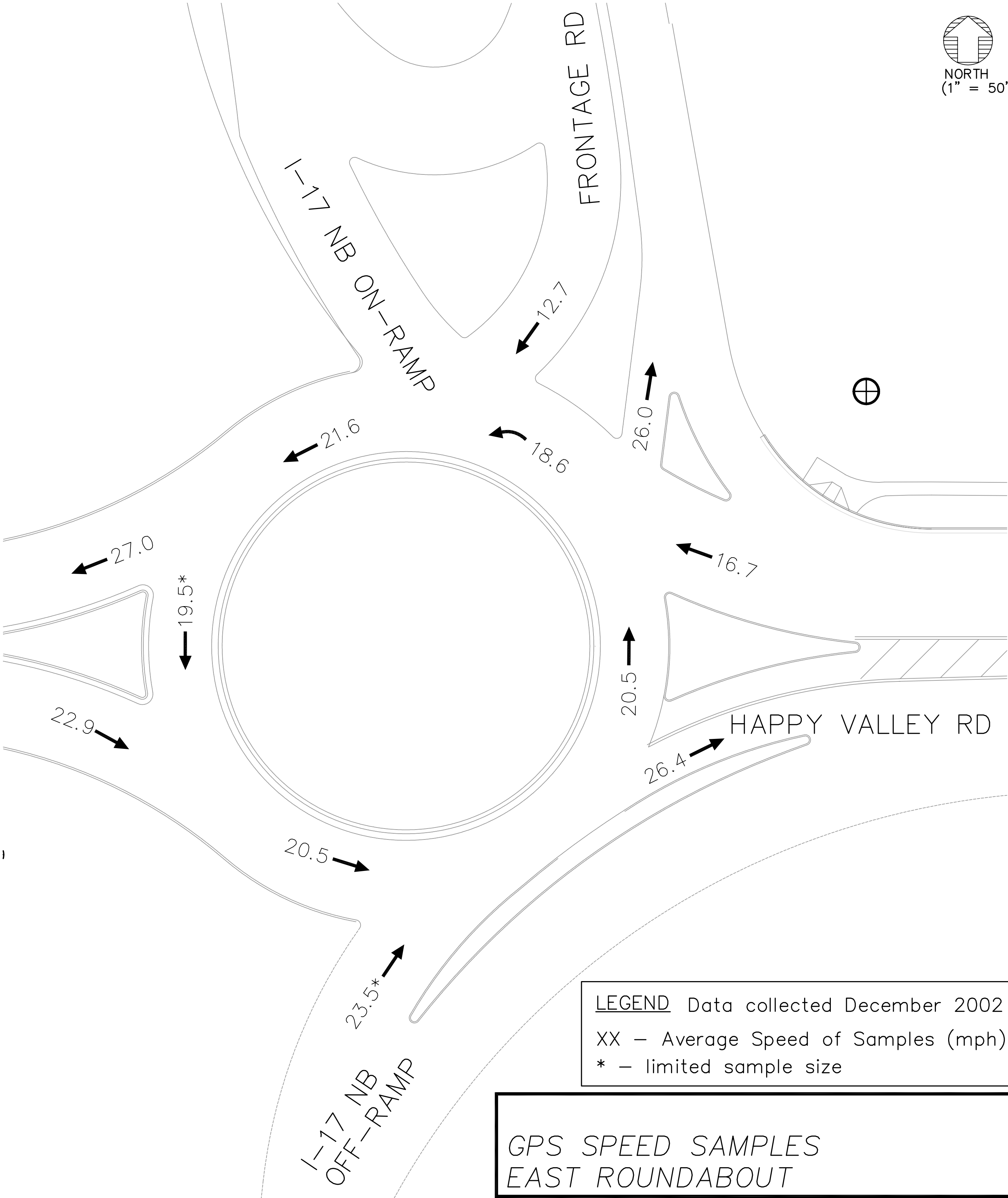
Direction/Area	East Approach Entering	East Approach Exiting	West Approach Entering	West Approach Exiting	Ramps Entering	Ramps Exiting	Frontage Road Entering	Frontage Road Exiting	Circulatory Areas East	Circulatory Areas North-east	Circulatory Areas North-west	Circulatory Areas South	Circulatory Areas West
Speed Samples	16.3	23.5	23.7	26.2	23.5	-	12.2	24.9	18.4	18.3	21.9	18.2	19.5
(mph)	17.0	28.3	25.5	25.4			14.1	22.4	17.3	17.7	19.8	21.0	
	14.8	28.0	25.7	31.4			14.5	28.5	23.5	19.9	25.3	21.3	
	23.5	25.0	28.6	27.6			18.3	26.0	20.7	19.2	21.6	24.5	
	13.6	26.4	11.9	27.6			9.0	28.1	20.8	22	22.5	17.4	
	17.7	27.3	25.2	27.0			8.2		22.5	16.4	21.5	22.6	
	14.0		22.3	25.5						19.6	21.3	19.9	
			23.5	26.5						15.3	22.3	19.9	
			19.6	28.3							22.7	19.5	
				22.0							17.6	21.8	
				30.5							25.4	19.0	
				25.7							22.4		
				27.1							17.6		
											20.8		
Average (mph)	*16.7*	*26.4*	*22.9*	*27.0*	*23.5*	*-*	*12.7*	*26.0*	*20.5*	*18.6*	*21.6*	*20.5*	*19.5*

West Roundabout

Direction/Area	East Approach Entering	East Approach Exiting	West Approach Entering	West Approach Exiting	Ramps Entering	Ramps Exiting	Frontage Road Entering	Frontage Road Exiting	Circulatory Areas East	Circulatory Areas North	Circulatory Areas West	Circulatory Areas South
Speed Samples	18.8	26.8	11.7	24.0	14.0	35.0	21.7	21.0	17.4	18.4	18.3	20.2
(mph)	14.7	28.5	24.5	26.7		24.8	22.0	20.3	16.1	17.7	27.2	19.5
	19.5	30.6	24.2	24.6		26.3	9.5	20.8		20.2	19.8	24.2
	19.0	30.0	7.3	27.4			13.8			19.5	17.8	18.3
	18.7	23.5	14.2	26.6						15.8	17.8	23.3
	14.0	29.2	23.7	30.3						20.7	19.6	19.5
	22.6	28.9	19.5	21.8						24.2	19.7	21.5
	28.2	25.6	18.2	32.5						18.1		21.6
	24.4	27.5		24.9						13.8		20.1
	15.4	29.6		27.1						23.1		17.8
	18.1			24.8						16.8		20.5
	9.4									19.5		22.6
	16.4											
Average (mph)	*18.4*	*28.0*	*17.9*	*26.4*	*14.0*	*28.7*	*16.8*	*20.7*	*16.8*	*19.0*	*20.0*	*20.8*

Other Areas

Direction/Area	Frontage Road RT	FR/WB HV Merge	EB HV RT Bypass	On Ramp Yield
Speed Samples	17.3	30.8	32.7	40.0
(mph)		27.0	28.0	36.2
		30.1		38.4
		29.8		34.0
		32.3		36.0
		32.1		
		37.0		
		29.0		
		30.5		
		32.8		
		15.7		
Average (mph)	*17.3*	*29.7*	*30.4*	*36.9*



LEGEND Data collected December 2002
XX – Average Speed of Samples (mph)
* – limited sample size

GPS SPEED SAMPLES
EAST ROUNDABOUT

SPR-545 ADOT ROUNDABOUT RESEARCH
PHOENIX, AZ
JULY 2003

FIGURE 19

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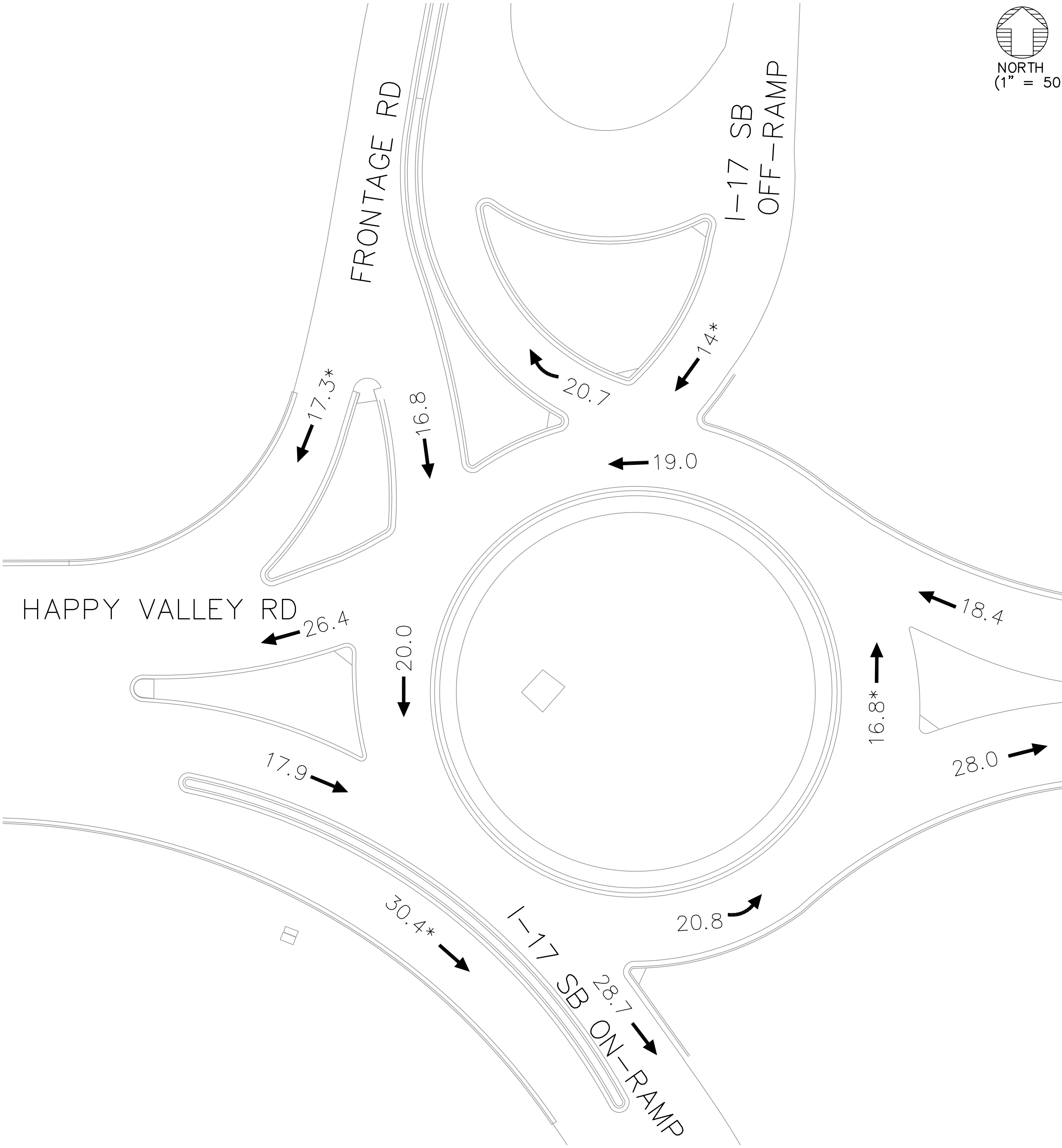
EAST_RBT_GPSSPEED



GPS SPEED SAMPLES
WEST ROUNDABOUT

SPR–545 ADOT ROUNDABOUT RESEARCH
PHOENIX, AZ
JULY 2003

FIGURE
20

LEE ENGINEERING

KITTELSON & ASSOCIATES, INC.

WEST_RBT_GPSSPEED

LEGEND Data collected December 2002
XX – Average Speed of Samples (mph)
* – limited sample size

The review of the data highlights a couple of generalizations with respect to speed at the two roundabouts. At the east roundabout the average speed around the circulatory roadway is about 20 mph. The difference in the average circulating speed and the typical entry speeds is generally five mph or less. The average entry speed for traffic entering the roundabout from the frontage road is lower than other entry speeds due to the distinct geometric deflection at this approach coupled with heavier conflicting traffic volumes. At the west roundabout, a similar situation is also present as the average circulatory speed is about 20 mph. At this location, the entry approach speeds from the frontage road and off-ramp are lower than the Happy Valley Road approach speeds due to geometric and conflicting volume influences. It is important to remember that the average speeds represent off-peak periods, but not completely free-flow conditions, which means the average speeds are influenced by inherent traffic conditions including slowing/stopping at the yield-control entries when dictated by traffic conditions.

3.2.6 Videotaping of Vehicle Conflict Points

Video cameras were placed at different locations near the roundabouts to capture the driving behavior of motorists as they entered and exited the facilities. Approximately 11 hours of videotape were recorded from three vantage points during different time periods throughout the day. Observations were also made at this time to help determine motorist driving tendencies within the circulatory road and at queue, merge, and diverge conflict points. The following camera vantage points were established:

- The west roundabout light tower to view the east roundabout: A camera was placed on the luminaire ring of the light tower and was elevated to its normal position 100 feet above ground level. The camera was aimed at the east roundabout (approximate distance of 1600 feet) by using remote pan/tilt/zoom capabilities. Taping occurred on 11/20/02 between the hours of 1:30 PM and 5:30 PM.
- The southwest quadrant of the west roundabout to observe west roundabout traffic: A rented moving truck was parked on the vacant property while two cameras were situated on top of the storage bed roof to optimize the viewing angle. Due to the close proximity of the cameras to the roundabout, the second camera was focused at the I-17 southbound on-ramp merge point. Data was collected at this location on 12/11/02 from 1:30 PM to 5:30 PM and on 12/12/02 from 7:20 AM to 8:30 AM.
- The northeast quadrant of the east roundabout to observe east roundabout traffic: The same truck rental application was used at this location to view the operation at the roundabout. Data was collected on 12/12/02 between the hours of 8:45 AM and 10:45 AM.

Other video collection techniques were pursued to capture the vehicle movements at the two roundabouts, but were not pursued due to related complications. Results of the video findings are contained in the next section.

3.2.7 On-Site Vehicle Observations of Driver Behavior and Truck Performance

General traffic operations as well as specific erratic maneuvers were observed during the manual turning movement counts, videotaping, and other site visits. Below are some of the more interesting observations made while conducting this data collection activity. A complete listing of comments can be found in **Appendix C**. Based on this listing, there were about 23 erratic maneuvers ranging from conflict/crash avoidance to wrong turns observed in approximately 15 hours of peak hour period observations.

- Overall, traffic flows well through the roundabouts. Only minor vehicle delays and queues were observed during the peak hours at all approaches. Maximum vehicle queues were observed in the PM peak period with relatively minor queues observed in the morning peak period.
  - At the east roundabout, a maximum queue of seven vehicles was observed at the frontage road and I-17 northbound off-ramp approach and a maximum vehicle queue of 20 vehicles at the westbound Happy Valley Road approach (under a single lane approach configuration). The maximum vehicular queues correspond to the USAA quitting time where a spike in demand volume occurs (it may be beneficial to stagger the quitting times as the USAA complex expands). Queue lengths for the I-17 off-ramp are relatively non-existent due to the nearly continuous entrance flow afforded to it by the light volume on the eastbound Happy Valley Road approach. However, since the vehicles circulate in single file, they preempt downstream entry for a significantly longer time than if they entered side by side.
  - At the west roundabout, a maximum of six vehicles were observed queued at the frontage road and the I-17 southbound off-ramp approaches, usually utilizing only one lane of the two-lane circulatory entry. Queue lengths on the Happy Valley Road approaches are relatively minor and of short duration. Despite heavy westbound traffic, there is little circulating traffic that conflicts with this approach (i.e., eastbound vehicles circulating to access the northbound frontage road). The queues at the eastbound approach are minor mainly because the demand in this direction is reduced.
- Vehicle approach speeds were perceived to be higher than the posted advisory speed of 20 mph, especially at the exclusive southbound I-17 on-ramp movement from east-bound Happy Valley Road.
- Drivers using the slip ramp from eastbound Happy Valley Road to I-17 southbound occasionally disregard a posted yield sign, not allowing priority to vehicles coming off the circulatory roadway. This could be due to the acute angle these two lanes meet at, the short reaction time motorists have to determine if a vehicle from the roundabout will be accessing the freeway, or the heavier vehicle flow being from the ramp as opposed to the circulatory roadway.
- Right-of-way within the circulatory roadway is confusing to some drivers, identified by motorists stopping within the circulatory roadway to allow vehicles waiting at the approaches to enter.

- Drivers were noted making some improper movements at both roundabouts, such as turning onto the freeway off-ramps, traveling clockwise against traffic around the circulatory roadway, passing at inappropriate times and locations, and making u-turns before and after the roundabout.
- Drivers will use the second approach lane if they feel the driver waiting at the approach is not accepting a proper gap to enter the traffic stream, or if vehicle queues are long.
- Aggressive motorists will try to pass slower vehicles and trucks within the circulating roadway or on the second/inside lane of the departure leg, if available (Happy Valley Road departure legs).

The following observations regarding heavy-truck performance are the result of the videotape recordings and the on-site visits at the roundabouts:

- Truck drivers, at times, knowing that the circulatory roadway is not wide enough for two vehicles will occupy both approach lanes to prevent a trailing vehicle from passing them within the roundabout.
- Trucks tend to place their inside wheels on the roll curb portion of the roundabout.
- Trucks or larger passenger vehicles on the inside lane stopped at the approach yield line block the vision of the motorist at the outside position. The outside motorist must wait until the inside driver makes a move before entering the roundabout.
- Some fully-loaded trucks look as if they may tip over as they complete their turn, especially the trucks hauling gravel, where their loads may also shift or the weight may not be evenly distributed. This is more predominant at the west roundabout than the east roundabout due to their travel destination.

3.2.8 Pedestrian and Bicycle Activity and Issues

No pedestrian activity was observed at the roundabouts. During the observation periods, three sets of bicyclists were observed traversing Happy Valley Road between the roundabouts. No accommodations are provided at the two roundabouts for pedestrians or bicyclists. Because of the adjacent land use and rural nature of the area, the existing roadway cross section was not designed for non-vehicular travel. This is evident from the existing bridge structure width over I-17, which has two travel lanes and no shoulders. Also, sidewalks are not present in the surrounding area, except on Happy Valley Road east of the east roundabout, where sidewalks are present in the two easterly quadrants. Modifications to the roundabouts would be required if pedestrian facilities are to be incorporated at the interchange.

3.3 PUBLIC OPINION SURVEY

3.3.1 Public Opinion Sampling Methods

Since the Happy Valley roundabouts are the first installations of modern roundabouts in Arizona, the public perception toward them and their operation is valuable information for future use and design. There are many methods for collecting public opinion information, with the five methods described below were considered for use in this project. The advantages and disadvantages of each were discussed with the TAC and ADOT and then a public opinion sampling plan was developed.

1. Direct Mailing – This method entails mailing return-postage-paid survey cards directly to the addresses associated with the vehicles observed passing through the roundabouts.
The advantage of this method is that the actual users of the roundabouts would be surveyed thereby providing effective and relevant responses. The collection of license plate data would also ensure a better proportion of repeat versus new drivers. The disadvantages of this method are the difficulties in accurately observing the license plate information and obtaining a valid associated address. Since some license plate data was from out-of-state vehicles, company vehicles, or other invalid sources, the number of raw license plate numbers collected may not yield a large enough number of addresses for study use. The typical response rate from this surveying method is about 25%.

2. Bulk Mailing – This surveying approach is similar to the direct mailing in that postage-paid surveys are sent out to residents, but differs in the procedure for determining the mailing addresses. Bulk mailing targets a selected region, usually determined by zip code(s) in close proximity to the roundabouts. Since the survey recipients would not necessarily have a connection to the roundabouts due to the regional mailings, the response rates are not likely to be as great for this method as compared to the direct mailing method. The prime advantage to bulk mailing method is its relative ease to coordinate and execute. The main disadvantages are the reduced response rate, the potential irrelevance of returned responses, and the cost of the numerous surveys needed. It is estimated that due to the diminished response rate expectation, some 20,000 surveys would have to be distributed to the area.

3. Survey Stations – This concept relies on the principle of the direct mailings by targeting the actual users of the roundabouts, but has some added disadvantages. Survey stations would be set up on the departures from the roundabouts and vehicles would be stopped and drivers asked to participate in the opinion survey. One disadvantage is that the survey questions would have to be concise and the overall survey would have to be brief (estimated at less than one minute to convey and receive responses). Another disadvantage of the survey station is the logistics of establishing the station area, where it would not hinder traffic operations. This might involve conspicuous signs, channelizing devices, a flagger, several survey personnel, and possibly police/DPS (Department of Public Safety) coordination and assistance. The advantages of this system are that actual users are surveyed, no postal processing would be necessary, and as surveys were conducted the total number of responses would be readily available. Alternatively,

survey cards could be handed out rather than administered at the survey stations, which would allow for more detailed questions and time for the respondent to develop answers. However, this would likely yield a lower overall response rate.

4. On-Line Surveying – This type of surveying has a very large potential, but is not without its shortcomings. The primary concern with an on-line/internet survey is informing the public that the survey exists and how to access it easily. Relying on common internet "traffic" is not nearly enough. Therefore, a public information promotion must be initiated in conjunction with the on-line survey establishment. Typically, this can be accomplished by contacting local newspapers or circulars and having a public notice or ad printed describing the project and how to access the survey. The disadvantage of the on-line surveying is that the reviewer is not sure of the respondents' perspectives or whether multiple entries have been submitted by the same person. The advantages of this method are that no postage is required and its potential to reach a large number of people.

5. Specific Delivery/Distribution – This type of surveying focuses on specific areas or users whose perspectives and opinions are of a particular interest to the project. Although this method requires the time and effort to specifically meet with the parties in order to distribute the survey and/or conduct interviews, it does provide a particular perspective that may be crucial to understanding the situations at hand.

3.3.2 Public Opinion Sampling Approach

The public opinion sampling approach sought to gain the perspectives of both the drivers who frequently use the facility and the drivers who travel a different route to by-pass the roundabouts. The following methods were developed and approved by the TAC and ADOT. It was noted that the data collected would not be statistically valid but would serve as an useful database. The following three sampling methods were used:

1) Direct Mailing – An introductory letter and a mail-back questionnaire for drivers observed using the roundabouts was developed to ascertain information from this user group. As vehicles were observed traveling through the roundabouts their license plates were recorded over an eight-hour period for two collection days. A total of 4,904 vehicle plates were initially recorded. Upon internal review of the initial database, additional plate sampling was not continued due the number of duplicate plate numbers being obtained. The database was filtered to remove all duplicate entries and was formatted for processing by ADOT's Motor Vehicle Division (MVD). The MVD processing of the database information yielded the addresses of 4,254 vehicle owners with some database records providing invalid results. The database was then "cleaned" to remove vehicle owners that lived outside of the state, rental vehicles, and business owned vehicles due to foreseen difficulty of identifying the operator of the vehicle. A total of 3,539 plates and their corresponding mailing addresses were acceptable for mail-back questionnaires. The letter and survey form, approved by ADOT and the TAC, were sent to the motorists on December 19, 2002 as shown in **Appendix D**.

2) Interviews with Local Business and Emergency Services – Representatives of local businesses were interviewed to discuss if the roundabouts presented any concern to their operations or if their employees have raised any issues regarding the facilities, whether positive or negative. Input from these businesses is thought to be constructive since they are most likely frequent users of the facilities, and operate different vehicle types. The following parties were contacted for their input:

   - City of Phoenix – Skunk Creek Landfill Operations
   - City of Phoenix Police Department
   - City of Phoenix Fire Department
   - USAA (large financial services company serving the U.S. military)
   - Madison Granite Supply

   Representatives were also provided numerous survey cards to be passed out to their employees or frequent users of the identified operation. The employees were asked to return the filled-out form to the representative for later pick-up. Employees were also asked that they not return more than one card, since they may have received the same survey card in the mail via the direct mailing efforts.

   Comments resulting from the interview process were recorded and are summarized below:

   Positive comments from the interview process:
   - The roundabouts operate more efficiently than the previous stop-controlled intersections.
   - There are fewer severe accidents at the roundabouts than at signal controlled intersections.
   - If accidents do occur, they happen at a reduced rate of speed with less vehicle damage than accidents at other intersection types.
   - The roundabouts can accommodate all vehicle types without special driving techniques required.
   - Delays and vehicle queues are nearly non-existent at the major approaches with the most vehicle volume.
   - The roll curb design for the infield section is beneficial to fire, emergency, long trucks, and also passenger vehicles that have to make sudden maneuvers to avoid collisions.
   - Approach sight distance leading into the roundabouts is good.

   Negative comments from the interview process:
   - There is negative superelevation at the west roundabout west side, possibly leading to some of the truck overturn accidents at this location.
   - There is more driver confusion approaching and within the circulatory roadway than at signal controlled intersections.
   - Signage is confusing.

- There are two entering lanes at most approaches and two exiting lanes at some departures, yet there is only one lane within the roundabout.

3) On-Line Survey – The questionnaire was placed on the consultant's website for any local resident or business that may have not been captured in the first two methods. Local newspapers and community newsletters were contacted to print a press release about the project and refer readers to the web-site where they may complete an on-line survey if interested. The following news groups were contacted:

    - Arrowhead Ranch Independent
    - Sonoran News
    - North Valley Partnership

    Unfortunately, news articles relating to the project were not published. However, limited exposure to the survey on the website was facilitated through phone calls made by citizens that had heard of the study and wanted to voice their opinions. In order to ensure that surveys completed on-line were not duplicates of previous on-line survey submittals, the IP (internet protocol) address of each on-line submittal was checked against any previously received submittals from the same IP address.

3.3.3 Public Opinion Sampling Results

Results from each of the three sampling techniques - license plate/mailback survey, interview/direct handout survey and the on-line survey – have been collected and tabulated to determine motorist sentiment toward the roundabouts. Survey responses were compiled for approximately two months from the end of 2002 through the beginning of 2003. Availability of the on-line survey broadened the basis for the public opinion responses by reaching motorists that had driven through the roundabout, but may have not been "captured" by the public opinion surveying methods. However, the number of on-line responses were hindered by a lack of public awareness since local community/neighborhood newspapers did not show much interest in presenting the information about the on-line survey. Table 2 identifies the number of questionnaires that were provided to each of the survey groups along with the number of completed questionnaires returned and the corresponding response rate per group.

Table 2 – Survey Card Distribution and Response

Survey Type	Number of Survey Cards Distributed	Number of Survey Cards Returned	Response Rate
License Plate Mailing	3539	1116	31.5 %
Direct Handouts			
Landfill	100	5	5.0 %
Police	50	34	68.0 %
Fire	58	12	20.7 %
USAA	1200	719	59.9 %
Quarry	50	0	0.0 %
Subtotal	*1458*	*770*	*52.8%*
Plate and Handout Subtotal	4997	1886	37.7 %
On-Line	n/a	12	n/a
Grand Total	n/a	1898	n/a

Due to the small number of responses received from some units, totals were summarized into two groups, USAA and all others. ***Figures 21 through 26*** illustrate the group response summaries to each question along with total sample results**.** ***Figure 27*** shows the write-in comments categorized by common themes. Due to the wide range of responses for this question, the comments were read and placed into one or more specific categories. Therefore, the total number of comments exceeds the number of returned cards.

The survey results that were collected from USAA and the other groups (landfill, quarry, police, and fire) receiving direct handouts were accounted for separately in addition to being considered components of the total public opinion as displayed in the following figures. The responses from these groups, particularly USAA (whose buildings are located in the northeast quadrant of the east roundabout), were examined in detail to help determine any inherent influence from these groups that have a greater opportunity to use the Happy Valley roundabouts.

In the case of USAA, the consideration of influence was also important due to the sheer proportion of USAA responses to the overall total of survey responses (USAA received 1200 of the nearly 5000 surveys sent out which yielded 719 responses out of the 1886 received). USAA employees have the insight of experiencing the operations of the roundabouts on a daily basis since the most direct route to access their facility is via the roundabouts at the interchange. This increased exposure and experience suggests that the USAA responses would be more informed and also of greater conviction. However, this perspective must not be misconstrued, especially given the proportion of USAA responses to the rest of the sample.

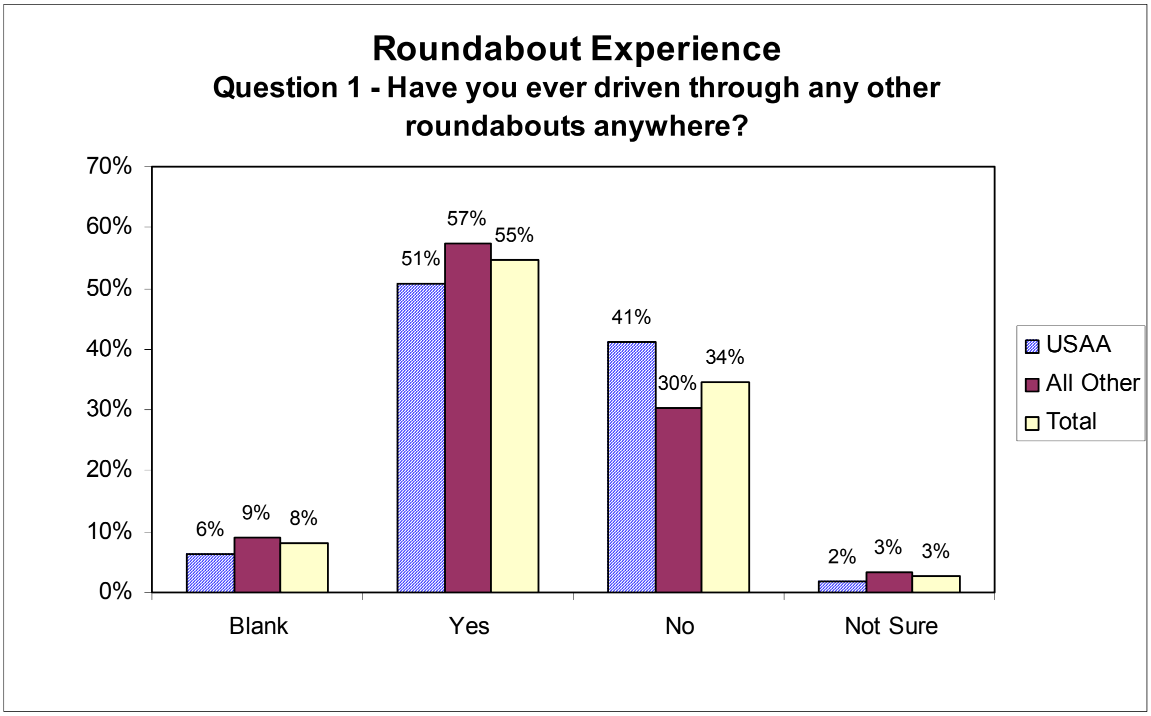


Figure 21 – Question 1 Results

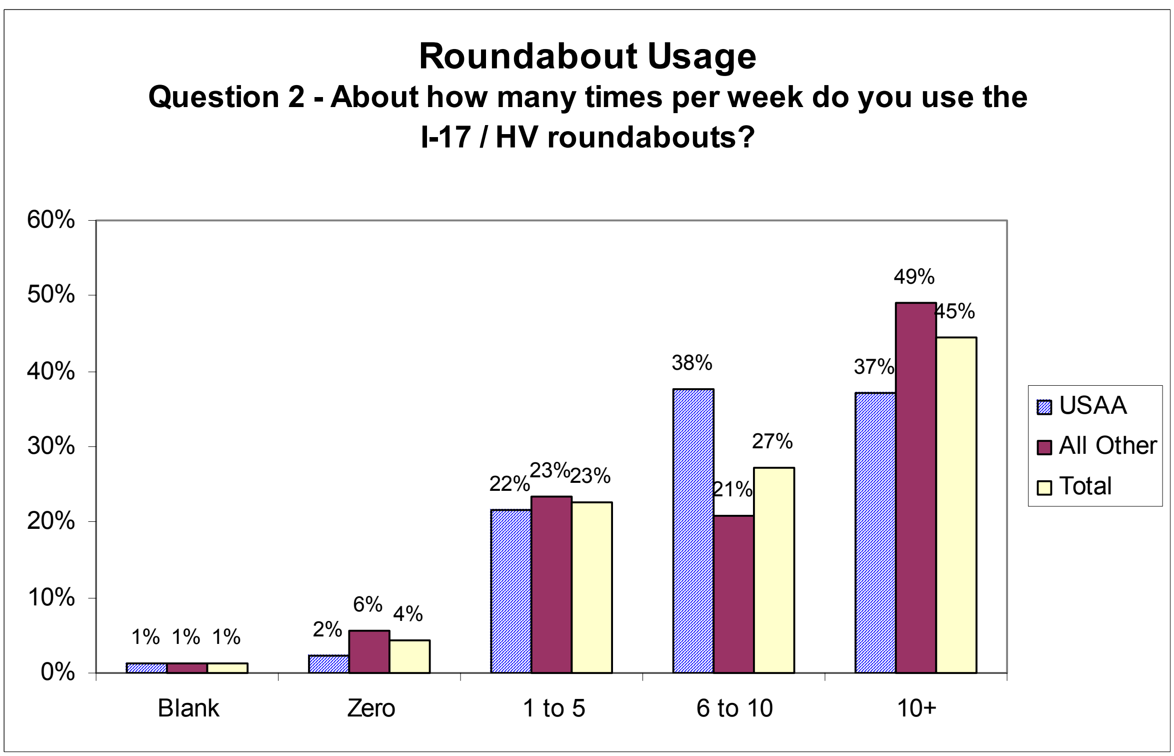


Figure 22 – Question 2 Results

Roundabout Comparison
Question 3 - Compared to typical freeway interchanges, I think the Happy Valley roundabouts are…

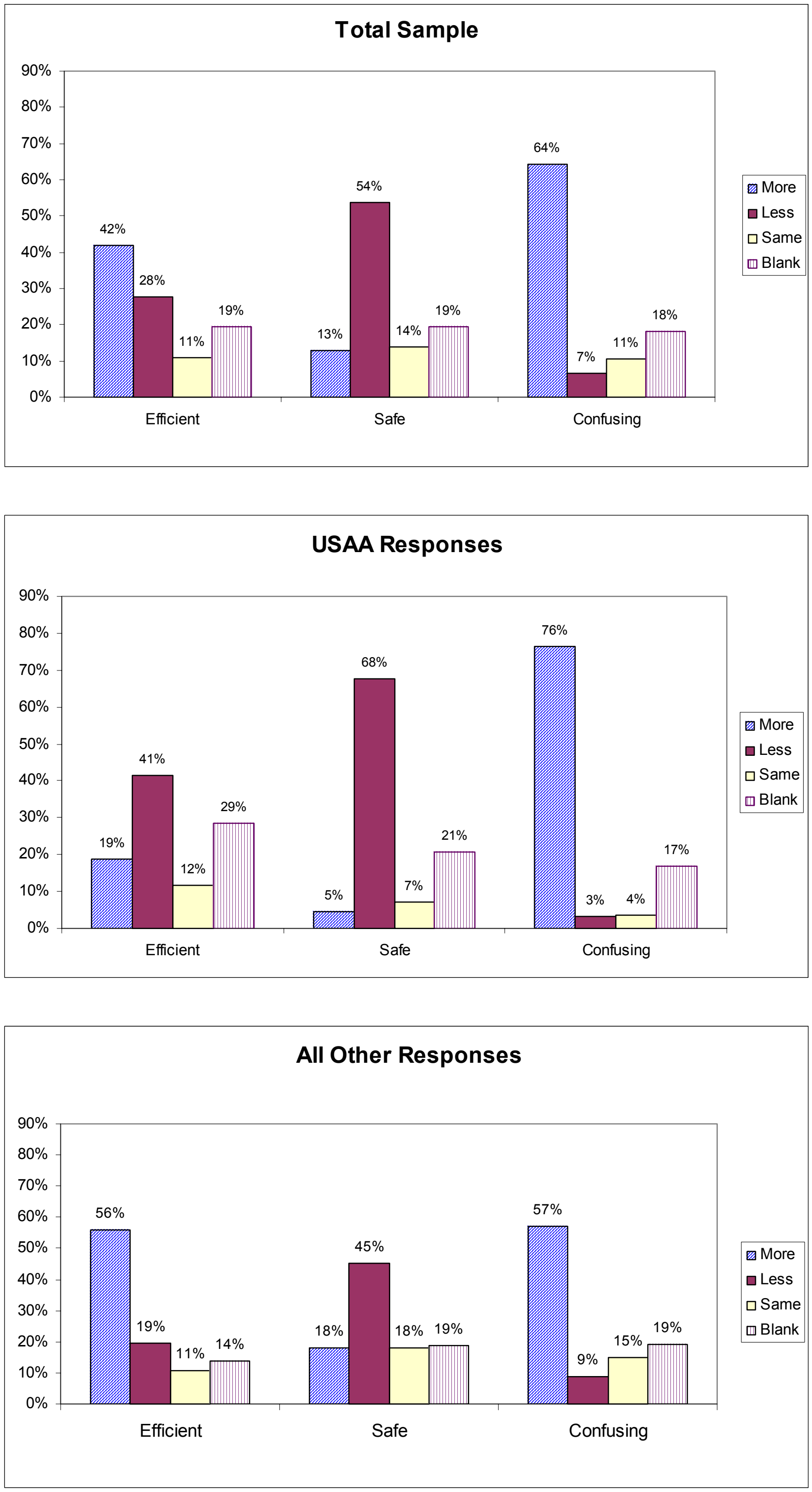


Figure 23 – Question 3 Results

Roundabout Comparison
Question 4 - When traveling through the Happy Valley roundabouts, I have a clear understanding of where to go and how to get there.

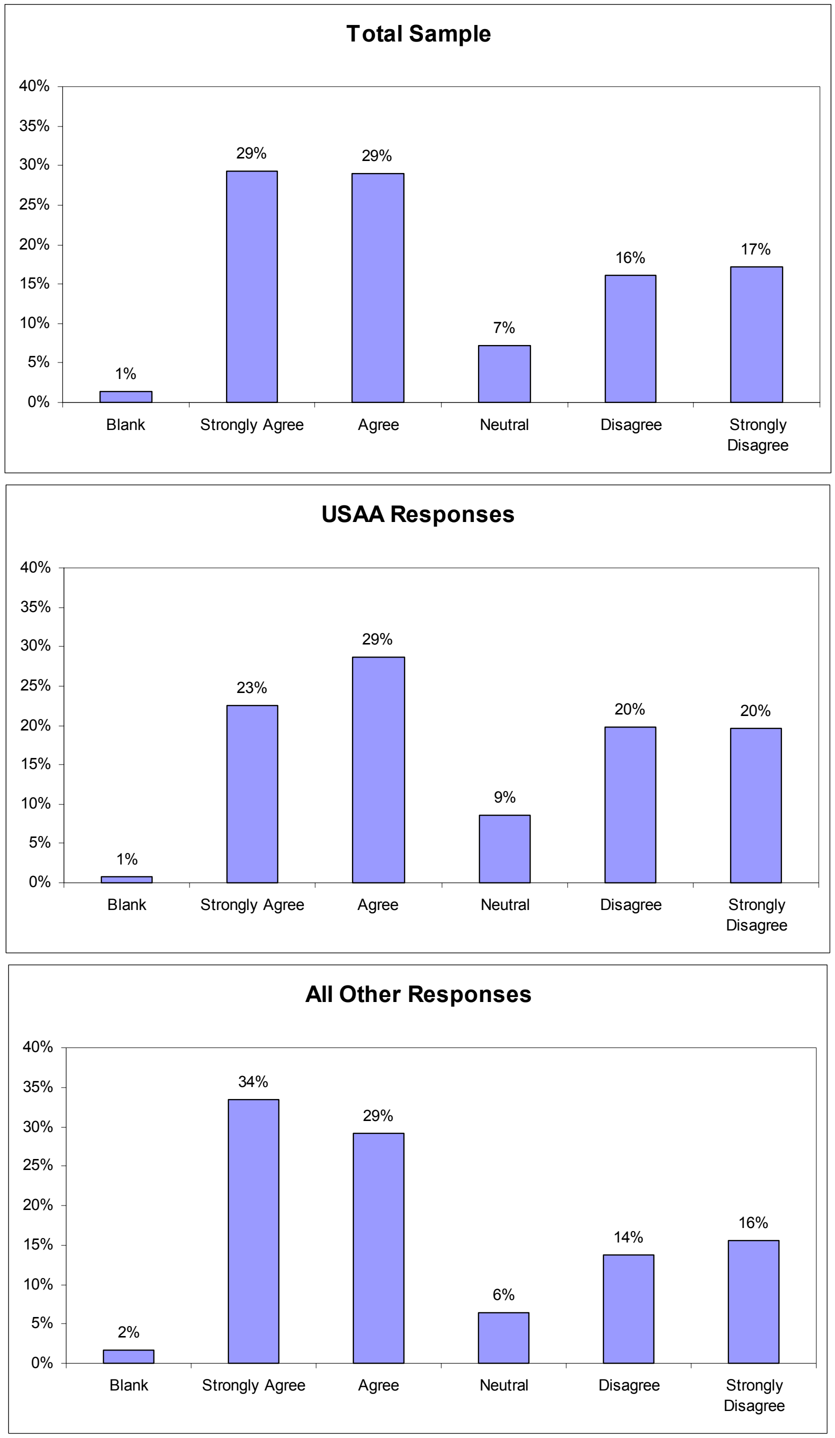
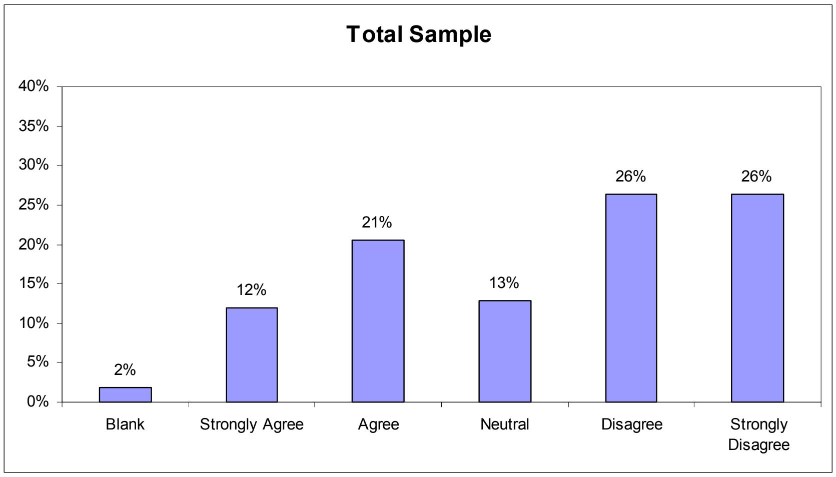
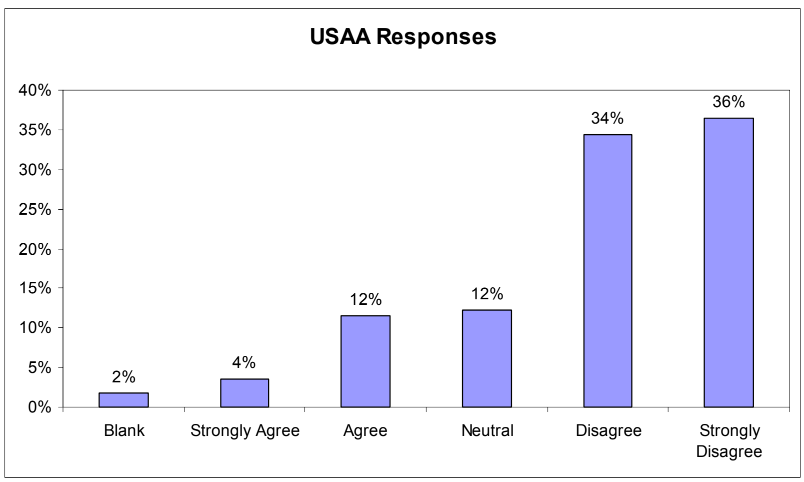


Figure 24 – Question 4 Results

Roundabout Guide Signs
Question 5 - Do you feel the directional guide signs are clearly understandable and visible to drivers?





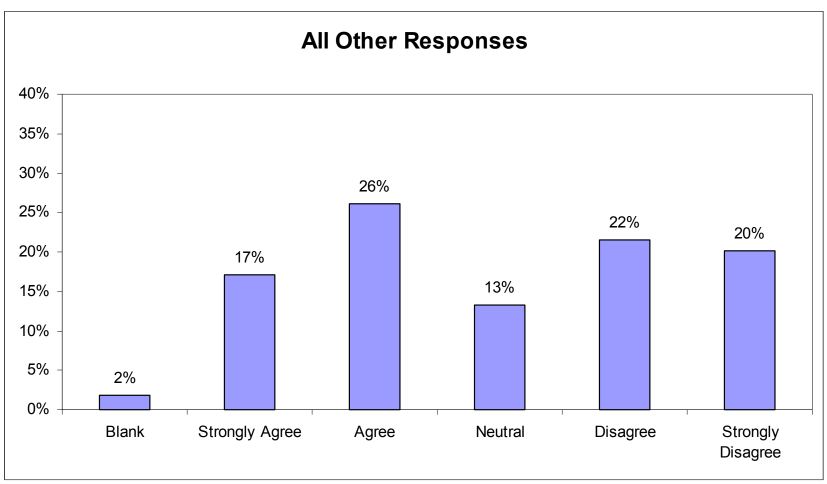


Figure 25 – Question 5 Results

Roundabout Acceptance
Question 6 - Overall, what do you think of these roundabouts?

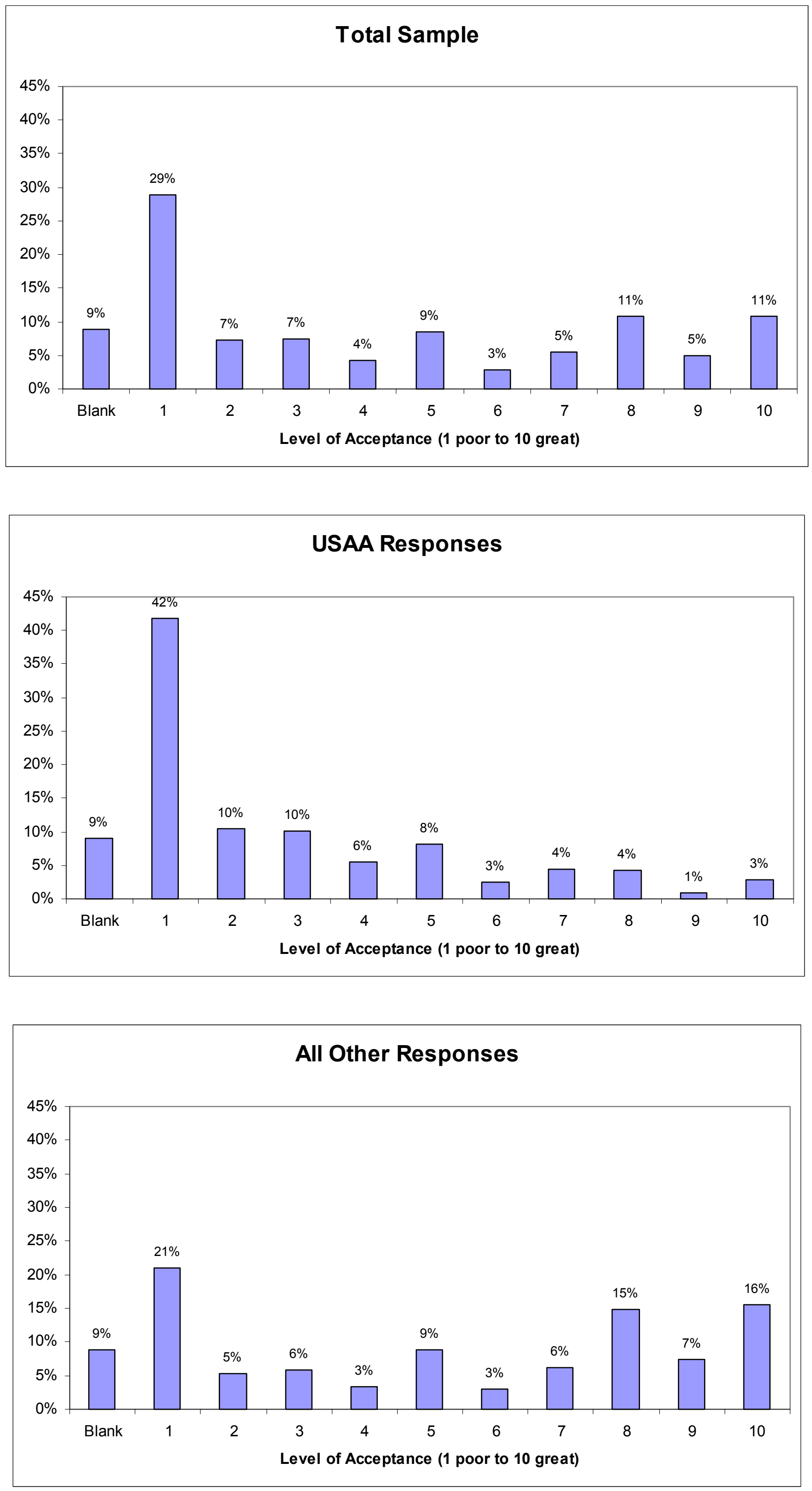


Figure 26 – Question 6 Results

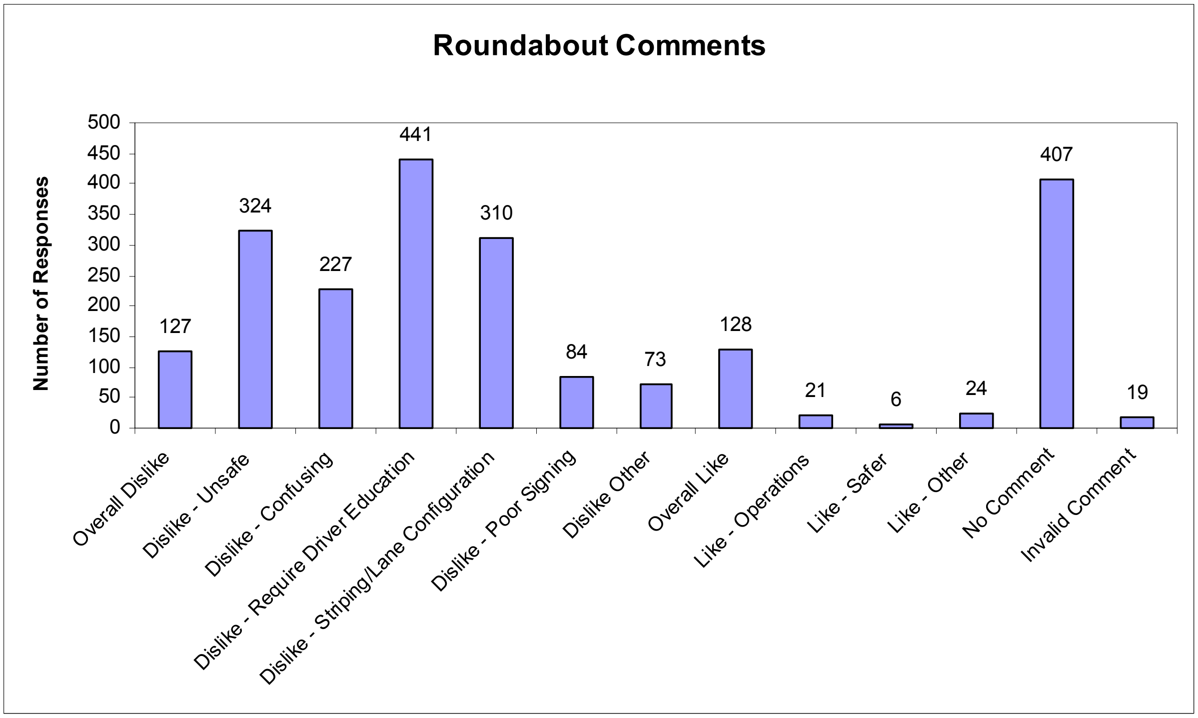


Figure 27 – Categorized Write-In Comments from Roundabout Survey

The following highlight the results of the questionnaire survey (a photocopy of the survey questionnaire is located in **Appendix D**):

- Question 1/Figure 21 - Over 50% of all respondents have driven through other roundabouts.
- Question 2/Figure 22 - 4% of the survey respondents indicated that they do not use the Happy Valley roundabouts regularly.
- Question 3/Figure 23 - The majority of respondents feel the roundabouts are more efficient (i.e., less delay/queuing), but less safe and more confusing than typical freeway interchanges.
- Question 3/Figure 23 - USAA personnel believe the roundabouts are less efficient than typical interchanges in contrast to other users who feel that they are more efficient.
- Question 4/Figure 24 - The majority of respondents feel they have a clear under-standing of how to navigate the roundabouts.
- Question 5/Figure 25 - Respondents feel that the guide signs are not clearly under-standable and visible to drivers.
- Question 6/Figure 26 - Overall, the majority of USAA personnel (62%) do not like the roundabouts (a response of 1 to 3 with 10 being the highest positive answer) with very few giving positive indications (a response of 7 to 10), whereas the survey group excluding the USAA sample identified a more positive response (44%) than negative (32%).
- Write-In Comments/Figure 27 - Respondents identified the need for driver educa-tion as the most notable problem at the roundabouts. This category encompassed a

wide response range that noted they like the roundabouts, but felt that other drivers did not know how to drive them properly. Other frequent comments were categorized as dislike due to being unsafe, poor striping/lane configurations, and confusing to navigate. A relatively small number of respondents provided specific comments identifying that they liked the roundabouts.

A further explanation of the write-in comment section is required to provide a better understanding of its results. If a respondent indicated a negative impression toward the roundabouts (a number of 1 through 3 to Question 6), they provided a mostly negative statement in the comment section. This is also true for most of the positive responses (7 through 10) to Question 6. Motorists that like the roundabouts indicated that first-time/part-time users are confused with the roundabout concept and/or that the lane configuration/striping could be improved. The results of the write-in comments from the surveys give the impression that a higher percentage of drivers would like the roundabouts if drivers were more educated on their concepts and if the lane configuration/ striping situation was remedied.

The review of ***Figures 21-27*** shows that the USAA responses tend to enhance responses that reflect negatively on the roundabouts' operations. This effect is particularly evident regarding Question 3 and 6. A portion of Question 3 concerns the perceived efficiency of the roundabouts compared to other typical interchange traffic control. The responses from the sample other than USAA resulted in a 56% response of the roundabouts operating more efficiently while the USAA component had only 19% of the respondents feeling the same way. This resulted in the total sample percentage of 42% for the same response. Question 6, which relates to the respondent's overall impression of the roundabouts, was also affected by the large USAA contingent that was overwhelmingly negative (about 68% with a "4" or less with 42% responding with "1", the lowest rating allowed by the survey). The sample results without the USAA component (***Figure 26***) show about half as many "negative" ("4" or less) responses. It is also important to realize that in all likelihood some portion of the responses from the license plate mailings (the main component of the "all other responses") were from USAA employees since they are frequent users of the roundabouts. Therefore, it is possible that the results from the "all other responses" will have some of the USAA disapproval shown to be inherent to the responses directly attributable to USAA.

A characteristic of the interchange that might be attributable to USAA's generally critical responses relates to the basic operation of roundabouts and the existing peak hour traffic conditions. Roundabout operation dictates that traffic flows counter-clockwise on the circulatory roadway. In the PM peak hour traffic conditions at the east roundabout, the heavy off-ramp traffic flow essentially has the right-of-way within the roundabout since the eastbound traffic from the bridge side of the roundabout is relatively light. Therefore, the off-ramp traffic movement is nearly free flow because of the standard yield control entry. This results in the "downstream" entries (the westbound approach of Happy Valley Road and the frontage road approach) to the roundabout being burdened with trying to find acceptable gaps in a nearly free-flow traffic stream to enter the roundabout. Subsequently, there are not that many acceptable gaps which either leads to the other entry traffic taking chances with less than acceptable gap distances or becoming frustrated with the roundabout design/operation. The USAA employees that wish to access southbound I-17, westbound Happy Valley Road, and to some extent northbound I-17 (since its on-ramp is via a U-turn originating from the frontage road) experience this frustration first-hand since they have no choice other than to enter the roundabout via the Happy Valley Road approach or the frontage road approach.

Another factor that may have influenced all responses is the particular design of the Happy Valley roundabouts. The roundabout operations at the Happy Valley interchange are made more complex through the operations of the two-way frontage roads. It is important to consider that even without the roundabout traffic control, two-way frontage roads generally tend to cause some confusion to drivers in an interchange configuration. Therefore, some of the negative responses may be associated with the basic roundabout operations only or may be influenced by the two-way frontage road operations at the roundabouts.

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3.4 GEOMETRIC LAYOUT EVALUATION

3.4.1 Original Design

Figures 28 and 29 show the original design of the east and west roundabouts, respectively. As shown in these figures, the roundabouts feature two-lane entries at all approaches. Right-turn bypass lanes also exist at all approaches where right-turn movements are possible. As noted previously, the primary motivation behind ADOT's installing roundabouts at these ramp terminal intersections was to enhance capacity at the intersections without widening of the existing two-lane overpass structure. To avoid merging conflicts over the bridge, the roundabouts were designed to allow only one lane of circulatory traffic despite two-lane entries on some approaches. More discussion on the number of entry and circulatory lanes is provided in the *Lane Balance* section of this report.

3.4.2 Subsequent Design Modifications

Subsequent to the roundabouts being constructed, the City of Phoenix completed the widening of the north half of Happy Valley Road on the east side of the I-17 interchange (substantially complete by October 2002). Similar widening of the south half of the roadway will occur in conjunction with land development on the south side of Happy Valley Road. Once the widening is complete, Happy Valley Road will have a six-lane cross section with a 24-foot median. Currently, the westbound leg to the east roundabout has two approach lanes that enter the roundabout and an exclusive right turn lane for traffic turning north onto the frontage road. The departing eastbound traffic merges with the right-turn bypass lane from the northbound I-17 off-ramp to form one eastbound lane about 300-600 feet east of the east roundabout.

Happy Valley Road west of the west roundabout will also be widened in the near future. The ultimate cross section for the roadway in this area will be a six-lane section with a 14-foot median. These improvements are planned to commence sometime in the summer of 2003 and continue for about a year. This particular cross section will continue west from I-17 to 35th Avenue. Currently, the eastbound traffic can approach the roundabout via two lanes or use a flared transition area in order to access the right-turn bypass lane and the southbound I-17 on-ramp. The departing westbound traffic merges with the right-turn bypass traffic from the frontage road into one westbound lane at a distance of about 200 feet west of the west roundabout.

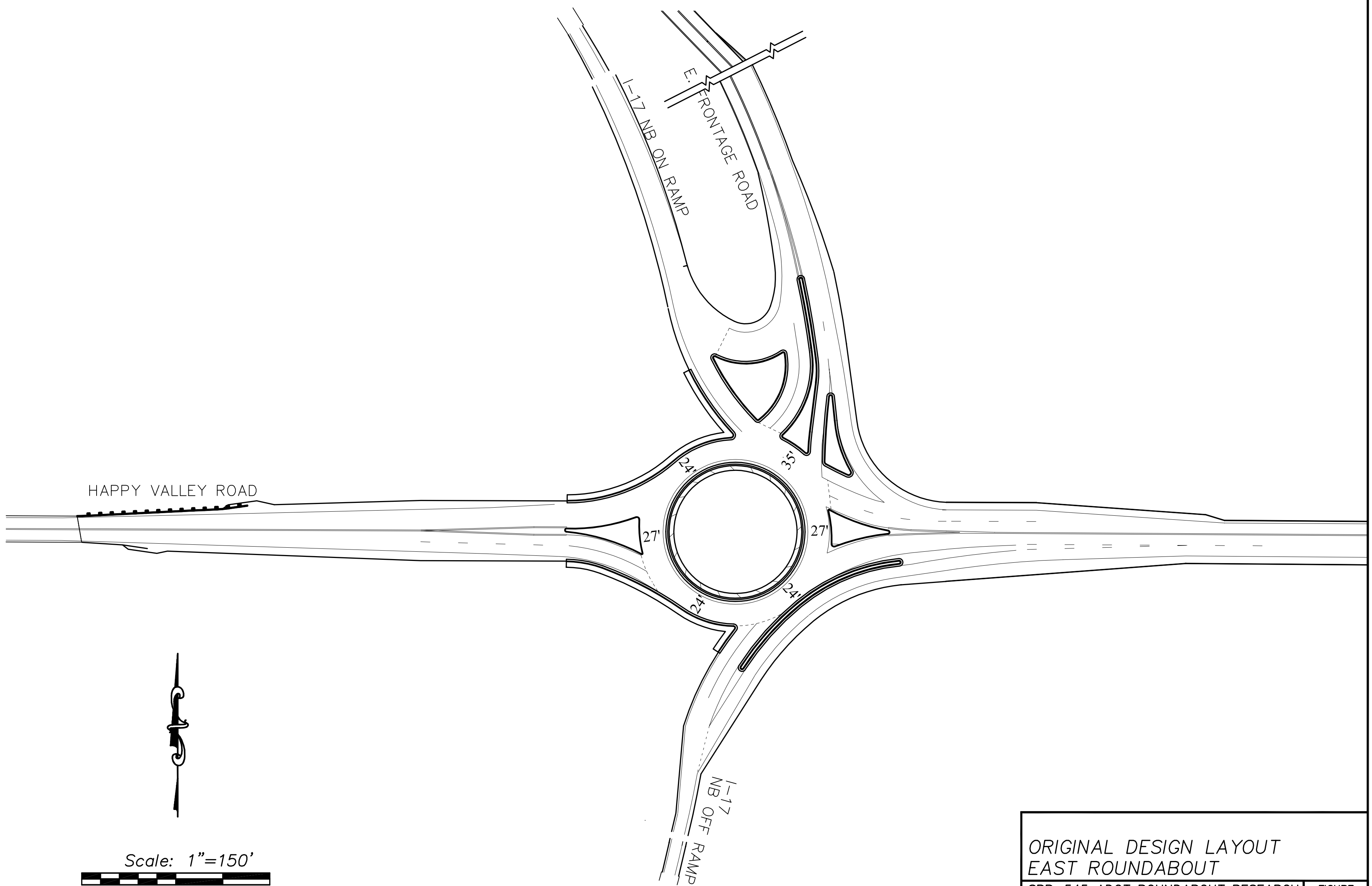
With the exception of minor signing and striping enhancements, the I-17 on-ramp and off-ramp legs at both roundabouts, the frontage road legs at both roundabouts, and the section of Happy Valley Road between the roundabouts have not been modified from the original design.

3.4.3 Geometric Evaluation

Fundamental principles for the geometric design of roundabouts are detailed in Chapter 6 of the *FHWA Guide* [1]. Additional guidance is from the research and practices developed in other countries with more roundabout experience than the United States, particularly the United Kingdom and Australia. The roundabouts at the I-17/Happy Valley Road interchange were evaluated in accordance with these design guidelines and principles. This section summarizes the fundamental geometric design principles and provides comments related to the I-17/Happy Valley Road roundabouts.

3.4.3.1 *Design Speed and Speed Consistency*

One of the most critical design objectives is achieving appropriate vehicular speed through the roundabout. Roundabouts operate most safely when their geometry forces traffic to enter and circulate at slow and relatively consistent speeds. To determine the speed of the vehicle at a roundabout, the fastest path allowed by the geometry is drawn. This is the smoothest, flattest path possible for a single vehicle, in the absence of other traffic and ignoring all lane markings. The fastest path is drawn for a vehicle traversing through the entry, around the central island, and out the exit. ***Figure 30*** illustrates how the fastest vehicle path is constructed for a through movement at a typical double-lane roundabout.



ORIGINAL DESIGN LAYOUT
EAST ROUNDABOUT

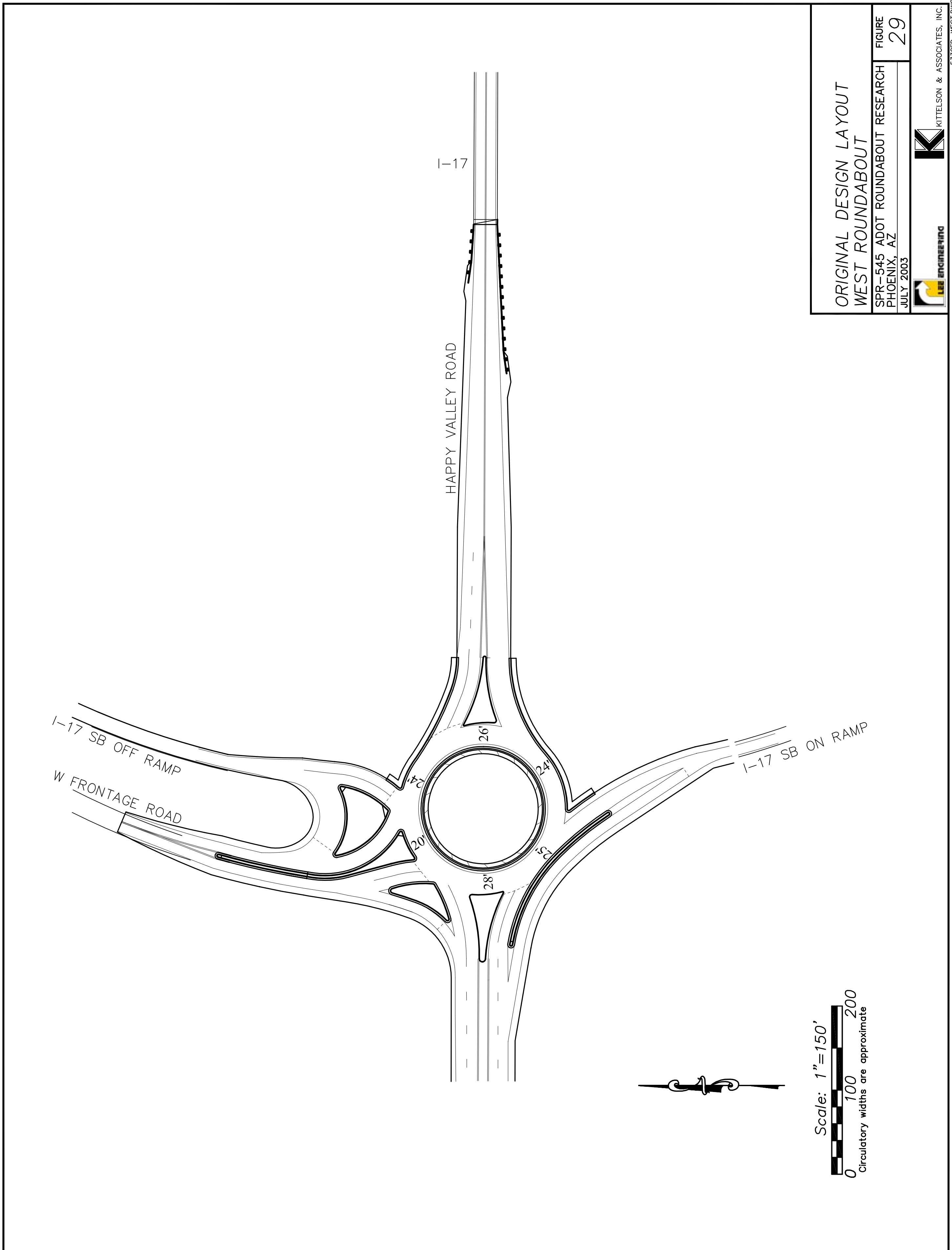
SPR-545 ADOT ROUNDABOUT RESEARCH
PHOENIX, AZ
JULY 2003

FIGURE 28

LEE ENGINEERING

KITTELSON & ASSOCIATES, INC.

5332FD-WEST.DWG


ORIGINAL DESIGN LAYOUT
WEST ROUNDABOUT
SPR-545 ADOT ROUNDABOUT RESEARCH
PHOENIX, AZ
JULY 2003
FIGURE
29
KITTELSON & ASSOCIATES, INC.
5332FD-WEST.DWG
LEE ENGINEERING
I-17
HAPPY VALLEY ROAD
I-17 SB OFF RAMP
W FRONTAGE ROAD
I-17 SB ON RAMP
26'
24'
24'
20'
25'
28'
Scale: 1"=150'
0
100
200
Circulatory widths are approximate

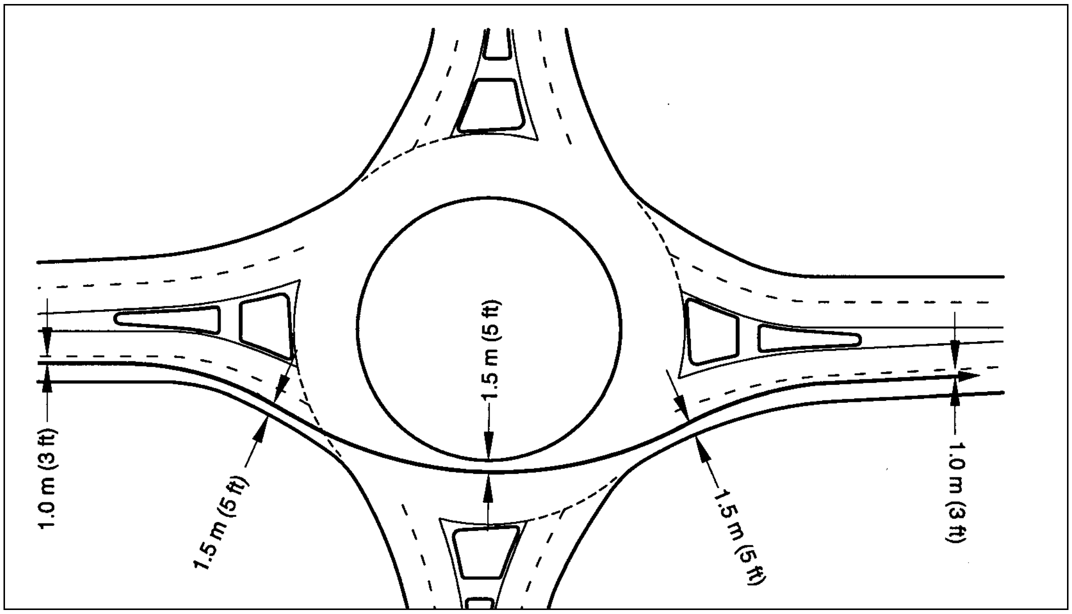


Figure 30
Construction of Fastest Path through Double-Lane Roundabout
(source: *FHWA Guide* Exhibit 6-6 [1])

Once the fastest path is drawn, the minimum radius of each curve along the path is measured. The corresponding design speed of each curve along the path is then calculated in accordance with the speed-curve equations in the standard AASHTO reference manual *A Policy on Geometric Design of Highways and Streets* [8]. **The recommended maximum design speed for typical single- and double-lane roundabouts in suburban environments is 25 mph**. In rural environments, it is often acceptable to allow design speeds up to 30 mph. It is most critical to achieve the target design speed at the roundabout entries. Exit speeds may be greater than the 25 mph target; however, they should generally be kept low to maximize safety for pedestrians.

In addition to achieving an appropriate design speed for the fastest movements, the relative speeds between consecutive geometric elements comprising the path should be minimized and the relative speeds between conflicting traffic streams should be minimized. The fastest paths are drawn for all movements at all approaches of the roundabout to determine these relative speeds. ***Figure 31*** illustrates the five critical path radii that must be checked at each approach.

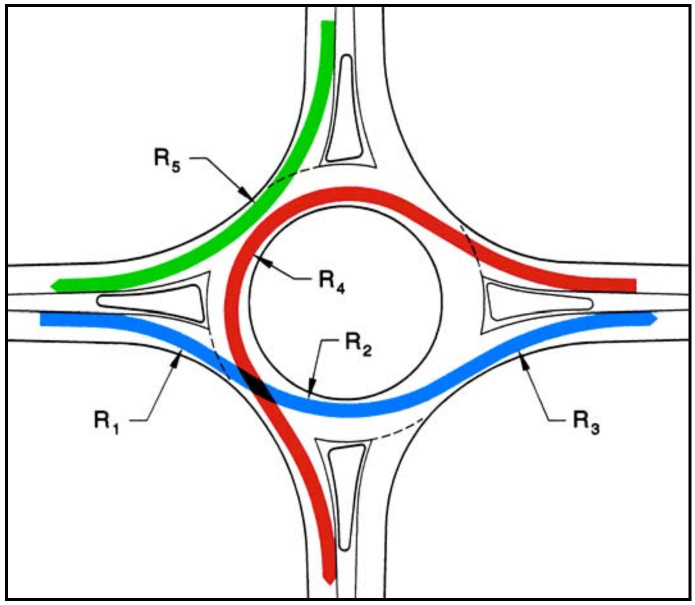


Figure 31
Vehicle Path Radii
(source: FHWA Guide [1])

Achieving speed consistency reduces the likelihood of loss-of-control crashes, entering-circulating crashes, and single-vehicle crashes. *It is advisable that the speed differentials should be no greater than 12 mph, and preferably less than six mph.* In other words, the difference between the design speeds of any two consecutive curves along a path or between two conflicting paths should less than 12 mph and preferably less than six mph.

The fastest paths at the I-17/Happy Valley Road interchange roundabouts were sketched in accordance with the guidelines shown in ***Figure 32***. Tables 3 and 4 summarize the design speeds of each of the five critical radii at each approach at the west and east roundabouts, respectively. Entry speeds greater than 25 mph and all speeds greater than 12 mph above the lowest circulatory speed are highlighted in bold. Figures displaying the fastest path sketches are provided in **Appendix E**.

Table 3
Roundabout Design Speeds at West Roundabout

Approach	Parameter	R1	R2	R3	R4	R5
Eastbound Happy Valley Road	Radius	240’	100’	240’	80’	410
	Speed	**29 mph**	19 mph	29 mph	18 mph	**35 mph**
Westbound Happy Valley Road	Radius	320’	100’	240’	80’	100’
	Speed	**32 mph**	19 mph	29 mph	18 mph	21 mph
Southbound I-17 Off-Ramp	Radius	125’	80’	410’	80’	360’
	Speed	23 mph	18 mph	**35 mph**	18 mph	**33 mph**
Southbound Frontage Road	Radius	410’	120’	410’	80’	115’
	Speed	**35 mph**	20 mph	**35 mph**	18 mph	22 mph

Table 4
Roundabout Design Speeds at East Roundabout

Approach	Parameter	R1	R2	R3	R4	R5
Eastbound Happy Valley Road	Radius	360’	100’	320’	80’	-
	Speed	**33 mph**	19 mph	**32 mph**	18 mph	-
Westbound Happy Valley Road	Radius	240’	100’	360’	80’	115’
	Speed	**29 mph**	19 mph	**33 mph**	18 mph	22 mph
Northbound I-17 Off-Ramp	Radius	240’	125’	715’	80’	360
	Speed	**29 mph**	20 mph	**>40 mph**	18 mph	**33 mph**
Southbound Frontage Road	Radius	115’	-	-	80’	480’
	Speed	22 mph	-	-	18 mph	**35 mph**

At the I-17/Happy Valley Road interchange, there are several locations where the design speed and speed consistency objectives are not met. As shown in the Tables 3 and 4, at the west roundabout the entry speeds of the eastbound Happy Valley Road (29 mph), the westbound Happy Valley Road (32 mph), and the southbound frontage road (35 mph) approaches are all over the target design speed of 25 mph. At the east roundabout, both the eastbound (33 mph) and westbound (29 mph) entry speeds are greater than 25 mph. In addition, the right-turn speeds (R5) and through-movement circulatory speeds (R3) of some approaches are over 30 mph.

The minimum speed within the roundabout is the left-turn path (R4), which is 18 mph. To reduce the speed differential between circulating vehicles and entering vehicles, the entry speed at all approaches should be less than 30 mph.

3.4.3.2 *Approach Alignment*

Ideally, the centerline of the roundabout approaches should align with the center of the roundabout. However, it is acceptable for the approach to be slightly offset to the left of the center point, since this alignment enhances the deflection of the entry path. If it is aligned too far to the left, the exiting traffic path will be more tangential which may cause higher exit speeds. If the alignment of the entry is offset to the right, the approach geometry may not provide enough deflection for the entering vehicles. Therefore, approach alignments offset to the right of the roundabout center should be avoided. ***Figure 32*** illustrates the preferred approach alignment for roundabouts in general.

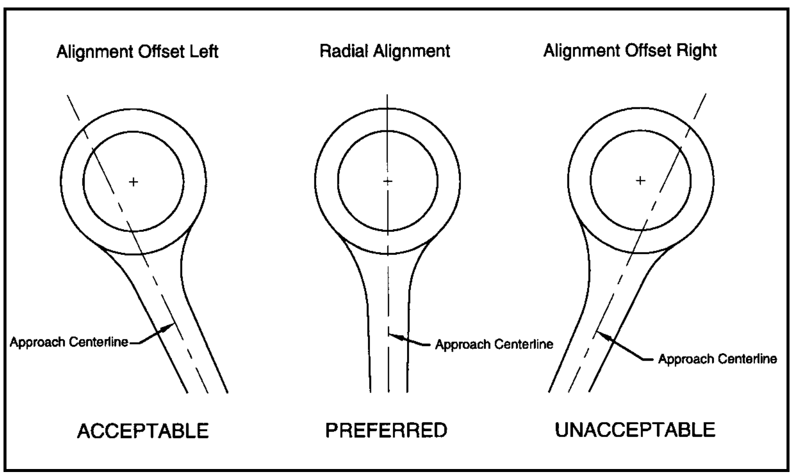


Figure 32
Approach Alignment Guidelines
(source: *FHWA Guide* [1])

At the west roundabout of the I-17/Happy Valley interchange, the alignment of the frontage road approach is offset far to the right of the roundabout center. As a result, this approach has a very high entry speed of 35 mph. At the east roundabout, the centerline of the frontage road is aligned far to the left of the roundabout center. Hence, the adjacent exit provides minimal curvature, which produces a very high exit path speed. Achieving slow exit speeds are generally less critical to the overall safety of the roundabout than entry speeds; however, excessive exit speeds may reduce pedestrian safety.

3.4.3.3 *Lane Balance*

To ensure consistency, *the circulatory roadway should be as wide as the widest entry approach*. Thus, at roundabouts with two-lane entries, the circulatory roadway should be wide enough for two adjacent traffic streams (although these circulatory lanes may not necessarily be striped). Failure to provide such consistency in the numbers of entry and circulatory lanes severely hampers the capacity of the roundabout. Furthermore, it may reduce the roundabout's safety as it causes confusion for drivers and can increase the likelihood for sideswipe crashes between adjacent entering traffic streams.

At the I-17/Happy Valley Road roundabout interchange, all approaches are striped for two-lane entries with widths ranging from 24 to 30 feet. However, the width of the circulatory roadway varies from 20 feet to 35 feet. Hence, at several approaches the capacity of the double-lane entries cannot be utilized as the circulatory width only accommodates a single-lane of traffic. Field observations revealed that the majority of drivers are familiar with the roundabout and choose a single entry-lane based on their desired turning movement. Drivers making through or left-turn movements generally use the left-hand entry lane, and drivers making right-turn movements choose the right-hand lane (at most approaches there is adequate circulatory width for right turns to occur simultaneously with through/left turns, but not adequate width for two through or left turn movements to occur simultaneously). Thus, the roundabouts effectively operate as single-lane roundabouts with the exclusion of right-turn traffic at most approaches.

Because of the familiarity and the overall courtesy of most users, the roundabouts are generally operating safely. However, unfamiliar drivers can be caught off-guard by the two-lane entries with no formal lane-use designations. These drivers may find themselves in the right-hand lane, for instance, intending to make a through movement. As they enter the roundabout, it causes conflicts with traffic in the left entry lane as both vehicles are competing for the single circulatory lane. Also, during the peak traffic periods when queues tend to form at the entries, assertive drivers occasionally disregard the tacit lane-use etiquette to bypass the queue, creating conflicts, confusion, and/or frustration at the entry points. As traffic volumes increase beyond the normal capacity of a single-lane roundabout, these operational issues will likely increase significantly.

3.4.3.4 *Angle and Spacing Between Legs*

In addition to the alignment and design speed objectives, it is generally desirable to equally space the distances and angles between the entries. Closely spaced approaches and/or small angles between approaches can result in more severe crossing angles between conflicting vehicles, difficult turning movements for oversized vehicles, and increased confusion for unfamiliar drivers navigating the roundabout. Furthermore, they often require wider pavement widths to accommodate tight right-turn movements, and this can result in ambiguous areas that do not meet driver expectancy.

At both the east and west roundabouts, the angles between the frontage road approaches and the adjacent legs are very small. The small angles and close spacing of these legs cause the yield lines of some entries to be set back approximately five to ten feet from the normal inscribed circle diameter. As a result, drivers at the yield line have a tendency to feel too far away from the circulatory roadway and tend to crawl forward beyond the striped yield line to be in better position to fill a gap in circulatory traffic. As they edge forward across the yield line, they may not anticipate circulating traffic exiting at the adjacent exit and occasionally block the exit. In some cases, vehicles at these entries have inadvertently clipped the corner of exiting vehicles.

3.4.3.5 *Path Overlap*

Path overlap exists at multi-lane roundabouts when the natural paths of vehicles in two adjacent traffic lanes cross or overlap one another. It occurs most often at entries, when the geometry causes vehicles in adjacent lanes to naturally travel into the same lane of the circulatory roadway. It may also occur at exits, where the exit geometry tends to cause side-by-side circulating vehicles to exit into the same lane. ***Figure 33*** illustrates path overlap at a typical roundabout.

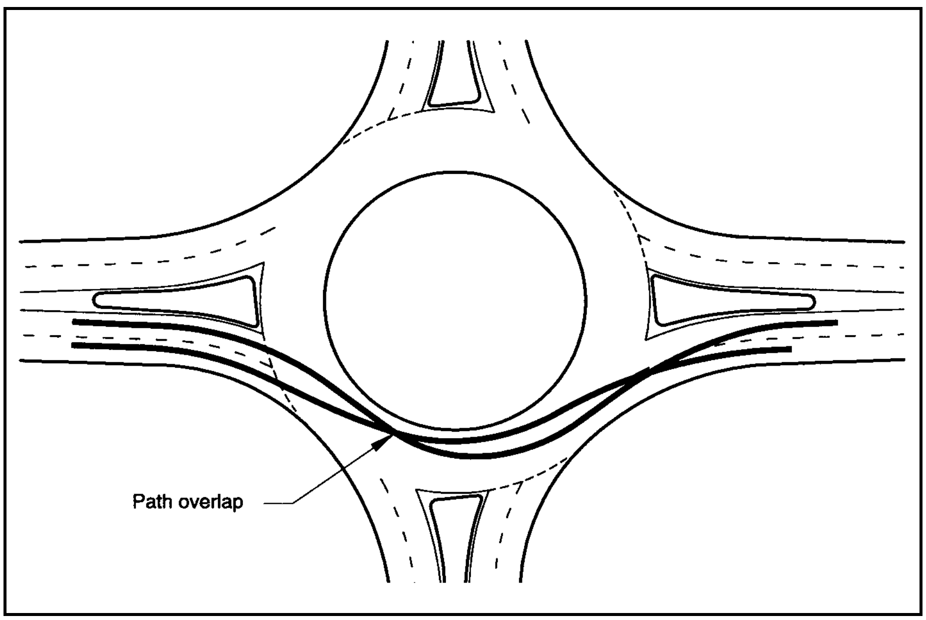


Figure 33
Path Overlap Example
(source: *FHWA Guide* [1])

Path overlap can be avoided at entries by ensuring that the geometry orients the natural trajectory of vehicles at the yield line into the appropriate circulatory lane. In other words, vehicles in the left-hand entry lane should be oriented toward the inside circulatory lane, while vehicles in the right-hand entry lane should be oriented toward the outer circulatory lane at the yield line. ***Figure 34*** illustrates the recommended design technique to avoid path overlap.

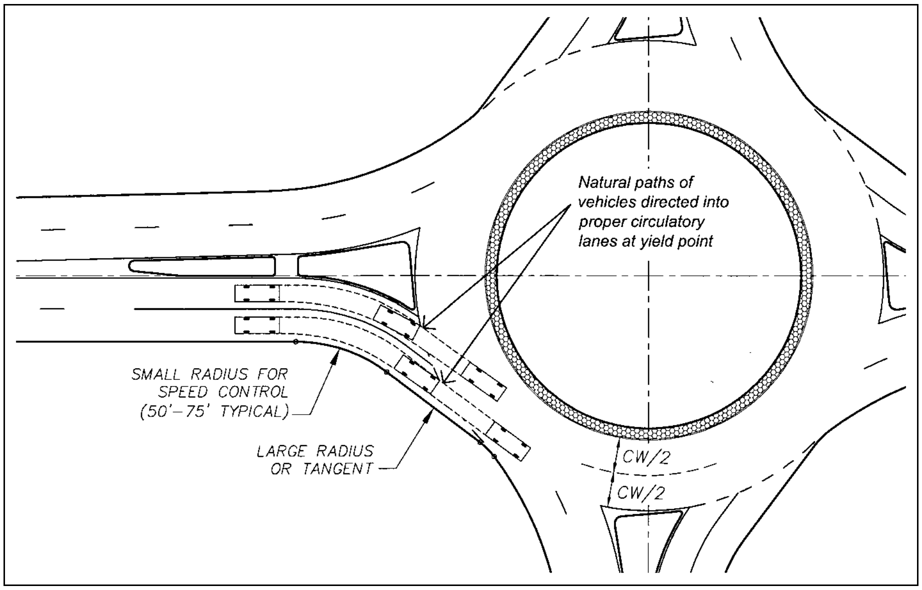


Figure 34
Recommended Multi-Lane Entry Design Technique

At the Happy Valley roundabouts, path overlap exists at all entries due to the narrow width of the circulatory roadway. The two-lane entries lead to a single-lane circulatory roadway, resulting in path overlap as vehicles in adjacent lanes must compete for the same space within the circulatory roadway. As most drivers are familiar with the roundabouts, vehicles generally use only one entry lane to avoid these path overlap conflicts. However, as improvements are considered, they should address the path overlap issues and ensure that the entries and exits are designed to promote clear and safe movements for two lanes of traffic through the roundabout geometry.

3.5 OPERATIONS/CAPACITY ANALYSIS

3.5.1 Introduction

Two analytical methodologies were used to evaluate roundabout capacity and operational performance at the study intersections:

- The procedure outlined in *Roundabouts: An Informational Guide* (*FHWA Guide* [1]), and
- SIDRA.

While SIDRA is an implementation of the Australian capacity model, the methodology in the *FHWA Guide* [1] is based on a combination of the British and German capacity models. SIDRA considers roundabout operations from a "gap-acceptance" perspective while the *FHWA Guide* methodology incorporates empirical data into its formulations. These different models generally yield similar results for roundabouts with moderate traffic volumes (moderate entry flows and/or moderate circulatory flows). However, in cases with high entry flows opposed by low circulatory volumes and vice versa (i.e. highly directional (unbalanced) flows), the models can yield significantly different results. Because there is very little data for actual roundabout performance in the United States, evaluation usually relies upon the worst-case capacity prediction to produce a more conservative design. In keeping with British and Australian practice, a maximum volume-to-capacity (V/C) ratio of 0.85 is targeted for design purposes.

3.5.2 Analysis of Traffic Volumes

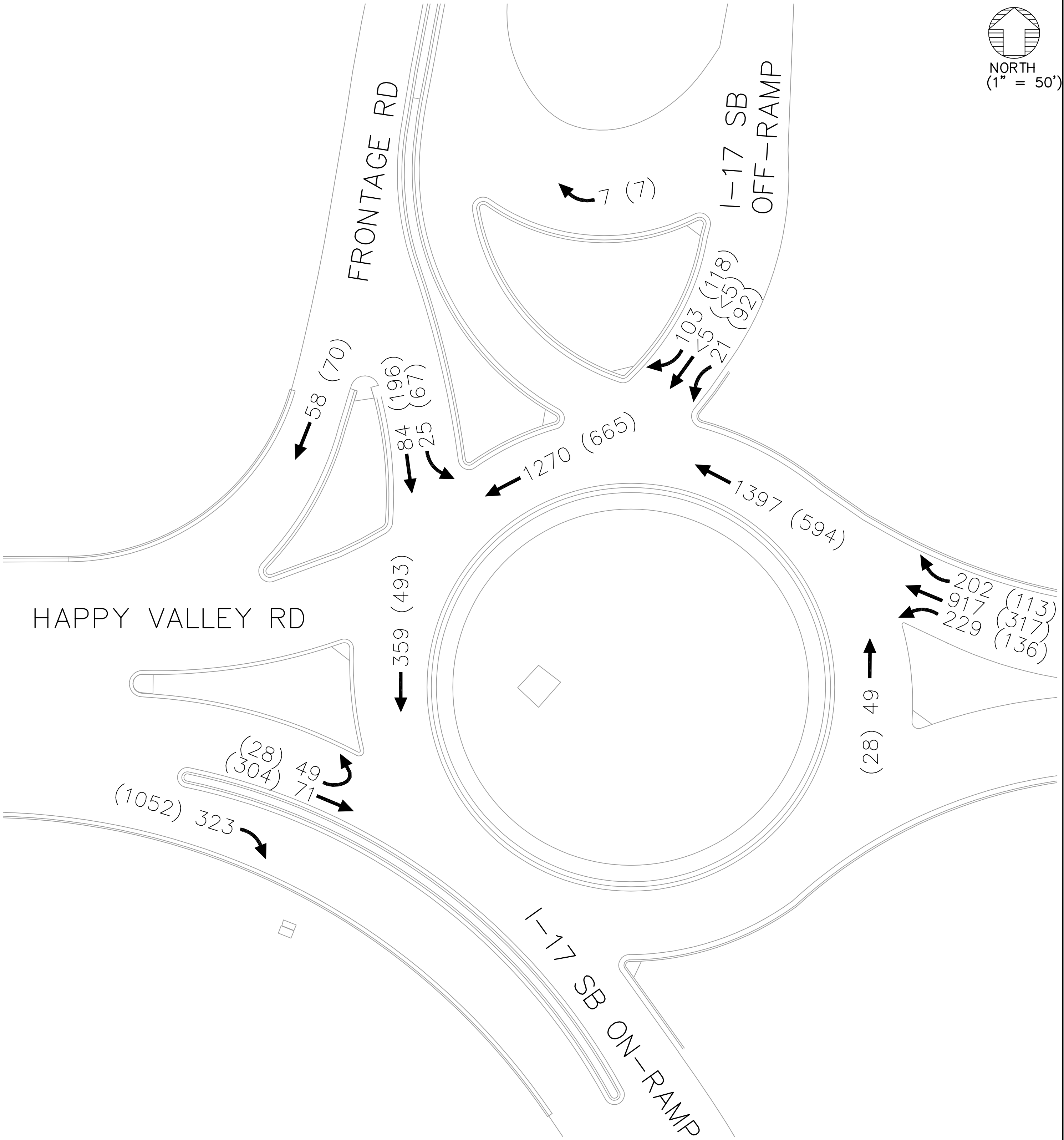
The existing intersection traffic volumes during the weekday AM and PM peak hours were obtained from the tube counts described in the *Data Collection* section. Turning movement volumes were estimated based on the origin-destination patterns determined from the actual observations of vehicle routing through the roundabouts (for more details, see the *Peak Period Turning Movement Counts* section of this report). ***Figures 35 and 36*** display the turning movement volumes used in this analysis at the west and east roundabouts, respectively. Roundabout operations have been evaluated for both the existing weekday AM and weekday PM peak hour traffic conditions.

3.5.3 FHWA Analysis Methodology

The *FHWA Guide* [1] provides a methodology for calculating the capacity of single- and double-lane roundabouts. According to the FHWA procedure, the maximum flow rate that can be accommodated at a given roundabout entry depends on two factors: 1) the circulatory flow within the roundabout that conflicts with the entry flow; and 2) the geometric elements of the roundabout.

Even though most of the approaches of the roundabouts have two-lane entries, the FHWA analysis was conducted for a single-lane roundabout because the varying circulatory roadway width forces traffic to enter in a single-lane fashion. At approaches where right-turn traffic tends to use the right-hand entry lane, the right-turn volume was removed from the analysis. The *Geometric Evaluation* section describes in more detail these geometric issues.

Table 5 summarizes the results of the roundabout analysis based on the FHWA methodology. Volume-to-capacity ratios greater than the 0.85 threshold are highlighted in bold. The FHWA analysis worksheets are included in **Appendix F**.



LEGEND
(XX) – AM PEAK
XX – PM PEAK
Data collected October 2002

TURNING MOVEMENT VOLUMES
WEST ROUNDABOUT

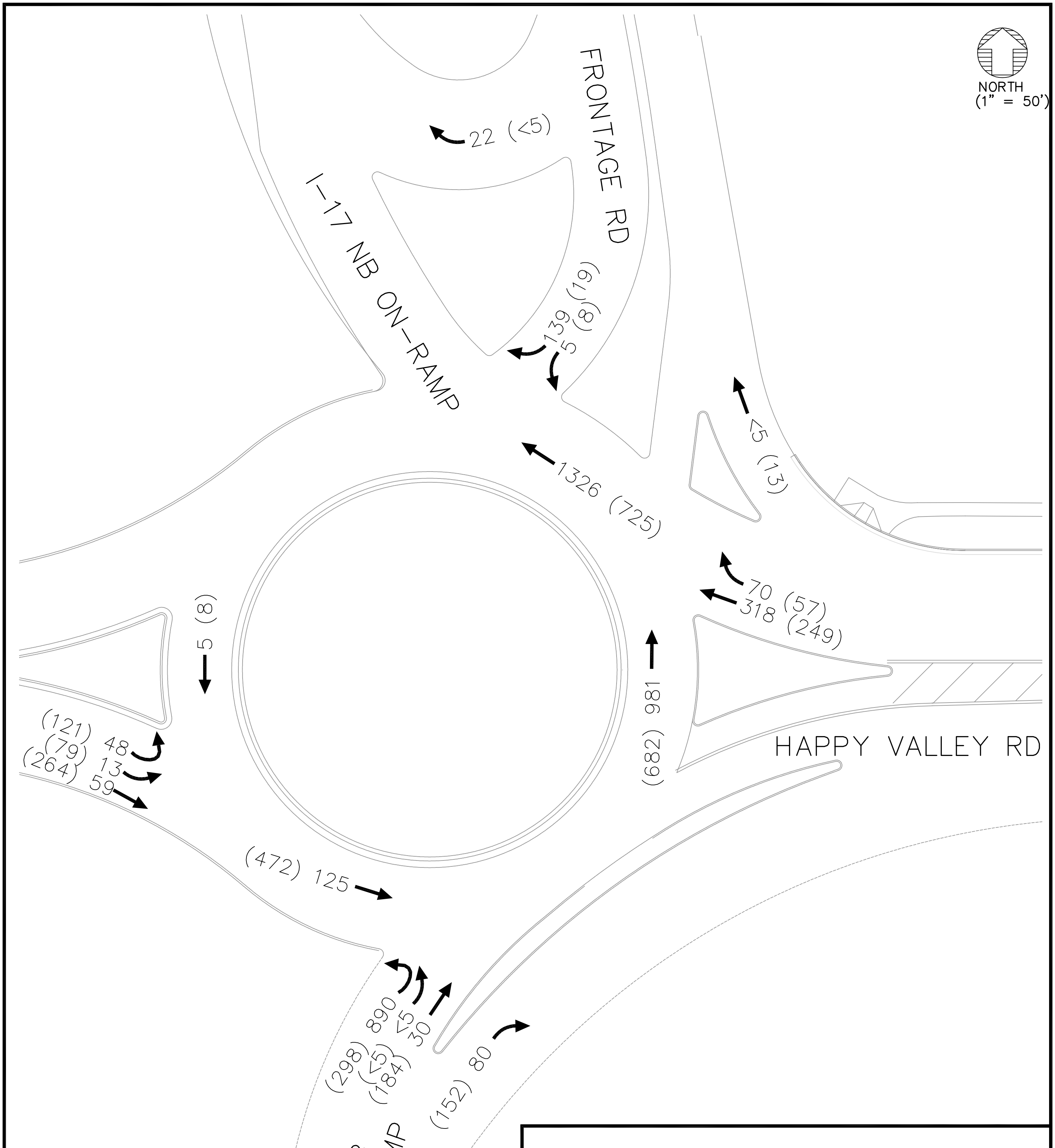
SPR-545 ADOT ROUNDABOUT RESEARCH
PHOENIX, AZ
JULY 2003

FIGURE
35

LEE ENGINEERING

KITTELSON & ASSOCIATES, INC.

VOL_WEST_RBT.DWG



TURNING MOVEMENT VOLUMES
EAST ROUNDABOUT

SPR-545 ADOT ROUNDABOUT RESEARCH
PHOENIX, AZ
JULY 2003

FIGURE 36

LEE ENGINEERING
KITTELSON & ASSOCIATES, INC.

VOL_EAST_RBT.DWG

Table 5
Existing Condition FHWA Operation Summary

I-17/Happy Valley Interchange	Approach	Weekday AM Peak Hour			Weekday PM Peak Hour		
		V/C	Control Delay (sec/veh)	95th%ile Queue (feet)	V/C	Control Delay (sec/veh)	95th%ile Queue (feet)
East Roundabout	I-17 NB Off Ramp	0.50	7.6	75	0.80	15.6	280
	SB Frontage Road	0.03	4.4	25	0.27	9.4	30
	EB Happy Valley Rd	0.38	4.8	50	0.10	3.3	10
	WB Happy Valley Rd	0.30	6.1	30	0.47	10.0	65
West Roundabout	I-17 SB Off Ramp	0.22	4.9	20	0.22	8.2	20
	SB Frontage Road	0.31	6.1	35	0.21	8.7	20
	EB Happy Valley Rd	0.35	5.9	40	0.12	4.0	10
	WB Happy Valley Rd	0.38	4.8	45	**0.97**	51.8	820

Legend: V/C = Volume-to-Capacity Ratio

As shown in Table 5, all approaches are currently operating below the 0.85 V/C target threshold, except the westbound (Happy Valley Road) approach at the west roundabout. Although the approach is not over capacity, a V/C ratio in this range indicates the approach may experience unstable operations with brief periods of long delays and lengthy queues. Field observations during the weekday PM peak hour confirmed that these conditions do occur. There were several observed instances where queues at this approach briefly extended back over the bridge and impeded traffic flow at the east roundabout. These occurrences were infrequent and the queues dissipated very quickly.

The FHWA analysis also shows the I-17 northbound off-ramp, operating at a 0.80 V/C ratio, is near the upper limit for acceptable operations. Since this approach “consumes” 80 percent of the time on the circulatory roadway in front of the westbound Happy Valley Road and southbound frontage road approaches, these entry approaches are unnecessarily delayed. If the northbound off-ramp traffic were able to fully utilize the two-lane entry then this situation would provide more capacity for the downstream approach entries.

3.5.4 SIDRA Analysis Methodology
SIDRA is an Australian software product developed by Akcelik & Associates. It utilizes the traffic flows, roundabout geometry, and gap-acceptance parameters to calculate the capacity at each entry. Unlike the FHWA model, SIDRA allows each lane of a multi-lane approach to be assigned a specific lane use. For instance, a two-lane entry can be designated with one shared left-turn/through lane and one exclusive right-turn lane.

SIDRA was used to compare the results of the FHWA analysis and gain a better understanding of the roundabout operations. Table 6 shows the results of the SIDRA analysis for the east and west roundabouts at the I-17/Happy Valley Road interchange during both weekday AM and PM peak hour conditions. The detailed SIDRA worksheets are included in **Appendix G**.

Table 6
Existing Condition SIDRA Operation Summary

I-17/Happy Valley Interchange	**Approach**	**Weekday AM Peak Hour**			**Weekday PM Peak Hour**		
		V/C	**Control Delay (sec/veh)**	**95th%^{ile} Queue (feet)**	**V/C**	**Control Delay (sec/veh)**	**95th%^{ile} Queue (feet)**
East Roundabout	I-17 NB Off Ramp	0.44	12.0	95	0.52	14.0	130
	SB Frontage Road	0.03	13.7	25	0.35	24.4	70
	EB Happy Valley Rd	0.24	9.4	40	0.06	10.3	10
	WB Happy Valley Rd	0.28	9.1	50	0.38	12.3	85
West Roundabout	I-17 SB Off Ramp	0.22	13.5	45	0.34	29.5	70
	SB Frontage Road	0.30	10.5	60	0.25	16.2	50
	EB Happy Valley Rd	0.55	6.7	65	0.17	7.3	25
	WB Happy Valley Rd	0.24	7.2	40	0.61	6.8	170

Legend: V/C = Volume-to-Capacity Ratio

As shown in Table 6, the SIDRA analysis indicates all approaches are currently below the 0.85 V/C threshold, with the maximum V/C being 0.61 at the westbound approach at the west roundabout.

In comparing the results in Tables 5 and 6, it is apparent that the operational results of the FHWA and SIDRA analyses are significantly different for some approaches, especially under weekday PM peak hour conditions. The primary differences between the SIDRA results and the FHWA results are due to the fundamental differences in the capacity formulae each model uses. In cases with high entry flows opposed by low circulatory volumes (such as the northbound approach at the east roundabout and the westbound approach at the west roundabout), SIDRA generally predicts significantly higher capacity than the FHWA model. At this time, it is not know if the higher capacity experienced in Australia will transfer to the U.S. driving environment.

Because there is very little data for actual roundabout performance in the U.S. to calibrate SIDRA for U.S. driving conditions, a lower capacity model has been typically used in order to produce a more conservative design. Furthermore, based on visual field observations, the lower capacity estimated by the FHWA model appears to more closely reflect actual operating conditions. Thus, this analysis suggests that the single-lane circulatory roadways at both roundabouts are near the limit of their capacities. The roundabouts will need to be expanded to two lanes within the circulatory roadway to accommodate near-term traffic growth.

3.6 SAFETY ANALYSIS

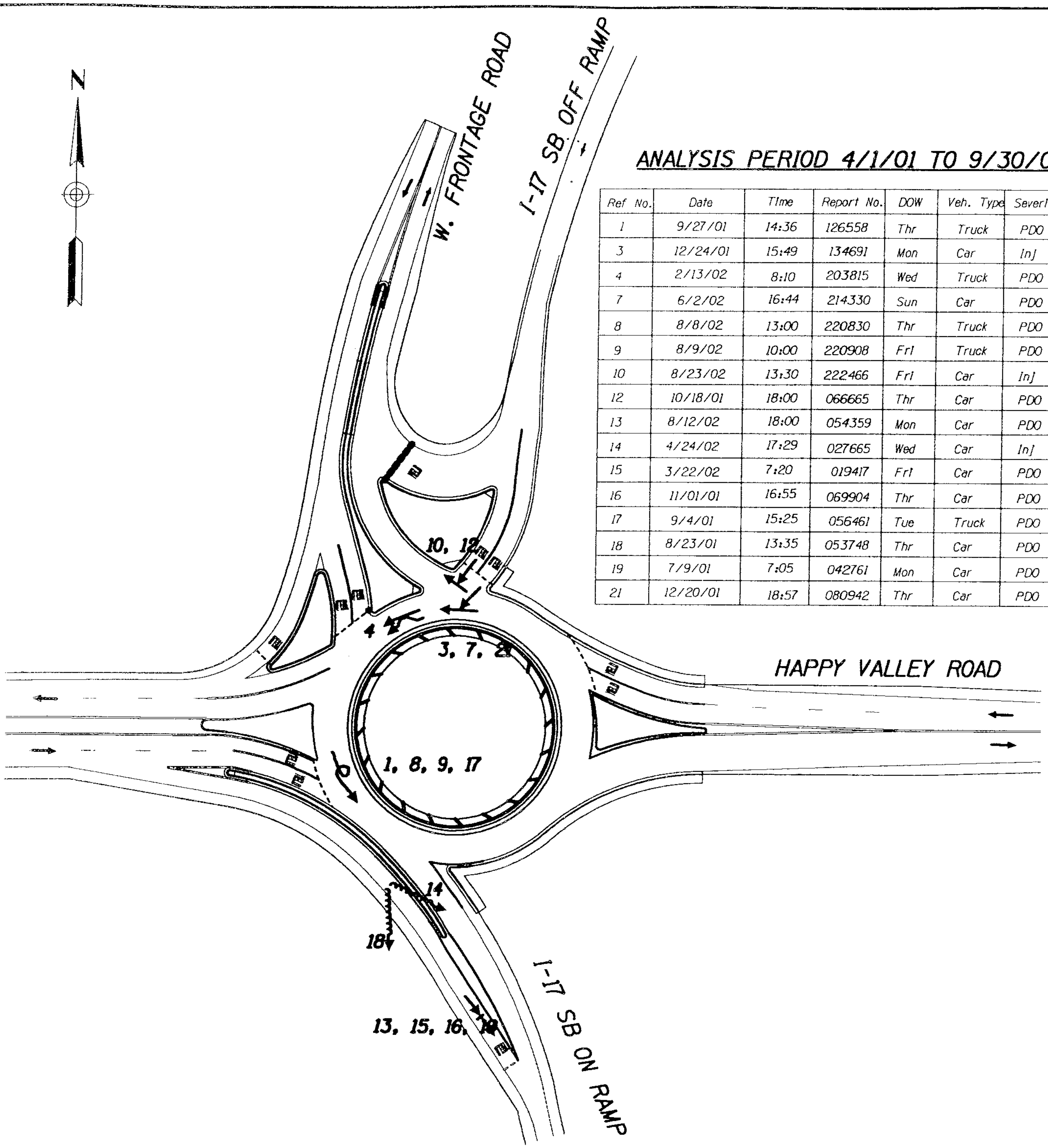
3.6.1 Collision Analysis

Information was collected from the City of Phoenix and the Arizona Department of Transportation to identify the number and types of reported collisions that have occurred at the roundabouts since their inception. Crash data collected from April 1, 2001 to September 30, 2002 indicates a total of 22 incidents including four injury crashes have taken place at the roundabouts over the 18-month period, six at the east roundabout (one injury) and 16 at the west roundabout (three injuries).

To determine the crash rate at each roundabout, the daily traffic volumes collected in October of 2002 were considered a typical demand volume throughout the 18 month period. Utilizing this volume, results indicate that the east roundabout has a crash rate of 0.64 per Million Entering Vehicles (MEV) and a rate of 1.16 per MEV at the west roundabout. A similar calculation to determine the injury crash rate was also conducted. Results identify at least one passenger being injured for every 0.11 MEV at the east roundabout and at a rate of 0.36 MEV at the west roundabout.

Collision diagrams were prepared at both locations to help identify the type and location of the occurrences and are presented in ***Figures 37 and 38***. Although not enough information has been compiled to make any conclusive statements, eight angle crashes (failure to yield), six rear-end crashes, and five overturn occurrences dominate the database. A field visit to the west roundabout where four rollover incidents took place identified a negative pavement superelevation of approximately two percent (-2%) as evident by a 6-foot slope indicator measurement. Review of the design files confirm that this -2 percent slope was proposed along the circulatory roadway. Further review of the crash diagrams reveals that trucks have been involved in six incidents: five overturns and one sideswipe.

The *FHWA Guide* [1] was reviewed to compare collision results to other U.S. roundabout locations or to determine averages. Insufficient detail is provided in the publication to compare this location to similar U.S. sites (based on design, volume, and how long after the roundabouts were open before the study was conducted). It does indicate that the injury crash rate for eight single-lane roundabouts in Florida and Maryland was 0.08 per MEV and that there was a total mean reduction of 51 percent for overall crashes and 73 percent for injury crashes when before-and-after studies where conducted. The inclusion of three additional studies of larger, multilane roundabouts identifies a reduction of 37 percent for all crash types and 51 percent for crashes involving injuries which corresponds with international studies using much larger sample sizes. The findings of these studies show that injury crashes are reduced more dramatically than crashes



ANALYSIS PERIOD 4/1/01 TO 9/30/02

Ref No.	Date	Time	Report No.	DOW	Veh. Type	Severity
1	9/27/01	14:36	126558	Thr	Truck	PDO
3	12/24/01	15:49	134691	Mon	Car	Inj
4	2/13/02	8:10	203815	Wed	Truck	PDO
7	6/2/02	16:44	214330	Sun	Car	PDO
8	8/8/02	13:00	220830	Thr	Truck	PDO
9	8/9/02	10:00	220908	Fri	Truck	PDO
10	8/23/02	13:30	222466	Fri	Car	Inj
12	10/18/01	18:00	066665	Thr	Car	PDO
13	8/12/02	18:00	054359	Mon	Car	PDO
14	4/24/02	17:29	027665	Wed	Car	Inj
15	3/22/02	7:20	019417	Fri	Car	PDO
16	11/01/01	16:55	069904	Thr	Car	PDO
17	9/4/01	15:25	056461	Tue	Truck	PDO
18	8/23/01	13:35	053748	Thr	Car	PDO
19	7/9/01	7:05	042761	Mon	Car	PDO
21	12/20/01	18:57	080942	Thr	Car	PDO

LEGEND

- ANGLE
- OUT OF CONTROL
- REAR-END
- OVERTURNED
- SIDESWIPE

CRASH DIAGRAM
WEST ROUNDABOUT

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PHOENIX, AZ

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FIGURE 37

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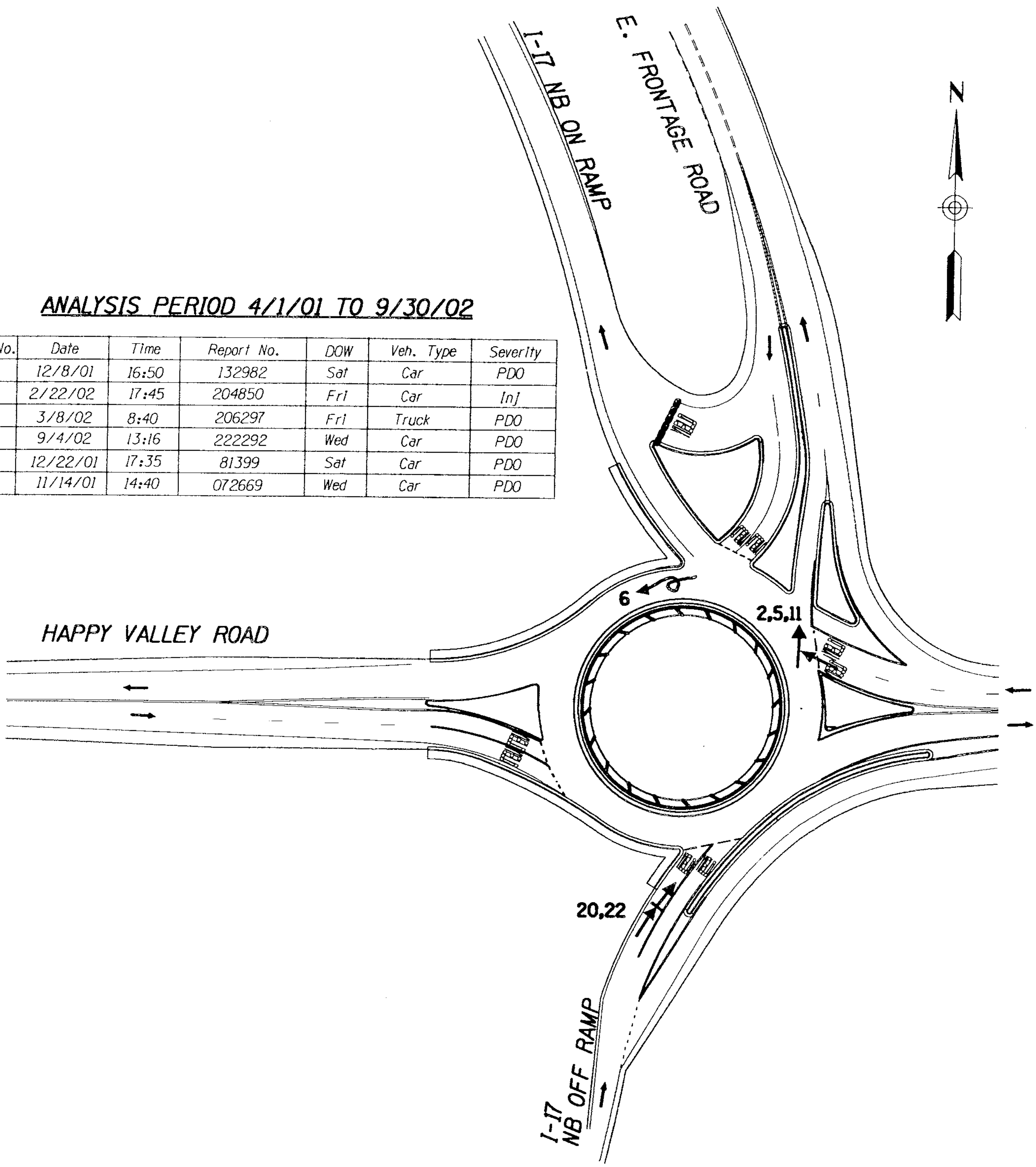


ANALYSIS PERIOD 4/1/01 TO 9/30/02

Ref No.	Date	Time	Report No.	DOW	Veh. Type	Severity
2	12/8/01	16:50	132982	Sat	Car	PDO
5	2/22/02	17:45	204850	Fri	Car	Inj
6	3/8/02	8:40	206297	Fri	Truck	PDO
11	9/4/02	13:16	222292	Wed	Car	PDO
20	12/22/01	17:35	81399	Sat	Car	PDO
22	11/14/01	14:40	072669	Wed	Car	PDO

LEGEND

- ANGLE
- OVERTURNED
- REAR-END

CRASH DIAGRAM
EAST ROUNDABOUT

SPR-545 ADOT ROUNDABOUT RESEARCH
PHOENIX, AZ

JULY 2003

FIGURE 38

LEE ENGINEERING

KITTELSON & ASSOCIATES, INC.

involving property damage only due to the configuration of roundabouts, which eliminates severe crash types such as left-turn, head-on, and right-angle collisions.

The Insurance Institute for Highway Safety conducted a study in March 2000 [9] to investigate crash reductions following installation of roundabouts in the United States. This before-and-after study was designed to provide a better estimate, as compared to previous studies, of the nature and magnitude of crash reductions following the installation of modern roundabouts. The study included a greater number of intersections and employed more powerful statistical analysis tools (e.g., using the empirical Bayes approach to account for regression to mean and normalizing for differences in traffic volumes between the before and after periods) than previous studies.

Results of the Insurance Institute for Highway Safety study are summarized below:

- Based on all of the intersections studied (conversions from stop control and signalized intersections of varying capacities), the study estimates highly significant reductions of 39 percent for all crash severities combined and 76 percent for all injury crashes.
- Reduction in the numbers of fatal and incapacitating injury crashes were estimated to be about 90 percent.
- For the group of nine urban intersections converted from stop control to urban single-lane roundabouts, the study estimates a highly significant 61 percent reduction for all crash severities combined and a 77 percent reduction for injury crashes.
- For the group of five rural intersections converted from stop control to rural single-lane roundabouts, the study estimates a 58 percent crash reduction for all severities combined and an 82 percent reduction for injury crashes.

The City of Phoenix provided information on three crashes that occurred in October and November of 2002. These crashes were not accounted for in the crash rate calculations or shown on the collision diagrams because they occurred after the decided upon analysis period (April 2001 through September 2002). These incidents include a hit-and-run rear-end crash in the westbound direction on the I-17 overpass (no injuries, 7:20 PM), a sideswipe crash between two westbound trucks with trailers on the east roundabout (no injuries, 1:47 PM), and an angle crash between a southbound motorist entering the west roundabout from the I-17 off-ramp and a westbound motorist attempting to exit the roundabout onto the northbound frontage road (no injuries, 7:23 AM). Also, there are reports of drunk or sleepy drivers exiting the east roundabout onto the northbound frontage road with the impression that they have entered onto northbound I-17. These incidents generally occur late at night and have resulted in some drivers running off the road some three miles to the north where the frontage road ends.

The above data was not included in the final results because complementary crash data from the same period could not be collected from the ADOT source and therefore acknowledging one source and not the other would bias the calculation and comparison of data.

3.6.2 Crash Prediction Models

Crash prediction models for U.S. roundabouts are not currently available. Therefore, the British crash prediction model was evaluated to understand the likelihood for crashes based on the existing roundabout geometry. The crash prediction model calculates injury crash rates based on data collected at 84 four-leg roundabouts of all sizes and geometry. The models are based on generalized linear regression of the exponential form, which assumes a Poisson distribution. The model does not analyze property-damage-only crashes.

Table 7 shows the results of the British crash prediction analysis for the existing roundabout geometries. The detailed worksheets for the crash prediction analysis are provided in **Appendix H**.

Table 7
British Crash Prediction Model Results, Existing Geometry

	Predicted Injury Crashes per Year				
Approach	**Entry-Circulating**	**Approaching**	**Single Vehicle**	**Other (vehicle)**	**Total**
East Roundabout					
I-17 Northbound Off Ramp	0.08	0.11	0.23	0.04	**0.46**
Westbound Happy Valley Rd	0.08	0.04	0.11	0.06	**0.29**
Southbound Frontage Rd	0.03	0.00	0.05	0.02	**0.10**
Eastbound Happy Valley Rd	0.02	0.02	0.13	0.00	**0.17**
Total	**0.21**	**0.17**	**0.52**	**0.12**	**1.02**
West Roundabout					
Westbound Happy Valley Rd	0.06	0.24	0.27	0.01	**0.58**
I-17 Southbound Off Ramp	0.06	0.02	0.05	0.04	**0.17**
Southbound Frontage Rd	0.09	0.01	0.02	0.03	**0.15**
Eastbound Happy Valley Rd	0.03	0.02	0.07	0.02	**0.14**
Total	**0.24**	**0.29**	**0.41**	**0.10**	**1.04**

As shown in Table 7, the British crash prediction model predicts approximately one injury crash per year at each of the roundabouts. Because this model is based on British data and is not calibrated to U.S. conditions, caution should be used in evaluating the results. Furthermore, the model was developed from data at four-leg roundabouts, while the Happy Valley Road roundabouts both have five legs. Therefore, the crash prediction results should not be used to quantify the absolute number of expected injury crashes.

However, the index can provide an indication of the **relative** safety of one layout versus another. The crash prediction model under the recommended geometric improvements has been evaluated and is presented later in this report.

3.7 RECOMMENDATIONS

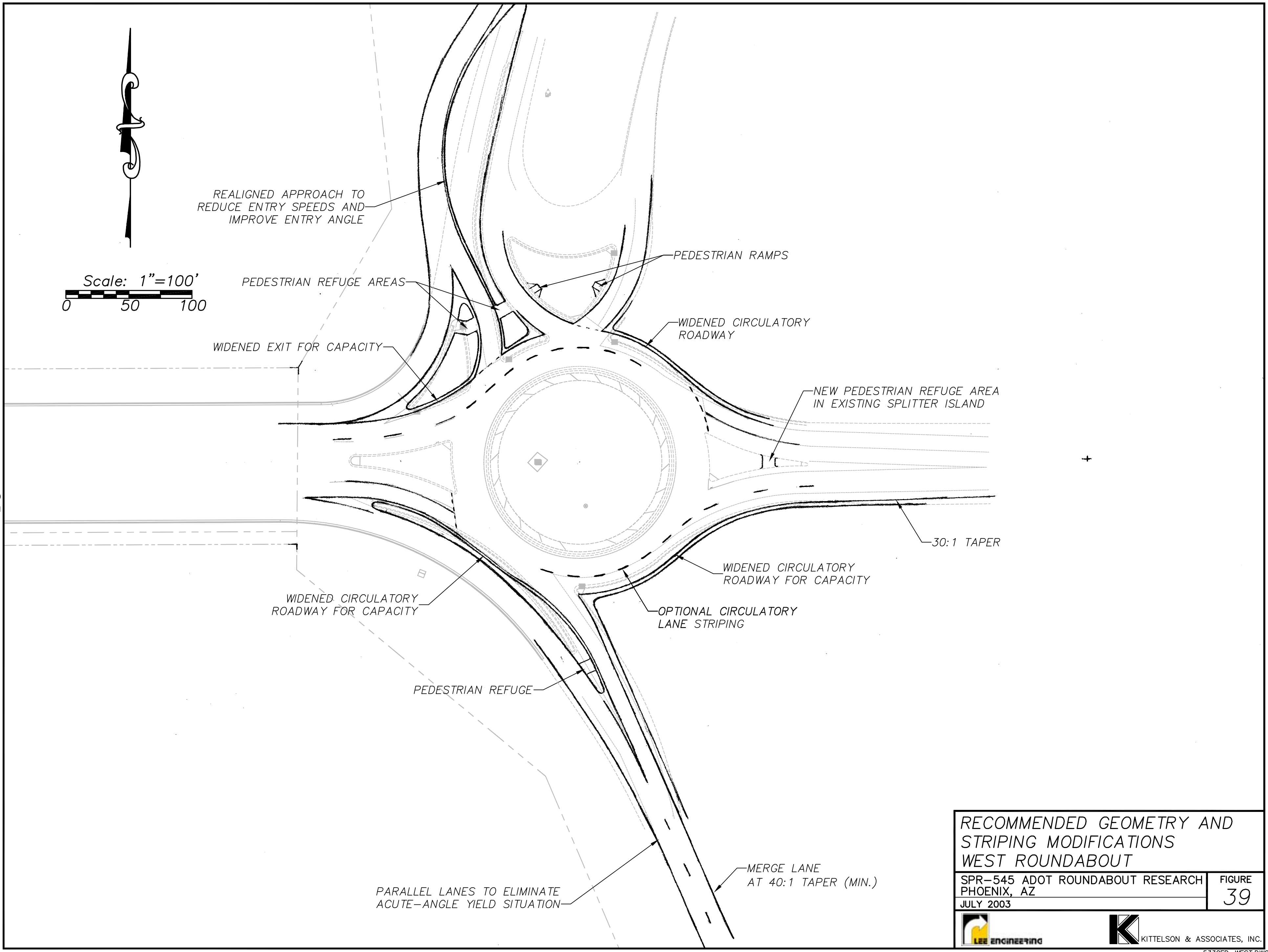
Based on this evaluation of traffic data, traffic operations, design features, and public opinion, the following recommendations are made for the west and east roundabouts, respectively, at the I-17/Happy Valley Road interchange.

3.7.1 West Roundabout

Figure 39 shows the recommended geometric and striping modifications for the west roundabout. As shown in this sketch, a number of geometric, striping, and signing modifications are recommended. A description and discussion of the recommendations for the west roundabout are outlined below.

3.7.1.1 *Geometric Adjustments*

- Widen the circulatory roadway to a constant width of at least 30 feet. This should be accomplished by widening the outside curb lines and splitter islands and maintaining the existing central island diameter.
- Adjust the exit geometry at the east leg of Happy Valley Road to accommodate two exit lanes for a distance of at least 75 feet. The second lane can then be merged at a typical taper rate in advance of the overpass structure.
- Adjust the entry geometry at the east leg (westbound approach) of Happy Valley Road to match to the widened circulatory roadway.
- Add pedestrian refuge area in the splitter island of the east leg of Happy Valley Road. The refuge area (and pedestrian crossing) should be located 40 to 50 feet back from the yield line.
- Reduce the entry width of the southbound I-17 off-ramp to provide a single entry lane.
- Realign the Frontage Road approach so that the roadway centerline is aligned through (or nearly through) the center of the roundabout. In addition, the entry width of this approach should be reduced to provide a single entry lane. This alignment modification will provide greater speed control by increasing the radius of the entry path curvature.
- Add pedestrian refuge areas to the splitter island and right-turn bypass island at the Frontage Road approach. The refuge areas (and pedestrian crossings) should be located approximately 25 feet back from the yield line. These pedestrian amenities may not be needed until a sidewalk or pedestrian path is constructed on the bridge over I-17.
- Add standard Handicapped-accessible ramps to the existing right-turn bypass island between the southbound I-17 off-ramp and the Frontage Road. The ramps should be located at the appropriate pedestrian crossing locations, approximately 25 feet back from the yield line. These pedestrian amenities may not be needed until a sidewalk or pedestrian path is constructed on the bridge over I-17.



RECOMMENDED GEOMETRY AND STRIPING MODIFICATIONS WEST ROUNDABOUT

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PHOENIX, AZ
JULY 2003

FIGURE 39

LEE ENGINEERING

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5332FD-WEST.DWG

- Remove the existing yield control between the eastbound right-turn bypass lane and the southbound I-17 on-ramp, and modify the geometry accordingly. The modified design should provide two parallel lanes for a distance of at least 100 feet followed by a standard lane-merge taper. The length of this on-ramp is sufficient to achieve this lane merge well in advance of the freeway merge point.

3.7.1.2 *Striping Modifications*

- Add circulatory lane striping within the circulatory roadway, as shown on the sketch (optional).
- Marked crosswalks could be added at the pedestrian crossing locations. However, they may not be necessary at this time as pedestrian activity within the interchange area is currently negligible.

3.7.1.3 *Signing Modifications*

The recommended signing modifications for the west roundabout are shown in ***Figure 40***. As shown on the sketch, the signing recommendations consist of the following:

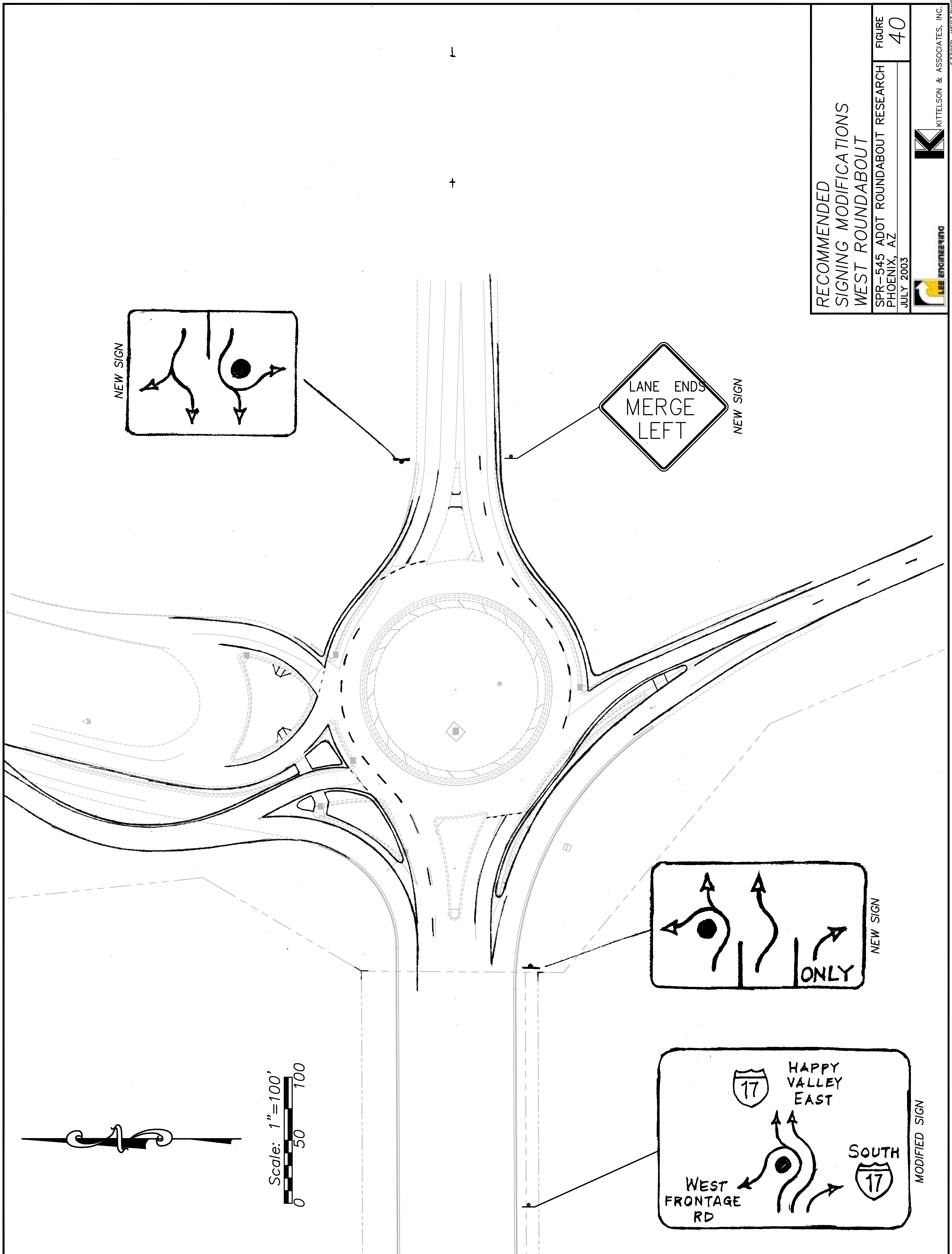
- Add lane-use signs at the eastbound and westbound Happy Valley Road (multi-lane) approaches, as shown on the sketch.
- Modify the existing diagrammatic sign at the eastbound approach to illustrate the appropriate turning movements from each lane, as shown on the sketch.

3.7.2 East Roundabout

Figure 41 shows a conceptual design sketch of the recommended modifications at the east roundabout. As shown in this sketch, a number of geometric and striping modifications are recommended. A description and discussion of the recommendations for the east roundabout are outlined below.

3.7.2.1 *Geometric Adjustments*

- Widen the circulatory roadway to a constant width of at least 30 feet. This should be accomplished by widening the outside curb lines and splitter islands and maintaining the existing central island diameter.
- Adjust the entry geometry of the I-17 northbound off-ramp and the east leg of Happy Valley Road (westbound approach) to match to the widened circulatory roadway. The modified geometry should be designed to avoid path overlap by orienting vehicles at the yield line into their appropriate circulatory lanes (as shown on the design sketch).
- Adjust the exit geometry at the east leg of Happy Valley Road to accommodate two exit lanes for a distance of at least 75 feet. The second lane can then be merged at a typical taper rate for lane reductions.
- Extend the splitter island at the east leg of Happy Valley Road and extend the right-turn bypass islands at the northbound I-17 off-ramp and westbound Happy Valley Road and add pedestrian refuges areas at the appropriate pedestrian crossing location (approximately 40 feet back from the yield line). These island modifications can be accommodated within the existing Happy Valley Road pavement section (i.e. with no widening).


RECOMMENDED
SIGNING MODIFICATIONS
WEST ROUNDABOUT
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PHOENIX, AZ
JULY 2003
FIGURE
40
LEE ENGINEERING
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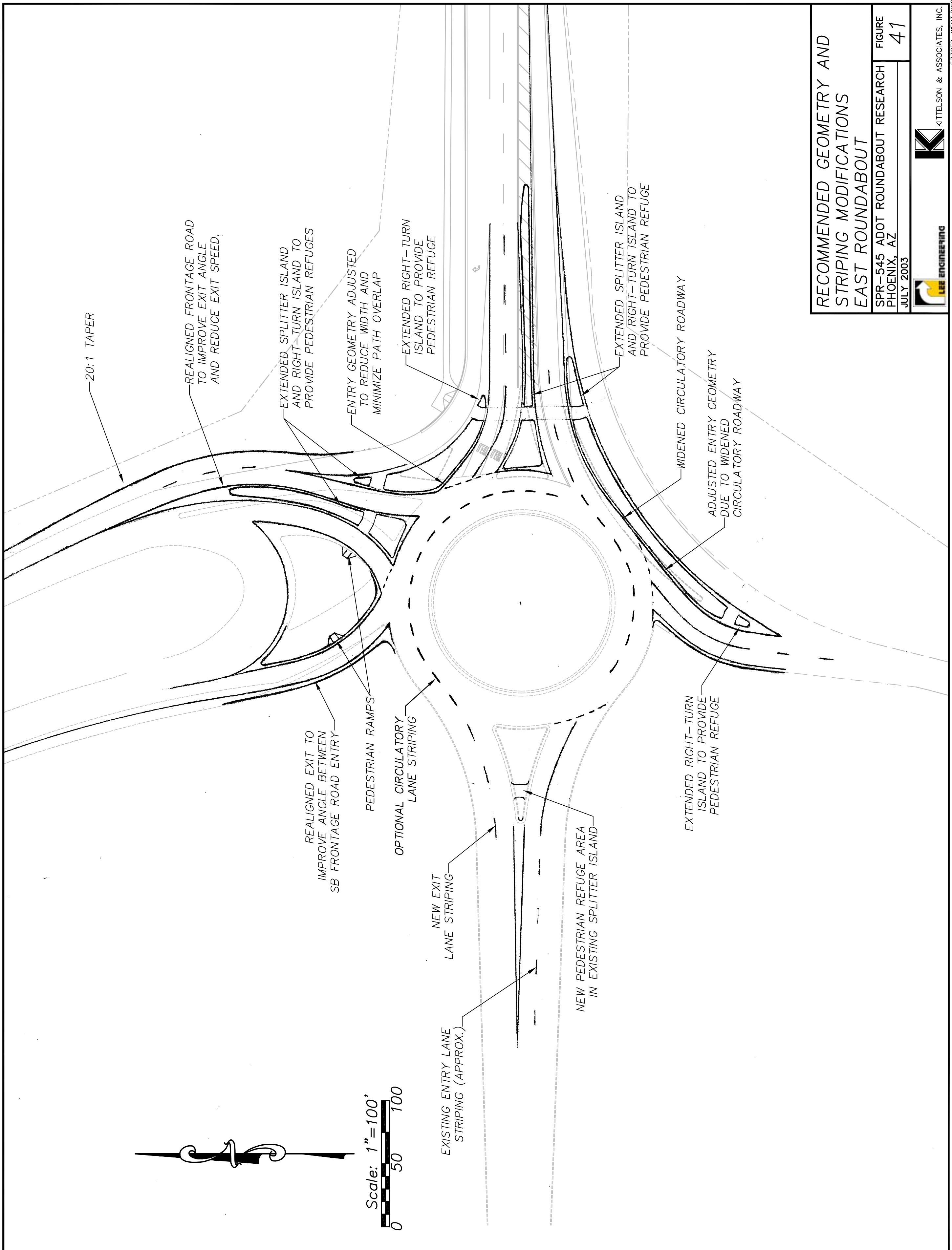
5332FD-WEST.DWG
NEW SIGN
LANE ENDS
MERGE
LEFT
NEW SIGN
NEW SIGN
ONLY
HAPPY
VALLEY
EAST
17
SOUTH
17
WEST
FRONTAGE
RD
MODIFIED SIGN
Scale: 1"=100'
0
50
100


RECOMMENDED GEOMETRY AND STRIPING MODIFICATIONS EAST ROUNDABOUT
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JULY 2003
FIGURE
41
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20:1 TAPER
REALIGNED FRONTAGE ROAD TO IMPROVE EXIT ANGLE AND REDUCE EXIT SPEED.
EXTENDED SPLITTER ISLAND AND RIGHT-TURN ISLAND TO PROVIDE PEDESTRIAN REFUGES
ENTRY GEOMETRY ADJUSTED TO REDUCE WIDTH AND MINIMIZE PATH OVERLAP
EXTENDED RIGHT-TURN ISLAND TO PROVIDE PEDESTRIAN REFUGE
EXTENDED SPLITTER ISLAND AND RIGHT-TURN ISLAND TO PROVIDE PEDESTRIAN REFUGE
WIDENED CIRCULATORY ROADWAY
ADJUSTED ENTRY GEOMETRY DUE TO WIDENED CIRCULATORY ROADWAY
EXTENDED RIGHT-TURN ISLAND TO PROVIDE PEDESTRIAN REFUGE
NEW PEDESTRIAN REFUGE AREA IN EXISTING SPLITTER ISLAND
NEW EXIT LANE STRIPING
OPTIONAL CIRCULATORY LANE STRIPING
PEDESTRIAN RAMPS
REALIGNED EXIT TO IMPROVE ANGLE BETWEEN SB FRONTAGE ROAD ENTRY
EXISTING ENTRY LANE STRIPING (APPROX.)
Scale: 1"=100'
0 50 100

- Realign the Frontage Road approach so that the projection of the alignment passes through (or nearly through) the roundabout center. This realignment will improve the crossing angle between the westbound Happy Valley entry and the Frontage Road exit as well as slightly increase the spacing between these two legs. Furthermore, the entry width of the Frontage Road should be reduced to a single lane to enhance the safety of this entry and reduce confusion for drivers.
- Adjust the exit geometry of the northbound I-17 on-ramp exit to increase the spacing and reduce the crossing angle between this exit and the southbound Frontage Road entrance.
- Add handicap-accessible ramps at the existing right-turn bypass island at the southbound Frontage Road approach. These pedestrian amenities may not be needed until a sidewalk or pedestrian path is constructed on the bridge over I-17.
- Add a pedestrian refuge area to the existing splitter island at the west leg of Happy Valley Road. These pedestrian amenities may not be needed until a sidewalk or pedestrian path is constructed on the bridge over I-17.

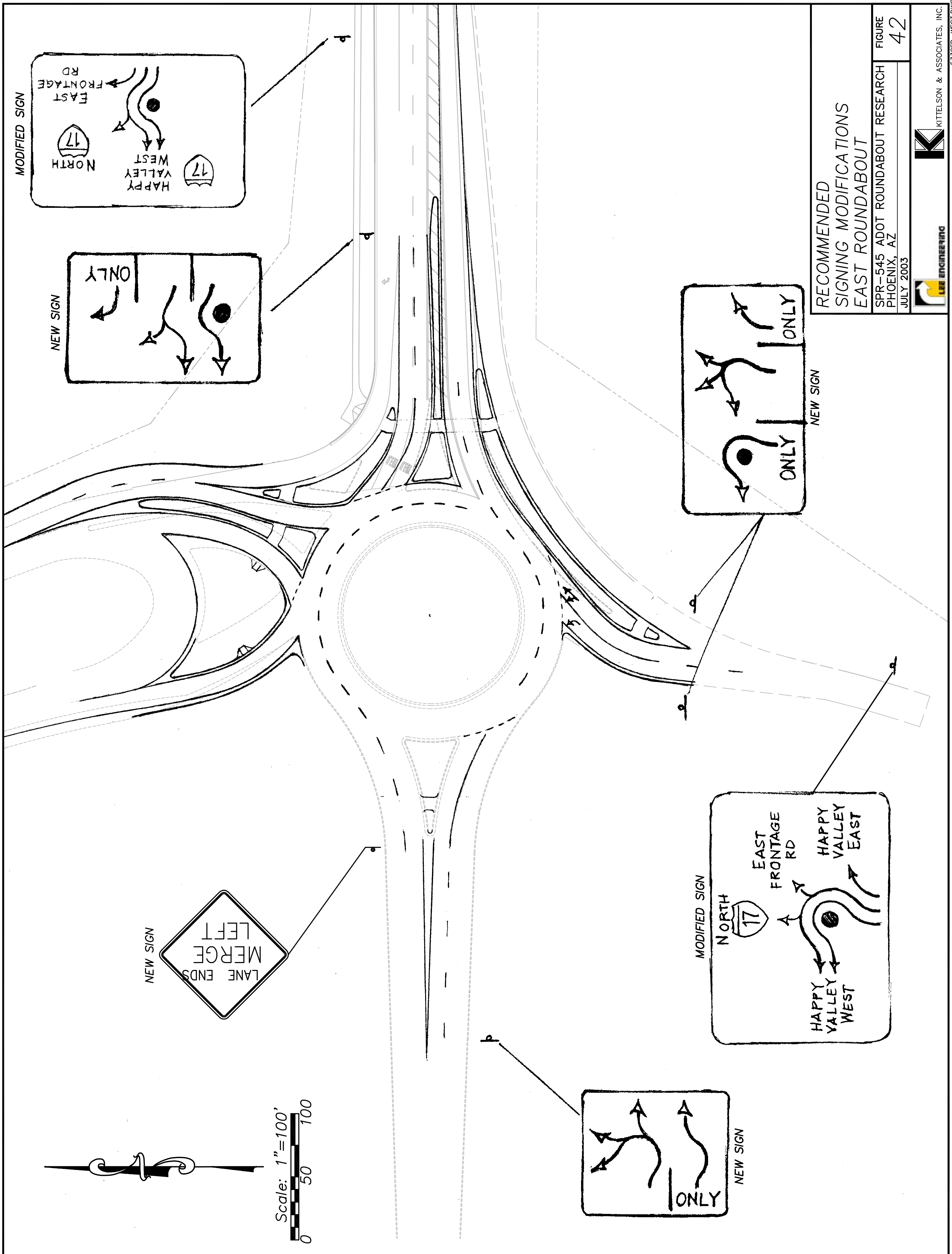
3.7.2.2 *Striping Modifications*

- Add circulatory lane striping and lane-use pavement markings at the multi-lane approaches, as shown in the conceptual design sketch (optional).
- Marked crosswalks could be added at the pedestrian crossing locations. However, they may not be necessary at this time as pedestrian activity within the interchange area is currently negligible.

3.7.2.3 *Signing Modifications*

The recommended signing modifications for the east roundabout are shown in ***Figure 42***. As shown on the sketch, the signing recommendations consist of the following:

- Add lane-use signs at each multi-lane approach, as shown on the conceptual design sketch.
- Modify the existing diagrammatic signs at the northbound and westbound approaches to illustrate the appropriate turning movements from each lane, as shown on the sketch.



RECOMMENDED
SIGNING MODIFICATIONS
EAST ROUNDABOUT
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JULY 2003
FIGURE
42
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5332FD-WEST.DWG
MODIFIED SIGN
NORTH
17
HAPPY VALLEY WEST
EAST FRONTAGE RD
NEW SIGN
ONLY
NEW SIGN
ONLY
ONLY
MODIFIED SIGN
NORTH
17
EAST FRONTAGE RD
HAPPY VALLEY EAST
HAPPY VALLEY WEST
NEW SIGN
LANE ENDS
MERGE
LEFT
NEW SIGN
ONLY
Scale: 1"=100'
0
50
100

3.7.3 Operational Characteristics under Recommended Improvements

The operational performance of the roundabouts with the recommended improvements was evaluated using the same traffic volumes and procedures as that described for the existing conditions. Tables 8 and 9 show the results of the FHWA and SIDRA operational analysis, respectively, considering the recommended geometry. The FHWA and SIDRA analysis worksheets are included in **Appendix I and J**, respectively**.**

Table 8
Recommended Condition FHWA Operation Summary

I-17/Happy Valley Interchange	Approach	Weekday AM Peak Hour			Weekday PM Peak Hour		
		V/C	Control Delay (sec/veh)	$95^{th}\%^{ile}$ Queue (feet)	V/C	Control Delay (sec/veh)	$95^{th}\%^{ile}$ Queue (feet)
East Roundabout	I-17 NB Off Ramp	0.27	2.7	30	0.45	3.2	65
	SB Frontage Road	0.03	3.8	5	0.19	5.8	20
	EB Happy Valley Rd	0.20	2.0	20	0.05	1.7	5
	WB Happy Valley Rd	0.13	2.1	10	0.18	2.6	20
West Roundabout	I-17 SB Off Ramp	0.20	4.3	20	0.16	5.5	15
	SB Frontage Road	0.27	5.1	30	0.14	5.6	15
	EB Happy Valley Rd	0.16	2.1	15	0.06	1.8	5
	WB Happy Valley Rd	0.20	2.0	20	0.51	3.3	80

Legend: V/C = Volume-to-Capacity Ratio

Table 9
Recommended Condition SIDRA Operation Summary

I-17/Happy Valley Interchange	Approach	Weekday AM Peak Hour			Weekday PM Peak Hour		
		V/C	Control Delay (sec/veh)	$95^{th}\%^{ile}$ Queue (feet)	V/C	Control Delay (sec/veh)	$95^{th}\%^{ile}$ Queue (feet)
East Roundabout	I-17 NB Off Ramp	0.22	10.7	30	0.31	13.8	45
	SB Frontage Road	0.03	11.7	5	0.20	12.8	25
	EB Happy Valley Rd	0.14	9.4	20	0.04	10.3	5
	WB Happy Valley Rd	0.16	7.3	20	0.22	8.5	30
West Roundabout	I-17 SB Off Ramp	0.21	11.5	25	0.18	12.3	25
	SB Frontage Road	0.30	9.4	45	0.17	10.6	25
	EB Happy Valley Rd	0.55	6.8	25	0.17	7.4	10
	WB Happy Valley Rd	0.17	7.2	25	0.41	6.7	70

Legend: V/C = Volume-to-Capacity Ratio

As shown in Tables 8 and 9, the operational performance of the roundabouts will be enhanced considerably by implementing the recommended geometric, striping, and signing modifications. Based on the FHWA model results, the critical approach at the two round-abouts would operate at a V/C of approximately 0.51. Thus, with these improvements, the roundabouts should provide ample capacity at the ramp terminal intersections to accommodate continued growth for several more years. It should be noted, however, that while the maximum exit capacity at a double-lane roundabout is roughly 2400 vehicles per hour, the maximum directional flow of the single-lane overpass is approximately 1,800-2,000 vehicles per hour. Therefore, with these recommended roundabout improvements, it is likely that the existing bridge width will become the next capacity constraint sooner than the roundabouts. At the time when the traffic demand exceeds the capacity of the existing bridge, additional interchange improvements should be considered (including widening the bridge and/or providing a new fly-over ramp or loop ramp for the heavy northbound-to-westbound movement). However, the roundabout improvements should allow several more years of acceptable operation until a major interchange upgrade is required.

3.7.4 Crash Prediction Characteristics with Recommended Improvements

To compare the expected safety performance of the recommended geometric improvements, the British crash prediction model was evaluated. These crash prediction results are shown in Table 10. The detailed worksheets for this crash prediction analysis are provided in **Appendix K** and the fastest path sketches for the recommended geometry are provided in **Appendix L**.

Table 10
British Crash Prediction Model Results
with Recommended Geometric Improvements

Approach	**Injury Crashes per Year**				
	Entry-Circulating	**Approaching**	**Single Vehicle**	**Other (vehicle)**	**Total**
East Roundabout					
I-17 Northbound Off Ramp	0.07	0.13	0.23	0.04	**0.47**
Westbound Happy Valley Rd	0.11	0.04	0.11	0.06	**0.32**
Southbound Frontage Rd	0.02	0.01	0.02	0.02	**0.07**
Eastbound Happy Valley Rd	0.02	0.02	0.12	0.00	**0.16**
Total	**0.22**	**0.20**	**0.48**	**0.12**	**1.02**
West Roundabout					
Westbound Happy Valley Rd	0.05	0.25	0.29	0.01	**0.60**
I-17 Southbound Off Ramp	0.05	0.02	0.06	0.04	**0.17**
Southbound Frontage Rd	0.04	0.02	0.04	0.03	**0.13**
Eastbound Happy Valley Rd	0.03	0.02	0.08	0.02	**0.15**
Total	**0.17**	**0.31**	**0.47**	**0.10**	**1.05**

As shown in Table 10, the crash prediction results under the recommended improvements are essentially the same as the results under existing conditions. This lack of change may be partly due to the British model's lack of sensitivity to changes in circulatory roadway width. British design philosophy is to provide a circulatory width at least as wide as the widest entry. Therefore, the British data likely does not reflect conditions in which the circulatory width is narrower than the entries (as currently exists at the Happy Valley interchange).

It should be noted that the recommended improvements are primarily intended to enhance the capacity of the two roundabouts. The improvements may also reduce the overall number of property-damage crashes by removing some confusion and friction between adjacent traffic lanes. The British crash prediction model confirms that, while the improvements may not lower the number of injury crashes, they should not increase the number.

4. GUIDELINES FOR THE SELECTION, EVALUATION AND DESIGN OF ROUNDABOUTS

4.1 GENERAL INFORMATION

Although roundabouts have been in widespread use in other countries for several decades, they have only recently been used within the United States. Roundabouts can offer several advantages over signalized and stop-controlled alternatives, including better overall safety performance, lower delays and shorter queues (particularly during off-peak periods), better speed management, while creating opportunities for community enhancement features. In some cases, roundabouts can avoid or defer the need for widening of intersection approaches (such as an overpass or underpass structure) that would otherwise be necessary for signalization.

Many of the guidelines in this document are based on the FHWA publication *Roundabouts: An Informational Guide* (Report No. FHWA-RD-00-067, hereafter referred to as the *FHWA Guide* [1]). For more discussion and details related to roundabouts, readers are encouraged to review the *FHWA Guide* and a paper drafted by Barry Crown titled "History of Gap Theory and Empirical Methods" [10].

4.1.1 Key Features

A roundabout is a type of circular intersection, but not all circular intersections are roundabouts. For instance, a *rotary* is a circular intersection form with different design and operational features from a roundabout. Rotaries are typically larger in size (often in excess of 300 feet in diameter) and promote high-speed weaving movements within the circulatory roadway. *Neighborhood traffic circles* also require traffic to circulate around a central island, but they are often stop-controlled or uncontrolled at the entries and may not accommodate larger vehicles.

A *roundabout* is a circular intersection with the following specific geometric and traffic control characteristics:

- Yield control at all entries, and
- Appropriate geometric features to promote slow and consistent speeds for all movements.

The key features of a roundabout are displayed in ***Figure 43*** and defined in Table 11.

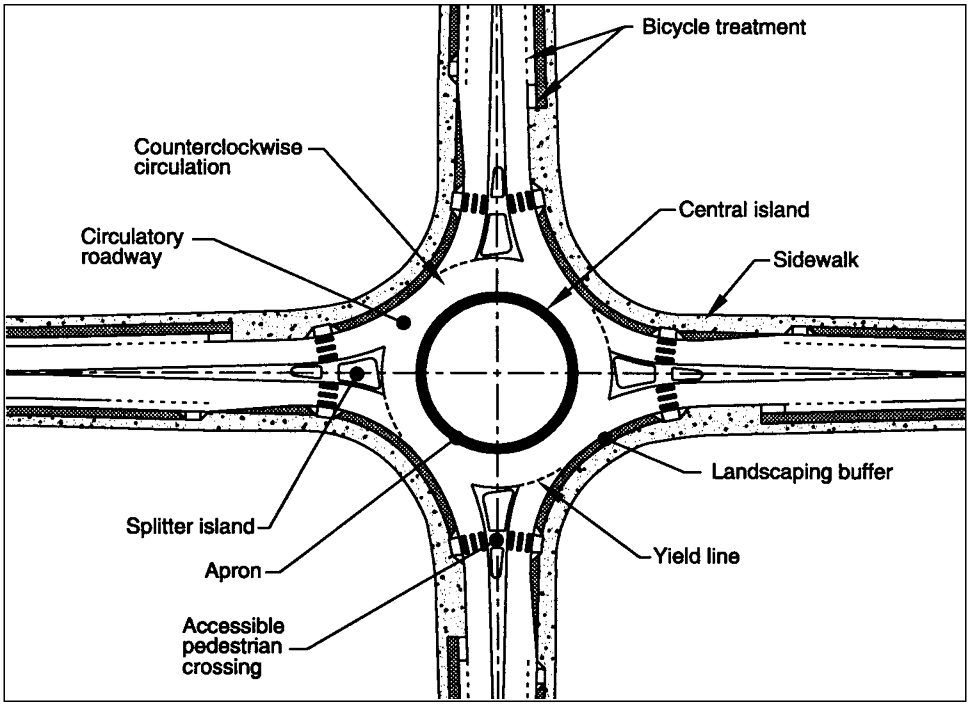


Figure 43
Key Roundabout Features

Table 11
Key Roundabout Features

Feature	Description
Central Island	The *central island* is the raised area in the center of a roundabout around which traffic circulates.
Splitter Island	A *splitter island* is a raised or painted area on an approach used to separate entering from exiting traffic, deflect and slow entering traffic, and provide storage space for pedestrians crossing the road in two stages.
Circulatory Roadway	The *circulatory roadway* is the curved path used by vehicles to travel in a counterclockwise fashion around the central island
Apron	If required to accommodate the wheel tracking of large vehicles, an *apron* is the mountable portion of the central island adjacent to the circulatory roadway.
Yield Line	A *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. Entering vehicles must yield to any circulating traffic coming from the left before crossing this line into the circulatory roadway.
Accessible Pedestrian Crossings	*Accessible pedestrian crossings* should be provided at all roundabouts. The crossing location is set back from the yield line, and the splitter island is cut to allow pedestrians, wheelchairs, strollers, and bicycles to pass through.
Bicycle Treatments	*Bicycle treatments* at roundabouts provide bicyclists the option of traveling through the roundabout either as a vehicle or as a pedestrian, depending on the bicyclist's level of comfort.
Landscaping Buffer	*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. Landscaping buffers can also significantly improve the aesthetics of the intersection.

4.1.2 Categories of Roundabouts

Roundabouts have been categorized according to size and environment to differentiate their design and operational characteristics within different contexts. There are six basic categories based on site environment, number of lanes, and size:

- Rural single-lane roundabouts
- Rural double-lane roundabouts
- Urban single-lane roundabouts
- Urban double-lane roundabouts
- Urban compact roundabouts
- Mini-roundabouts

A brief description of each of these basic roundabout categories follows.

4.1.2.1 *Rural Single-Lane Roundabouts*

Rural roundabouts often have larger diameters than urban roundabouts to allow slightly higher speeds at the entries, on the circulatory roadway, and at the exits. This is possible if few pedestrians are expected at these intersections and if land is available at the intersection corners. Geometric design elements include extended and raised splitter islands, a non-mountable central island, and adequate horizontal deflection to reduce vehicular speeds entering and circulating the roundabout. Because they are often located in high-speed environments, they may require supplementary geometric and traffic control device treatments on approaches to encourage drivers to slow to an appropriate speed before arriving at the roundabout. Often, there is no apron because their larger diameters typically accommodate larger vehicles.

4.1.2.2 *Rural Double-Lane Roundabouts*

Rural double-lane roundabouts have similar speed and environmental characteristics to rural single-lane roundabouts. They differ in having two entry lanes, or entries flared from one to two lanes, on one or more approaches. Consequently, many of the characteristics and design features of rural double-lane roundabouts mirror those of their urban counterparts. The main design differences are designs with slightly higher entry speeds and larger diameters, and recommended supplementary approach treatments.

4.1.2.3 *Urban Single-Lane Roundabouts*

This type of roundabout is characterized as having a single-lane entry at all legs and one circulatory lane. They are distinguished from urban compact roundabouts by their larger inscribed circle diameters (typically 120 to 140 feet) and more tangential entries and exits, resulting in higher capacities. Their design allows slightly higher speeds at the entry, on the circulatory roadway, and at the exit. The roundabout design is focused on achieving consistent entering and circulating vehicle speeds. The geometric design includes raised splitter islands, a non-mountable central island, and may include a truck apron.

4.1.2.4 *Urban Double-Lane Roundabouts*

Urban double-lane roundabouts include all roundabouts in urban areas that have at least one entry with two lanes. These roundabouts require wider circulatory roadways to accommodate two vehicles traveling side-by-side. The speeds at the entry, on the circulatory roadway, and at the exit are similar to those for the urban single-lane roundabouts. As with the previous categories, the vehicular speeds should be consistent throughout the roundabout. The geometric design will include raised splitter islands, a non-mountable central island, and may include a truck apron.

4.1.2.5 *Urban Compact Roundabouts*

Urban compact roundabouts are characterized by their relatively small diameter (typically 100 to 120 feet), a non-mountable central island, and nearly perpendicular entry geometry. These roundabouts are intended to be pedestrian- and bicyclist-friendly because their perpendicular approach legs require very low vehicle speeds to make a distinct right turn into and out of the circulatory roadway. All legs have single-lane entries. The principal objective of this design is to enable pedestrians to have safe and effective use of the intersection. Capacity should not be a critical issue when considering a roundabout of this type. The geometric design includes raised splitter islands, incorporating at-grade pedestrian refuge areas, and a non-mountable central island. Being compact, there is usually an apron surrounding the non-mountable part of the central island to accommodate large vehicles.

4.1.2.6 *Mini Roundabouts*

Mini-roundabouts are small roundabouts used in built-up urban environments. Because of their small size, the central island is fully mountable, and larger vehicles may cross over the central island, but not to the left of it. However, the mini-roundabout is designed to accommodate passenger cars without requiring them to drive over the central island, and speed control should be provided by requiring vehicles to negotiate around the mountable central island.

They can be useful in low-speed urban environments in cases where conventional roundabout design is precluded by right-of-way constraints. In retrofit applications, mini-roundabouts are relatively inexpensive because they typically require minimal additional pavement at the intersecting roads, for example, minor widening at the corner curbs. Capacity for this type of roundabout is expected to be similar to but less than that of the compact urban roundabout.

Mini-roundabouts are generally not suitable for use on state highways. Guidelines for designing mini-roundabouts are not provided in this document. For guidance and more information related to mini-roundabouts, readers are encouraged to refer to the *FHWA Guide* [1].

4.1.3 Overall Design & Evaluation Process

Roundabout design is an iterative process requiring the designer to consider operational and safety effects of the geometric elements. The recommended process for designing a roundabout is generally:

1. Identify the intersection context (rural or urban) and design vehicle.
2. Perform operational analysis to determine the number of lanes required. In general, the number of entry lanes and exit lanes should be kept to the minimum necessary based on the design year traffic projections. For example, if the designer determines that a two-lane roundabout is required, he/she should then optimize each of the approaches to determine if the demand can be served for any of the approaches with just single-lane entries. It is also desirable to minimize the number of exit lanes, as exits are the most difficult for pedestrians to cross.

3. Prepare an initial roundabout layout at a sketch level. A scale of 1"=50' is generally preferred for this sketch-level design. ***Figure 44*** shows an example conceptual design sketch.

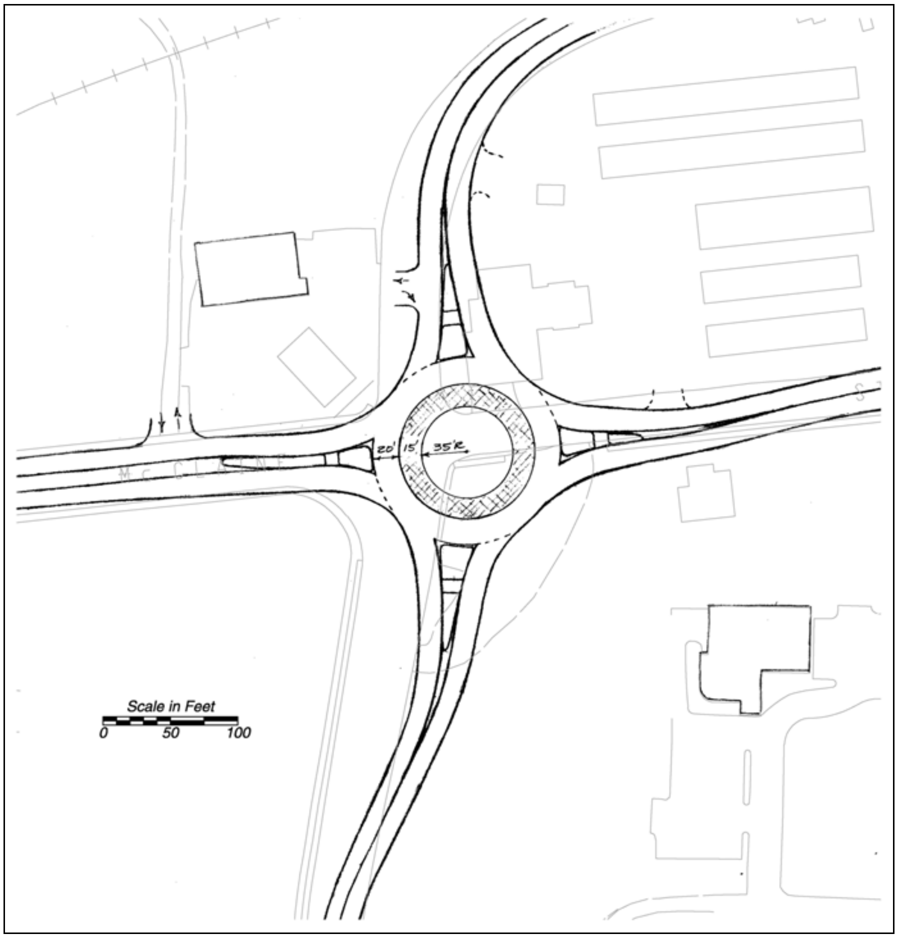


Figure 44
Example Roundabout Design Sketch

4. Check the design speeds of all movements at all legs of the roundabout. Avoid designs that result in entry speeds greater than 25 mph or speed differentials of greater than 12 mph.
5. If necessary, revise the sketched geometry to meet design speed and speed consistency objectives. Then check the design speeds of the revised design and continue to refine the geometry as necessary.
6. Check the design vehicle turning movement paths at each leg.
7. Revise the sketch if needed to accommodate the design vehicle. It may require using a larger diameter roundabout to meet the speed objectives and accommodate the design vehicle. Shifting the location of the inscribed circle can also help achieve speed objectives.
8. Re-analyze the operational performance if necessary to reflect the geometric parameters. Note that this may not be necessary for intersections with a volume-to-capacity (V/C) ratio less than approximately 0.50.

9. Prepare and evaluate alternative roundabout layouts following the same process above. Different inscribed diameters or different approach alignments may be evaluated to determine the optimal design compared to potential right-of-way impacts.

4.2 SITE SELECTION GUIDELINES

This section identifies locations and conditions at which roundabouts often provide advantages over other traffic control forms. Planners and designers are encouraged to consider and evaluate roundabouts as alternatives to conventional intersection forms at these locations. This section also identifies locations and conditions that can make a roundabout complicated, difficult, or undesirable. At these locations, planners and designers are encouraged to use extra care when considering roundabouts.

4.2.1 Sites Where Roundabouts Are Often Advantageous

Roundabouts are often advantageous over other traffic control at the following locations and conditions:

- Intersections with historical safety problems.
- Intersections with relatively balanced traffic volumes.
- Intersections with a high percentage of turning movements.
- Intersections with a high influx of traffic at peak hours but relatively low traffic volumes during non-peak hours.
- Existing two-way stop-controlled intersections with high side-street delays (particularly those that do not meet signal warrants).
- Intersections that must accommodate a high number of left turns or U-turns.
- At a gateway or entry point to a campus, neighborhood, or commercial development.
- Intersections where widening one or more approach may be difficult or cost-prohibitive, such as at bridge terminals.
- Intersections where traffic growth is expected to be high and future traffic patterns are uncertain.
- Locations where the speed environment of the road changes (for instance, at the fringe of an urban environment).
- Locations with a need to provide a transition between land use environments (such as between residential and commercial uses).
- Roads with a historical problem of excessive speeds.

4.2.2 Sites at Which Extra Care Should Be Exercised with Roundabouts

There are a number of locations and site conditions that often present complications or difficulties for installing roundabouts. Some of these locations can also be difficult or problematic for other intersection alternatives as well. Therefore, these site conditions should not necessarily preclude a roundabout from consideration. However, extra care should be exercised when considering roundabouts at these locations:

- Intersections in close proximity to a signalized intersection where queues may spill back into the roundabout.
- Intersections located within a coordinated arterial signal system.
- Intersections with a heavy flow of through traffic on the major street opposed by relatively light traffic on the minor street.

- Intersections with physical or geometric complications.
- Locations with steep grades and unfavorable topography that may limit visibility and complicate construction.
- Intersections with heavy bicycle or pedestrian volumes. Some international studies have shown cyclists may be more at risk at roundabouts than at other intersection types. Until more data is available for bicycle and pedestrian safety at U.S. roundabouts, extra care should be taken when evaluating roundabouts at intersections with significant bicycle/pedestrian activity. In particular, extra care should be taken for pedestrians and bicyclists at roundabouts with more than two lanes.

4.2.3 Roundabouts at Interchanges

Roundabouts can be acceptable and, in some locations, advantageous solutions for ramp terminal intersections within freeway service interchanges. Using a roundabout in an interchange does not represent a new or unique interchange form. Rather, the roundabout can be used within a variety of conventional interchange forms as the means of controlling traffic at the ramp terminal intersections. Most commonly, roundabouts are used at diamond interchanges. They may also be used within partial cloverleaf interchanges at the termini of loop ramps or diagonal ramps. There are two variations of diamond interchanges that can be used with roundabouts. The more common form, shown in ***Figure 45***, consists of two roundabouts, one on each side of the freeway. There is typically a single bridge structure (or, in some cases, two structures if the freeway crosses over the cross street) between roundabouts. For these interchanges, it is best if the ramp terminal intersections are spread relatively far apart (more than 500 feet between intersections) to avoid the need for widening of the bridge structure and prevent queues from spilling back between intersections. In some cases, the central islands may be raindrop-shaped with no yielding required for traffic between the two roundabouts. If the intersections consist of frontage roads or need to accommodate U-turns, however, raindrop-shaped central islands should not be used.

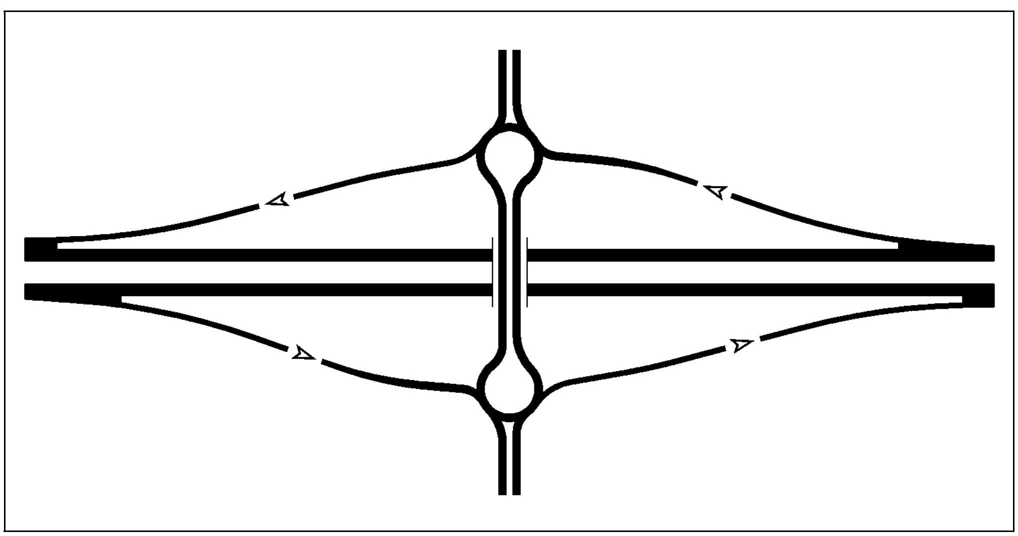


Figure 45
Typical Diamond Interchange with Roundabouts at Ramp Terminal Intersections

Roundabouts can often be an advantageous solution at diamond interchanges that include frontage roads. In general, it is preferable to realign frontage roads outside of the interchange area to simplify the ramp terminal intersections. However, in cases where such realignment cannot be achieved, roundabouts may accommodate the resulting unusual geometry or multi-leg ramp terminal intersections better than other traffic control forms. ***Figure 46*** displays an example of roundabouts at a diamond interchange with two-way frontage roads on one side of the interchange. In general, a primary design objective in this case is to align the approach roadways at relatively equal angles between legs. This allows even spacing between each entrance and exit within the roundabout and results in consistent speeds between all approaches. Roundabouts with more than four legs or with highly skewed angles between approaches often require larger diameters.

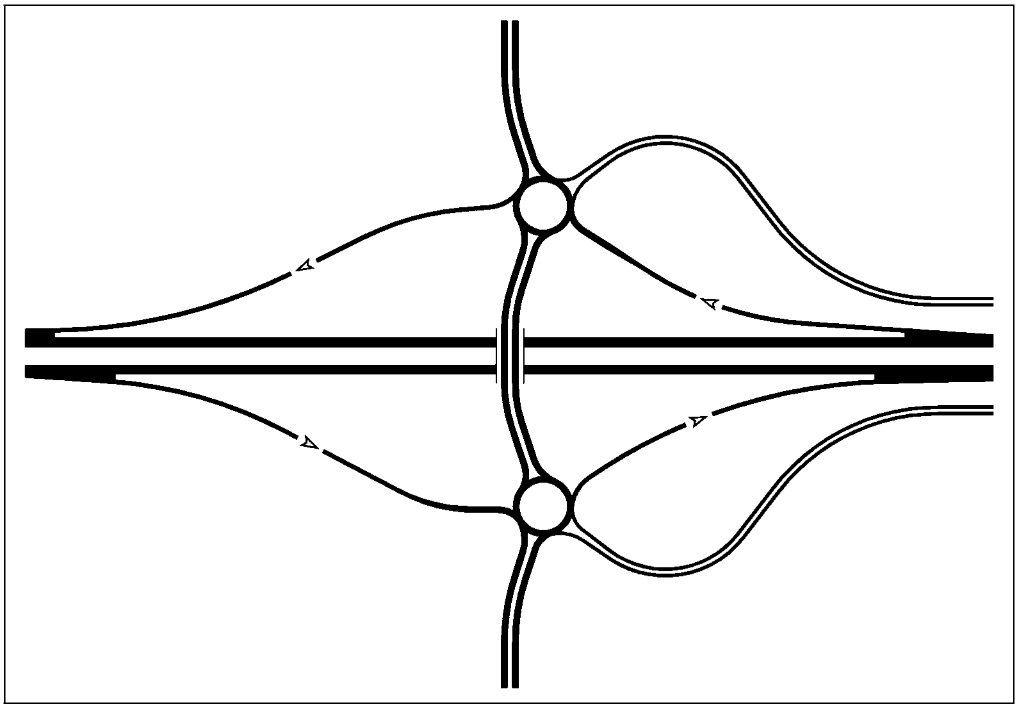


Figure 46
Roundabouts at Typical Diamond Interchange with Frontage Roads

Another variation of the diamond interchange with roundabouts consists of a single, large-diameter roundabout centered over or under the freeway. ***Figure 47*** illustrates this interchange form. As shown in the figure, the interchange requires two overpass or underpass structures. This interchange form can be likened to a typical single-point diamond interchange, where freeway turning traffic interchanges with arterial traffic at a single (albeit large) intersection. Due to the large size of this roundabout, care should be taken to ensure adequate entry curvature is achieved to control speeds.

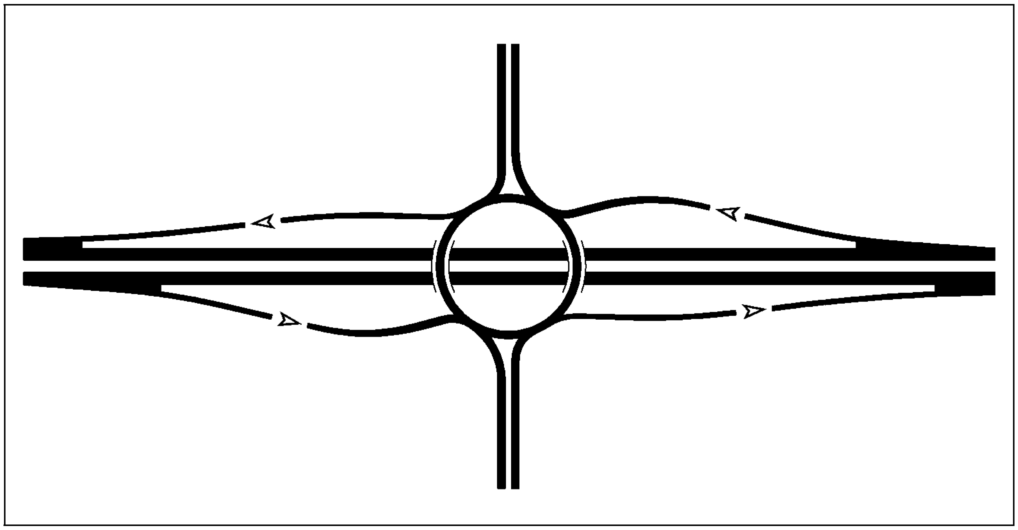


Figure 47
Diamond Interchange With Roundabout
At Single Ramp Terminal Intersection

4.3 ROUNDABOUT PERFORMANCE ANALYSIS

The maximum flow rate that can be accommodated at a roundabout entry depends on two factors: the circulating flow in the roundabout that conflicts with the entry flow, and the geometric elements of the roundabout. The capacity is computed at each entry and compared with the demand traffic volume. **The maximum volume-to-capacity ratio (V/C) threshold for a roundabout entry should be 0.85.** Higher degrees of saturation can lead to unstable operation in which high delays and lengthy queues may occur at the roundabout approach.

At this time, there are several acceptable methods for conducting performance analysis at roundabouts:

- The analysis procedure outlined in the *FHWA Guide* [1];
- aaSIDRA software package (Australia; gap acceptance);
- RODEL and ARCADY software packages (U.K.; empirical);
- Traffic simulation software packages (those capable of modeling roundabouts; e.g. CORSIM).

The capacity model described in the *FHWA Guide* [1] should be used as the initial method for evaluating a roundabout's capacity. The Australian and British models may also be used for comparison purposes and to perform more detailed modeling. These different models generally yield similar results for roundabouts with moderate traffic volumes (moderate entry flows and/or moderate circulatory flows). However, in cases with high entry flows opposed by low circulatory volumes and vice versa (i.e. highly directional/unbalanced flows), the models can yield significantly different results. Because there is limited data for actual roundabout performance in the United States, the worst-case capacity prediction should generally be used to produce a more conservative design.

4.3.1 FHWA Analysis Procedure

The *FHWA Guide* [1] provides basic capacity models for urban compact roundabouts, typical single-lane roundabouts, and typical double-lane roundabouts. The only input to these models is the circulatory traffic volume. The resulting capacity forecasts were developed based on typical geometric parameters and simplified regression relationships from the British and German models. For background discussion and more detailed information on this capacity model, refer to the Chapter 4 of the *FHWA Guide*.

4.3.1.1 *Traffic Volumes*

The analysis method requires specific traffic volumes for each approach to the roundabout, including the hourly flow rate for each directional movement. Hourly volumes must be converted to *passenger car equivalents* (pce), using the standard conversion factors and methodology from the *Highway Capacity Manual* [11]. Intersection turning movement flows must then be converted to roundabout flows. This process will result in an *entry volume* and a *circulatory volume* at each entry to the roundabout. For more details on how to convert intersection turning movement volumes to roundabout flows, refer to the Chapter 4 of the *FHWA Guide* [1].

4.3.1.2 *Single-lane Roundabout Capacity*

Figure 48 shows the expected capacity of a single-lane roundabout for both the urban compact and typical single-lane designs.

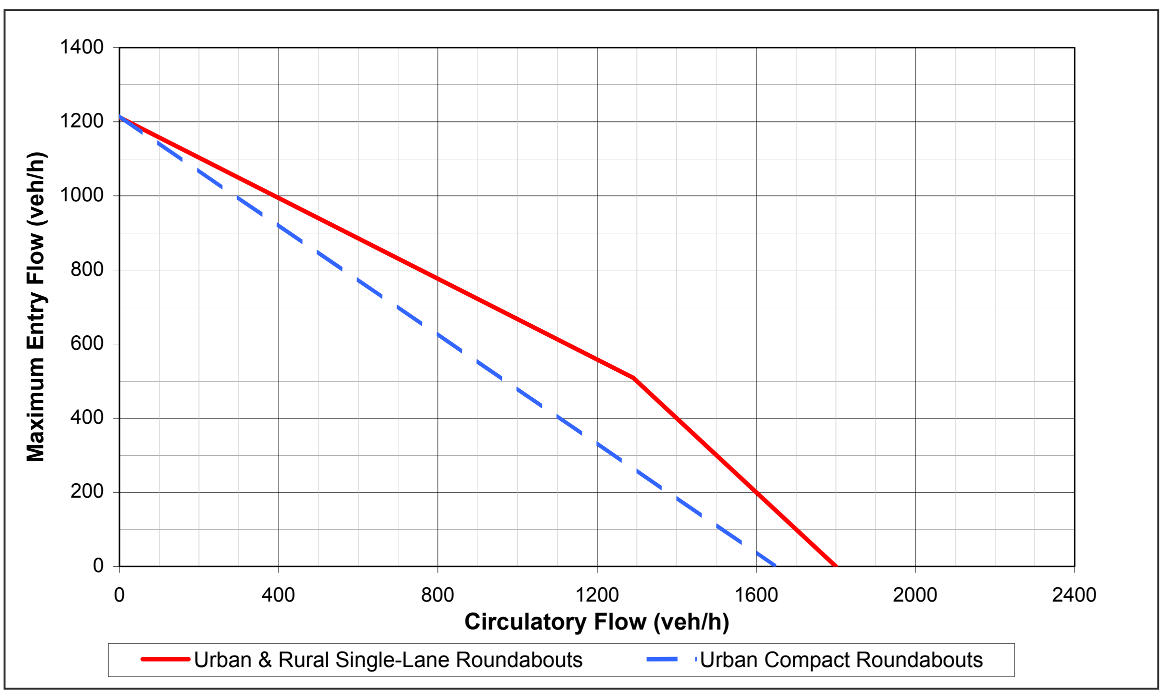


Figure 48
Entry Capacity of a Single-Lane Roundabout

The equations for entry capacity at single-lane roundabouts and urban compact roundabouts, respectively, are expressed below:

Single-lane Roundabouts: $Q_E = Min\{(1212 - 0.5447Q_C), (1800 - Q_C)\}$

Urban Compact Roundabouts: $Q_E = 1218 - 0.74Q_C$

where: Q_E = entry capacity, pce/h
Q_C = circulating flow, pce/h

4.3.1.3 *Double-lane Roundabout Capacity*
Figure 49 shows the expected capacity of a typical double-lane roundabout.

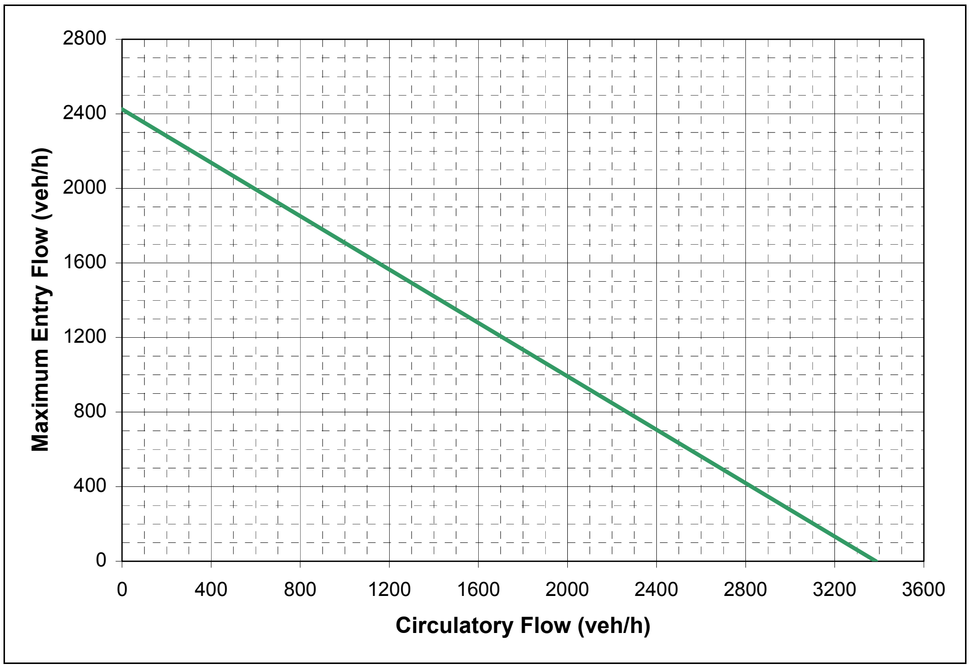


Figure 49
Entry Capacity of a Double-Lane Roundabout

The equation for a double-lane roundabout entry is expressed below:
Double-lane Roundabouts: $Q_E = 2424 - 0.7159Q_C$

where: Q_E = entry capacity, pce/h
Q_C = circulating flow, pce/h

4.3.1.4 *Capacity Effect of Short Lanes or Flared Entries*
In some cases, a single-lane approach may be widened (or *flared*) to two lanes at the roundabout entry to improve the performance. This additional entry lane is referred to as a short lane because it is typically only added for a short distance from the yield line of the roundabout. The amount of additional capacity achieved depends on the length of the short lane.

The capacity of a flared approach is computed by first determining the capacity of a standard double-lane entry, and then applying a reduction factor based on the short lane length. Table 12 displays the capacity reduction factors to be applied for various lengths of short lane. It can be assumed that each vehicle space is equivalent to 25 feet.

Table 12
Capacity Reduction Factors for Short Lanes

Number of vehicle spaces in the short lane, n_f	Factor (applied to double-lane approach capacity)
0	0.500
1	0.707
2	0.794
4	0.871
6	0.906
8	0.926
10	0.939

4.3.1.5 *Pedestrian Effects on Entry Capacity*
Pedestrians have priority over entering motor vehicles at all roundabout entries. At intersections with high volumes of pedestrians, the crossings can have a significant effect on entry capacity. In such cases, the vehicular capacity is reduced by the reduction factors (*M*) shown in ***Figure 50***. Note that the pedestrian impedance decreases as the circulatory flow rate (in front of the subject approach) increases. This occurs because pedestrians cross between queued vehicles at the approach.

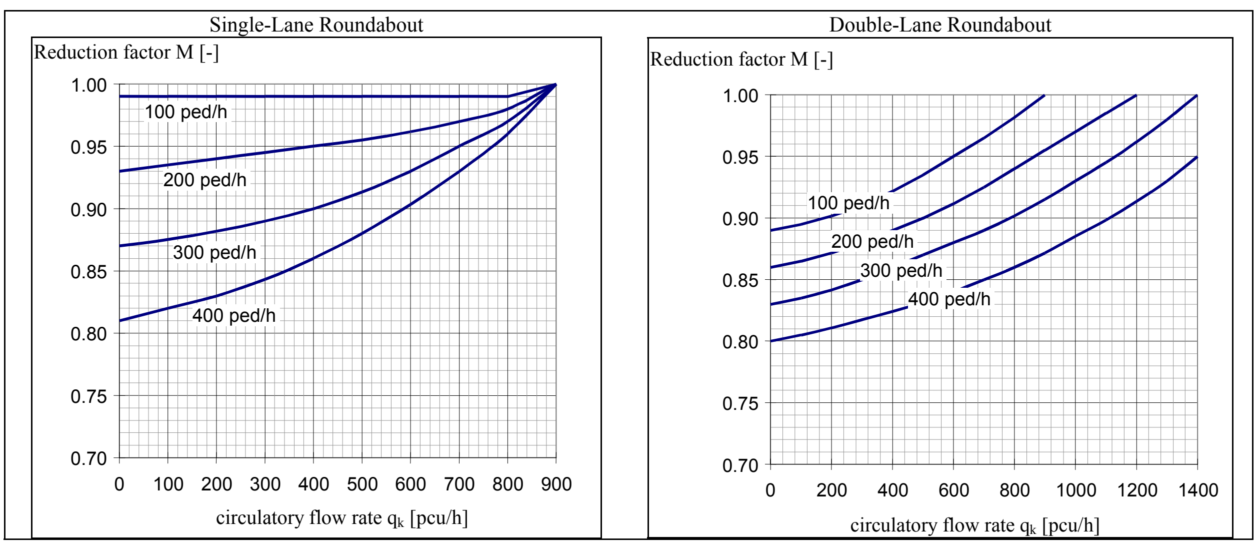


Figure 50
Capacity Reduction Factors Due to Pedestrians

4.3.1.6 *Queues*
Figure 51 shows how the 95th-percentile queue length varies with the V/C ratio of an approach. Individual lines are shown for the product of *T* and entry capacity. To determine the 95th-percentile queue length during time *T*, enter the graph at the computed V/C ratio. Move vertically until the computed curve line is reached. Then move horizontally to the left to determine the 95th-percentile queue length.

In most cases, T should be 0.25 hours to represent the analysis of the peak 15-minute period. If the analysis has been conducted for the peak 1-hour condition, then T should be 1.0. Note that this queue length estimation figure is not exclusively for roundabouts.

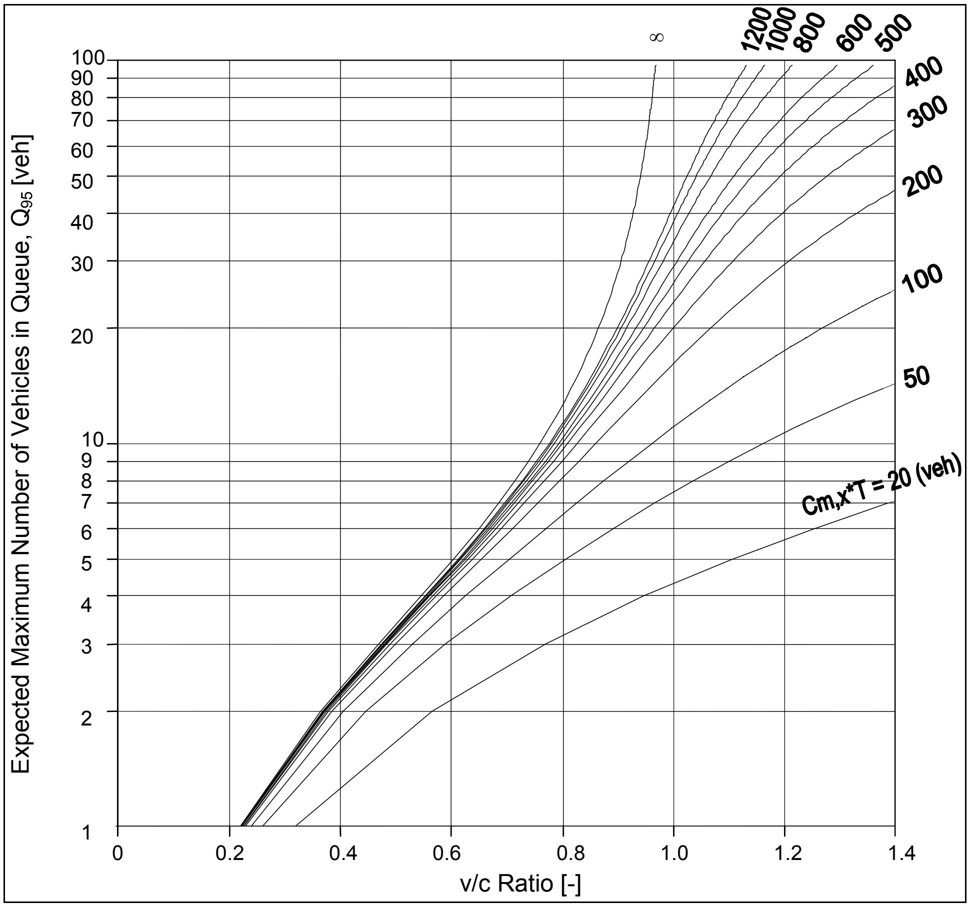


Figure 51
95th-Percentile Queue Length Estimation

4.3.1.7 *Delay*

The FHWA procedure cites the use of the *Highway Capacity Manual* (HCM) [11] delay equation for calculating delay at roundabouts. Currently, the HCM only includes control delay, the delay attributable to the control device. Geometric delay is the second component of delay, which is the delay experienced by a single vehicle with no conflicting flows due to geometric features encountered when negotiating the intersection. This delay is computed using the following formula.

Control Delay: $$d = \frac{3600}{c_{m,x}} + 900T \times \left[\frac{v_x}{c_{m,x}} - 1 + \sqrt{\left(\frac{v_x}{c_{m,x}} - 1\right)^2 + \frac{\left(\frac{3600}{c_{m,x}}\right)\left(\frac{v_x}{c_{m,x}}\right)}{450T}} \right]$$

where: d = average control delay, sec/veh;
v_x = flow rate for movement x, veh/h;
$c_{m,x}$ = capacity of movement x, veh/h; and
T = analysis time period, h (T = 0.25 for a 15-minute period)

Figure 52 shows how control delay at an entry varies with entry capacity and circulating flow.

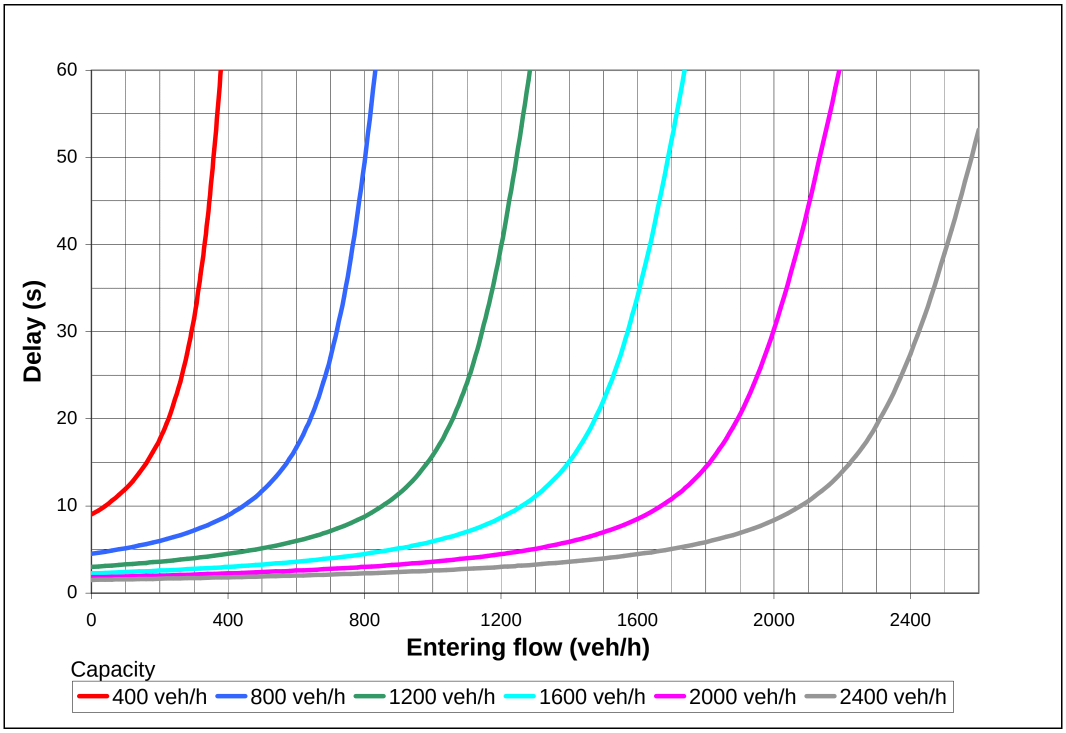


Figure 52
Control Delay as a Function of Capacity and Entering Flow

4.4 GEOMETRIC DESIGN

The successful implementation of a roundabout project depends heavily on providing a sound and appropriate design. Principles for the geometric design of roundabouts are outlined in detail in Chapter 6 of the *FHWA Guide* [1]. Additional guidance can also be found from the research and practices developed in other countries with more roundabout history than the United States, particularly the United Kingdom and Australia. This section summarizes the fundamental design principles and specific criteria for various geometric elements.

4.4.1 Fundamental Principles

Fundamentally, the principles of roundabout design are no different than other roadways and intersection types. The designer must consider the context of the project and provide suitable geometry and traffic control devices according to established engineering tools and design standards. These considerations include design speed, design vehicle, lane numbers, lane arrangements, user types, and physical environment. Some of the geometric features and operational objectives are slightly different for roundabouts, however, than for other intersection forms. The fundamental principles guiding roundabout design are discussed below.

4.4.1.1 *Design Speed*

One of the most critical design objectives is achieving appropriate vehicular speed through the roundabout. Roundabouts operate most effectively when their geometry forces traffic to enter and circulate at slow speeds. The curvature imposed by the roundabout geometry on a vehicle's path is often referred to as *deflection*.

The fastest path allowed by the geometry determines the design speed of a roundabout. This is the smoothest, flattest path possible for a single vehicle, in the absence of other traffic and ignoring all lane markings. The fastest path is drawn for a vehicle traversing through the entry, around the central island, and out the exit. Once the fastest paths are drawn, the minimum radii along the paths are measured and the corresponding design speed of each radius is computed. The fastest paths must be drawn for all approaches and all movements, including left-turn movements (which generally represent the slowest of the fastest paths) and right-turn movements (which may be faster than the through movement paths at some roundabouts). ***Figure 53*** illustrates the five critical path radii that must be checked at each approach.

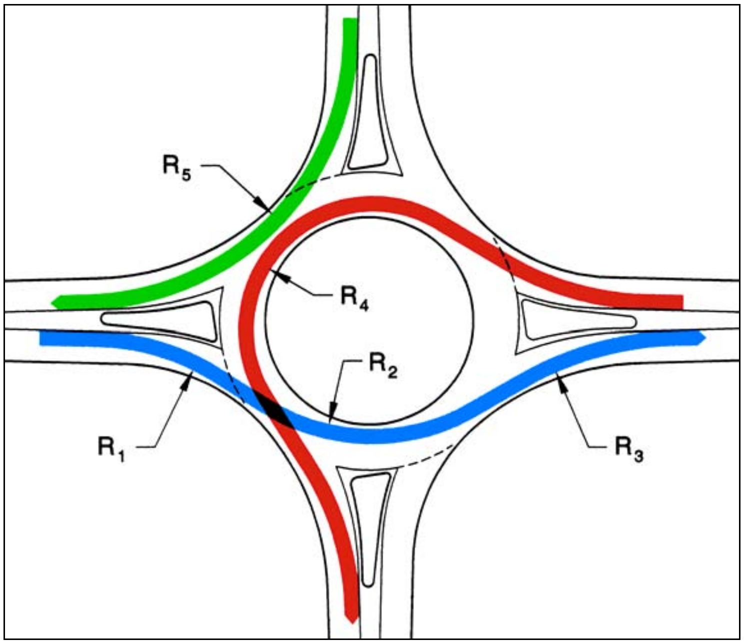


Figure 53
Vehicle Path Radii

As shown in ***Figure 53***, the fastest path is drawn assuming a vehicle starts at the left-hand edge of the approach lane, moves to the right side as it enters the roundabouts, cuts to the left side of the circulatory roadway, then moves back to the right side at the exit, and completes its move at the left-hand side of the departure lane. The centerline of the vehicle path is drawn using the following minimum offset distances:

- 5 feet from concrete curbs,
- 5 feet from roadway centerline, and
- 3 feet from striped edge lines or lane.

Figure 54 illustrates the construction of the fastest vehicle path for a through movement at a typical single-lane roundabout.

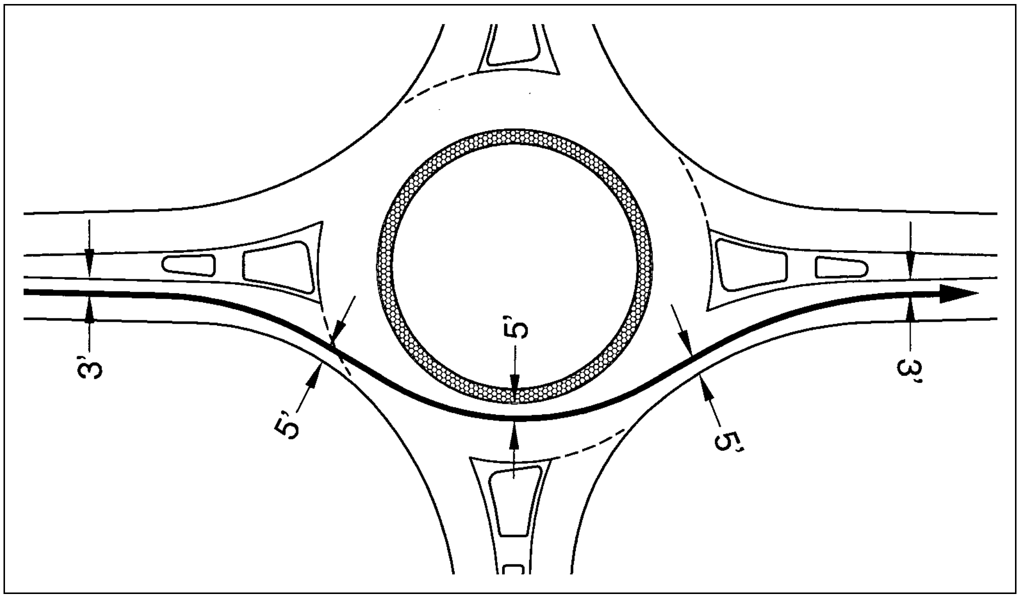


Figure 54
Fastest Vehicular Path at a Single-Lane Roundabout

In some cases the right-turn path may be faster than the through movement path. Thus, the right-turn fastest path should be drawn carefully using the same principles and offsets described above. ***Figure 55*** shows a sample right-turn path.

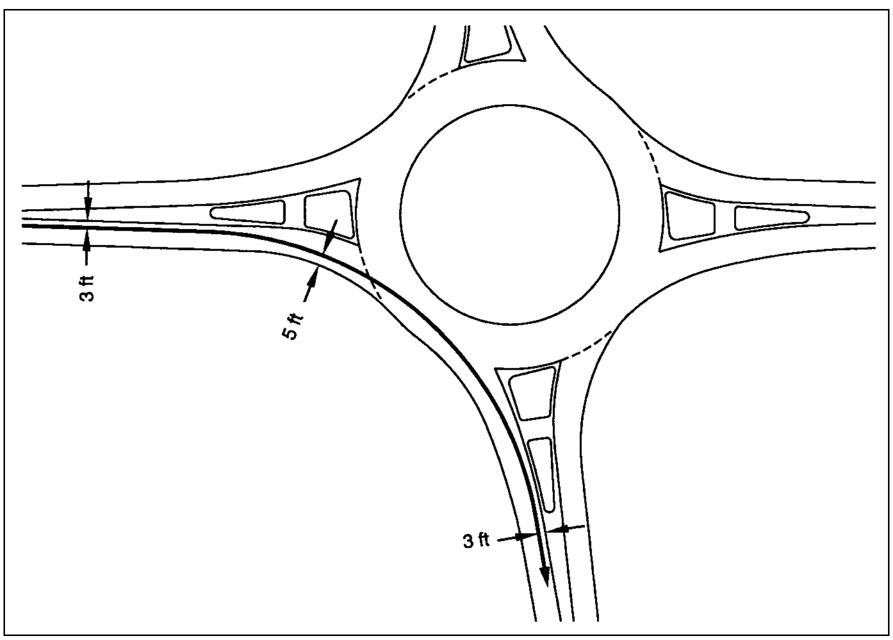


Figure 55
Fastest Vehicular Path for a Critical Right-Turn Movement

At double-lane roundabouts, the fastest path is drawn assuming the vehicle approaches in the right lane, cuts across into the left hand circulatory lane, and then exits into the right lane. ***Figure 56*** illustrates the fastest path at a typical double-lane roundabout.

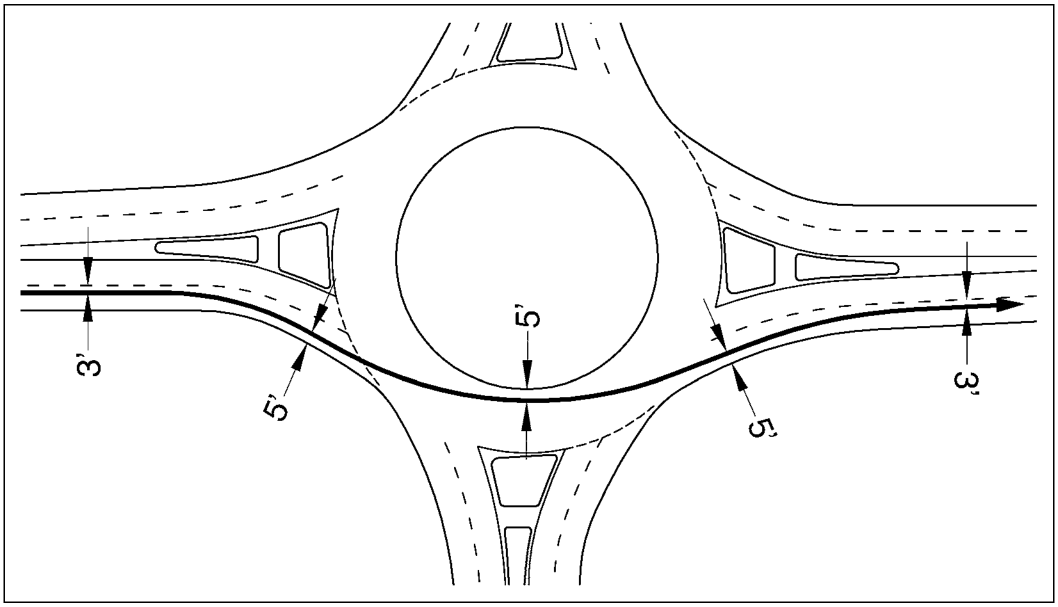


Figure 56
Fastest Vehicular Path at a Double-Lane Roundabout

Once the fastest paths are drawn, the minimum radii along these paths are then measured, and the corresponding design speed is calculated according to the methodology in the AASHTO publication *A Policy on Geometric Design of Highways and Streets* (commonly referred to as the "Green Book") [8]. The equation for the design speed with respect to horizontal curve radius is given below.

Speed-Radius Relationship: $V = \sqrt{15R(e + f)}$

where: V = Design speed, mph
R = Radius, ft
e = superelevation, ft/ft
f = side friction factor

Superelevation values are usually assumed to be +0.02 for entry and exit curves (R_1, R_3, and R_5 from figure 53) and –0.02 for curves around the central island (R_2 and R_4 from figure 53). More details related to superelevation design are provided later in this Chapter.

Values for side friction factor can be determined in accordance with AASHTO standards for curves at intersections (see AASHTO *Green Book* [8]). The coefficient of friction between a vehicle's tires and the pavement varies with the vehicle's speed. Using the appropriate friction factors corresponding to each speed, ***Figure 57*** was developed to graphically show the speed-radius relationship for curves on both a +0.02 superelevation and –0.02 superelevation.

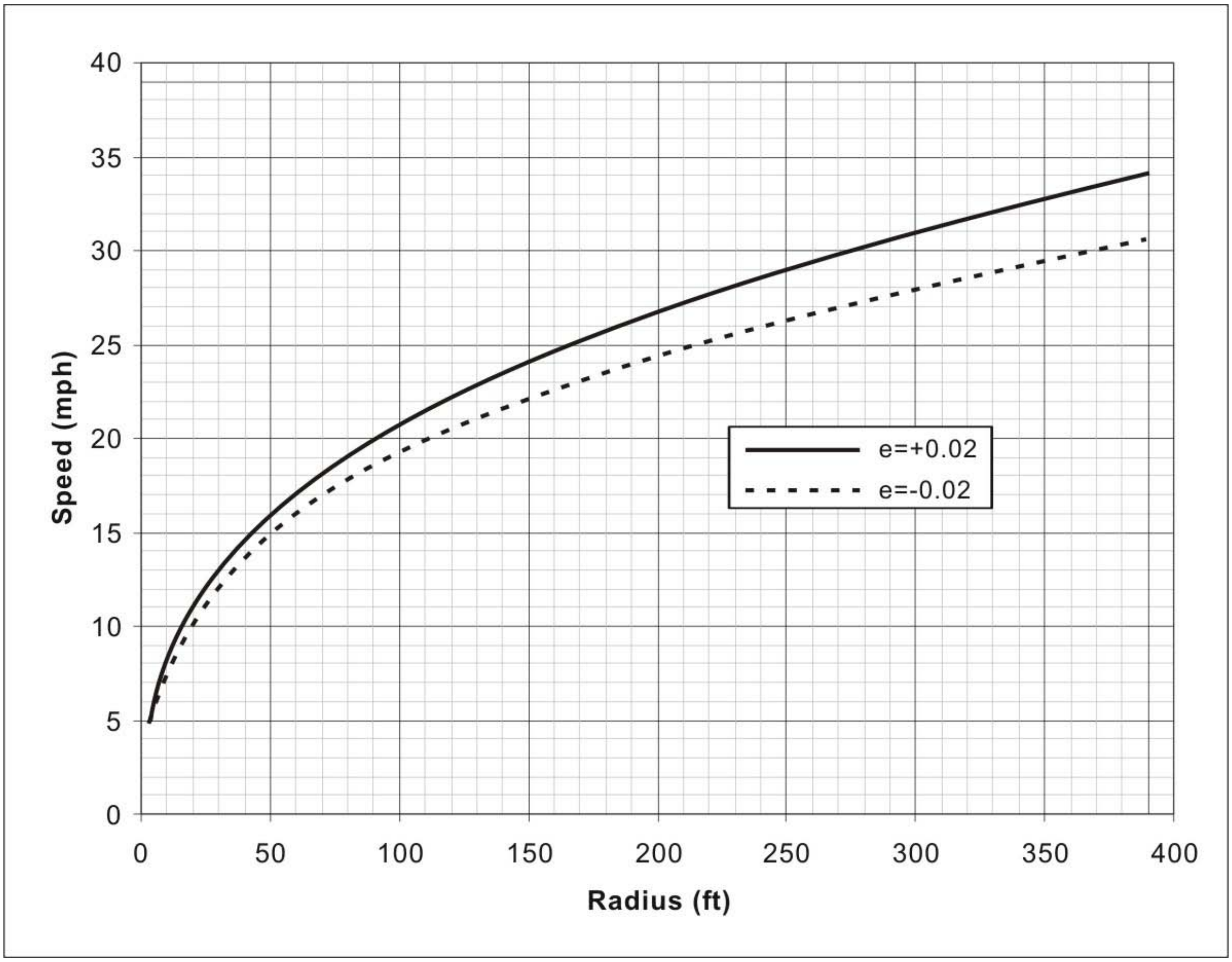


Figure 57
Speed-Radius Relationship

Table 13 displays the maximum recommended design speeds for various roundabout categories.

Table 13
Roundabout Design Speeds

Site Category	Maximum Entry (R_1) Design Speed
Mini Roundabout	20 mph
Urban Compact Roundabout	20 mph
Urban Single-Lane Roundabout	25 mph
Rural Single-Lane Roundabout	25 mph
Urban Double-Lane Roundabout	25 mph
Rural Double-Lane Roundabout	30 mph

4.4.1.2 *Speed Consistency*
In addition to achieving the appropriate design speed for the fastest movements, the relative speeds between consecutive geometric elements should be minimized and the relative speeds between conflicting traffic streams should be minimized. Ideally, the relative differences between all speeds within the roundabout should be no more than 6 mph. However, it is often

difficult to achieve this goal, particularly at roundabouts that must accommodate large trucks. In these cases, the maximum speed differential between movements should be no more than 12 mph.

Once a preliminary geometric design for a roundabout has been developed, the fastest path radii and speeds should be summarized in a tabular format, as shown in Table 14. This tabular summary should be provided along with the sketched fastest path diagrams for all conceptual and/or preliminary roundabout design plans submitted to ADOT and/or other governing agencies for review.

Table 14
Sample Design Speed Table

Approach	Curve	Radius (feet)	Speed (mph)	Relative Speed Difference* (mph)
Northbound	R1	150	24	7
	R2	125	21	4
	R3	150	24	7
	R4	80	17	0
	R5	150	24	7
Southbound	R1	140	23	6
	R2	115	20	3
	R3	150	24	7
	R4	80	17	0
	R5	150	24	7
Eastbound	R1	100	20	3
	R2	150	22	11
	R3	225	28	11
	R4	80	17	0
	R5	100	20	3
Westbound	R1	175	25	8
	R2	125	21	4
	R3	175	25	8
	R4	80	17	0
	R5	125	22	5

* Relative difference is from minimum speed within roundabout (typically, R4 speed).

The exit radius, R_3, should not be less than R_1 or R_2 to minimize loss-of-control crashes. At single-lane roundabouts with pedestrian activity, exit radii may still be small (the same or slightly larger than R_2) in order to minimize exit speeds. However, at double-lane roundabouts, additional care must be taken to minimize the likelihood of exiting path overlap. Exit path overlap can occur at the exit when a vehicle on the left side of the circulatory roadway (next to the central island) exits into the right-hand exit lane. More guidance related to path overlap at multi-lane roundabouts is provided later in this section. At multi-lane roundabouts and single-lane roundabouts where no pedestrians are expected, it is acceptable for the design speed of the exit radius (R_3) to be slightly higher than 25 mph. Where pedestrians are present, tighter exit curvature may be necessary to ensure sufficiently low speeds at the downstream pedestrian crossing.

4.4.1.3 *Approach Alignment*
Ideally, the centerline of the roundabout approaches should align through the center of the roundabout. However, it is acceptable for the approach to be slightly offset to the left of the center point, as this alignment enhances the deflection of the entry path. If it is aligned too far to the left, however, excessive tangential exit may occur, causing higher exit speeds. If the alignment of the entry is offset to the right, the approach geometry often does not provide enough deflection for the entering vehicles. Therefore, approach alignments offset to the right of the roundabout center should be avoided. ***Figure 58*** illustrates the preferred approach alignment for roundabouts in general.

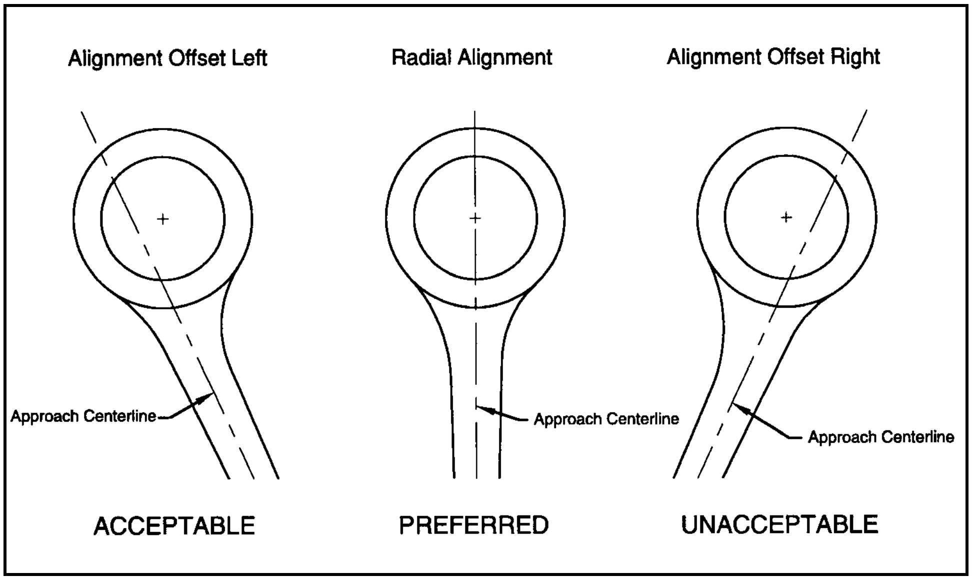


Figure 58
Approach Alignment Guidelines

4.4.1.4 *Angles Between Approaches*
Similar to signalized and stop-controlled intersections, the angle between approach legs is an important design consideration. Although it is not necessary for opposing legs to align directly opposite one another (as it is for conventional intersections), it is generally preferable for the approaches to intersect at perpendicular or near-perpendicular intersection angles. If two approach legs intersect at an angle significantly less than or greater than 90 degrees, it will often result in excessive speeds for one or more right-turn movements. At the same time, left-turn movements from all approaches will be relatively low, resulting in a higher speed differential than desired. Designing the approaches at perpendicular or near-perpendicular angles generally results in relatively slow and consistent speeds for all movements. Highly skewed intersection angles can often require significantly larger inscribed circle diameters to achieve the speed objectives.

Figure 59 illustrates the fastest paths at a roundabout with perpendicular approach angles versus a roundabout with obtuse approach angles.

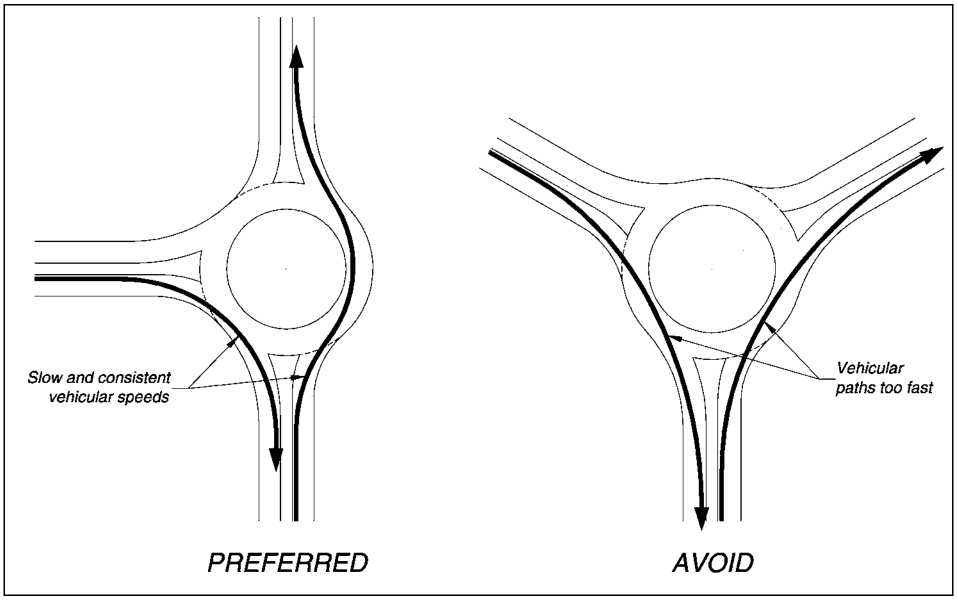


Figure 59
Perpendicular Approach Angles Versus Obtuse Approach Angles

As this figure implies, roundabout T-intersections should intersect as close to 90 degrees as possible. Y-shaped roundabout intersections will typically result in higher speeds than desired.

4.4.1.5 *Design Vehicle*
Aside from approach geometry, accommodating oversized vehicles has the greatest influence on a roundabout's design. Because roundabouts are intentionally designed to slow traffic, narrow curb-to-curb widths and tight turning radii are used. However, if the widths and turning requirements are designed too tight, it can create difficulties for oversized vehicles. Large trucks and buses often dictate many of the roundabout's dimensions, particularly for single-lane roundabouts. Therefore, the design vehicle must be established at the start of the design and investigation process. ***Figure 60*** illustrates an example of a roundabout that does not adequately accommodate a truck, and one that does by way of a truck apron.

Example of roundabout not properly designed to accommodate large trucks

Example of roundabout designed properly for large trucks

Figure 60
Truck Accommodations at Roundabouts

Selecting the design vehicle is determined by considering the types of roadways involved, the area where the intersection is located, and the types and volume of vehicles using the intersection. Typical design vehicles for various roadway types are given in Table 15. The appropriate staff from ADOT and/or the governing local agencies should be consulted early in the design process to identify the design vehicle at each project location.

Table 15
Recommended Design Vehicle

Intersection Type	Design Vehicle
State Highway Routes	WB-67
Ramp Terminal	WB-67
Other Rural	WB-50
Urban Major Streets	WB-50
Other Urban	Bus or SU

Vehicle turning path templates or CAD-based vehicle turning path simulation software (such as AutoTURN) should be used during the design process to establish the turning path requirements of the design vehicle. Section 407 of the Arizona Department of Transportation *Roadway Design Guidelines* [12] provides minimum turning radii and turning path templates for a variety of standard design vehicles.

4.4.1.6 *Pedestrian Accommodations*

As with any intersection form, providing safe and comfortable accommodations for pedestrians is a fundamental objective. At roundabouts, pedestrian crosswalks are set back from the yield line approximately one vehicle length to separate driver decision tasks. This distance allows drivers to first focus on the pedestrian crossing prior to arriving at the yield line where they are focusing on other traffic. Appropriately sized refuge areas in the splitter islands enable pedestrians to cross the traffic streams in two stages, by first crossing the entrance lanes and then crossing the exit lanes. ***Figure 61*** displays a typical pedestrian crossing at a single-lane roundabout leg.

Figure 61
Pedestrian Crossing at a Roundabout

More detailed guidelines for the design of pedestrian accommodations are provided later in this Chapter.

4.4.2 Elements of Design

This section focuses on specific geometric elements and provides guidelines for their dimensions.

4.4.2.1 *Inscribed Circle Diameter*

The inscribed circle diameter is the distance across the circle inscribed by the outer curb face (or edge) of the circulatory roadway. It is the sum of the central island diameter and twice the circulatory roadway. The inscribed circle diameter is determined by a number of design objectives. The designer often has to experiment with varying diameters before determining the optimal size at a given location.

At single-lane roundabouts, the size of the inscribed circle is largely dependent upon the turning requirements of the design vehicle. The diameter must be large enough to accommodate the design vehicle while maintaining adequate deflection curvature to ensure safe travel speeds for smaller vehicles. However, the circulatory roadway width, entry and exit widths, entry and exit radii, and approach angles also play a significant role in accommodating the design vehicle and providing deflection. Carefully selecting these geometric elements may allow a smaller inscribed circle diameter to be used in constrained locations.

In general, smaller inscribed diameters are better for overall safety because they help to maintain lower circulatory speeds. In high-speed environments, however, the design of the approach geometry is more critical than in low-speed environments. Larger inscribed diameters generally provide better approach geometry, which leads to a decrease in vehicle approach speeds. Larger inscribed diameters also reduce the angle formed between entering and circulating vehicle paths, reducing the relative speed between these vehicles and leading to reduced entering-circulating crash rates. Therefore, roundabouts in high-speed environments may require diameters that are somewhat larger than those recommended for low-speed environments.

For intersections with large semi-trailers, it is often necessary to use larger inscribed circle diameters to accommodate the design vehicle while achieving adequate speed reduction at the entries. In addition, the angle between approach legs can affect the diameter. As the angle between legs decreases, it generally requires using a larger inscribed diameter to accommodate turning paths and achieve adequate speed reduction.

Table 15 provides recommended ranges of inscribed circle diameters for various site categories. The inscribed diameter values in this table are intended as guidelines to assist designers in beginning the design of a roundabout. These values are not intended to be maximum or minimum design standards. It may be appropriate to use inscribed diameters outside of these typical ranges, provided the geometry achieves the fundamental speed reduction objectives and accommodates pedestrians and the design vehicle.

Table 16
Typical Inscribed Circle Diameter Ranges

Site Category	Typical Design Vehicle	Inscribed Circle Diameter Range*
Rural Single Lane	WB-67	130 – 200 ft
Rural Double Lane	WB-67	175 – 250 ft
Urban Single Lane	WB-50	120 – 150 ft
Urban Double Lane	WB-50	150 – 220 ft
Urban Compact	Single-Unit Truck/Bus	90 – 120 ft
Mini-Roundabout	Single-Unit Truck	50 – 90 ft

* Assumes 90-degree angles between entries and no more than four legs.

4.4.2.2 *Circulatory Roadway*

The required width of the circulatory roadway is determined from the width of the entries and the turning requirements of the design vehicle. In general, it should always be at least as wide as the maximum entry width and should remain constant throughout the roundabout.

4.4.2.2.1 Single-Lane Roundabouts

The circulatory roadway at single-lane roundabouts is usually between 18 feet and 20 feet wide. The circulatory roadway should just accommodate the design vehicle. However, in many cases (particularly where the inscribed diameter is relatively small or the design vehicle is a large semi-trailer) the turning path of the design vehicle may dictate that the circulatory roadway be so wide that the deflection for passenger vehicles is compromised. In such cases, the circulatory roadway width can be reduced by placing a truck apron behind a mountable curb on the central island. Buses and single-unit trucks should usually be accommodated within the circulatory roadway (without using the apron). Truck aprons should be used only when there is no other means of providing adequate deflection while accommodating the design vehicle. More details related to truck apron design are presented in the *Central Island* section.

Appropriate vehicle-turning templates or a CAD-based computer program should be used to determine the swept path of the design vehicle through each of the turning movements. Usually, the left-turn movement is the critical path for determining circulatory roadway width. A minimum clearance of one foot should be provided between the outside edge of the vehicle's tire track and the curb line.

4.4.2.2.2 Multi-Lane Roundabouts

At multi-lane roundabouts, the circulatory roadway width is usually not governed by the design vehicle. The width required for two or three vehicles, depending on the number of lanes at the widest entry, to travel simultaneously through the roundabout should be used to establish the circulatory roadway width. The combination of vehicle types to be accommodated side-by-side is dependent upon the specific traffic conditions at each site. In many urban locations, it may be a bus or single-unit truck in combination with a passenger vehicle. If large semi-trailers are relatively infrequent, it is often appropriate to design the circulatory roadway such that these large trucks sweep across both lanes within the circulatory roadway. However, if large trucks are relatively common, it may be necessary to accommodate a semi-trailer in combination with a passenger vehicle. The appropriate staff from ADOT and/or other governing agencies should be consulted early in the design process to determine the choice of vehicle types to be accommodated side-by-side.

Figure 62 displays an example of the swept paths of two vehicles circulating side-by-side through a roundabout geometry. In this case, the roundabout was located on a predominantly recreational route and was designed to accommodate two motorhome vehicles with boat trailers circulating side-by-side.

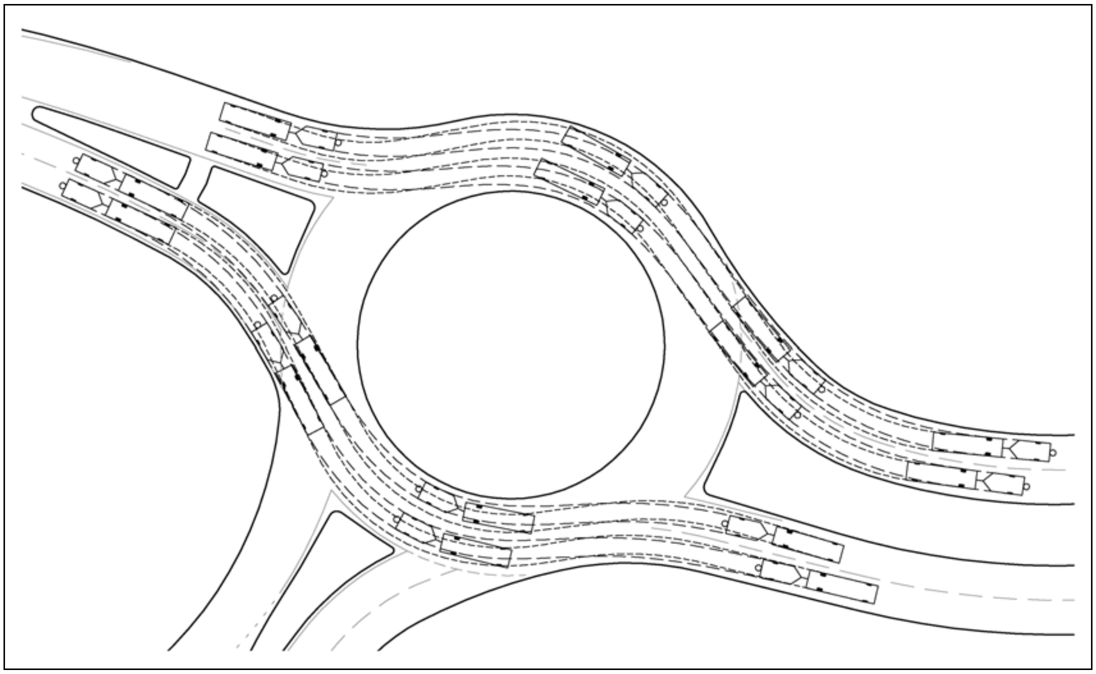


Figure 62
Example Design: Circulatory Roadway Accommodates Side-By-Side Motorhomes with Boat Trailers.

Table 17 provides minimum recommended circulatory roadway widths for two-lane roundabouts where semi-trailer traffic is relatively infrequent.

Table 17
Minimum Circulatory Lane Widths for Two-Lane Roundabouts.

Inscribed Circle Diameter	Minimum Circulatory Lane Width*	Central Island Diameter
150 ft	32 ft	86 ft
165 ft	31 ft	103 ft
180 ft	30 ft	120 ft
200 ft	30 ft	140 ft
215 ft	29 ft	157 ft
230 ft	29 ft	172 ft

* Based on 2001 AASHTO Exhibit 3-55, Case III(A) [8]. Assumes infrequent semi-trailer use.

4.4.2.3 *Central Island*
The central island is the raised area inside the circulatory roadway. In many cases, the outer portion of the central island consists of a mountable area, known as the truck apron, to accommodate the overtracking of large semi-trailers.

The central island size is determined by the width of the circulatory roadway and the diameter of the inscribed circle. Circular-shaped central islands are always preferable over other shapes because they promote uniform circulatory speeds and are consistent with driver expectations. However, in cases with severe right-of-way or topographic constraints, the central island may be oval or elliptical in shape. Irregular shaped central islands are generally not a problem if they are relatively small and speeds are low.

The central island should always be raised above the circulatory roadway and delineated by a raised curb. If a truck apron is used, it should be designed to handle the wheel tracking of semi-trailers, but discourage passenger vehicles from driving over it. Aprons should generally be no more than 15 feet wide (preferably less than 10 feet), and should be sloped outward. To discourage use by passenger cars, the outer edge of the apron should be raised approximately three inches above the normal surface elevation of the circulatory roadway. ***Figure 63*** displays a typical cross section of a roundabout circulatory roadway and truck apron.

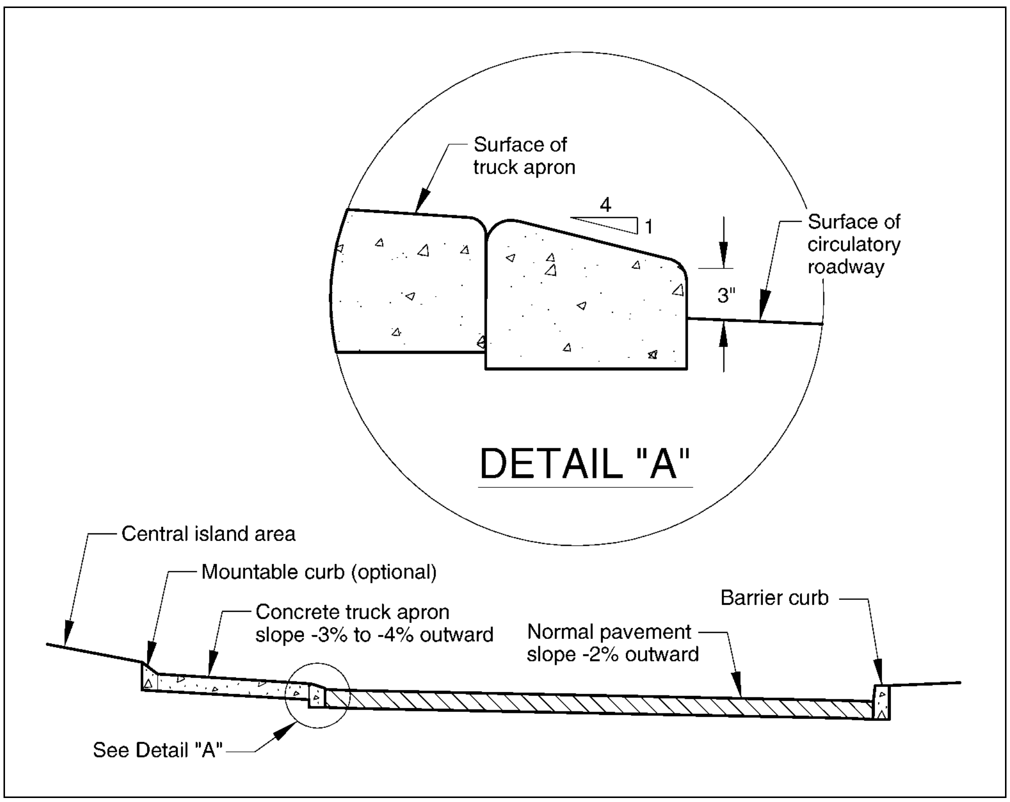


Figure 63
Typical Section of Circulatory Roadway and Truck Apron

4.4.2.4 *Entries*
To maximize the roundabout's safety, entry widths should be no wider than needed to serve design vehicles. The capacity requirements and performance objectives will determine the num-

ber of entry lanes for each approach. In addition, the turning requirements of the design vehicle may require that the entry be wider still. However, larger entry and circulatory widths increase crash frequency. Therefore, determining the entry width and circulatory roadway width requires balancing between capacity and safety considerations. The design should provide the minimum width necessary for capacity while accommodating the design vehicle. Typical entry widths for single-lane entrances range from 14 to 18 feet; however, values slightly higher or lower than this range may be required for site-specific design vehicles and speed requirements for critical vehicle paths.

Entry curb radii at urban single-lane roundabouts typically range from 35 to 100 feet. Larger radii may be used, but the radii should not be so large as to result in excessive entry speeds. At local street roundabouts, entry radii may be below 35 feet if the design vehicle is small. Note that the entry *curb* radius should not be confused with the entry *path* radius (R_1) described earlier in the Design Speed discussion. The entry curb radius refers to the design radius of the curb line at the roundabout entry.

At multi-lane roundabouts, the design of entry curves is more complicated due to considerations for side-by-side traffic streams entering the roundabout. Detailed guidelines for multi-lane entries are provided later in this Chapter.

4.4.2.5 *Exits*

Exit curves usually have larger radii than entry curves to minimize the likelihood of congestion at the exits. This, however, is balanced by the need to maintain low speeds at the pedestrian crossing on exit. The exit curve should produce an exit *path* radius (R_3 in ***Figure 53***) no smaller than the circulating path radius (R_2). If the exit path radius is smaller than the circulating path radius, vehicles will be traveling too fast to negotiate the exit geometry and may crash into the splitter island or into oncoming traffic in the adjacent approach lane. Likewise, the exit path radius should not be significantly greater than the circulating path radius to ensure low speeds are maintained at the pedestrian crossing.

4.4.2.6 *Splitter Islands*

Splitter islands should be constructed on all roundabouts, except those with very small diameters at which the splitter island would obstruct the visibility of the central island. Splitter islands serve to separate and guide entering and exiting traffic, provide shelter for pedestrians (including wheelchairs, bicycles, and baby strollers), assist in controlling vehicle speeds, deter wrong way movements, and provide a place to mount signs.

The splitter island envelope is formed by the entry and exit curves on an approach. The extension of these curves should be tangent to the outside edge of the central island. The total length of splitter island should generally be at least 75 to 100 feet to provide sufficient protection for pedestrians and to alert approaching drivers to the roundabout geometry. As an absolute minimum, the splitter island should be 50 feet in length for a single-lane roundabout. Additionally, the splitter island should extend beyond the end of the exit curve to prevent exiting traffic from accidentally crossing into the path of approaching traffic.

The minimum width of the splitter island should be six feet, measured at the pedestrian crossing. Additional details related to treatments within the pedestrian refuge area are provided in the subsequent section. ***Figure 64*** shows the minimum dimensions for a splitter island at a single lane roundabout, including the location of the pedestrian crossing and location of detectable warning surfaces within the pedestrian refuge area.

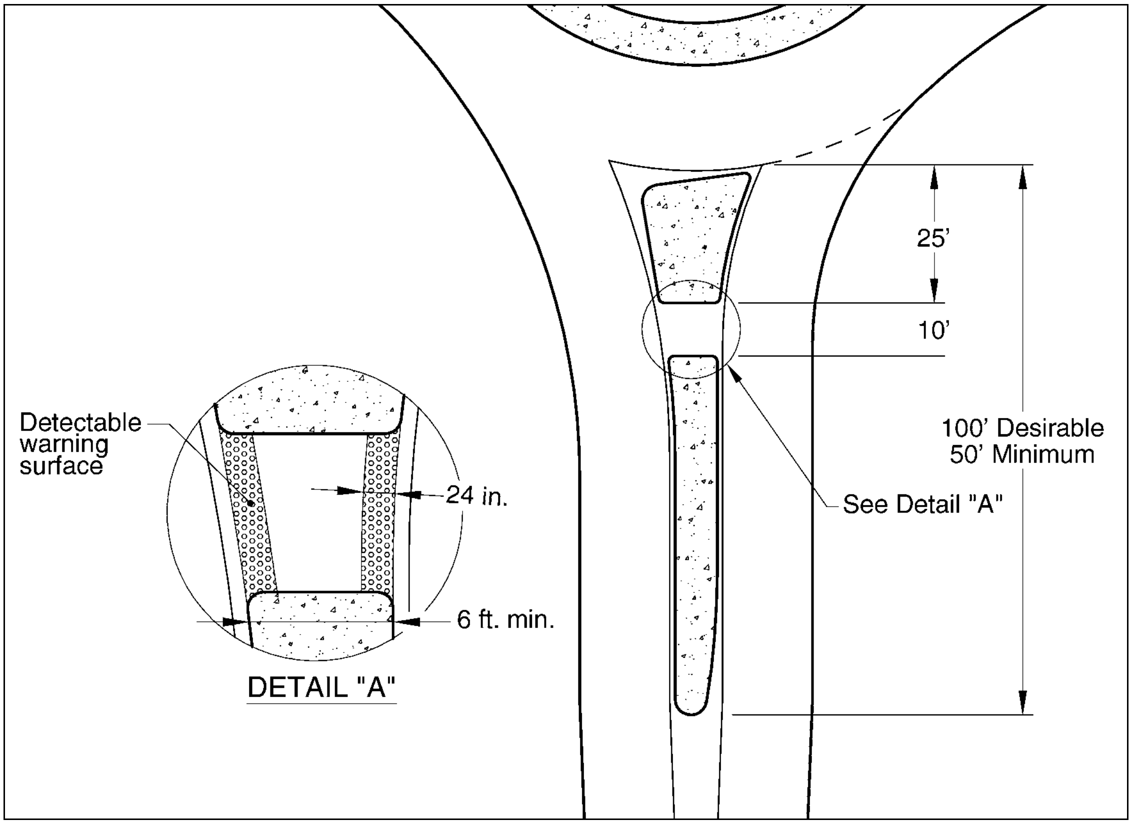


Figure 64
Minimum Splitter Island Dimensions

While ***Figure 64*** provides minimum dimensions for splitter islands, there are benefits to providing larger islands. Longer splitter islands may be appropriate on facilities where vehicle speeds are sufficiently high in relation to the operating speed of the roundabout. The increased splitter island length provides additional warning to drivers of the impending intersection and need for speed reductions.

An increased splitter island width results in greater separation between the entering and exiting traffic streams of the same leg and increases the time for approaching drivers to distinguish between exiting and circulating vehicles. In this way larger splitter islands can help reduce confusion for entering motorists. Larger widths should not preclude achieving adequate deflection and speed reduction. Increases in the splitter island width generally require increasing the inscribed circle diameter and thus may have higher construction costs and greater land impacts.

Standard channelization design principles should be followed for splitter islands. This includes using larger nose radii at approach corners to maximize island visibility and offsetting curb lines at the approach ends to create a funneling effect. The funneling treatment also aids in reducing speeds as vehicles approach the roundabout. ***Figure 65*** shows the minimum splitter island nose radii and offset dimensions from the entry and exit traveled way.

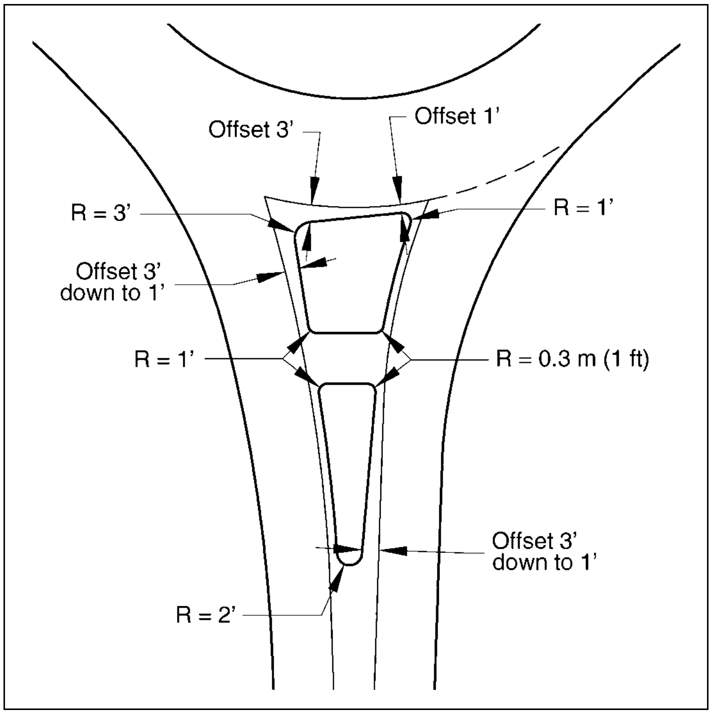


Figure 65
Minimum Splitter Island Nose Radii and Offsets

4.4.3 Pedestrian Crossing Provisions

As discussed in the *FHWA Guide* [1], pedestrian crossings at roundabouts should balance pedestrian convenience, pedestrian safety, and roundabout operations. To strike this balance, several geometric elements should be considered when designing pedestrian facilities at a roundabout as described below, including

- Location of the pedestrian crossing
- Crossing alignment
- Splitter islands / pedestrian refuge design
- Providing for visually impaired pedestrians
- Discouraging pedestrians from crossing to the central island
- Multi-modal sidewalk usage

4.4.3.1 *Pedestrian Crossing Location*

Pedestrian crossings should be located one vehicle length, 25 feet, away from the yield line at both single-lane and multi-lane roundabouts, except where signalized pedestrian crossings are being considered. For approaches with pedestrian signals, the crossing location should be determined based upon the interaction between the roundabout and signal. The pedestrian signal should be placed far enough from the roundabout to prevent exiting vehicle queues from extending into the roundabout. Guidelines for the marking of pedestrian crossings are provided in the Traffic Design section of this Chapter.

4.4.3.2 *Curb Ramps and Crossing Alignment*
Curb ramps should be provided at each end of the crosswalk to connect the crosswalk to the sidewalk and other crosswalks around the roundabout. Curb ramps should be aligned with the crossing to guide pedestrians in the proper direction. Pedestrian crossings should be provided in a straight continuous alignment across the entire intersection approach. Crossings that curve or change alignment at the pedestrian refuge should be avoided. A straight alignment allows a visually impaired pedestrian to cross the approach and find the opposite curb ramp without the need to change direction.

Pedestrian refuge areas within the splitter island should be designed at street level, rather than elevated to the height of the splitter island. This eliminates the need for ramps within the refuge area, which may be cumbersome for wheelchairs. ***Figure 66*** illustrates this concept. However, detectable warning surfaces should be used to indicate when the pedestrian reaches and exits the splitter island. The following section as well as Detail A in the previous ***Figure 64*** provide more details concerning detectable warning surfaces.

Photo: Oregon DOT

At a single lane roundabout, pedestrian crossings should be placed one vehicle length away from the yield line as shown in the photo at left.
Pedestrian crossings should be provided in a straight alignment, with the surface of the pedestrian refuge at street level.

Photo: Oregon DOT

Avoid placing drainage structures in the crossing area. Stormwater inlets such as the one shown in the photo at left may pose a potential hazard for visually impaired pedestrians.
Curb ramps should be centered on the pedestrian crossing. In this case the curb ramp had to be offset to the right side of the crossing to avoid the inlet.

Figure 66
Pedestrian Crossing Illustrations

4.4.3.3 *Provisions for Visually Impaired Pedestrians*
At roundabouts and other intersections, pedestrians with visual impairments are presented with travel challenges that may not be experienced by sighted pedestrians. These challenges can be broken down into two general categories: way-finding and gap detection. The following section discusses design treatments and current requirements for assisting visually impaired pedestrians

with way-finding (i.e. detecting and navigating the crossing). Additional research is needed to adequately address the issue of the ability for visually impaired pedestrians to detect acceptable gaps in traffic.

The Americans with Disabilities Act Accessibility Guidelines (ADAAG, 1991) [13] requires that a detectable warning surface be applied to the surface of the curb ramps and within the refuge of a splitter island (defined in the ADAAG as "hazardous vehicle areas") to provide tactile cues to individuals with visual impairments. Detectable warnings consist of a surface of truncated domes built in or applied to walking surfaces that provides a distinctive texture detectable by cane or underfoot. This surface works to alert visually impaired pedestrians of the presence of the vehicular travel-way, and provides physical cues to assist pedestrians in detecting the boundary from sidewalk to street where curb ramps and blended transitions are devoid of other tactile cues typically provided by a curb face. The detectable warning surface should be applied at the bottom of the curb ramp. It should be a 24-inch wide strip in the direction of travel along the full width of the ramp (excluding the side flares). It should be noted that ADOT is currently evaluating truncated dome designs and thus has not yet adopted a standard.

Within the refuge area of the splitter island, the detectable warning surface shall begin between six and eight inches behind the curb line and extend into the pedestrian refuge area a distance of 24 inches (perpendicular to the direction of vehicular travel). This creates a minimum 12-inch clear space between the detectable warning surfaces for a minimum splitter island width of six feet at the pedestrian crossing. It is preferable to design pedestrian refuge areas eight feet in width (perpendicular to vehicular travel) or more, so that the clear space at the center of the refuge will be over 24 inches wide.

Table 18 provides a summary of the ADAAG [13] requirements for detectable warning surfaces.

The Draft Guidelines on Accessible Public Rights-of-Way (June 14, 2002) [14], developed by the Access Board, issued a recommendation for using a 24-inch width for detectable warning surfaces. This is consistent with the existing ADAAG requirements for truncated dome detectable warning surfaces at transit platforms. The draft public right-of-way guidelines are based upon the Public Rights of Way Access Advisory Committee recommendations, as published in the report *Building a True Community*. For detectable warning surfaces, both the U.S. Access Board and FHWA are encouraging the use of the new (recommended) design over the original ADAAG [13] requirements.

While the detectable warning surfaces required by the ADAAG [13] assist pedestrians in locating the crossing and the pedestrian refuge area, blind or visually impaired pedestrians may require further assistance in navigating a roundabout. For locations where motorized volume does not provide sufficient gaps for pedestrians, designers may consider using a flashing pedestrian indication or other signal equipped with audible devices to assist people with visual disabilities. While this treatment is not typical, any leg of a roundabout could be equipped with a pedestrian-activated indicator at the pedestrian crossing if a balanced design requires assisting pedestrians at that location. If a pedestrian-activated signal is considered, the crossing and signal should be located sufficiently upstream of the yield line to minimize the possibility of exiting vehicle queues spilling back into the circulatory roadway.

Table 18
Requirements for Detectable Warning Surfaces

Legislation	**Americans with Disabilities Act Accessibility Guidelines (ADAAG) [13]**	***Draft* Guidelines on Accessible Public Rights-of-Way [14]**
Applicability	Required under existing regulations	These guidelines are in the rulemaking process and are therefore *not* enforceable. These guidelines are ultimately intended to be incorporated into the ADAAG, however the recommendations listed below are subject to revision prior to the issuance of a final rule.
Type	Raised truncated domes*	Raised truncated domes* aligned in a square grid pattern
Dome Size	A nominal diameter of 23 mm (0.9 in), A nominal height of 5 mm (0.2 in),	A base diameter of 0.9 inches (23 mm) minimum to 1.4 inches (36 mm) maximum A top diameter of 50% of the base diameter minimum to 65% of the base diameter maximum A height of 0.2 inches (5 mm).
Dome Spacing	A nominal center-to-center spacing of 60 mm (2.35 in).	A center-to-center spacing of 1.6 inches (41 mm) minimum and 2.4 inches (61 mm) maximum, A base-to-base spacing of 0.65 inches (16 mm) minimum, measured between the most adjacent domes on square grid.
Contrast	Detectable warning surfaces shall contrast visually with adjacent walking surfaces either light-on-dark, or dark-on-light. The material used to provide contrast shall be an integral part of the walking surface.	Detectable warning surfaces shall contrast visually with adjacent walking surfaces either light-on-dark, or dark-on-light.
Size	**At curb ramps:** The detectable warning shall extend the full width and depth of the curb ramp **Within splitter island:** boundary between the (curbs) shall be defined by a continuous detectable warning which is 36 inch (915 mm) wide, beginning at the curb line.	**At curb ramps, landings, or blended transitions connecting to a crosswalk:** Detectable warning surfaces shall extend 24 inches (610 mm) minimum in the direction of travel and the full width of the curb ramp, landing, or blended transition. The detectable warning surface shall be located so that the edge nearest the curb line is 6 inches (150 mm) minimum and 8 inches (205 mm) maximum from the curb line. **Within Splitter Island:** The detectable warning surface shall begin at the curb line and extend into the pedestrian refuge a minimum of 24 inches (600 mm). Detectable warnings shall be separated by a 24 inch (610 mm) minimum length of walkway without detectable warnings

*Note: ADOT is currently evaluating truncated dome designs and thus has not yet adopted a standard

Research is being conducted to improve accessibility for visually impaired pedestrians at roundabouts. This research is required to develop the information necessary for jurisdictions to determine where roundabouts may be appropriate and what design features are required for people with disabilities. Until specific standards or guidelines are adopted, such as the *Draft Guidelines on Accessible Public Rights-of-Way* [14], engineers and jurisdictions must rely on existing related research and professional judgment to design pedestrian features so that they are usable by pedestrians with disabilities.

4.4.3.4 *Sidewalk Considerations*

To deter pedestrians from crossing to the central island, sidewalks should be set back from the circulatory roadway to provide a buffer area. A five-foot setback distance is recommended (minimum of two feet) where possible. The area between the sidewalk and circulatory roadway can be planted with grass or low shrubbery to provide a visual barrier. Hardscape or other features such as hand rails may be considered as long as appropriate sight distance is maintained. ***Figures 67 and 68*** show an example of the landscape buffer treatment.

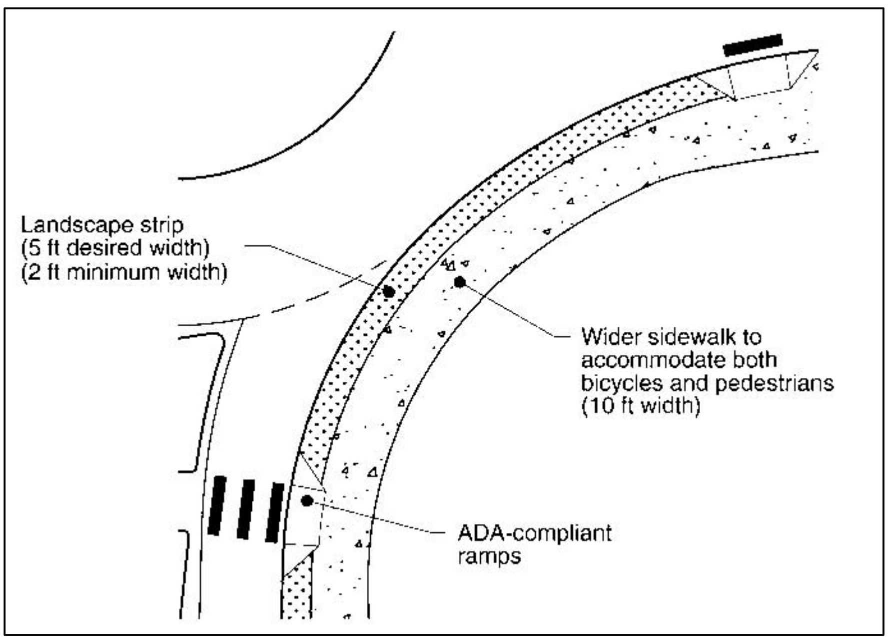


Figure 67
Sidewalk Treatments

Figure 68
Example Sidewalk Setback

4.4.4 Bicycle Provisions

Bike lanes should be terminated in advance of a roundabout to encourage cyclists to mix with vehicle traffic and navigate the roundabout as a vehicle. Bicycle riders uncomfortable with riding through the roundabout may choose to dismount and circulate around the roundabout as a pedestrian using the provided sidewalks and crossings. Bike lanes should be terminated 100 feet upstream of the yield line to allow for merging with vehicles and/or entering the sidewalk.
To accommodate bicyclists who prefer not to use the circulatory roadway, a widened sidewalk or shared bicycle/pedestrian path may be used provided it is physically separated from the circulatory roadway. Ramps or other suitable connections should be provided between the sidewalk or path and the bike lanes, shoulders, or road surface on the approaching and departing roadways as shown in ***Figure 69***. Care should be taken when locating and designing bicycle ramps to ensure that they are not misconstrued as an unmarked pedestrian crossing. The AASHTO *Guide for Development of Bicycle Facilities* [15] provides further guidance on the design requirements for bicycle and shared-use path design.

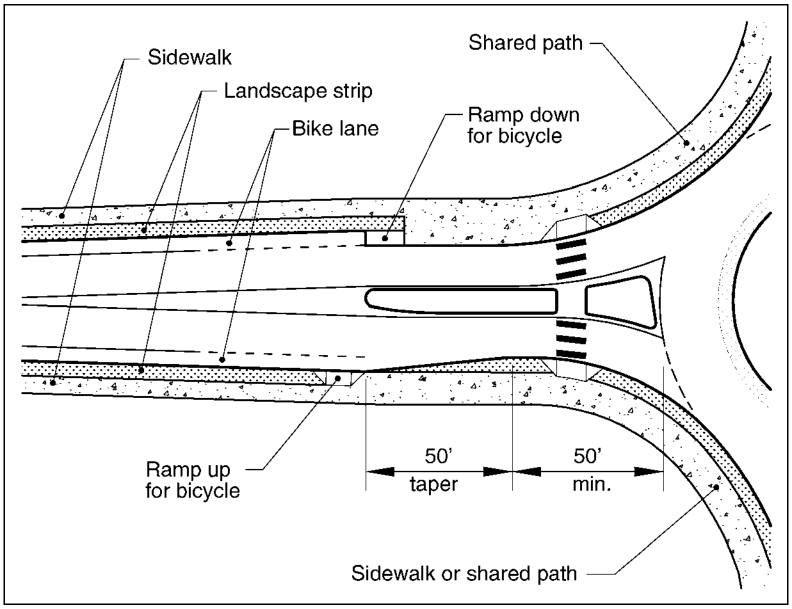


Figure 69
Provisions for Bicycles

Figure 70 displays a photographic example of bicycle provisions at a roundabout.

Grand Junction, CO

Figure 70
Photograph Example of Bicycle Provisions

4.4.5 Right-Turn Bypass Lanes

In general, right-turn bypass lanes (or *right-turn slip lanes*) should be avoided, especially in urban areas with bicycle and pedestrian activity. The entries and exits of bypass lanes can increase conflicts with bicyclists. The generally higher speeds of bypass lanes and the lower expectation of drivers to stop also increase the risk of collisions with pedestrians. However, in locations with minimal pedestrian and bicycle activity, right-turn bypass lanes can be used to improve capacity when heavy right turning traffic exists. In some situations, providing a right-turn bypass lane may prevent the need for a multi-lane roundabout. Thus, the potential adverse safety effects created by the bypass lane may be offset by the safety benefits of maintaining single-lane entries within the roundabout.

The design speed of the right-turn bypass lanes should be consistent with the design speed of the roundabout. In other words, the speed of vehicles within the right-turn bypass lane should be comparable to the speed of vehicles entering, circulating, and exiting the roundabout. Thus, the fundamental roundabout design speeds shown in Table 13 should also govern the design of the right-turn bypass lane.

There are two design options for right-turn bypass lanes. The first option, shown in ***Figure 71*** is to carry the bypass lane parallel to the adjacent exit roadway, and then merge it into the main exit lane from the roundabout. Under this option, the bypass lane should be carried alongside the main roadway for a sufficient distance to allow vehicles in the bypass lane and vehicles exiting the roundabout to achieve similar speeds and safely merge. The bypass lane is then merged at a taper rate equal to the ratio of the design speed (in mph) to one.

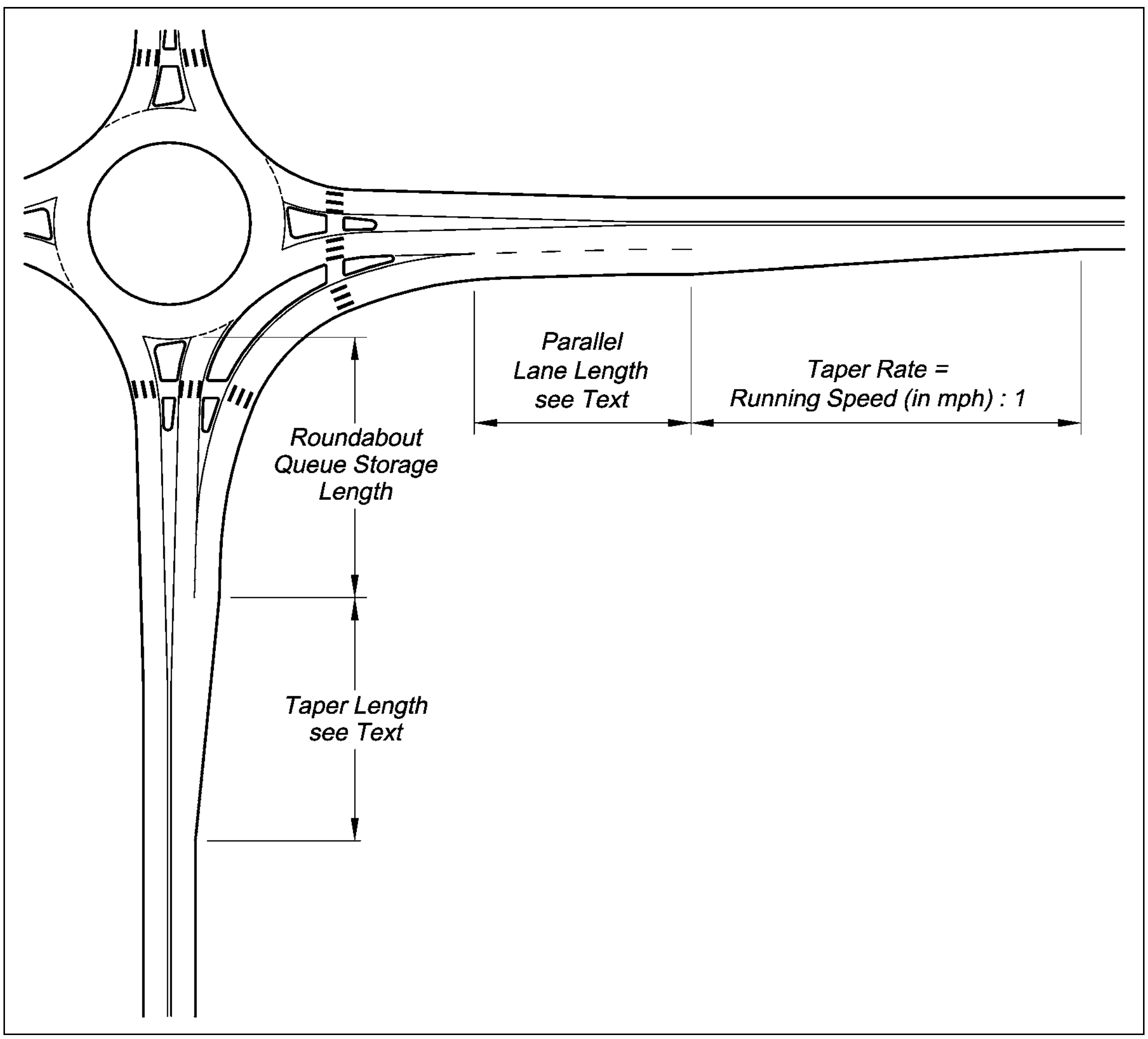


Figure 71
Right-Turn Bypass Configuration (Merge)

The second design option for a right-turn bypass lane, shown in ***Figure 72***, is to provide a yield-controlled entrance onto the adjacent exit roadway. This option generally requires less widening and right-of-way downstream of the roundabout than the first. It is also generally more amenable to bicyclists, as they do not have to cross free-flowing traffic from the bypass lane. However, it often requires more right-of-way at the corner with this design option to achieve adequate speed reduction for the right-turn movement while providing pedestrian refuge areas. Consideration should also be given for the intersection angle at the yield point between the bypass traffic stream and traffic stream exiting the roundabout. If the intersection angle at the yield point is too small, it may be difficult for drivers (particularly older drivers) to perceive and react to conflicting vehicles from the roundabout.

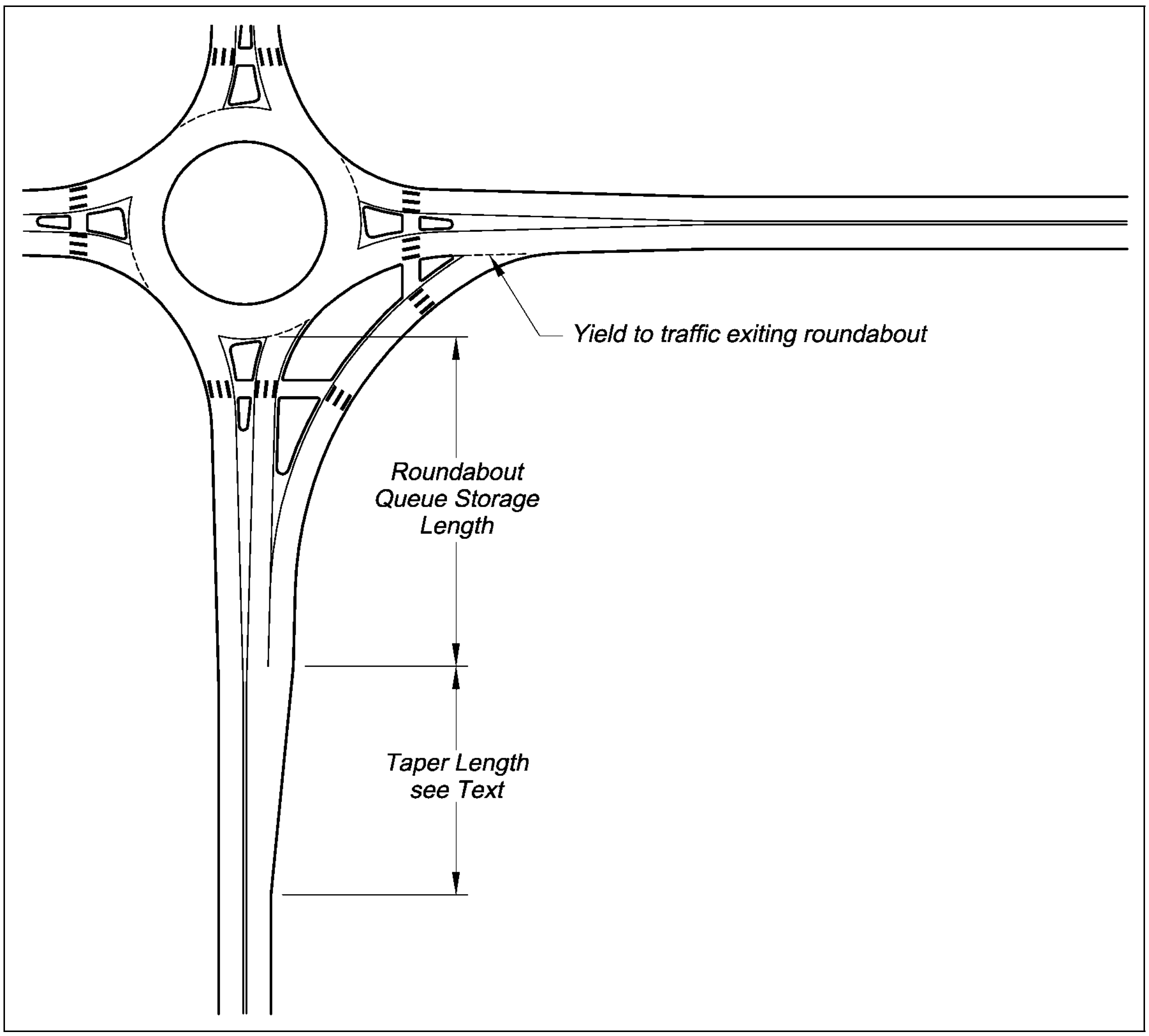


Figure 72
Right-Turn Bypass Configuration (Yield)

The design of the approach taper for the right-turn bypass lane is developed in a manner similar to right-turn lanes at signalized and stop-controlled intersections. The bay taper, which guides motorists into the right-turn lane, should be developed along the right edge of traveled way. The minimum length of the taper is 60 feet for approach design speeds up to 35 mph. Bay tapers of 90 feet should be used for approach design speeds of 40 mph to 50 mph and 140 feet should be used for design speeds in excess of 50 mph.

The length of the right-turn bypass lane should be designed, at a minimum, to accommodate the 95th-percentile queue at the roundabout entrance without blocking the entrance to the right-turn bypass lane.

4.4.6 Sight Distance at Roundabouts

As with all roadways, adequate stopping sight distance must be provided at all locations within the roundabout and on the approaches to avoid objects and other vehicles in the road. Intersection sight distance must also be provided at the entries to enable drivers to perceive vehicles from other approaches and safely enter the roundabout. The design speeds from the fastest path evaluation are used in the calculation of stopping sight distance and intersection sight distance requirements.

4.4.6.1 *Stopping Sight Distance*

At roundabouts, stopping sight distance should be checked at a minimum of three locations:

- Approach sight distance (***Figure 73***)
- Sight distance on the circulatory roadway (***Figure 74***)
- Sight distance to crosswalk on the immediate downstream exit (***Figure 75***)

Stopping sight distance should be measured using an assumed drivers eye height of 3.5 feet and an assumed height of object of two feet, in accordance with current AASHTO policies [8].

Equations and design values for determining the stopping sight distance required in ***Figures 73 through 75*** are provided in section 6.3.9 of the *FHWA Guide* [1] and in the *Elements of Design* section of the AASHTO *Green Book* [8].

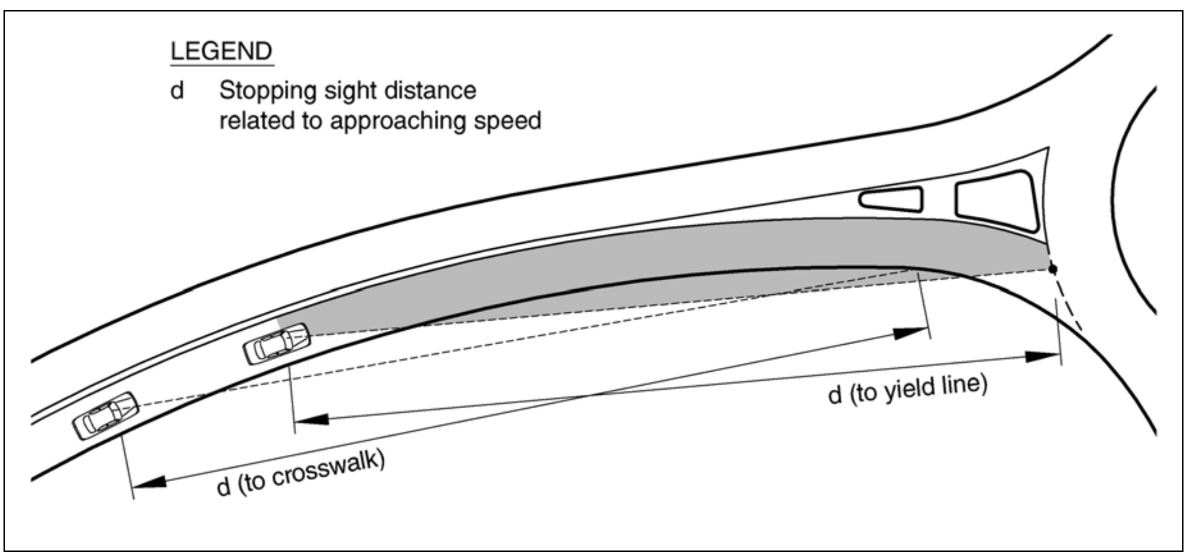


Figure 73
Approach Sight Distance

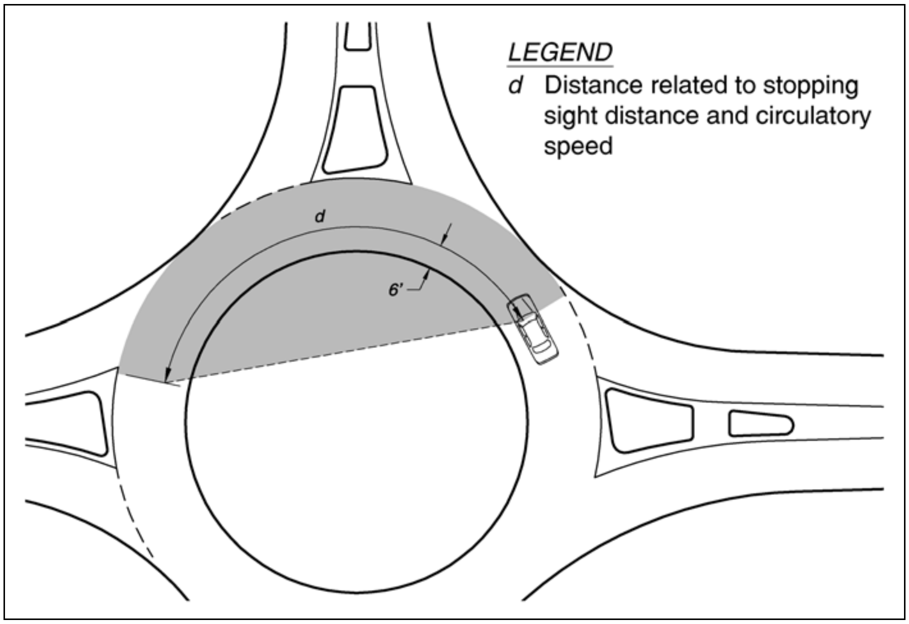


Figure 74
Sight Distance on Circulatory Roadway

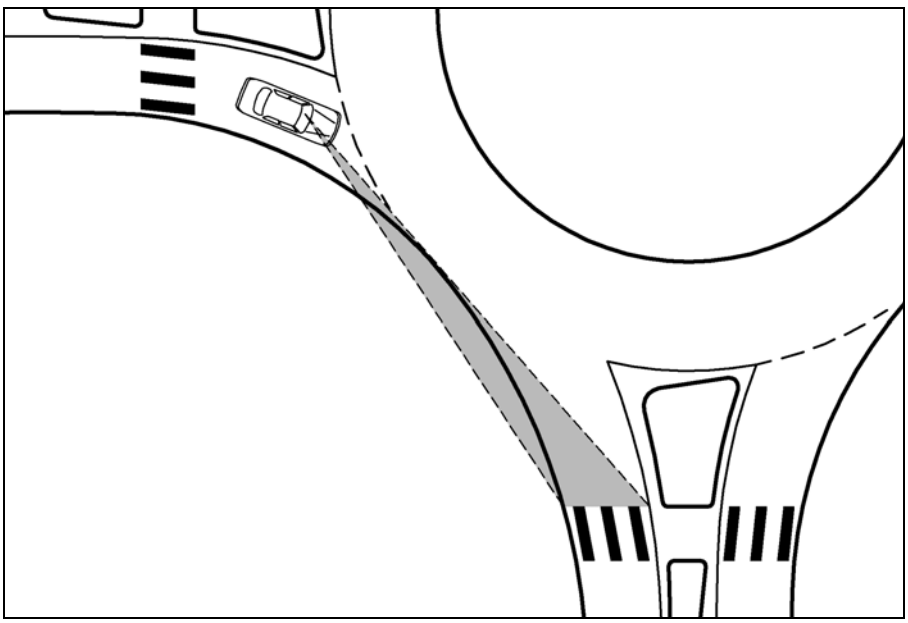


Figure 75
Sight Distance to Crosswalk on Exit

4.4.6.2 *Intersection Sight Distance*
Intersection sight distance is the distance required for a driver approaching the roundabout, without the right of way, to perceive and react to the presence of conflicting vehicles on the circulatory roadway and immediate upstream entry. At roundabouts, the only locations requiring evaluation of intersection sight distance are the entries.

The traditional method of using sight triangles to measure intersection sight distance is used. For roundabouts, the limits of the sight triangle are determined through the calculation of sight distance for the two independent conflicting traffic streams: the circulating stream and the entering stream on the immediate upstream entry. The sight distance required for each stream is measured along the curved vehicle path, *not* as a straight line. ***Figure 76*** presents a diagram showing the method for determining intersection sight distance.

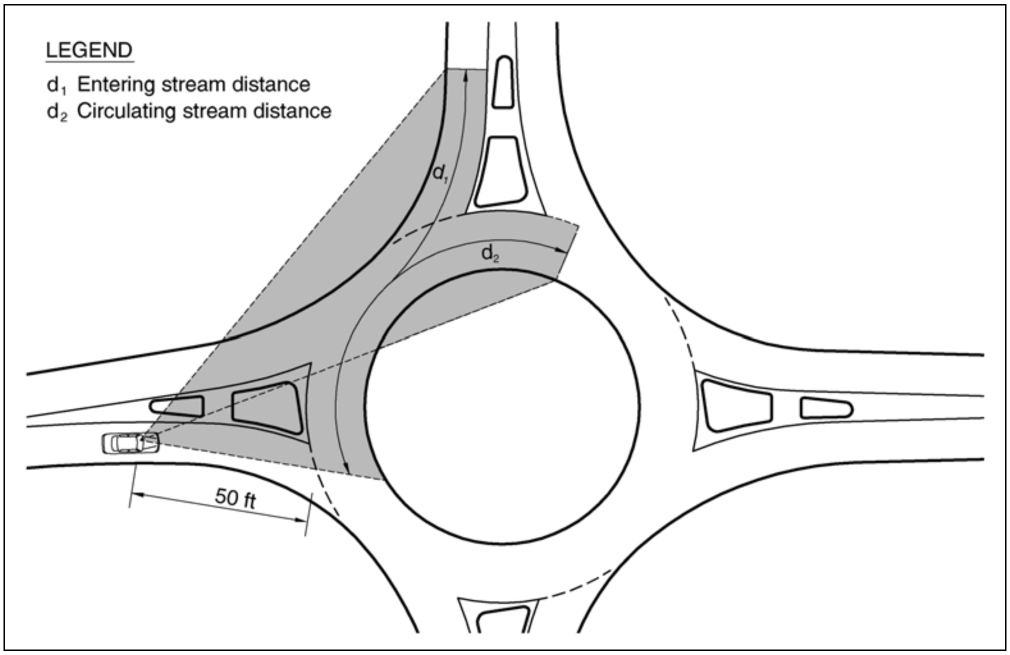


Figure 76
Intersection Sight Distance

Intersection sight distance should be measured using an assumed drivers eye height of 3.5 feet and an assumed height of object of 3.5 feet in accordance with the AASHTO *Green Book* [8].

Equations and design values for determining the intersection sight distance components required in ***Figure 76*** are provided in section 6.3.10 of the *FHWA Guide* [1]. The equations are also provided in the *Intersections* section of the AASHTO *Green Book* [8]. Calculations for intersection sight distance should assume a critical gap value of 6.5 seconds, based on research of critical gaps at stop-controlled intersections, adjusted for yield-controlled conditions as documented in *NCHRP Report 383* [16]. However, in locations where sight distance may be constrained by adjacent topographic features or buildings, the critical gap may be reduced to 4.6 seconds. This value is consistent with the lower bound identified for roundabouts in the *Highway Capacity Manual* [11].

Speeds for the entering stream can be approximated by averaging the entry path speed and circulating path speed (paths with radius R_1 and R_2 respectively). Speeds for the circulating stream can be approximated by taking the speed of left-turning vehicles (path with radius R_4).

Excessive intersection sight distance can often lead to higher speeds that reduce intersection safety. Therefore, whenever possible, designers should not provide more than the minimum required intersection sight distance on each approach. Landscaping can be effective in restricting sight distance to the minimum required.

During design and review, roundabouts should be checked to ensure that adequate stopping and intersection sight distance is being provided. Checks for each approach should be overlaid onto a single drawing, as shown in ***Figure** 77*, to illustrate for all team members the clear vision areas for the intersection. This provides guidance on the appropriate locations for various types of landscaping or other treatments. The compiled drawing should be kept in the project file for future reference in the event landscaping or street furniture is contemplated after the project is completed.

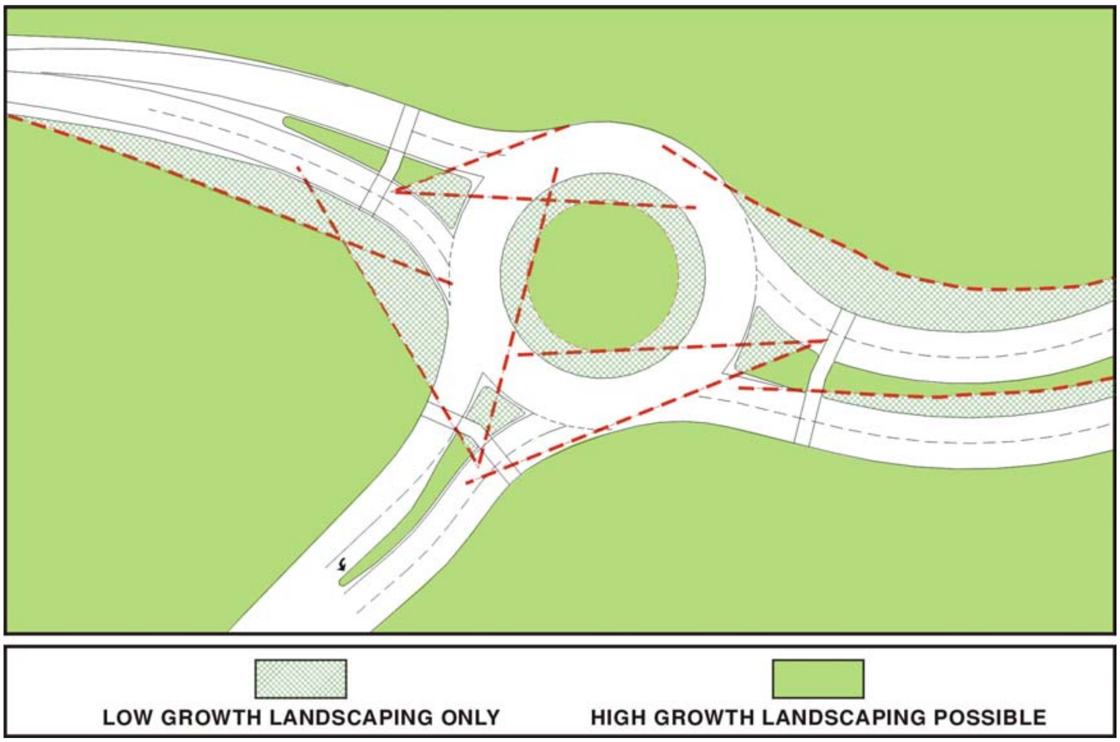


Figure 77
Example Sight Distance Diagram

The hatched portions in ***Figure** 77* are areas that should be clear of tall obstructions that may hinder driver visibility. Objects such as low growth vegetation, poles, sign posts, and narrow trees may be acceptable within these areas provided they do not significantly obstruct visibility of other vehicles, the splitter islands, the central island, or other key roundabout components. In the remaining areas (with solid shading), especially within the central island, taller landscaping may be used to break the forward view for through vehicles, thereby contributing to speed reductions and reducing oncoming headlight glare.

4.4.6.3 *Grades and Superelevation*
Section of 6.3.11 of the *FHWA Guide* [1] provides guidance on developing of the vertical profile and locating drainage structures. Roundabouts should be generally designed to slope away from the central island with drainage inlets located on the outer curb line. This will help to raise the elevation of the central island and increase its conspicuity and visibility. The slope of the circulatory roadway should prevent water from collecting or pooling around the central island. For large central islands, additional drainage inlets may be required within the central island. As with any intersection, care should be taken to ensure that low points and inlets are not placed in crosswalks.

4.4.7 Multi-Lane Design Issues

Designing multi-lane roundabouts is significantly more complex than single-lane roundabouts. Factors include the additional conflicts present with multiple traffic streams entering, circulating, and exiting the roundabout in adjacent lanes. With single-lane roundabouts, the primary design objective is to ensure the fastest vehicular paths are sufficiently slow and relatively consistent. With multi-lane roundabouts, the designer must also consider the *natural paths* of vehicles. The natural path is the path a vehicle will follow based on the speed and orientation imposed by the geometry. While the fastest path assumes a vehicle will intentionally cut across the lane markings to maximize speed, the natural path assumes there are other vehicles present and all vehicles will attempt to stay within the proper lane.

Designers may determine the natural path by assuming the vehicle stays within the center of the lane up to the yield line. At the yield point, the vehicle will maintain its natural trajectory into the circulatory roadway. The vehicle will then continue into the circulatory roadway and exit with no sudden changes in curvature or speed. If the roundabout geometry tends to lead vehicles into the wrong lane, this can result in operational or safety deficiencies.

4.4.7.1 *Path Overlap*

Path overlap occurs when the natural paths of vehicles in adjacent lanes overlap or cross one another. It occurs most commonly at entries, where the geometry of the right-hand lane tends to lead vehicles into the left-hand circulatory lane. ***Figure 78*** illustrates an example of path overlap at a multi-lane roundabout entry.

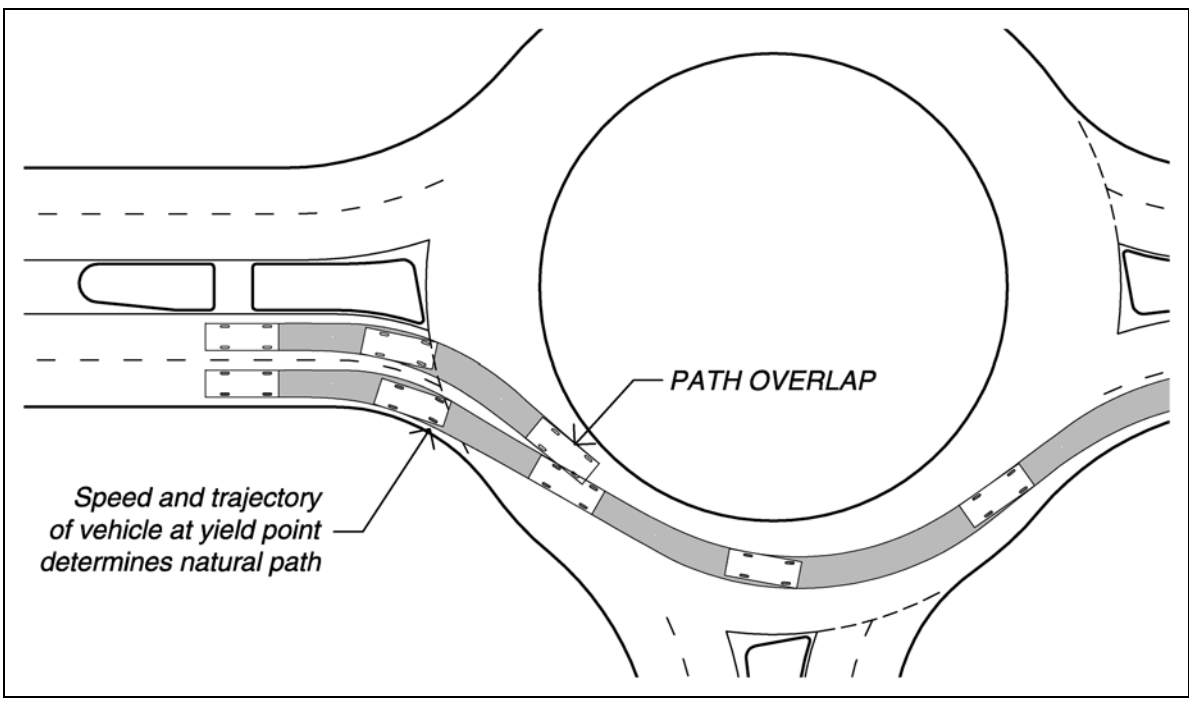


Figure 78
Path Overlap

In the design shown in ***Figure 78***, the geometry consists of a tight-radius entry curve located tangential to the outside edge of the circulatory roadway. At the yield line, vehicles in the right-hand lane are oriented toward the inside lane of the circulatory roadway. If vehicles follow this natural path, they will cut off vehicles in the left lane, which must make a sharp turn within the circulatory roadway to avoid the central island.

4.4.7.2 *Multi-Lane Entry Design Technique*
The preferred design technique to minimize path overlap at multi-lane entries is illustrated in ***Figure 79***.

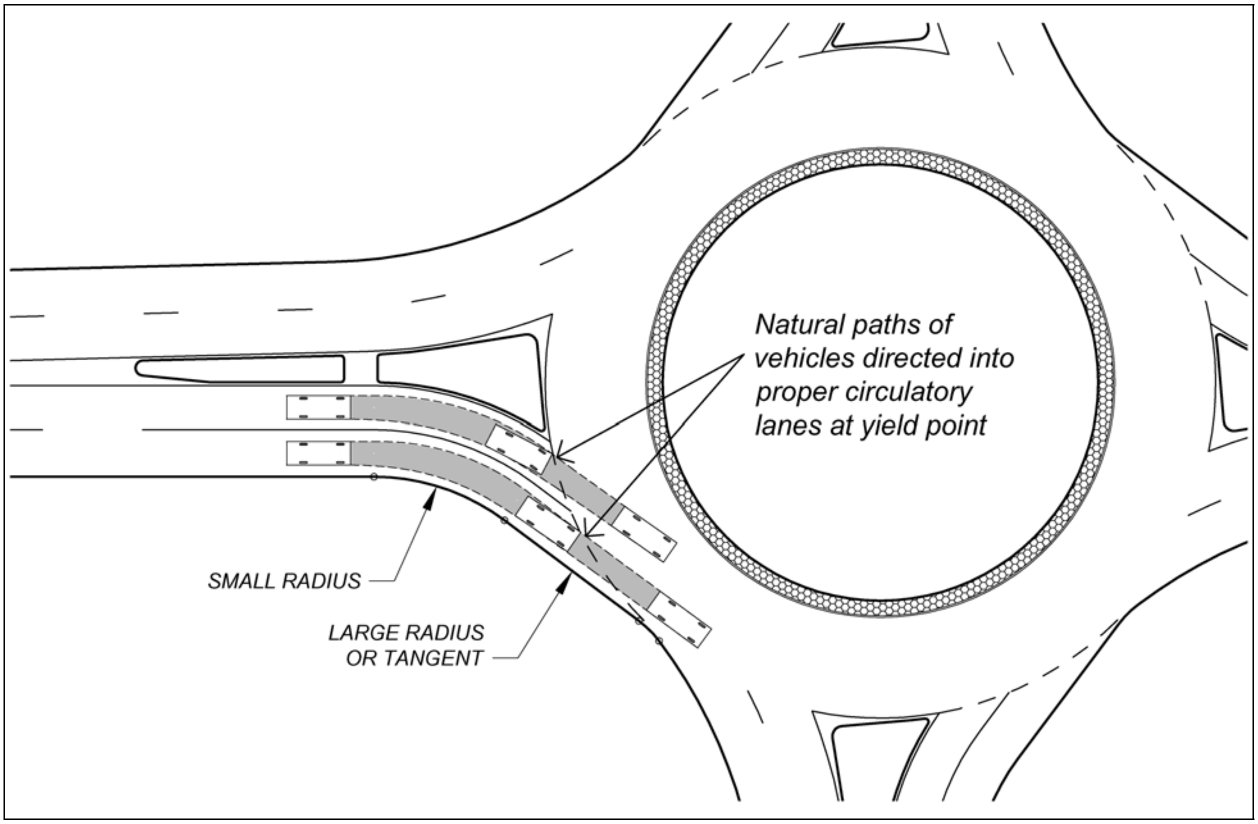


Figure 79
Design Technique to Avoid Path Overlap at Entry

As shown in ***Figure 79***, the design consists of small-radius entry curve set back from the edge of the circulatory roadway. A short section of tangent is provided between the entry curve and the circulatory roadway to ensure vehicles are directed into the proper circulatory lane at the yield point.

Typically, the entry curve radius is approximately 50-100 feet and set back approximately 10-20 feet from the edge of the circulatory roadway. A tangent or large-radius (greater than 150 feet) curve is then fitted between the entry curve and the outside edge of the circulatory roadway. ***Figure 80*** illustrates the entry design technique in greater detail.

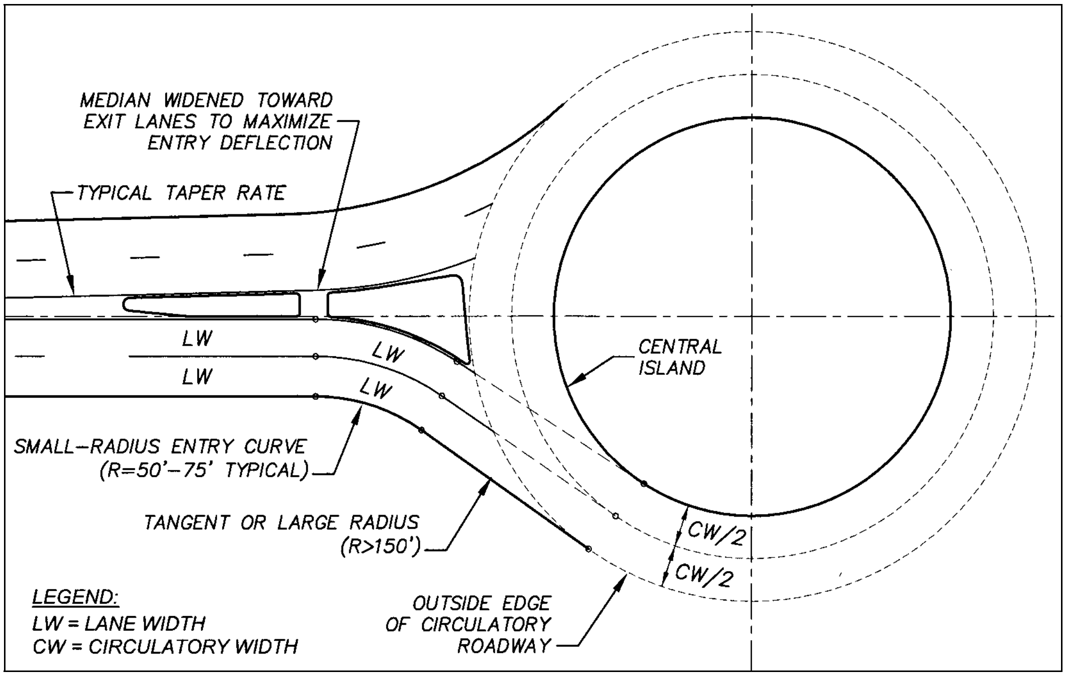


Figure 80
Multi-Lane Entry Design Details

The primary objective of this design technique is to locate the entry curve at the optimal placement so that the projection of the inside entry lane at the yield point forms a line tangential to the central island, as shown in ***Figure 80***. The location of the entry curve directly affects path overlap. If it is located too close to the circulatory roadway, it can result in path overlap. However, if it is located too far away from the circulatory roadway, it can result in inadequate deflection (i.e. entry speeds too fast).

4.4.7.3 *Design Techniques to Increase Entry Deflection*

Designing multi-lane roundabouts without path overlap while achieving adequate deflection to control entry speeds can be difficult. The same measures that improve path overlap issues generally result in increased fastest path speeds. When the entry speed of a multi-lane roundabout is too fast, one technique for reducing the entry speed without creating path overlap is to increase the inscribed circle diameter of the roundabout. Often the inscribed circle of a double-lane roundabout must be 175-200 feet in diameter, or more, to achieve a satisfactory entry design. However, increasing the diameter will result in slightly faster circulatory speeds. Therefore, the designer is challenged to balance the entry speeds and circulatory speeds. This often requires many iterations of design, speed checks, and path overlap checks.

In cases where right-of-way or other physical constraints restrict the size of a multi-lane roundabout, the technique shown in ***Figure 81*** may be used.

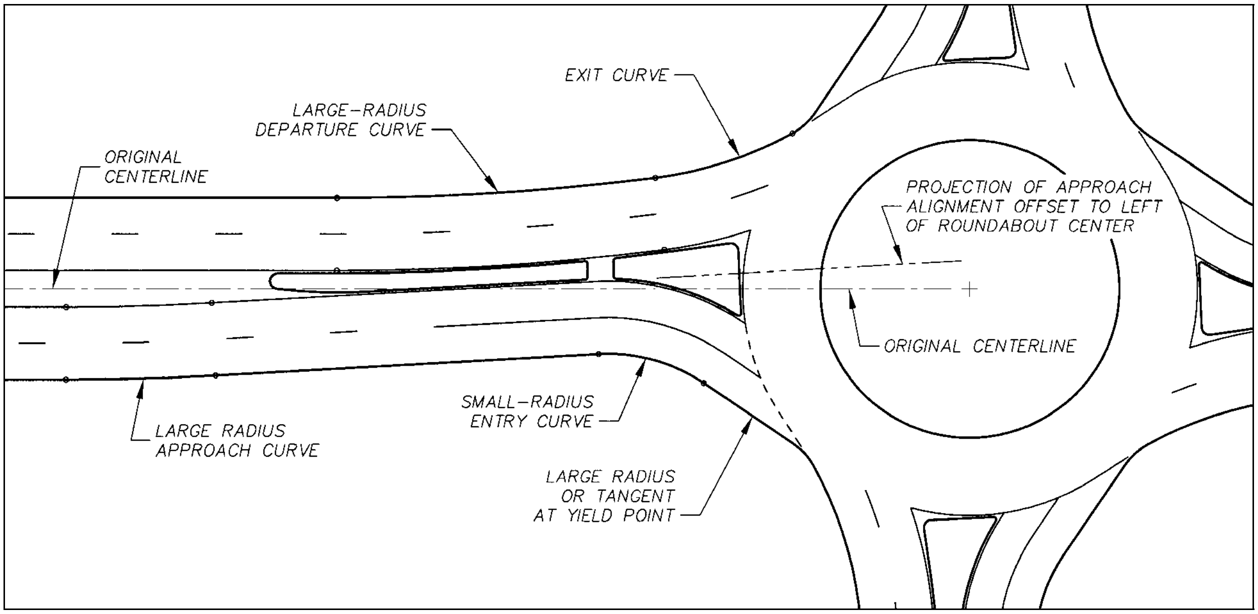


Figure 81
Approach Offset to Increase Entry Deflection

In the design shown in ***Figure 81***, shifting the approach alignment slightly towards the left of the roundabout center enhances the entry deflection. This technique of offsetting the approach alignment left of the roundabout center is effective at increasing entry deflection. However, it also reduces the deflection of the exit on the same leg. The geometry should maintain a level of deflection at exits to keep speeds relatively low within the pedestrian crosswalk location. Therefore, the distance of the approach offset from the roundabout center should generally be kept to a minimum to maximize safety for pedestrians.

4.5 TRAFFIC DESIGN

4.5.1 Signing

The signing requirements for roundabouts vary slightly depending on the environment and lane configuration. Signing for typical roundabouts in rural environments and urban environments are displayed in ***Figure 82 and Figure 83***, respectively.

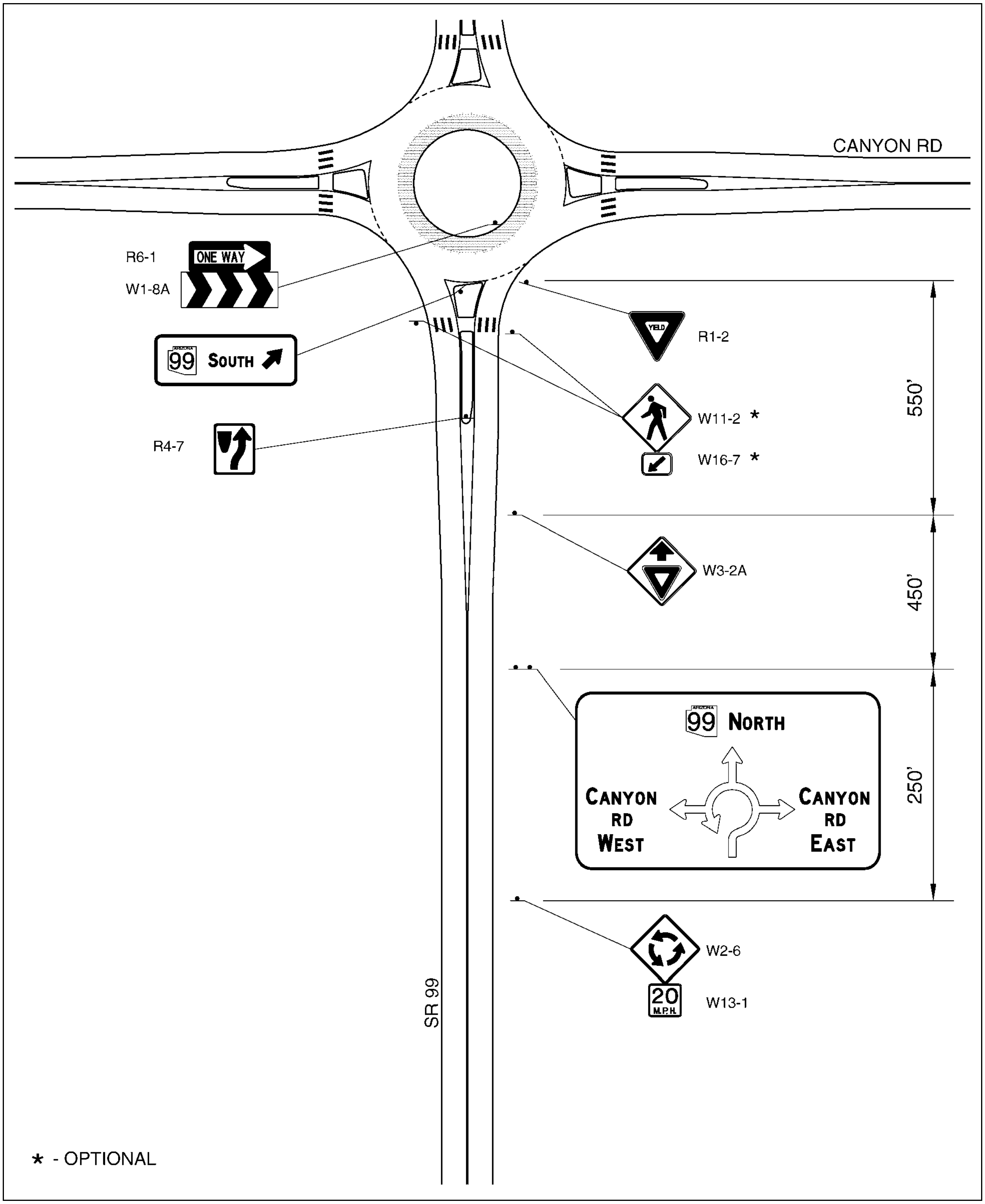


Figure 82
Typical Signing at Rural Roundabouts

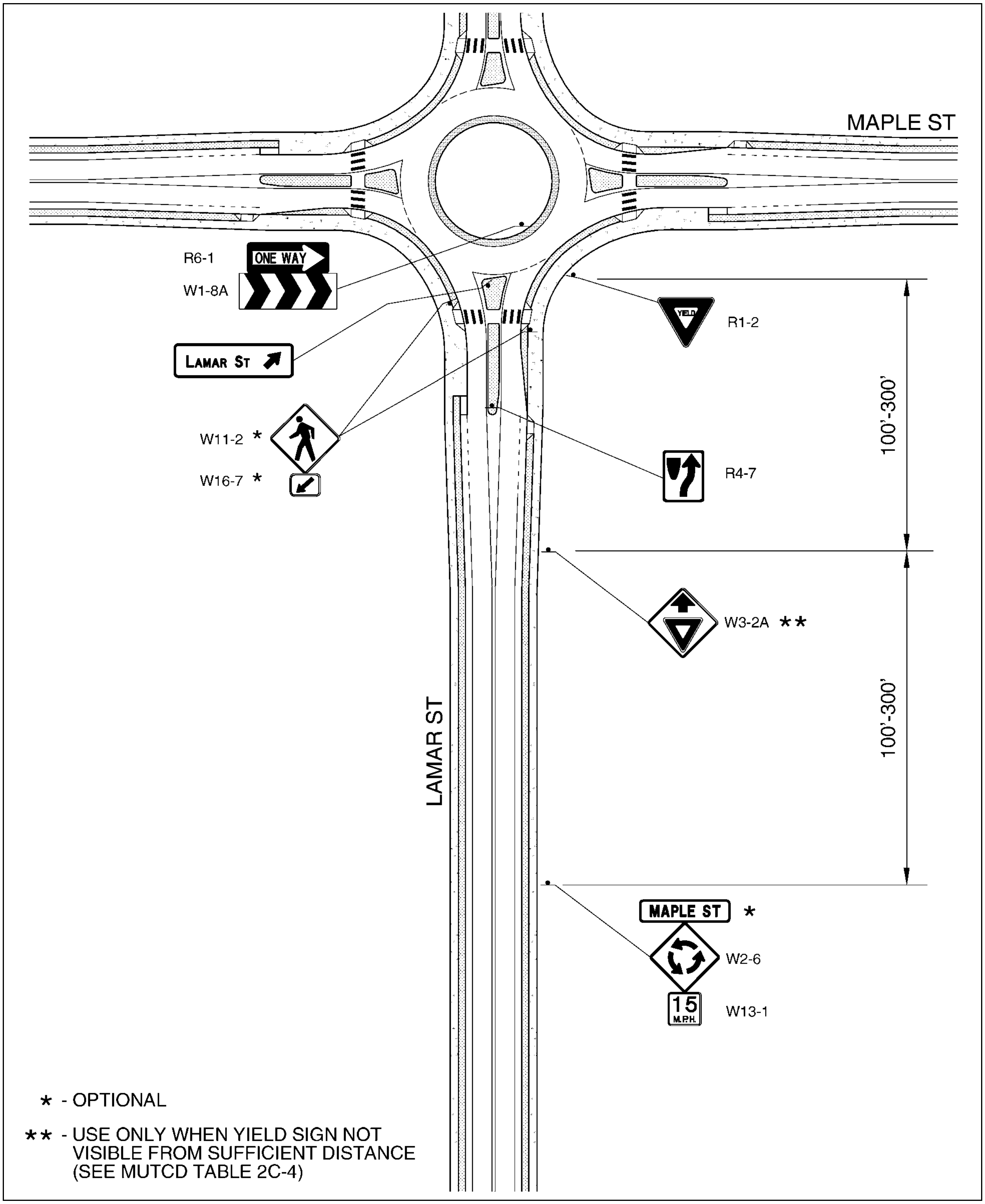


Figure 83
Typical Signing at Urban Roundabouts

As indicated in ***Figure 82***, diagrammatic guide signs should be used for all rural roundabouts to indicate the upcoming highway junction and to provide directional guidance. In general for urban roundabouts, these large diagrammatic signs are not necessary. However, a diagrammatic sign may be appropriate at an urban intersection with any of the following conditions:

- The intersection is the junction of two major highway routes,
- The signed highway route makes a bend though the roundabout, or
- The intersection layout or signed route configuration is potentially confusing to unfamiliar drivers.

4.5.1.1 *Multi-Lane Considerations*

In general, signing at typical multi-lane roundabouts is essentially the same as at single-lane roundabouts, as shown in ***Figure 82 and Figure 83***. However, supplemental signs may be needed to enhance clarity and guidance for drivers. The primary differences are related to supplemental YIELD signs and lane-use control signs.

4.5.1.1.1 YIELD Signs

For roundabout approaches with more than one lane, YIELD signs should be placed on both the left and right side of the approach. The sign on the left side of the approach is located within the splitter island. YIELD signs should be placed to ensure the faces of the signs are not visible to traffic within the circulatory roadway. If the YIELD sign is visible from the circulatory roadway, it may cause circulating vehicles to yield unnecessarily.

For most intersections, the size of the YIELD signs should be 36” x 36” x 36”, in accordance with guidelines from the FHWA *Manual on Uniform Traffic Control Devices* (MUTCD) [17]. Oversized YIELD signs may be considered in special cases based on MUTCD guidance.

4.5.1.1.2 Lane-Use Control Signs

For some multi-lane roundabouts, lane-use control signs may be needed on one or more approaches. Lane-use controls at roundabouts follow the same general principles as those at conventional intersections. For conventional two-lane approaches, at which through movements can be made from either of the two approach lanes, lane-use control signs are not necessary. This is because the rules of the road at intersections require left-turning traffic to use only the left lane, right-turning traffic to use only the right lane, and through traffic to use both lanes unless official traffic control devices indicate otherwise. However, in cases where the turning movement designations for an approach lane may not meet driver expectancy, lane-use control signs should be used.

Lane-use control signs should be used for the following conditions:

- Where a single exit lane is provided opposite two entry lanes, lane use designations should be made to indicate that an entry lane drops as a turning movement.
- Where left- or right-turning traffic demand dictates the need for more than one left-turn lane or more than one right-turn lane for capacity reasons.

Figure 84 displays a typical lane-use control sign at a multi-lane roundabout approach. In the example, the northbound approach has two entry lanes, in which left-turns may be made from either lane. The leg directly opposite the northbound entry has only one exit lane. Therefore lane-use control signage is necessary to indicate that vehicles in the left-hand entrance lane must exit at the west exit leg (or they may also complete a U-turn), and vehicles in the right-hand entrance lane may exit at the west, north, or east exit legs.

In this example, the eastbound and westbound approaches provide two continuous through lanes (i.e. through movements may be made from either the left-hand or right-hand entrance lanes). Therefore, lane-use control signs are not required on these approaches.

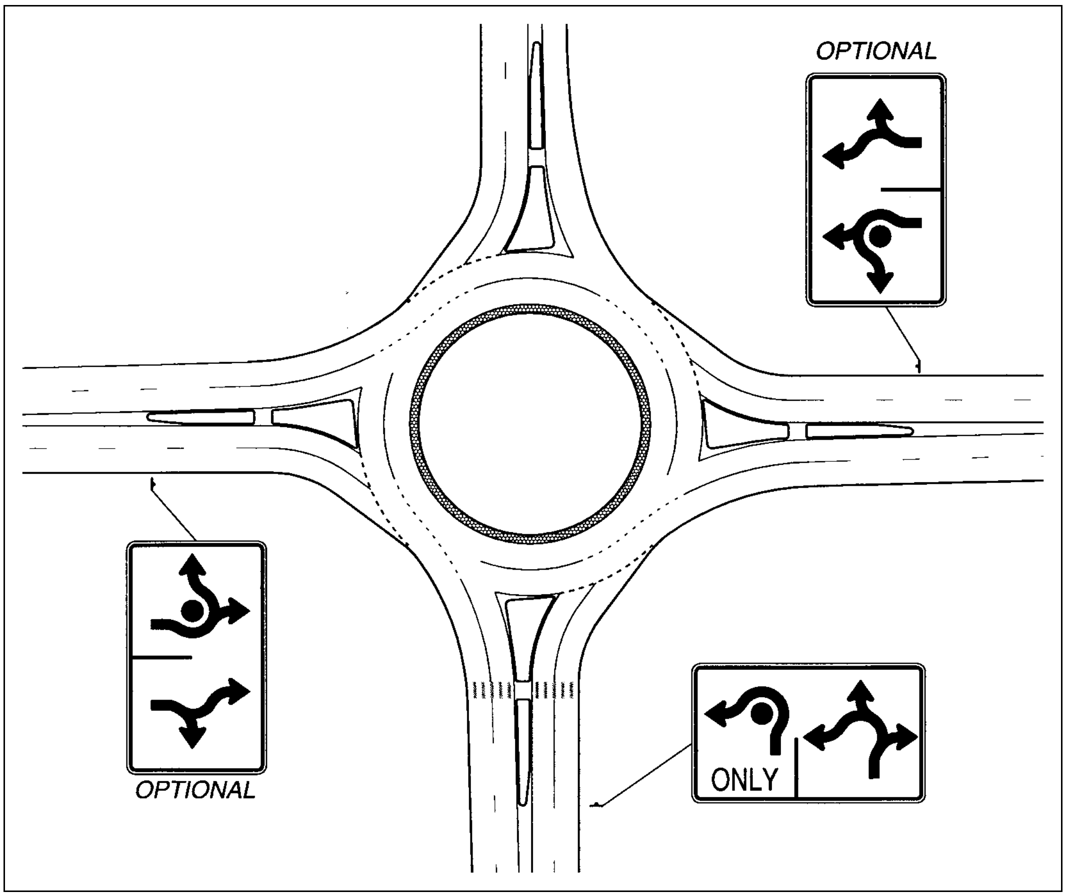


Figure 84
Example Lane-Use Control Sign at
a Multi-Lane Roundabout Approach

As shown in ***Figure 84***, the lane-use control signs at roundabouts are similar to lane-use control signs at signalized intersections. However, the arrows are modified to indicate counterclockwise circulation around the central island.

Lane-use control signs should always be used in combination with appropriate circulatory lane striping. Design guidance for circulatory lane striping is provided later in this Chapter.

4.5.2 Pavement Marking

Striping and pavement marking specifications for a typical roundabout approach are shown in ***Figure 85***.

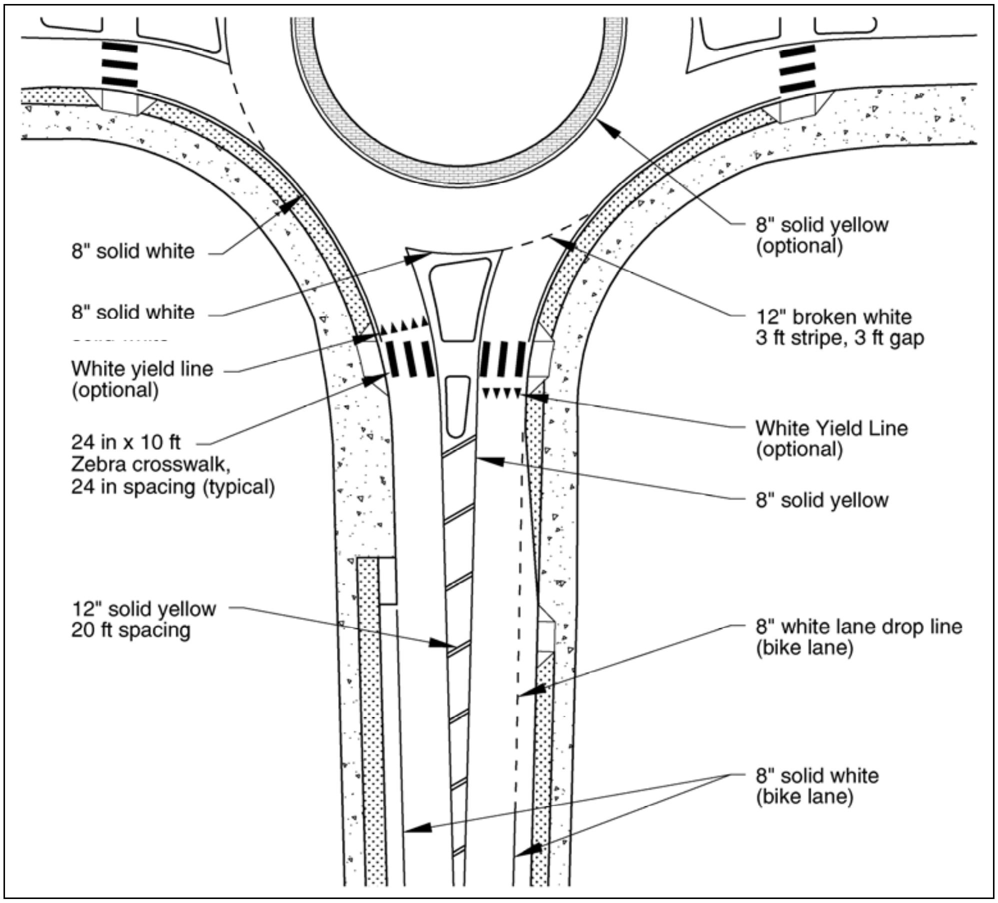


Figure 85
Pavement Markings at a Typical Roundabout Approach

4.5.2.1 *Multi-Lane Considerations*

In general at multi-lane roundabouts, lane lines should not be striped within the circulatory roadway. This generally promotes more even use of the entry lanes, and it causes entering and circulating drivers to be cognizant of other vehicles in the roundabout. It also encourages large semi-trailers and oversized vehicles to use the entire width of the circulatory, which may reduce the overall width required for the circulatory roadway and truck apron. In some cases, however, providing circulatory lane markings can enhance the capacity or safety of a multi-lane roundabout.

When circulatory lane markings are considered at a multi-lane roundabout, two options for the design of these markings are available. These two options are:

- Partial concentric lane markings, and
- Exit lane markings.

The applications and design details for each of these striping schemes are discussed in the next sections.

4.5.2.1.1 Partial Concentric Lane Markings

Partial concentric lane markings consist of a solid white stripe placed at a uniform offset from the central island. The stripe is broken between each entry and the adjacent upstream exit to enable entering and exiting movements. Thus, the lane markings are provided only in front of the splitter islands. ***Figure 86*** displays an example of partial concentric circulatory lane markings [18].

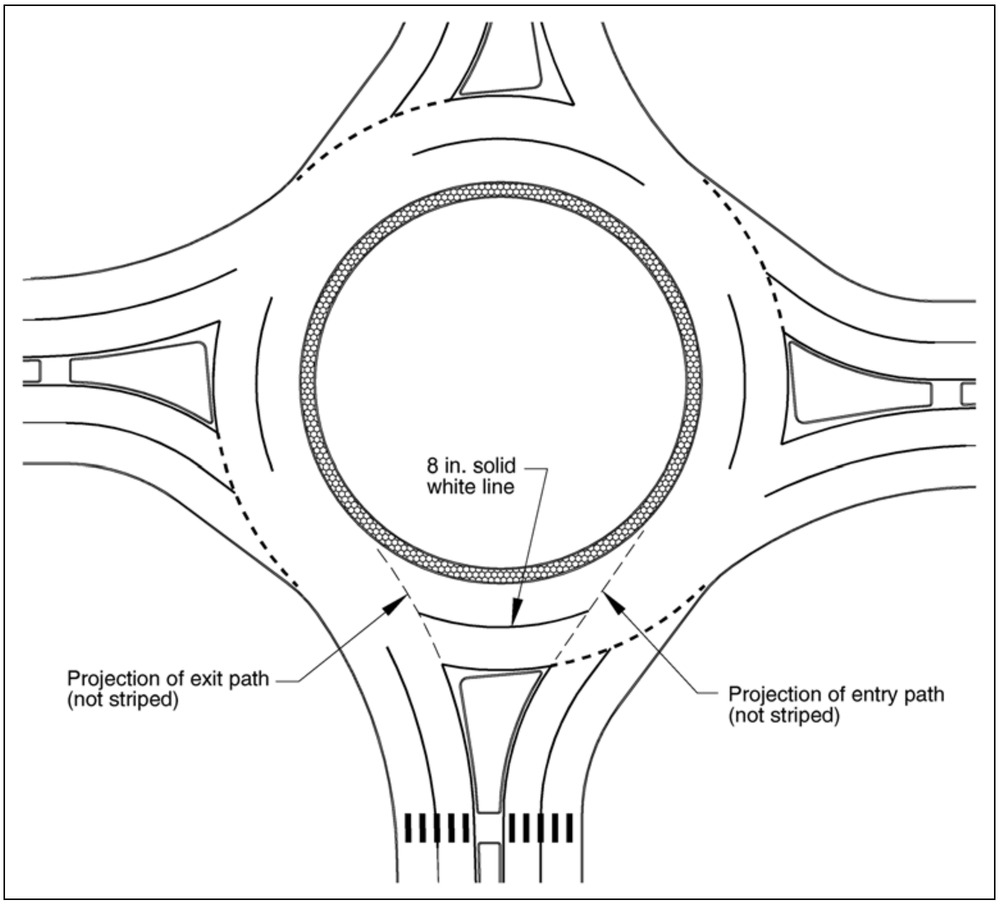


Figure 86
Partial Concentric Circulatory Lane Markings

Partial concentric circulatory lane markings can assist drivers in entering into the appropriate circulatory lanes. These markings should be considered at existing roundabouts with a known problem of entering vehicles cutting across the circulatory roadway. In particular, they can be beneficial at roundabouts where vehicles in the right-hand entry lane commonly enter into the inside of the circulatory roadway, cutting in front of vehicles in the left-hand entry lane.

4.5.2.1.2 Exit Lane Markings

Exit lane markings (sometimes referred to as "Alberta" markings) consist of solid white lines in front of the splitter islands, as described above for partial concentric lane markings, plus dotted extension lines to direct circulating vehicles into the appropriate exit lane. Similar to the dotted extension line striping within a signalized intersection, the exit extension lines provide clear direction for circulating vehicles but can be crossed by vehicles at the conflicting entrance. ***Figure 87*** displays an example of a roundabout with exit lane markings [19].

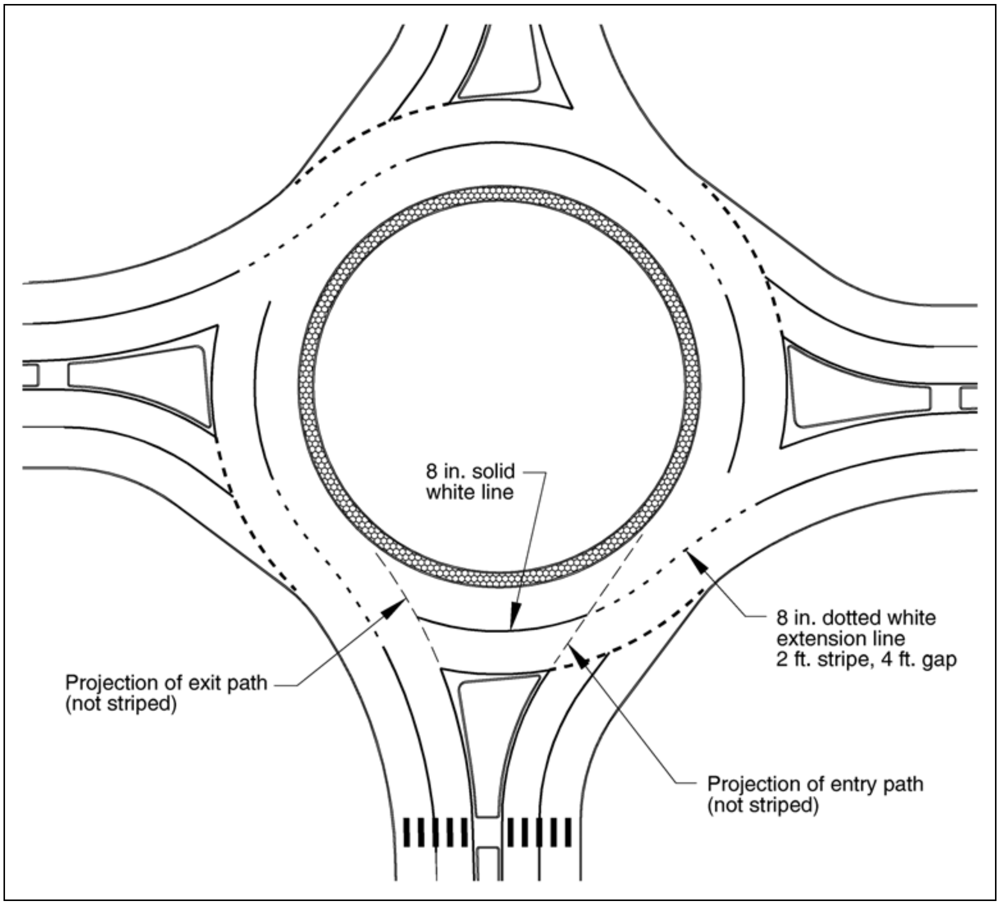


Figure 87
Exit Lane Markings

Exit lane markings should be considered at roundabouts with the following conditions:

- A roundabout with a particularly high volume of turning movements at one or more approaches.
- A roundabout with historical safety issues caused by incorrect lane selection at entry or erratic lane changes within the roundabout.
- A roundabout with poor exit geometry that induces vehicle path overlap.

4.5.3 Illumination

This section presents recommended guidelines for lighting of roundabouts on ADOT facilities. The information in this section is based on the following sources:

- *FHWA Guid*e [1]
- ANSI / IESNA RP-8-00, *American National Standard Practice for Roadway Lighting*, 2000 [20]. (Note: The illumination guidance in this document is more current and supercedes the information in the *FHWA Guide*.)
- AS/NZS 1158.1.3:1997, *Road Lighting*, Australian/New Zealand Standard, 1997 [21].

- Centre d'Etudes sur les Réseaux les Transports, l'Urbanisme et les constructions publiques (CERTU), *L'Éclairage des Carrefours à Sens Giratoire (The Illumination of Roundabout Intersections),* Lyon, France: CERTU, 1991 [22].

4.5.3.1 *General Requirements*

Lighting should be provided at all roundabouts, whether in rural or urban settings. The specific lighting requirements for each setting are discussed below.

Lighting should be installed and operational before the roundabout is open to traffic. If a portion of the roundabout will be opened to accommodate traffic on a temporary basis, lighting should be provided. If permanent lighting cannot be installed to meet construction schedules, temporary lighting will be allowed, with the approval of the engineer.

4.5.3.2 *Lighting in Urban and Suburban Areas*

The standards and methods for determining proper roadway illumination are provided in ANSI/IESNA RP-8-00 [20], published by the Illuminating Engineering Society of North America. The discussion in this section focuses on the illuminance method, which is commonly used for illumination design at roundabouts. RP-8-00 discusses other methods such as luminance and small target visibility; refer to that document for discussion of those methods, as well as discussion on the proper method to calculate the critical values for each criterion.

The basic principle behind the lighting of roundabouts in urban and suburban areas is that the amount of light on the intersection should be proportional to the classification of the intersecting streets and equal to the sum of the values used for each separate street. Put more succinctly, if Street A is illuminated at a level of x and Street B is illuminated at a level of y, the intersection should be illuminated at a level of $x + y$. In addition, RP-8-00 [20] specifies that if an intersecting roadway is illuminated above the recommended value, then the intersection illuminance value should be proportionately increased. Therefore, the illumination design for a roundabout in an urban or suburban area should be designed to properly illuminate the roundabout while being compatible with the illumination levels on approaching roadways.

Table 19 presents the recommended illuminance for roundabouts located on continuously illuminated streets. Separate values have been provided for portland cement concrete road surfaces (RP-8-00 [20] Road Surface Classification R1) and typical asphalt road surfaces (RP-8-00 Road Surface Classification R2/R3). Table 20 presents the roadway and pedestrian area classifications used for determining the appropriate illuminance levels in Table 19. RP-8-00 clarifies that although the definitions given in Table 20 may be used and defined differently by other documents, zoning by-laws, and agencies, the area or roadway used for illumination calculations should best fit the descriptions contained in Table 20 and not how classified by others (RP-8-00, Section 2.0, p.3). Note that the predominant surface type should be used for illumination calculations; for example, a roundabout with an asphalt concrete circulatory roadway and portland cement concrete truck apron should be designed using a surface type of R2/R3.

Table 19
Recommended Illuminance for the Intersection of Continuously Lighted Urban and Suburban Streets

Pavement Classification[1]	Roadway Classification	Average Maintained Illuminance at Pavement[2] — Pedestrian/Area Classification: High (lux (fc))	Medium (lux (fc))	Low (lux (fc))	Uniformity Ratio (E_{avg}/E_{min})	Veiling Luminance Ratio (L_{vmax}/L_{avg})
R1	Major/Major	24.0 (2.4)	18.0 (1.8)	12.0 (1.2)	3.0	0.3
	Major/Collector	20.0 (2.0)	15.0 (1.5)	10.0 (1.0)	3.0	0.3
	Major/Local	18.0 (1.8)	14.0 (1.4)	9.0 (0.9)	3.0	0.3
	Collector/Collector	16.0 (1.6)	12.0 (1.2)	8.0 (0.8)	4.0	0.4
	Collector/Local	14.0 (1.4)	11.0 (1.1)	7.0 (0.7)	4.0	0.4
	Local/Local	12.0 (1.2)	10.0 (1.0)	6.0 (0.6)	6.0	0.4
R2/R3	Major/Major	34.0 (3.4)	26.0 (2.6)	18.0 (1.8)	3.0	0.3
	Major/Collector	29.0 (2.9)	22.0 (2.2)	15.0 (1.5)	3.0	0.3
	Major/Local	26.0 (2.6)	20.0 (2.0)	13.0 (1.3)	3.0	0.3
	Collector/Collector	24.0 (2.4)	18.0 (1.8)	12.0 (1.2)	4.0	0.4
	Collector/Local	21.0 (2.1)	16.0 (1.6)	10.0 (1.0)	4.0	0.4
	Local/Local	18.0 (1.8)	14.0 (1.4)	8.0 (0.8)	6.0	0.4

Notes: [1] R1 is typical for portland cement concrete surface; R2/R3 is typical for asphalt surface
[2] fc = footcandles
Source: ANSI / IESNA RP-8-00 [20] Table 9 (for R2/R3 values); R1 values adapted from Table 2

Table 20
ANSI / IESNA RP-8-00 Guidance for Roadway and Pedestrian/Area Classification for Purposes of Determining Intersection Illumination Levels

Roadway Classification	Description	Daily Vehicular Traffic Volumes[1]
Major	That part of the roadway system that serves as the principle network for through-traffic flow. The routes connect areas of principle traffic generation and important rural roadways leaving the city. Also often known as "arterials," thoroughfares," or "preferentials."	Over 3,500 ADT
Collector	Roadways servicing traffic between major and local streets. These are streets used mainly for traffic movements within residential, commercial, and industrial areas. They do not handle long, through trips.	1,500 to 3,500 ADT
Local	Local streets are used primarily for direct access to residential, commercial, industrial, or other abutting property.	100 to 1,500 ADT
Pedestrian Conflict Area Classification	**Description**	**Guidance on Pedestrian Traffic Volumes[2]**
High	Areas with significant numbers of pedestrians expected to be on the sidewalks or crossing the streets during darkness. Examples are downtown retail areas, near theaters, concert halls, stadiums, and transit terminals.	Over 100 pedestrians/hour
Medium	Areas where lesser numbers of pedestrians use the streets at night. Typical are downtown office areas, blocks with libraries, apartments, neighborhood shopping, industrial, older city areas, and streets with transit lines.	11 to 100 pedestrians/hour
Low	Areas with very low volumes of night pedestrian usage. These can occur in any of the cited roadway classifications but may be typified by suburban single family streets, very low density residential developments, and rural or semi-rural areas.	10 or fewer pedestrians/hour

Notes: [1] For purposes of intersection lighting levels only
[2] Pedestrian volumes during the average annual first hour of darkness (typically 18:00-19:00), representing the total number of pedestrians walking on both sides of the street plus those crossing the street at non-intersection locations in a typical block or 200 m (656 ft) section. RP-8-00 clearly specifies that the pedestrian volume thresholds presented here are a local option and should not be construed as a fixed warrant.

Source: ANSI / IESNA RP-8-00 [20] Sections 2.1, 2.2, and 3.6

4.5.3.3 *Lighting in Rural Areas*
Table 21 provides recommended illuminance levels for rural isolated intersections with unlit approaches.

Table 21
Recommended Illuminance for the Intersection of Unlit Rural Roadways

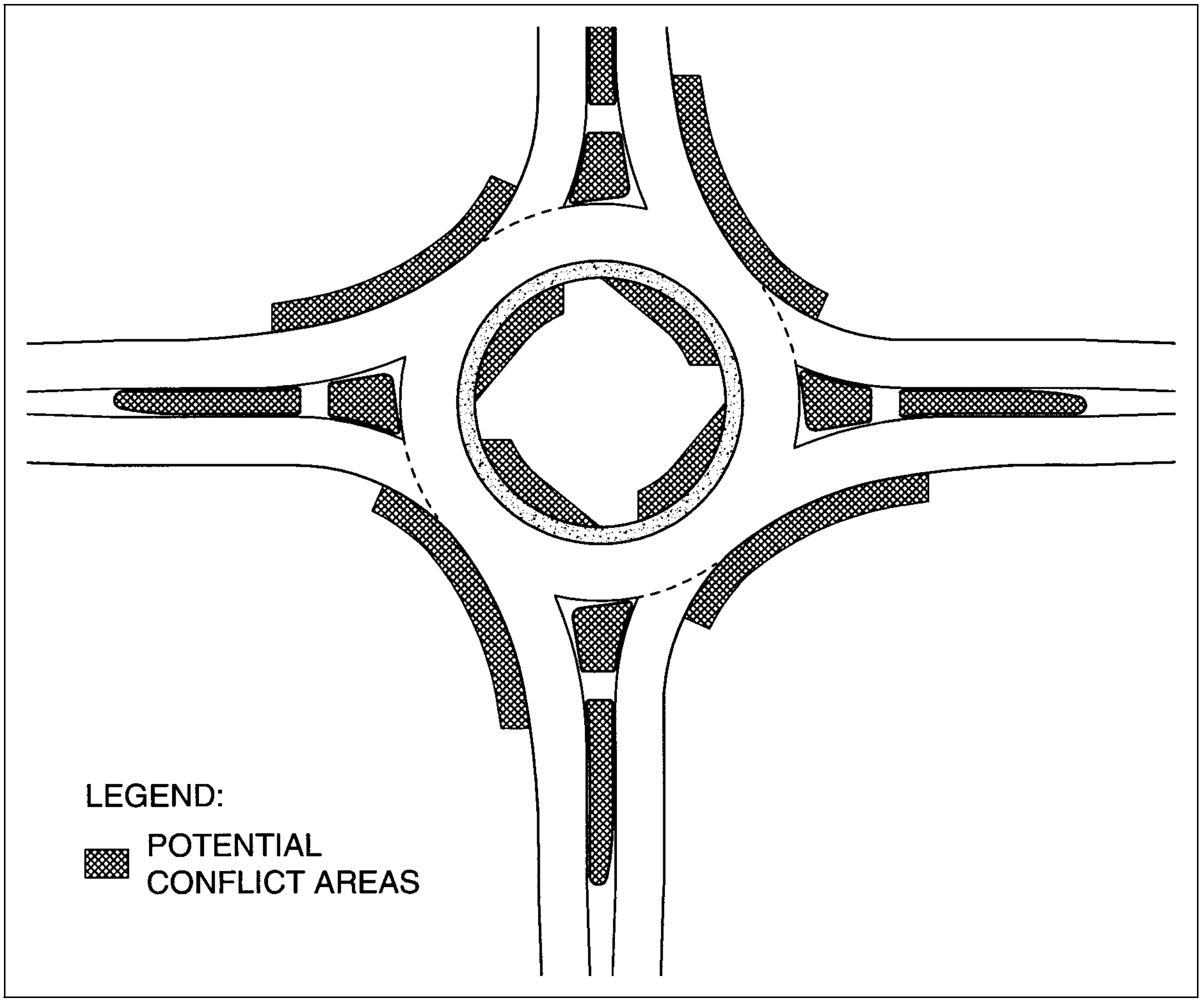
Pavement Classification[1]	Average Maintained Illuminance at Pavement[2] (lux (fc))	Uniformity Ratio (E_{avg}/E_{min})	Veiling Luminance Ratio (L_{vmax}/L_{avg})
R1	6.0 (0.6)	4.0	0.3
R2/R3	9.0 (0.9)	4.0	0.3

Notes: [1] R1 is typical for portland cement concrete surface; R2/R3 is typical for asphalt surface
[2] fc = footcandles
Source: ANSI / IESNA RP-8-00 [20] Table D1

4.5.3.4 *Equipment Type and Location*
A photometric analysis is required to determine luminaire wattage, mounting height, luminaire arm length, and pole placement at a roundabout. In general, the use of fewer luminaires with higher wattage mounted on traditional luminaire arms ("cobra-style") is preferable to minimize the number of fixed objects in the public right-of-way, provided that the illuminance requirements identified above are met. However, in urban areas where high pedestrian activity is expected or desirable, pedestal-mounted illumination at lower mounting heights is often more consistent with urban design goals and should be considered. These types of luminaires may need to be supplemented by strategically located traditional cobra-style luminaires to provide adequate lighting at key conflict areas.

The position of lighting poles relative to the curbs at a roundabout is governed in part by the speed environment in which the roundabout is located and the potential speeds of errant vehicles that can be reasonably expected. For installations on rural arterials and high-speed rural collectors, the AASHTO *Roadside Design Guide* [23] should be referenced. For installations on low-speed rural collectors and rural local roads, a minimum clear-zone width of 10 feet should be provided (AASHTO *Green Book* [8], pp. 322-323). For installations on urban arterials, collectors, and local streets where curbs are used, a clearance between curb face and lighting pole of 1.5 feet should be provided as a minimum, with additional separation desirable. For areas within or on the approach to a roundabout where the overhang of a turning truck could strike a lighting pole, a minimum offset distance of 3 feet should be provided (AASHTO *Green Book* [8], pp. 485-486).

Figure 88 suggests critical conflict areas where run-off-the-road crashes are most prevalent at roundabouts. In these areas, lighting poles should be placed as far back from the curb face as practical. In rural areas where pedestrian activity is low, breakaway pole bases are recommended for poles located in these critical areas.



Source: Adapted from AS/NZS 1158.1.3:1997, Road lighting, Australian/New Zealand Standard, 1997 [21], Figure 8.2, p. 39.

Figure 88
Critical Conflict Areas Affecting Lighting Pole Placement

Roundabouts can be illuminated from a set of luminaires in the middle of the central island, from luminaires arrayed around the periphery of the roundabout, or by a combination of the two. Table 22 provides a summary of the key advantages and disadvantages of central and peripheral illumination. In general, illumination from the periphery of the roundabout is recommended due to a greater ability to provide maximum illumination at key conflict areas.

Table 22
Summary of Key Advantages and Disadvantages of Central and Peripheral Illumination at Roundabouts

	Advantages	**Disadvantages**
Central illumination	• Assists in perception of the roundabout at a distance by illuminating the central island • Requires fewer poles to achieve same illumination • Pole in central island is clear of critical conflict areas for all but the smallest of roundabouts • Exit guide signs on the periphery appear in positive contrast (frontlit) and thus are clearly visible	• Illumination is weakest in critical pedestrian and bicycle areas • Signs on the approach are in negative contrast (backlit) • A path is needed to the base of the central pole for maintenance • There is a greater risk of glare • The central pole affects central island landscaping plan • High mast lighting may be inappropriate in urban areas, especially residential areas
Peripheral illumination	• Illumination can be strongest around critical bicycle and pedestrian areas. • Maintains a continuity of poles and luminaires for the illumination of the lanes, as well as good visual guidance on the circulatory roadway • Approach signs appear in positive contrast and thus are clearly visible • Maintenance of luminaires is easier due to curbside location	• Illumination is weakest in central island, which may limit visibility of round-about from a distance • Requires more poles to achieve same illumination level • Poles may need to be located in critical conflict areas to achieve illumina-tion levels and uniformity

Source: Adapted from Centre d'Etudes sur les Réseaux les Transports, l'Urbanisme et les constructions publiques (CERTU), *L'Éclairage des Carrefours à Sens Giratoire (The Illumination of Roundabout Intersections),* Lyon, France: CERTU, 1991 [22], with additions by the authors.

APPENDIX A
Cost History Information

ITEMIZED ESTIMATE

PROJECT NUMBER: 017 MA 218 H 4628 01 L	ROUTE: I-17
LOCATION: Happy Valley Road T.I. @ I-17	August 27, 1998

ITEM	UNIT	QUANTITY	PRICE ($)	AMOUNT ($)
Remove Existing Pavement	SY	11,480	5.00	57,400
Remove Guardrail	LF	1,500	2.00	3,000
Remove Embankment Curb	LF	2,670	1.50	4,000
Remove and Salvage Cattleguards	EA	2	1,200.00	2,400
Borrow	CY	54,000	3.50	189,000
Asphaltic Concrete (Misc. Struct.) (4")	Ton	6,160	40.00	246,400
Aggregate Base Course (10")	CY	7,600	25.00	190,000
Asphaltic Concrete Friction Course (Misc.)	Ton	1,540	55.00	84,700
Guard Rail	LF	400	20.00	8,000
Guard Rail Terminal	EA	4	3,000.00	12,000
Concrete Curb	LF	4,990	15.00	74,900
Pipe, Corrugated Metal, 30" (Extension)	LF	136	40.00	5,400
Pavement Marking (Thermoplastic)	LF	5,900	0.50	3,000
Remove and Salvage Existing Light poles	EA	6	500.00	3,000
Relocate Existing Lighting Load Center	LSUM	1	2,000.00	2,000
Intersection Lighting	LSUM	1	30,000.00	30,000
Signing	LSUM	1	15,000.00	15,000
Seeding	ACRE	2	2,000.00	4,000
Right-of-Way Fence	LF	450	5.00	2,300
SUBTOTAL				937,000
Erosion Control (1%)				9,400
Construction Survey (2%)				18,700
Quality Control (2%)				18,700
Water Supply/Dust Palliative (2%)				18,700
Maintenance/Protection of Traffic (15%)				140,600
Mobilization (10%)				93,700
Construction Engineering & Contingencies (30%)				281,100
TOTAL CONSTRUCTION COST				**1,518,000**
Preliminary Engineering				151,800
Right-of-Way Acquisition				6,000
TOTAL PROJECT COST				**1,676,000**
City of Phoenix Participation				(150,000)
ADOT PROJECT COST				**1,526,000**

COMBINED ESTIMATE

CONTRACT # 1999152

TRACS No.	Project No.	Item	County	District	Gross Length	Net Length	Prepared By:
017 MA 218 H462801C	STP 17-1-(348)	25200	MARICOPA	PHOENIX	0.1		Pierson Donald

Highway Termini	Location	Work Description
• PHOENIX-CORDES JUNCTION	•HAPPY VALLEY ROAD	•INTMDT TI IMPRVT

Printed: 01/10/2003

COMBINED ESTIMATE FOR CONTRACT # 1999152

Item No.	Item Description	Unit	Quantity	Unit Price	Amount
2010001	CLEARING AND GRUBBING	L.SUM	1	$20,000.00	$20,000.00
2020001	REMOVAL OF STRUCTURES AND OBSTRUCTIONS	L.SUM	1	$21,000.00	$21,000.00
2020029	REMOVAL OF ASPHALTIC CONCRETE PAVEMENT	SQ.YD.	20,180	$2.50	$50,450.00
2020037	REMOVE AND SALVAGE CATTLE GUARDS	EACH	4	$2,000.00	$8,000.00
2020072	REMOVE AND SALVAGE GUARD RAIL	L.FT.	2,235	$2.50	$5,587.50
2020076	REMOVE AND SALVAGE BREAKAWAY CABLE TERMINAL	EACH	4	$500.00	$2,000.00
2030301	ROADWAY EXCAVATION	CU.YD.	94,390	$3.00	$283,170.00
2030401	DRAINAGE EXCAVATION	CU.YD.	32	$20.00	$640.00
2070001	DUST PALLIATIVE	M.GAL.	2,000	$11.00	$22,000.00
3030022	AGGREGATE BASE, CLASS 2	CU.YD.	10,150	$20.00	$203,000.00
4040078	EMULSIFIED ASPHALT (FOR FOG COAT) (SS-1)	TON	2	$275.00	$550.00
4040111	BITUMINOUS TACK COAT	TON	10	$200.00	$2,000.00

COMBINED ESTIMATE FOR CONTRACT # 1999152

Item No.	Item Description	Unit	Quantity	Unit Price	Amount
4040116	APPLY BITUMINOUS TACK COAT	HOUR	80	$140.00	$11,200.00
4040163	BLOTTER MATERIAL	TON	7	$30.00	$210.00
4040262	ASPHALT BINDER (PG 64-16)	TON	18	$225.00	$4,050.00
4040282	ASPHALT BINDER (PG 76-16)	TON	773	$250.00	$193,250.00
4060006	ASPHALTIC CONCRETE (3/4" MIX)	TON	12,880	$20.00	$257,600.00
4060026	MINERAL ADMIXTURE (FOR 3/4" MIX)	TON	129	$90.00	$11,610.00
4060027	MINERAL ADMIXTURE (FOR ACFC)	TON	1	$90.00	$90.00
4070001	ASPHALTIC CONCRETE FRICTION COURSE	TON	983	$40.00	$39,320.00
5010007	PIPE, CORRUGATED METAL, 18"	L.FT.	540	$40.00	$21,600.00
5010011	PIPE, CORRUGATED METAL, 24"	L.FT.	978	$50.00	$48,900.00
5010017	PIPE, CORRUGATED METAL, 30"	L.FT.	818	$50.00	$40,900.00
5014118	FLARED END SECTION (18") (C-13.20)	EACH	11	$400.00	$4,400.00

COMBINED ESTIMATE FOR CONTRACT # 1999152

Item No.	Item Description	Unit	Quantity	Unit Price	Amount
5014124	FLARED END SECTION (24") (C-13.20)	EACH	8	$400.00	$3,200.00
5014130	FLARED END SECTION (30") (C-13.20)	EACH	8	$400.00	$3,200.00
5030001	CONCRETE CATCH BASIN (C-15.10) SINGLE, H=8' OR LESS	EACH	11	$2,500.00	$27,500.00
5030141	CONCRETE CATCH BASIN (MEDIAN)	EACH	2	$2,500.00	$5,000.00
5050001	MANHOLE (C-18.10) (NO. 1) (FOR PIPES 6" TO 36")	EACH	2	$4,000.00	$8,000.00
6070040	SLIP BASE SIGN POST (P-2)	EACH	48	$150.00	$7,200.00
6070041	SIGN POST (P-1) (PERFORATED) (SINGLE)	L.FT.	1,173	$10.00	$11,730.00
6070042	SIGN POST (P-2) (PERFORATED) (TELESCOPING)	L.FT.	185	$11.00	$2,035.00
6070046	FOUNDATION FOR SIGN POST (P-1)(PERFORATED)	EACH	108	$150.00	$16,200.00
6070047	FOUNDATION FOR SIGN POST (P-2)(PERFORATED)	EACH	16	$150.00	$2,400.00
6080002	REGULATORY,WARN, OR MARKER SIGN PANEL W/TYP II SHEET	SQ.FT.	967	$20.00	$19,340.00
6080022	FLAT SHEET ALUM W/DIR-APP OR SLK SCRN CHAR.,TYP II SHEET	SQ.FT.	404	$21.00	$8,484.00

COMBINED ESTIMATE FOR CONTRACT # 1999152

Item No.	Item Description	Unit	Quantity	Unit Price	Amount
7015041	TEMPORARY PAINTED MARKING (ARROW, SYMBOL OR LEGEND)	EACH	5	$90.00	$450.00
7015042	TEMPORARY PAINTED MARKING (STRIPE)	L.FT	10,825	$0.13	$1,407.25
7015052	OBLITERATE PAVEMENT MARKING (STRIPE)	L.FT.	1,000	$0.50	$500.00
7015090	SPECIALTY SIGNS(WITH TYPE II SHEETING)	SQ.FT.	432	$10.00	$4,320.00
7016030	BARRICADE (TYPE II, VERT.PANEL, TUBULAR MARKER)	EACH-DAY	42,650	$0.40	$17,060.00
7016031	BARRICADE (TYPE III, HIGH LEVEL FLAG TREES)	EACH-DAY	120	$1.00	$120.00
7016032	PORTABLE SIGN STANDS (RIGID)	EACH-DAY	1,720	$1.00	$1,720.00
7016035	WARNING LIGHTS (TYPE A)	EACH-DAY	6,240	$1.00	$6,240.00
7016037	WARNING LIGHTS (TYPE C)	EACH-DAY	42,650	$0.75	$31,987.50
7016038	TRAFFIC CONE (28 INCHES)	EACH-DAY	2,000	$0.35	$700.00
7016039	EMBEDDED SIGN POST	EACH-DAY	10,920	$0.10	$1,092.00
7016047	TEMPORARY SIGN (TYPE II) (LESS THAN 10 S.F.)	EACH-DAY	3,240	$1.00	$3,240.00

COMBINED ESTIMATE FOR CONTRACT # 1999152

Item No.	Item Description	Unit	Quantity	Unit Price	Amount
7016048	TEMPORARY SIGN (TYPE II) (10 S.F. OR MORE)	EACH-DAY	3,240	$1.25	$4,050.00
7016066	CHANGEABLE MESSAGE SIGN	EACH-DAY	380	$120.00	$45,600.00
7016075	FLAGGING SERVICES (CIVILIAN)	HOUR	800	$22.00	$17,600.00
7030021	REFERENCE MARKER (4-M-6.01)(M9-10 (1) OR (2)	EACH	4	$75.00	$300.00
7040003	PAVEMENT MARKING (WHITE SPRAYED THERMOPLASTIC)(0.060")	L.FT.	11,800	$0.50	$5,900.00
7040004	PAVEMENT MARKING (YELLOW SPRAYED THERMOPLASTIC)(0.060")	L.FT.	6,600	$0.50	$3,300.00
7040070	PAVEMENT MARKING (WHITE THERMOPLASTIC) (0.090")	L.FT.	1,090	$1.00	$1,090.00
7050021	PAVEMENT MARKING, PREFORMED, TYPE I, YELLOW STRIPE	L.FT.	1,350	$1.00	$1,350.00
7050023	PAVEMENT MARKING, PREFORMED, TYPE I, SINGLE ARROW	EACH	1	$100.00	$100.00
7050026	PAVEMENT MARKING, PREFORMED, TYPE I, LEGEND (ONLY)	EACH	21	$100.00	$2,100.00
7050029	PAVEMENT MARKING, PREFORMED, TYPE I, FREEWAY ARROW	EACH	2	$150.00	$300.00
7060015	PAVEMENT MARKER, RAISED, TYPE D	EACH	30	$6.00	$180.00

COMBINED ESTIMATE FOR CONTRACT # 1999152

Item No.	Item Description	Unit	Quantity	Unit Price	Amount
7060018	PAVEMENT MARKER, RAISED, TYPE G	EACH	45	$6.00	$270.00
7080301	PAINT BULL NOSE	EACH	13	$100.00	$1,300.00
7310090	POLE (TYPE H) (STANDARD BASE)	EACH	20	$1,400.00	$28,000.00
7310180	POLE (FOR 100 FT. HIGH MAST)	EACH	2	$9,000.00	$18,000.00
7310201	BREAKAWAY BASE FOR LIGHTING POLES (OVER 30')	EACH	20	$500.00	$10,000.00
7310272	POLE FOUNDATION (TYPE H) (BREAKAWAY)	EACH	20	$600.00	$12,000.00
7310360	POLE FOUNDATION (FOR 100 FT. HIGH MAST)	EACH	2	$3,000.00	$6,000.00
7310551	MAST ARM (20 FT.) (TAPERED)	EACH	20	$600.00	$12,000.00
7310630	HIGH MAST RAISING AND LOWERING DEVICE	EACH	2	$10,000.00	$20,000.00
7320050	ELECTRICAL CONDUIT (2") (PVC)	L.FT.	5,365	$4.50	$24,142.50
7320071	ELECTRICAL CONDUIT (3") (PVC) (BORED)	L.FT.	212	$40.00	$8,480.00
7320410	PULL BOX (NO. 5)	EACH	37	$250.00	$9,250.00

COMBINED ESTIMATE FOR CONTRACT # 1999152

Item No.	Item Description	Unit	Quantity	Unit Price	Amount
7320420	PULL BOX (NO. 7)	EACH	2	$275.00	$550.00
7320500	CONDUCTOR (NO. 12)	L.FT.	960	$0.25	$240.00
7320520	CONDUCTOR (NO. 8)	L.FT.	49,250	$0.40	$19,700.00
7320530	CONDUCTOR (NO. 6)	L.FT.	300	$0.45	$135.00
7320590	CONDUCTOR (INSULATED BOND) (NO. 8)	L.FT.	12,235	$0.40	$4,894.00
7320720	TRENCHING (FOR SERVICE CONDUCTORS)	L.FT.	100	$10.00	$1,000.00
7360020	LUMINAIRE (HORIZONTAL MOUNT) (HPS 150 WATT)	EACH	8	$400.00	$3,200.00
7360030	LUMINAIRE (HORIZONTAL MOUNT) (HPS 250 WATT)	EACH	4	$400.00	$1,600.00
7360050	LUMINAIRE (HORIZONTAL MOUNT) (HPS 400 WATT)	EACH	8	$400.00	$3,200.00
7360080	LUMINAIRE (HIGH MAST) (HPS 400 WATT)	EACH	12	$900.00	$10,800.00
7360221	LOAD CENTER CABINET (TYPE II) (240/480 VOLT)	EACH	1	$7,000.00	$7,000.00
7360330	TEMPORARY DETOUR LIGHTING	L.SUM	1	$3,500.00	$3,500.00

COMBINED ESTIMATE FOR CONTRACT # 1999152

Item No.	Item Description	Unit	Quantity	Unit Price	Amount
7370310	REMOVE AND SALVAGE ELECTRICAL EQUIPMENT	L.SUM	1	$5,000.00	$5,000.00
7370455	MISCELLANEOUS ELECTRICAL (AS-BUILT DRAWINGS)	L.SUM	1	$1,000.00	$1,000.00
8030103	DECOMPOSED GRANITE	SQ.YD.	5,774	$1.25	$7,217.50
8050003	SEEDING (CLASS II)	ACRE	3	$2,000.00	$6,000.00
8101009	EROSION CONTROL (RIPRAP) (GRADATION 'C')	CU.YD.	50	$35.00	$1,750.00
8101014	EROSION CONTROL (SEDIMENT WATTLE)	L.FT.	5,731	$0.75	$4,298.25
9010001	MOBILIZATION	L.SUM	1	$198,700.00	$198,700.00
9020021	CHAIN LINK FENCE, TYPE 2	L.FT.	270	$10.00	$2,700.00
9030012	BARBED WIRE FENCE, TYPE 2	L.FT.	2,991	$1.50	$4,486.50
9050001	GUARD RAIL, W-BEAM, SINGLE FACE	L.FT.	240	$18.00	$4,320.00
9050026	GUARD RAIL TERMINAL (TANGENT TYPE)	EACH	4	$2,500.00	$10,000.00
9050403	GUARD RAIL TRANSITION, W-BEAM TO THRIE BEAM	EACH	4	$4,500.00	$18,000.00

COMBINED ESTIMATE FOR CONTRACT # 1999152

Item No.	Item Description	Unit	Quantity	Unit Price	Amount
9080041	CONCRETE CURB (C-05.10)(TYPE C-1, H=3")	L.FT.	904	$10.00	$9,040.00
9080042	CONCRETE CURB (C-05.10)(TYPE D, H=6")	L.FT.	3,443	$10.00	$34,430.00
9110001	RIGHT-OF-WAY MARKER	EACH	13	$150.00	$1,950.00
9130001	RIPRAP (DUMPED)	CU.YD.	34	$100.00	$3,400.00
9160001	EMBANKMENT CURB	L.FT.	92	$8.00	$736.00
9170001	EMBANKMENT SPILLWAY (C-4.10)	L.FT.	345	$50.00	$17,250.00
9210011	MEDIAN PAVING	SQ.YD.	56	$30.00	$1,680.00
9230001	PROVIDE ON-THE-JOB TRAINING	HOUR	700	$0.80	$560.00
9240017	FORCE ACCOUNT WORK (PROVIDE ELECTRICAL SERVICE)	L.SUM	1	$5,000.00	$5,000.00
9240102	MISCELLANEOUS WORK (CONSTRUCT DETOURS)	L.SUM	1	$105,000.00	$105,000.00
9240121	MISCELLANEOUS WORK (MEDIAN NOSE TRANSITION-STD C-05.40)	EACH	22	$800.00	$17,600.00
9240170	CONTRACTOR QUALITY CONTROL	L.SUM	1	$29,700.00	$29,700.00

Printed: 01/10/2003

COMBINED ESTIMATE FOR CONTRACT # 1999152

Item No.	Item Description	Unit	Quantity	Unit Price	Amount
9250001	CONSTRUCTION SURVEYING AND LAYOUT	L.SUM	1	$39,700.00	$39,700.00

Total for : $2,251,303.00

TOTAL FOR CONTRACT # 1999152 : $2,251,303.00

ARIZONA DEPARTMENT OF TRANSPORTATION

COFA LOG

STP-017-1(348)P / H462801C

RESIDENT ENGINEER: Paul E. Sullivan

ORG: 7740

Summary

Contract Amount	$2,174,362.95	Total Change Orders	$298,061.76
5 % Contingency	$108,718.15	Total Force Accounts	$0.00
Additional Requested	$188,882.85		
Total Available	$297,601.00		
Remaining Available	-$15,493.45		

LETTERS OF AGREEMENT:

Total Amount Available	$50,000.00
Total Letter Agreements	$15,032.69
Remaining	$34,967.31

Catagories:

1	Value Engineering	($59,717.32)	-2.75%
2A	Additional or Extra Work Out of Scope - ADOT funded	$113,737.05	5.23%
2B	Additional or Extra Work Out of Scope - Other Jurisdiction funding	$0.00	0.00%
3	Quantity Omissions	$75,241.39	3.46%
4	Plans Revisions and Oversights	$175,647.02	8.08%
5	Changed Conditions	$0.00	0.00%
6	Penalties - Bonus	$0.00	0.00%
7	Other	$8,186.31	0.38%

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Number		Catagory	Emerg Auth Date	RE App Date	Contr App Date	Sent to Dist	Dist App Date	Return Date	Amount	Description	Accum Amount	% Of Orig Contract
CO	1	7	10/17/00	10/17/00	10/17/00	10/24/00	10/31/00	11/21/00	$0.00	Misc AC	$0.00	0.00%
LA	1	7	10/17/00	10/24/01	10/24/01	10/24/00			($646.97)	Partnering	($646.97)	-0.03%
CO	2	4	11/08/00	11/27/00	11/08/00	11/28/00	12/12/00	01/22/01	$41,692.98	Changes to curb & gutter, irrigation sleeves	$41,046.01	1.89%
CO	3	4	11/08/00	11/07/00	11/27/00	11/28/00	02/15/01	02/26/01	$7,309.42	Change load center, add YIELD legends	$48,355.43	2.22%
LA	2	7	11/22/00	11/27/00	11/27/00				$785.00	Locator tape	$49,140.43	2.26%
CO	5	7	11/29/00	12/20/00	11/27/00		01/19/01	02/26/01	$0.00	Diesel Fuel Price Adjustment	$49,140.43	2.26%
CO	4	1	01/24/01	12/20/00	01/07/00		01/17/01	02/26/01	($59,717.32)	Eliminate Detours - VE	($10,576.89)	-0.49%
CO	6	3	01/24/01	01/31/01	02/07/01	02/08/01	02/14/01	02/26/01	$67,132.00	Seeding	$56,555.11	2.60%
CO	7	4	01/29/01	01/31/01	02/07/01	02/08/01	02/14/01	02/26/01	$21,387.68	Pipe Protection Slabs	$77,942.79	3.58%
LA	3	7	02/05/01	02/15/01	02/23/01	02/27/01			$7,281.18	Prepare ADOT Owned Well	$85,223.97	3.92%
LA	4	7	02/13/01	02/15/01	02/23/01	02/27/01			($1,716.00)	Referee Testing for Lot #7	$83,507.97	3.84%
CO	8	2A	02/13/01	02/22/01	02/22/01	03/02/01	03/14/01	03/26/01	$77,611.05	Mill and Overlay Ramps	$161,119.02	7.41%
CO	9	4	02/14/01	02/20/01	02/20/01	03/02/01	03/12/01	03/26/01	$36,622.40	Signing and Striping Changes	$197,741.42	9.09%
LA	5	7	02/16/01	02/21/01	02/27/01	02/27/01			$388.00	Additional Coring	$198,129.42	9.11%
CO	10	4	02/27/01	02/28/01	02/28/01	03/02/01	03/14/01	03/26/01	$63,680.07	Drainage on East happy valley Road	$261,809.49	12.04%

Number	Catagory	Emerg Auth Date	RE App Date	Contr App Date	Sent to Dist	Dist App Date	Return Date	Amount	Description	Accum Amount	% Of Orig Contract
CO 11	3	04/09/01	04/24/01	05/02/01	05/03/01	05/04/01	06/08/01	$6,217.48	Inlets & Outlets (C-4.10)	$268,026.97	12.33%
LA 6	4	05/29/01	05/31/01	06/12/01				$1,013.47	Adjust One-Way Signs & Change Arrows on the Guide Signs	$269,040.44	12.37%
LA 7	4	05/29/01	05/31/01	06/12/01				$3,941.00	Relocate Load Center	$272,981.44	12.55%
LA 8	3	05/29/01	05/31/01	06/12/01				$1,891.91	Additional Traffic Control	$274,873.35	12.64%
CO 12	4	05/30/01	05/31/01	06/12/01	06/13/01	07/31/01	08/08/01	$0.00	Sales Tax Adjustment	$274,873.35	12.64%
LA 9	7	08/08/01	08/27/01	08/16/01				$2,095.10	Additional Work from Final Inspection	$276,968.45	12.74%
CO 13	2A	11/28/01	01/25/01	02/27/02	01/29/01	03/09/02	04/16/02	$36,126.00	Repair I-17 @ Jackson	$313,094.45	14.40%

APPENDIX B
Automatic Traffic Recorder (ATR) Raw Data

START	WEST ROUNDABOUT COUNT LOCATIONS - WEDNESDAY, 10/16/02										
TIME	LOC 12*	LOC 13	LOC 14	LOC 15	LOC 16	LOC 17	LOC 18	LOC 19	LOC 20	LOC 21*	LOC 22
0:00	2	4	5	2	2	25	7	5	7	12	2
0:15	2	5	3	1	1	14	4	3	4	8	0
0:30	2	6	5	6	1	17	3	5	7	9	4
0:45	2	5	3	2	1	10	3	4	13	4	1
1:00	1	6	5	5	1	4	6	3	10	11	0
1:15	2	2	4	1	1	10	2	2	4	4	0
1:30	2	8	8	2	0	11	4	4	5	4	0
1:45	0	0	1	0	0	5	3	3	4	3	0
2:00	0	2	1	1	1	2	4	2	4	3	0
2:15	8	2	2	1	0	4	4	4	1	4	0
2:30	1	1	2	5	2	7	8	2	10	1	0
2:45	4	3	5	0	0	2	5	3	5	8	0
3:00	1	1	0	1	0	6	20	8	18	2	0
3:15	1	0	1	1	0	8	18	7	5	6	0
3:30	1	1	1	0	0	3	20	17	15	4	0
3:45	6	2	1	3	0	7	35	11	14	4	1
4:00	4	4	4	10	0	4	51	24	23	16	0
4:15	7	4	4	7	1	17	62	25	33	13	5
4:30	2	1	2	12	0	25	95	46	45	19	1
4:45	6	3	1	10	1	16	117	58	56	30	0
5:00	3	2	4	22	6	22	179	96	88	59	0
5:15	19	11	8	23	3	46	181	99	122	94	0
5:30	13	21	18	35	5	69	197	152	150	94	3
5:45	18	47	37	38	2	106	320	132	191	110	6
6:00	26	52	60	48	6	94	343	185	205	56	12
6:15	31	46	41	54	9	102	353	265	248	68	10
6:30	23	39	54	61	4	88	357	261	343	71	5
6:45	52	44	40	65	12	120	374	284	364	83	10
7:00	63	43	51	93	15	144	396	282	350	77	22
7:15	59	29	28	100	28	159	374	291	394	86	5
7:30	44	40	43	77	12	95	257	306	424	65	11
7:45	46	44	44	86	13	110	248	256	402	75	24
8:00	44	46	48	73	14	108	264	200	324	52	13
8:15	37	37	36	90	36	125	251	184	275	54	12
8:30	38	43	43	62	19	91	202	214	271	64	16
8:45	42	40	32	42	12	113	172	183	272	68	19
9:00	23	37	36	42	12	79	145	149	234	50	14
9:15	26	35	39	32	9	88	150	109	195	49	13
9:30	22	26	28	41	7	79	135	120	166	54	10
9:45	28	31	25	38	10	80	128	118	183	43	8
10:00	23	45	43	37	10	90	133	92	168	64	10
10:15	31	33	44	46	4	84	117	96	126	72	20
10:30	24	39	36	37	7	92	116	94	159	75	16
10:45	23	27	24	53	16	91	123	81	165	79	6
11:00	30	21	26	32	7	105	130	87	137	73	1
11:15	33	35	25	30	8	116	143	92	155	92	15
11:30	39	30	28	29	7	106	119	84	145	89	15
11:45	33	34	23	36	7	102	123	91	134	104	11
12:00	32	37	32	52	10	105	123	76	154	89	18
12:15	24	46	36	32	12	101	144	81	174	94	13
12:30	24	46	54	57	12	104	119	90	131	84	16
12:45	37	35	32	38	13	109	103	97	171	95	15
13:00	27	35	31	33	10	110	114	83	161	85	8
13:15	33	32	39	27	4	118	118	74	131	85	3
13:30	29	35	32	43	10	126	122	86	125	102	7
13:45	40	24	24	43	14	145	181	99	148	103	8
14:00	28	28	28	39	5	139	176	78	160	113	7
14:15	40	39	30	30	7	147	144	145	167	128	19
14:30	29	59	58	51	14	156	134	134	223	130	12
14:45	40	29	32	64	16	186	151	103	239	136	6
15:00	51	33	30	55	9	203	186	94	195	176	14
15:15	30	48	41	47	17	188	152	101	212	157	15
15:30	42	66	57	36	10	184	128	119	185	199	32
15:45	39	49	72	49	10	204	115	99	203	181	22
16:00	30	53	49	44	13	240	117	75	178	253	15
16:15	45	50	45	40	16	229	137	76	173	212	14
16:30	36	71	64	47	14	248	109	83	194	306	16
16:45	26	64	66	35	9	232	128	85	216	239	20
17:00	19	68	59	47	12	267	107	68	136	265	15
17:15	22	70	75	44	19	258	104	76	139	256	19
17:30	25	69	71	48	13	263	153	73	143	219	17
17:45	30	65	62	44	15	246	150	64	135	211	17
18:00	34	76	80	48	15	259	105	100	132	231	23
18:15	29	66	64	41	7	199	87	101	208	168	16
18:30	27	48	50	33	15	169	85	64	150	137	13
18:45	11	54	56	23	5	114	66	64	112	136	11
19:00	8	53	43	27	5	112	52	55	104	102	10
19:15	16	45	57	23	5	90	58	37	83	112	10
19:30	14	48	48	29	6	94	46	30	64	90	10
19:45	8	40	42	14	3	100	51	39	65	97	3
20:00	14	25	29	20	6	81	40	39	54	91	3
20:15	13	32	31	14	0	101	51	27	74	80	5
20:30	13	32	27	6	4	82	47	24	50	74	10
20:45	8	23	32	12	4	73	47	33	31	74	6
21:00	13	31	27	14	5	88	38	33	58	78	8
21:15	8	23	28	10	5	78	38	35	51	56	3
21:30	9	29	25	8	3	85	37	27	56	70	4
21:45	5	19	22	8	1	54	32	28	45	67	7
22:00	5	19	19	15	5	66	26	22	70	60	1
22:15	4	19	17	6	3	48	16	27	52	48	4
22:30	7	24	20	4	3	46	10	13	61	66	6
22:45	3	15	19	2	1	35	20	8	36	23	2
23:00	2	8	10	8	2	25	15	12	15	26	1
23:15	0	11	8	5	0	30	7	7	11	23	3
23:30	2	8	14	7	3	26	10	8	15	17	2
23:45	1	9	8	4	1	23	16	2	17	18	4
TOTAL	1979	2945	2917	2918	703	9287	10716	7833	12380	8047	834

Note: Loc 21 - Machine error no data available for this day, count data derived from turn movement percentages

RAW AXLE PAIR COUNT DATA SUMMARY

START	WEST ROUNDABOUT COUNT LOCATIONS - TUESDAY, 10/15/02										
TIME	LOC 12	LOC 13	LOC 14	LOC 15	LOC 16	LOC 17	LOC 18	LOC 19	LOC 20	LOC 21*	LOC 22
0:00	1	5	6	3	2	15	10	5	6	11	2
0:15	1	4	3	3	1	17	5	5	7	14	2
0:30	0	3	2	3	1	15	11	7	7	10	0
0:45	3	3	3	1	0	7	4	10	8	7	0
1:00	0	2	3	2	0	15	6	3	16	8	3
1:15	4	2	2	3	1	10	6	2	5	8	0
1:30	1	3	4	2	3	6	2	5	6	7	0
1:45	1	1	0	0	0	8	3	2	4	2	1
2:00	3	7	7	2	0	5	3	1	1	4	0
2:15	0	1	2	0	0	1	4	3	5	8	0
2:30	3	1	0	5	2	5	2	3	5	4	0
2:45	0	6	5	1	0	4	12	4	5	3	0
3:00	1	0	4	1	0	2	13	2	8	4	0
3:15	3	1	1	1	0	5	12	13	9	7	0
3:30	4	1	0	3	0	4	16	8	19	8	0
3:45	2	2	5	8	3	9	26	11	14	16	0
4:00	4	0	0	9	2	5	38	14	25	17	0
4:15	9	4	1	9	0	17	68	28	25	27	0
4:30	4	0	2	12	1	23	93	37	43	24	0
4:45	10	3	1	9	0	16	121	56	58	46	1
5:00	11	3	5	15	4	20	195	104	80	80	0
5:15	13	5	4	27	3	43	194	110	131	137	2
5:30	16	25	21	31	4	83	236	154	177	111	14
5:45	14	44	34	42	1	100	312	158	190	180	6
6:00	26	48	57	44	3	83	356	201	225	107	3
6:15	19	44	48	34	6	87	359	254	259	125	5
6:30	24	45	71	58	5	94	335	311	322	115	11
6:45	40	57	53	75	9	108	368	258	374	138	18
7:00	51	34	46	78	24	112	395	294	376	143	9
7:15	68	26	33	85	24	166	362	280	385	148	9
7:30	56	23	29	90	16	107	246	283	377	128	7
7:45	40	45	32	85	14	103	256	249	375	119	11
8:00	23	40	47	71	11	108	260	199	332	99	6
8:15	37	37	36	86	30	130	194	197	288	106	12
8:30	44	35	34	60	15	90	162	208	278	123	15
8:45	35	35	33	54	16	99	176	127	273	104	17
9:00	26	32	41	42	4	87	141	131	192	92	9
9:15	29	25	26	46	10	87	150	126	194	83	7
9:30	25	28	27	48	17	80	125	116	180	89	11
9:45	29	24	22	38	4	88	109	96	159	80	9
10:00	29	31	31	34	11	92	133	95	138	113	2
10:15	27	31	26	32	7	99	123	82	132	102	9
10:30	27	31	32	36	5	90	120	107	138	111	9
10:45	26	24	24	39	11	98	137	77	142	124	12
11:00	31	27	22	29	7	123	100	71	121	131	9
11:15	39	43	36	30	8	99	135	91	120	119	15
11:30	24	29	21	43	8	119	132	78	142	144	8
11:45	30	23	30	35	17	88	125	108	139	145	8
12:00	27	36	24	31	7	96	142	98	168	133	11
12:15	30	39	37	29	11	125	131	97	153	121	8
12:30	27	39	40	41	14	110	117	112	147	114	9
12:45	22	29	24	52	19	95	127	85	157	125	12
13:00	28	36	34	34	9	89	119	96	159	125	7
13:15	27	29	29	40	3	123	117	93	154	138	9
13:30	35	27	25	47	8	113	136	94	138	133	4
13:45	36	35	30	33	4	109	181	73	140	147	11
14:00	32	32	22	35	5	138	156	100	134	175	16
14:15	26	33	38	38	10	143	158	134	205	205	11
14:30	31	39	37	56	11	161	117	107	195	208	14
14:45	40	50	42	53	14	155	119	118	233	192	12
15:00	36	47	46	46	9	183	179	86	233	268	19
15:15	29	41	49	43	25	184	165	93	168	221	11
15:30	45	50	36	39	13	189	135	128	158	289	16
15:45	39	67	61	45	12	206	117	97	208	317	37
16:00	35	51	48	44	9	234	137	88	194	365	16
16:15	32	70	65	34	10	253	133	81	203	311	17
16:30	30	66	65	40	14	51	116	89	185	369	22
16:45	36	57	54	51	19	239	95	76	205	320	22
17:00	33	66	74	35	9	270	114	72	141	330	15
17:15	31	67	52	39	21	276	116	58	140	308	19
17:30	28	68	67	45	10	254	108	76	107	305	26
17:45	24	78	73	30	8	230	125	79	181	283	20
18:00	19	63	75	30	11	233	120	80	132	262	15
18:15	20	63	68	43	15	207	100	86	177	184	12
18:30	20	39	40	39	12	161	87	65	150	165	9
18:45	23	42	44	27	10	131	50	55	112	153	17
19:00	17	36	36	34	12	130	39	43	98	116	12
19:15	7	52	47	26	7	96	55	30	76	123	16
19:30	9	35	42	20	12	96	61	21	55	107	7
19:45	3	43	43	21	8	81	57	31	49	108	18
20:00	23	36	34	18	7	107	55	41	69	108	12
20:15	8	36	43	11	2	67	55	36	69	93	9
20:30	17	35	32	15	3	77	51	37	64	102	10
20:45	9	39	28	15	8	66	44	25	55	88	14
21:00	10	42	49	17	3	77	35	39	55	82	9
21:15	6	32	23	13	4	71	38	16	83	76	15
21:30	6	15	27	7	5	75	32	23	40	66	7
21:45	11	22	22	11	3	64	23	21	37	60	9
22:00	13	21	21	9	3	53	19	26	52	51	5
22:15	5	20	17	11	3	50	19	18	39	46	1
22:30	8	11	17	5	1	31	20	14	67	68	2
22:45	8	10	14	4	0	25	23	11	42	38	3
23:00	6	10	11	9	5	37	4	9	19	27	1
23:15	3	13	10	2	0	33	5	8	18	17	6
23:30	2	10	13	5	1	32	9	6	10	13	1
23:45	0	5	5	5	5	12	4	3	10	17	1
TOTAL	1925	2825	2805	2841	724	8910	10556	7758	12199	11203	837

Note: Loc 21 - Machine error no data available for this day, count data derived from turn movement percentages

START TIME	EAST ROUNDABOUT COUNT LOCATIONS - WEDNESDAY, 10/16/02										
	LOC 1	LOC 2	LOC 3	LOC 4	LOC 5	LOC 6	LOC 7	LOC 8	LOC 9	LOC 10	LOC 11
0:00	22	0			0	1	0	0	2	3	0
0:15	14	1			0	1	0	0	2	1	0
0:30	14	0			0	0	2	0	2	1	2
0:45	5	0			0	1	2	2	1	2	0
1:00	19	1			0	0	0	1	1	1	0
1:15	7	0			0	0	0	0	1	0	0
1:30	7	0			0	0	0	0	2	1	0
1:45	6	2			0	0	0	0	2	4	0
2:00	4	1			0	0	1	0	0	5	0
2:15	7	1			0	0	1	1	0	1	0
2:30	2	0			0	0	0	1	2	1	0
2:45	14	0			0	0	0	0	0	1	0
3:00	4	0			0	0	0	0	3	4	0
3:15	10	2			0	0	0	0	1	4	0
3:30	8	2			0	0	0	0	2	7	0
3:45	8	3			0	1	0	0	3	8	0
4:00	28	6			1	0	0	0	6	10	0
4:15	24	1			0	0	0	0	4	10	0
4:30	34	3			0	2	0	0	6	18	0
4:45	53	8			1	1	0	0	2	26	0
5:00	106	12			0	15	0	0	12	39	0
5:15	166	14			0	15	1	1	10	60	1
5:30	166	38			0	28	2	1	22	32	0
5:45	185	38			0	14	9	7	25	83	3
6:00	119	54			1	30	0	3	28	91	0
6:15	143	71			1	18	2	0	31	87	0
6:30	148	32			1	41	2	3	56	83	0
6:45	172	20			1	39	3	1	24	112	0
7:00	160	36			3	73	3	3	34	115	1
7:15	173	24			4	69	7	3	49	127	0
7:30	122	32			0	101	11	10	40	74	1
7:45	144	31			2	40	11	8	28	81	3
8:00	101	23			1	38	7	8	30	75	2
8:15	112	22			1	26	3	2	38	62	1
8:30	130	21			1	20	4	2	43	63	0
8:45	132	15			0	29	9	9	30	63	0
9:00	104	30			0	42	1	0	38	44	2
9:15	101	27			1	22	2	2	48	35	0
9:30	110	22			1	17	4	3	35	47	1
9:45	92	21			0	12	0	1	27	51	1
10:00	87	32			1	7	7	2	20	40	2
10:15	103	27			1	8	3	6	23	41	1
10:30	104	27			1	7	6	6	25	39	3
10:45	110	20			3	16	6	6	22	41	0
11:00	102	21			1	15	5	4	26	46	0
11:15	122	25			1	6	13	11	30	51	4
11:30	121	26			0	10	9	11	24	49	5
11:45	137	36			0	7	14	10	34	55	0
12:00	118	33			0	22	12	17	23	42	0
12:15	122	24			7	16	15	10	33	52	2
12:30	111	22			1	13	11	13	37	42	0
12:45	128	22	51	63	1	16	10	4	33	39	1
13:00	118	23	57	68	2	8	7	9	18	35	2
13:15	113	22	48	70	0	7	10	8	19	35	1
13:30	147	28	56	67	0	9	3	4	28	41	1
13:45	147	15	38	62	0	9	4	4	19	47	0
14:00	157	26	39	66	2	9	9	7	29	66	5
14:15	174	15	53	90	1	8	13	12	40	47	2
14:30	159	27	63	81	1	13	28	20	23	54	0
14:45	184	25	60	67	2	16	14	17	33	50	0
15:00	173	18	51	76	2	26	26	22	33	63	1
15:15	164	14	47	120	2	13	13	12	38	37	1
15:30	194	24	43	99	0	3	32	20	41	48	0
15:45	190	19	49	79	0	7	14	22	29	31	0
16:00	226	17	49	84	2	11	62	45	40	43	4
16:15	210	19	41	117	2	19	31	39	29	51	0
16:30	251	18	44	132	0	29	98	59	54	26	0
16:45	255	13	44	128	2	19	15	38	31	35	1
17:00	258	22	24	80	1	9	42	32	38	27	0
17:15	257	20	50	89	3	8	33	26	33	38	3
17:30	216	23	34	103	0	9	32	27	39	41	2
17:45	226	21	46	93	1	12	12	14	43	43	3
18:00	197	17	34	85	1	3	66	47	39	36	1
18:15	164	21	47	84	0	2	27	27	38	26	1
18:30	149	22	27	46	1	1	6	11	25	20	0
18:45	142	22	49	54	0	4	12	11	15	17	0
19:00	105	18	33	32	0	0	10	10	13	13	0
19:15	124	19	35	23	1	4	2	2	7	23	0
19:30	95	16	27	26	0	2	6	5	11	11	1
19:45	105	5	18	24	1	2	4	2	18	14	0
20:00	96	8	16	18	0	1	24	17	7	9	0
20:15	101	11	14	18	0	0	5	9	11	15	3
20:30	96	4	16	18	0	0	2	3	6	14	1
20:45	98	17	20	17	0	0	0	0	11	11	0
21:00	90	13	22	13	0	1	13	9	11	6	0
21:15	70	5	14	19	1	2	5	8	11	10	0
21:30	74	9	10	17	0	1	18	12	6	6	0
21:45	69	6	12	15	0	0	19	9	8	6	1
22:00	63	9	13	27	0	3	16	23	5	2	2
22:15	43	4	7	11	1	4	20	14	6	3	0
22:30	40	1	7	4	0	1	45	45	5	6	3
22:45	27	3	4	9	0	0	3	8	4	6	0
23:00	33	4	4	8	0	1	1	1	3	5	0
23:15	30	3	8	3	0	1	1	0	6	1	0
23:30	21	2	3	6	0	1	1	1	4	2	0
23:45	20	3	3	6	1	0	4	4	2	4	0
TOTAL	10212	1580	1430	2417	67	1117	1006	887	1949	3193	75

Note: Loc 3 and Loc 4 - Traffic shift on roadway created erroneous data from 11:00PM on 10/15 to 12:45PM on 10/16

START TIME	EAST ROUNDABOUT COUNT LOCATIONS - TUESDAY, 10/15/02										
	LOC 1	LOC 2	LOC 3	LOC 4	LOC 5	LOC 6	LOC 7	LOC 8	LOC 9	LOC 10	LOC 11
0:00	19	1	3	1	1	1	0	0	1	2	0
0:15	14	0	2	7	0	0	1	1	1	2	2
0:30	16	1	3	1	0	1	1	0	1	4	0
0:45	8	1	3	1	0	1	2	0	2	0	0
1:00	10	3	4	4	0	0	0	2	3	1	0
1:15	8	1	2	5	0	0	0	0	0	2	0
1:30	11	1	1	1	0	0	0	0	5	2	0
1:45	4	1	1	0	0	1	0	0	2	3	0
2:00	6	0	3	0	0	0	1	1	1	3	0
2:15	9	0	3	5	0	0	0	0	0	1	0
2:30	3	0	0	4	0	0	0	0	2	0	0
2:45	5	0	0	0	0	0	0	0	3	1	0
3:00	6	1	0	1	0	0	0	0	1	2	0
3:15	6	0	1	5	0	0	0	0	0	4	0
3:30	2	1	1	9	0	1	0	0	0	6	0
3:45	15	1	3	9	1	0	0	0	1	4	0
4:00	18	0	4	10	0	0	0	0	6	8	0
4:15	31	4	3	12	0	0	0	0	2	15	0
4:30	23	7	12	13	0	3	1	0	5	19	0
4:45	48	11	17	23	1	1	2	2	8	23	4
5:00	106	5	20	27	0	16	0	4	4	30	4
5:15	192	11	19	34	0	25	4	1	7	58	0
5:30	155	28	38	27	1	25	5	6	13	47	3
5:45	233	46	54	58	1	25	5	5	18	79	2
6:00	110	53	92	71	0	36	1	1	23	72	0
6:15	152	78	110	68	0	26	1	1	42	90	2
6:30	121	28	110	72	2	44	3	3	43	78	0
6:45	172	25	57	69	0	55	5	4	40	126	0
7:00	146	28	87	92	4	81	4	4	37	112	3
7:15	174	27	59	81	5	71	6	4	52	144	0
7:30	139	37	96	71	1	79	11	10	45	74	1
7:45	125	46	159	70	3	55	8	8	37	75	5
8:00	106	23	101	61	2	36	3	10	33	61	1
8:15	115	27	84	63	0	13	5	3	37	63	3
8:30	126	27	71	79	1	29	3	5	27	56	1
8:45	127	23	74	53	0	32	5	3	24	57	3
9:00	101	15	51	53	0	47	5	3	33	43	1
9:15	98	33	56	45	2	23	3	4	33	54	0
9:30	102	32	62	48	4	16	5	6	26	40	2
9:45	88	29	77	48	1	7	2	1	31	43	0
10:00	93	26	61	56	1	5	8	4	32	35	0
10:15	82	12	44	53	1	9	5	3	22	47	2
10:30	102	13	44	45	0	6	7	6	20	41	1
10:45	110	12	47	58	0	8	5	4	27	62	0
11:00	109	12	37	63	0	14	9	8	24	38	0
11:15	100	21	36	56	0	11	8	9	30	47	2
11:30	112	23	54	76	0	10	10	9	19	25	0
11:45	138	17	48	60	0	15	5	4	27	44	0
12:00	132	31	50	44	0	28	11	9	19	43	0
12:15	96	24	58	58	1	8	13	10	35	33	0
12:30	113	26	43	44	0	18	3	4	21	34	0
12:45	111	16	58	57	0	7	6	5	19	42	0
13:00	120	32	51	49	0	8	7	6	25	45	1
13:15	119	20	40	63	2	13	10	5	31	41	0
13:30	110	21	50	67	1	6	7	5	21	49	3
13:45	135	19	60	67	0	3	2	3	22	64	0
14:00	148	19	48	89	0	3	5	4	29	52	0
14:15	173	23	72	101	1	5	9	8	43	45	0
14:30	172	15	43	94	1	15	21	18	43	44	0
14:45	181	22	50	69	2	15	18	15	29	47	0
15:00	182	25	64	94	2	23	35	36	22	48	3
15:15	155	21	69	89	3	16	13	13	30	53	0
15:30	220	17	39	85	1	5	28	21	34	47	0
15:45	214	22	56	135	2	4	20	18	32	39	0
16:00	233	24	49	132	0	12	59	47	38	36	0
16:15	224	17	48	102	2	19	34	34	29	51	1
16:30	249	18	46	109	2	38	69	54	32	33	1
16:45	258	24	44	85	3	13	25	37	42	35	1
17:00	254	22	44	92	3	19	34	26	41	32	0
17:15	233	18	42	85	0	11	37	28	44	22	1
17:30	251	23	27	66	0	5	33	21	41	31	0
17:45	222	11	38	73	1	3	30	31	33	30	2
18:00	192	18	27	46	0	6	64	49	34	36	0
18:15	152	20	36	25	0	2	34	37	28	39	3
18:30	157	24	33	21	0	4	10	13	37	28	2
18:45	138	18	39	21	1	3	16	16	32	17	1
19:00	106	16	22	15	0	2	11	7	23	10	0
19:15	108	10	29	27	0	3	6	6	13	15	1
19:30	99	12	13	13	0	2	10	6	8	14	0
19:45	106	8	20	10	0	4	7	8	15	13	0
20:00	82	10	14	32	1	2	26	18	15	13	0
20:15	100	7	15	15	0	1	8	11	8	13	2
20:30	93	14	15	35	0	4	5	4	10	10	0
20:45	89	12	21	22	0	1	5	6	6	12	0
21:00	81	14	25	12	0	1	15	11	9	4	0
21:15	83	12	24	12	0	1	5	7	7	9	0
21:30	64	10	13	9	0	2	13	11	6	6	0
21:45	59	5	16	12	0	1	7	4	4	3	1
22:00	36	7	7	12	0	0	18	13	5	5	0
22:15	37	6	14	8	0	4	15	15	4	7	0
22:30	30	2	10	1	1	3	56	55	9	12	3
22:45	43	5	0	2	0	0	5	10	3	11	0
23:00	36	1			0	0	0	0	8	0	0
23:15	23	3			0	0	0	0	9	1	0
23:30	13	2			0	0	4	2	3	3	2
23:45	22	3			0	0	0	2	3	0	0
TOTAL	10050	1540	3496	4067	62	1171	1018	908	1904	3120	70

Note: Loc 3 and Loc 4 - Traffic shift on roadway created erroneous data from 11:00PM on 10/15 to 12:45PM on 10/16

TRAFFIC RESEARCH & ANALYSIS, INC.
3844 E. INDIAN SCHOOL RD
PHOENIX, AZ 85018
(602) 840-1500 FAX (602) 840-1577

Site Code: 1329525
Latitude: 33' 71287.000 North
Longitude: 112' 12164.000 West
Station ID: 02175
HAPPY VALLEY RD W OF I17 FRONTAGE RD
EB

Start Time	Mon A.M.	03-Mar- P.M.	Tue A.M.	04-Mar- P.M.	Wed A.M.	05-Mar- P.M.	Daily Average A.M.	Daily Average P.M.
12:00	*	*	3	125	13	123	8	124
12:15	*	*	4	110	4	113	4	112
12:30	*	*	5	134	3	136	4	135
12:45	*	*	6	152	8	127	7	140
01:00	*	*	6	140	4	108	5	124
01:15	*	*	2	127	2	113	2	120
01:30	*	*	5	113	2	99	4	106
01:45	*	*	3	107	4	122	4	114
02:00	*	*	2	124	0	95	1	110
02:15	*	*	3	168	2	160	2	164
02:30	*	*	8	167	2	127	5	147
02:45	*	*	6	156	6	138	6	147
03:00	*	*	4	165	8	147	6	156
03:15	*	*	5	137	10	192	8	164
03:30	*	*	11	179	10	169	10	174
03:45	*	*	16	172	13	134	14	153
04:00	*	*	13	126	16	121	14	124
04:15	*	*	25	142	18	120	22	131
04:30	*	*	29	114	44	91	36	102
04:45	*	*	49	141	49	120	49	130
05:00	*	*	71	148	71	143	71	146
05:15	*	*	102	153	106	120	104	136
05:30	*	*	150	160	150	134	150	147
05:45	*	*	181	112	192	136	186	124
06:00	*	*	212	134	225	141	218	138
06:15	*	*	262	119	240	116	251	118
06:30	*	*	333	119	301	108	317	114
06:45	*	*	353	86	362	116	358	101
07:00	*	*	358	82	388	115	373	98
07:15	*	*	372	70	340	75	356	72
07:30	*	*	391	65	366	77	378	71
07:45	*	*	362	52	353	69	358	60
08:00	*	*	315	52	286	101	300	76
08:15	*	*	299	47	289	52	294	50
08:30	*	*	251	50	265	40	258	45
08:45	*	*	226	55	241	38	234	46
09:00	*	*	181	53	181	42	181	48
09:15	*	*	147	38	147	38	147	38
09:30	*	*	153	43	131	39	142	41
09:45	*	*	140	40	118	50	129	45
10:00	*	*	147	31	123	24	135	28
10:15	*	*	127	28	140	25	134	26
10:30	*	*	106	23	114	18	110	20
10:45	*	*	131	14	97	11	114	12
11:00	*	*	116	15	107	13	112	14
11:15	*	*	117	12	109	11	113	12
11:30	*	*	138	10	115	11	126	10
11:45	*	*	111	9	124	6	118	8
Total	0	0	6057	4619	5899	4424	5978	4521
Combined Total	0		10676		10323		10499	
Peak			07:00	02:15	06:45	02:45	06:45	03:00
Volume			1483	656	1456	646	1465	647
P.H.F.			0.948	0.916	0.938	0.841	0.969	0.930
ADT	Not Calculated							

TRAFFIC RESEARCH & ANALYSIS, INC.
3844 E. INDIAN SCHOOL RD
PHOENIX, AZ 85018
(602) 840-1500 FAX (602) 840-1577

Site Code: 1329524A
Latitude: 33' 71443.000 North
Longitude: 112' 11494.000 West
Station ID: 02175
FRONTAGE RD N OF HAPPY VALLEY RD
SB

Start Time	Mon A.M.	03-Mar- P.M.	Tue A.M.	04-Mar- P.M.	Wed A.M.	05-Mar- P.M.	Daily Average A.M.	Daily Average P.M.
12:00	*	*	3	13	2	18	2	16
12:15	*	*	1	8	3	8	2	8
12:30	*	*	2	4	1	13	2	8
12:45	*	*	0	9	0	7	0	8
01:00	*	*	1	11	2	12	2	12
01:15	*	*	1	6	2	7	2	6
01:30	*	*	1	9	0	8	0	8
01:45	*	*	0	5	2	10	1	8
02:00	*	*	0	3	0	6	0	4
02:15	*	*	0	6	0	7	0	6
02:30	*	*	0	10	0	13	0	12
02:45	*	*	0	5	0	9	0	7
03:00	*	*	0	14	0	14	0	14
03:15	*	*	0	10	0	6	0	8
03:30	*	*	0	48	0	64	0	56
03:45	*	*	0	20	0	16	0	18
04:00	*	*	0	65	0	59	0	62
04:15	*	*	1	34	0	33	0	34
04:30	*	*	2	77	0	79	1	78
04:45	*	*	0	19	1	25	0	22
05:00	*	*	0	49	3	54	2	52
05:15	*	*	0	29	0	26	0	28
05:30	*	*	3	32	0	41	2	36
05:45	*	*	2	25	3	14	2	20
06:00	*	*	5	30	2	30	4	30
06:15	*	*	3	12	1	7	2	10
06:30	*	*	2	30	2	32	2	31
06:45	*	*	2	11	6	11	4	11
07:00	*	*	6	71	2	60	4	66
07:15	*	*	4	16	7	22	6	19
07:30	*	*	9	12	6	11	8	12
07:45	*	*	4	3	8	3	6	3
08:00	*	*	4	9	6	12	5	10
08:15	*	*	7	8	6	6	6	7
08:30	*	*	7	5	3	4	5	4
08:45	*	*	6	1	7	2	6	2
09:00	*	*	2	19	2	25	2	22
09:15	*	*	2	7	2	1	2	4
09:30	*	*	5	3	8	1	6	2
09:45	*	*	2	3	5	3	4	3
10:00	*	*	2	16	2	13	2	14
10:15	*	*	6	6	10	9	8	8
10:30	*	*	1	4	7	11	4	8
10:45	*	*	6	6	1	7	4	6
11:00	*	*	4	27	9	21	6	24
11:15	*	*	1	7	7	7	4	7
11:30	*	*	10	29	9	21	10	25
11:45	*	*	14	9	8	5	11	7
Total	0	0	131	855	145	873	139	866
Combined Total	0		986		1018		1005	
Peak			11:00	03:45	11:00	04:00	11:00	04:00
Volume			29	196	33	196	31	196
P.H.F.			0.518	0.636	0.825	0.620	0.705	0.628
ADT	Not Calculated							

TRAFFIC RESEARCH & ANALYSIS, INC.
3844 E. INDIAN SCHOOL RD
PHOENIX, AZ 85018
(602) 840-1500 FAX (602) 840-1577

Site Code: 1329524
Latitude: 33' 71443.000 North
Longitude: 112' 11494.000 West
Station ID: 02175
FRONTAGE RD N OF HAPPY VALLEY RD
NB

Start Time	Mon A.M.	03-Mar- P.M.	Tue A.M.	04-Mar- P.M.	Wed A.M.	05-Mar- P.M.	Daily Average A.M.	Daily Average P.M.
12:00	*	*	1	15	2	18	2	16
12:15	*	*	1	11	0	17	0	14
12:30	*	*	0	14	1	11	0	12
12:45	*	*	0	6	0	14	0	10
01:00	*	*	1	5	2	7	2	6
01:15	*	*	1	11	0	7	0	9
01:30	*	*	0	9	0	12	0	10
01:45	*	*	0	7	1	13	0	10
02:00	*	*	0	2	0	11	0	6
02:15	*	*	0	5	0	7	0	6
02:30	*	*	0	9	0	7	0	8
02:45	*	*	0	11	0	6	0	8
03:00	*	*	0	3	0	12	0	8
03:15	*	*	0	5	0	2	0	4
03:30	*	*	0	8	0	3	0	6
03:45	*	*	1	6	0	5	0	6
04:00	*	*	0	2	0	4	0	3
04:15	*	*	0	10	0	10	0	10
04:30	*	*	1	7	2	3	2	5
04:45	*	*	1	7	0	3	0	5
05:00	*	*	0	4	0	3	0	4
05:15	*	*	3	6	2	10	2	8
05:30	*	*	7	23	4	33	6	28
05:45	*	*	8	35	16	33	12	34
06:00	*	*	17	12	21	11	19	12
06:15	*	*	35	16	29	13	32	14
06:30	*	*	35	12	32	13	34	12
06:45	*	*	78	13	66	10	72	12
07:00	*	*	49	2	51	6	50	4
07:15	*	*	73	9	71	7	72	8
07:30	*	*	65	1	56	0	56	0
07:45	*	*	95	0	93	1	94	0
08:00	*	*	50	1	31	2	40	2
08:15	*	*	53	2	61	2	57	2
08:30	*	*	30	0	26	1	28	0
08:45	*	*	39	2	48	0	44	1
09:00	*	*	21	0	21	0	21	0
09:15	*	*	28	2	36	1	32	2
09:30	*	*	19	1	19	0	19	0
09:45	*	*	23	0	20	2	22	1
10:00	*	*	21	1	18	2	20	2
10:15	*	*	25	1	26	0	26	0
10:30	*	*	7	1	12	1	10	1
10:45	*	*	8	0	7	1	8	0
11:00	*	*	8	2	11	1	10	2
11:15	*	*	10	1	9	0	10	0
11:30	*	*	7	0	11	0	9	0
11:45	*	*	14	0	10	0	12	0
Total	0	0	825	300	815	325	823	311
Combined Total	0		1125		1140		1134	
Peak			07:15	05:30	07:00	05:30	07:00	05:30
Volume			273	86	271	90	272	88
P.H.F.			0.718	0.614	0.728	0.682	0.723	0.647
ADT	Not Calculated							

TRAFFIC RESEARCH & ANALYSIS, INC.
3844 E. INDIAN SCHOOL RD
PHOENIX, AZ 85018
(602) 840-1500 FAX (602) 840-1577

Site Code: 1329523
Latitude: 33' 71154.000 North
Longitude: 112' 11519.000 West
Station ID: 02175
I17 & HAPPY VALLEY RD (NB) OFF RAMP
NB

Start Time	Mon 03-Mar- A.M.	P.M.	Tue 04-Mar- A.M.	P.M.	Wed 05-Mar- A.M.	P.M.	Daily Average A.M.	P.M.
12:00	*	*	7	105	17	121	12	113
12:15	*	*	13	142	24	153	18	148
12:30	*	*	13	130	20	128	16	129
12:45	*	*	16	134	16	131	16	132
01:00	*	*	10	132	20	128	15	130
01:15	*	*	9	115	18	118	14	116
01:30	*	*	6	104	14	114	10	109
01:45	*	*	7	123	15	128	11	126
02:00	*	*	8	121	11	116	10	118
02:15	*	*	5	161	6	140	6	150
02:30	*	*	8	156	10	160	9	158
02:45	*	*	5	171	9	164	7	168
03:00	*	*	3	153	2	170	2	162
03:15	*	*	6	192	11	177	8	184
03:30	*	*	5	191	4	193	4	192
03:45	*	*	12	184	11	190	12	187
04:00	*	*	11	195	2	211	6	203
04:15	*	*	11	218	12	193	12	206
04:30	*	*	9	198	16	215	12	206
04:45	*	*	13	228	18	216	16	222
05:00	*	*	18	268	14	270	16	269
05:15	*	*	28	261	40	244	34	252
05:30	*	*	44	261	37	258	40	260
05:45	*	*	73	263	74	281	74	272
06:00	*	*	116	220	104	238	110	229
06:15	*	*	216	222	186	220	201	221
06:30	*	*	216	221	155	193	186	207
06:45	*	*	258	193	217	178	238	186
07:00	*	*	165	161	168	125	166	143
07:15	*	*	152	156	184	158	168	157
07:30	*	*	174	120	176	128	175	124
07:45	*	*	205	122	203	87	204	104
08:00	*	*	158	87	122	123	140	105
08:15	*	*	156	108	155	101	156	104
08:30	*	*	102	94	96	112	99	103
08:45	*	*	130	95	122	130	126	112
09:00	*	*	110	100	86	132	98	116
09:15	*	*	117	124	115	105	116	114
09:30	*	*	101	101	118	111	110	106
09:45	*	*	135	75	118	113	126	94
10:00	*	*	83	76	86	79	84	78
10:15	*	*	120	78	109	74	114	76
10:30	*	*	93	59	103	50	98	54
10:45	*	*	94	47	111	50	102	48
11:00	*	*	105	35	127	51	116	43
11:15	*	*	133	40	118	33	126	36
11:30	*	*	111	28	118	26	114	27
11:45	*	*	120	27	121	27	120	27
Total	0	0	3710	6795	3639	6863	3673	6826
Combined Total	0		10505		10502		10499	
Peak			06:15	05:00	06:45	05:00	06:15	05:00
Volume			855	1053	745	1053	791	1053
P.H.F.			0.828	0.982	0.858	0.937	0.831	0.968
ADT	Not Calculated							

TRAFFIC RESEARCH & ANALYSIS, INC.
3844 E. INDIAN SCHOOL RD
PHOENIX, AZ 85018
(602) 840-1500 FAX (602) 840-1577

Site Code: 1329522
Latitude: 33' 71294.000 North
Longitude: 112' 11153.000 West
Station ID: 02175
HAPPY VALLEY RD E OF I17 FRONTAGE RD
WB

Start Time	Mon A.M.	03-Mar- P.M.	Tue A.M.	04-Mar- P.M.	Wed A.M.	05-Mar- P.M.	Daily Average A.M.	Daily Average P.M.
12:00	*	*	2	71	4	86	3	78
12:15	*	*	1	74	6	62	4	68
12:30	*	*	3	73	6	65	4	69
12:45	*	*	5	62	0	79	2	70
01:00	*	*	3	78	0	88	2	83
01:15	*	*	2	66	3	85	2	76
01:30	*	*	0	81	0	77	0	79
01:45	*	*	1	69	1	69	1	69
02:00	*	*	1	71	0	82	0	76
02:15	*	*	4	74	4	57	4	66
02:30	*	*	1	96	1	90	1	93
02:45	*	*	1	78	1	63	1	70
03:00	*	*	1	88	0	104	0	96
03:15	*	*	2	118	1	107	2	112
03:30	*	*	4	163	4	147	4	155
03:45	*	*	2	87	1	94	2	90
04:00	*	*	2	138	3	114	2	126
04:15	*	*	0	158	1	135	0	146
04:30	*	*	10	139	3	146	6	142
04:45	*	*	1	101	5	112	3	106
05:00	*	*	11	155	8	139	10	147
05:15	*	*	16	144	19	134	18	139
05:30	*	*	26	104	21	134	24	119
05:45	*	*	37	117	25	114	31	116
06:00	*	*	22	114	26	79	24	96
06:15	*	*	38	65	39	71	38	68
06:30	*	*	57	67	45	71	51	69
06:45	*	*	69	41	56	55	62	48
07:00	*	*	61	61	61	46	61	54
07:15	*	*	88	36	81	48	84	42
07:30	*	*	95	39	91	30	93	34
07:45	*	*	89	26	77	32	83	29
08:00	*	*	68	22	81	26	74	24
08:15	*	*	90	27	63	37	76	32
08:30	*	*	72	24	76	18	74	21
08:45	*	*	67	29	76	23	72	26
09:00	*	*	82	32	67	23	74	28
09:15	*	*	70	20	62	20	66	20
09:30	*	*	72	12	77	20	74	16
09:45	*	*	75	15	69	15	72	15
10:00	*	*	52	13	60	24	56	18
10:15	*	*	64	11	77	15	70	13
10:30	*	*	63	6	58	11	60	8
10:45	*	*	72	8	73	4	72	6
11:00	*	*	61	3	72	6	66	4
11:15	*	*	84	3	70	6	77	4
11:30	*	*	80	10	72	8	76	9
11:45	*	*	58	3	74	2	66	2
Total	0	0	1785	3092	1720	3073	1747	3077
Combined Total	0		4877		4793		4824	
Peak			07:30	04:15	07:15	04:15	07:15	04:15
Volume			342	553	330	532	334	541
P.H.F.			0.900	0.848	0.907	0.905	0.898	0.873
ADT	Not Calculated							

TRAFFIC RESEARCH & ANALYSIS, INC.
3844 E. INDIAN SCHOOL RD
PHOENIX, AZ 85018
(602) 840-1500 FAX (602) 840-1577

Site Code: 1329521R
Latitude: 33' 71286.000 North
Longitude: 112' 11645.000 West
Station ID: 02175
HAPPY VALLEY RD E OF I17
EB

Start Time	Tue A.M.	11-Mar- P.M.	Wed A.M.	12-Mar- P.M.	Thu A.M.	13-Mar- P.M.	Daily Average A.M.	Daily Average P.M.
12:00	*	37	2	44	*	*	2	40
12:15	*	47	0	36	*	*	0	42
12:30	*	61	1	50	*	*	1	56
12:45	*	55	0	45	*	*	0	50
01:00	*	38	0	50	*	*	0	44
01:15	*	54	3	56	*	*	3	55
01:30	*	48	0	*	*	*	0	48
01:45	*	56	0	*	*	*	0	56
02:00	*	48	4	*	*	*	4	48
02:15	*	73	3	*	*	*	3	73
02:30	*	63	3	*	*	*	3	63
02:45	*	67	4	*	*	*	4	67
03:00	*	46	1	*	*	*	1	46
03:15	*	46	4	*	*	*	4	46
03:30	*	56	2	*	*	*	2	56
03:45	*	44	2	*	*	*	2	44
04:00	*	55	4	*	*	*	4	55
04:15	*	55	10	*	*	*	10	55
04:30	*	57	13	*	*	*	13	57
04:45	*	31	12	*	*	*	12	31
05:00	*	35	10	*	*	*	10	35
05:15	*	47	20	*	*	*	20	47
05:30	*	53	40	*	*	*	40	53
05:45	*	57	58	*	*	*	58	57
06:00	*	41	43	*	*	*	43	41
06:15	*	31	77	*	*	*	77	31
06:30	*	37	108	*	*	*	108	37
06:45	*	35	142	*	*	*	142	35
07:00	*	24	117	*	*	*	117	24
07:15	*	18	136	*	*	*	136	18
07:30	*	12	171	*	*	*	171	12
07:45	*	19	179	*	*	*	179	19
08:00	*	13	117	*	*	*	117	13
08:15	*	15	126	*	*	*	126	15
08:30	*	13	83	*	*	*	83	13
08:45	*	18	93	*	*	*	93	18
09:00	*	26	64	*	*	*	64	26
09:15	*	16	66	*	*	*	66	16
09:30	*	18	50	*	*	*	50	18
09:45	*	21	67	*	*	*	67	21
10:00	54	7	43	*	*	*	48	7
10:15	48	5	67	*	*	*	58	5
10:30	45	6	52	*	*	*	48	6
10:45	48	7	54	*	*	*	51	7
11:00	31	3	45	*	*	*	38	3
11:15	43	7	34	*	*	*	38	7
11:30	45	3	39	*	*	*	42	3
11:45	57	3	55	*	*	*	56	3
Total	371	1627	2224	281	0	0	2214	1622
Combined Total	1998		2505		0		3836	
Peak	10:00	02:00	07:00	00:30			07:00	02:00
Volume	195	251	603	201			603	251
P.H.F.	0.855	0.860	0.842	0.897			0.842	0.860
ADT	Not Calculated							

TRAFFIC RESEARCH & ANALYSIS, INC.
3844 E. INDIAN SCHOOL RD
PHOENIX, AZ 85018
(602) 840-1500 FAX (602) 840-1577

Site Code: 1329528A
Latitude: 33' 71434.000 North
Longitude: 112' 12020.000 West
Station ID: 02175
FRONTAGE RD N OF HAPPY VALLEY RD
SB

Start Time	Mon A.M.	03-Mar- P.M.	Tue A.M.	04-Mar- P.M.	Wed A.M.	05-Mar- P.M.	Daily Average A.M.	Daily Average P.M.
12:00	*	*	1	40	3	44	2	42
12:15	*	*	5	49	4	42	4	46
12:30	*	*	4	40	1	42	2	41
12:45	*	*	3	35	4	46	4	40
01:00	*	*	1	40	3	37	2	38
01:15	*	*	0	50	3	39	2	44
01:30	*	*	2	49	2	32	2	40
01:45	*	*	0	39	0	42	0	40
02:00	*	*	1	27	0	56	0	42
02:15	*	*	0	43	2	45	1	44
02:30	*	*	1	37	0	44	0	40
02:45	*	*	3	46	3	48	3	47
03:00	*	*	2	36	2	44	2	40
03:15	*	*	3	49	4	53	4	51
03:30	*	*	3	53	4	42	4	48
03:45	*	*	5	49	4	42	4	46
04:00	*	*	4	61	7	46	6	48
04:15	*	*	7	32	3	52	5	42
04:30	*	*	11	39	13	36	12	38
04:45	*	*	13	52	13	43	13	48
05:00	*	*	11	44	7	40	9	42
05:15	*	*	21	40	24	36	22	38
05:30	*	*	36	47	37	43	36	45
05:45	*	*	45	32	53	40	49	36
06:00	*	*	57	46	46	44	52	45
06:15	*	*	62	36	69	51	66	44
06:30	*	*	55	50	64	36	60	43
06:45	*	*	71	31	72	46	72	38
07:00	*	*	88	41	77	48	82	44
07:15	*	*	112	28	104	23	108	26
07:30	*	*	95	19	122	24	108	22
07:45	*	*	92	25	75	30	84	28
08:00	*	*	86	17	79	33	82	25
08:15	*	*	68	24	78	25	73	24
08:30	*	*	83	20	82	15	82	18
08:45	*	*	52	22	60	13	56	18
09:00	*	*	62	17	48	19	55	18
09:15	*	*	44	15	45	14	44	14
09:30	*	*	45	18	48	14	46	16
09:45	*	*	51	17	50	10	50	14
10:00	*	*	37	9	29	9	33	9
10:15	*	*	44	9	46	9	45	9
10:30	*	*	44	9	46	11	45	10
10:45	*	*	45	7	45	4	45	6
11:00	*	*	43	3	45	8	44	6
11:15	*	*	33	10	50	9	42	10
11:30	*	*	59	7	45	4	52	6
11:45	*	*	57	3	42	4	50	4
Total	0	0	1667	1502	1663	1537	1664	1523
Combined Total	0		3169		3200		3187	
Peak			07:00	03:15	07:15	02:00	07:00	03:15
Volume			387	202	380	193	382	193
P.H.F.			0.864	0.953	0.779	0.862	0.884	0.946
ADT	Not Calculated							

TRAFFIC RESEARCH & ANALYSIS, INC.
3844 E. INDIAN SCHOOL RD
PHOENIX, AZ 85018
(602) 840-1500 FAX (602) 840-1577

Site Code: 1329528
Latitude: 33' 71434.000 North
Longitude: 112' 12020.000 West
Station ID: 02175
FRONTAGE RD N OF HAPPY VALLEY RD
NB

Start Time	Mon 03-Mar- A.M.	P.M.	Tue 04-Mar- A.M.	P.M.	Wed 05-Mar- A.M.	P.M.	Daily Average A.M.	P.M.
12:00	*	*	5	41	8	37	6	39
12:15	*	*	4	41	5	48	4	44
12:30	*	*	6	42	7	55	6	48
12:45	*	*	4	58	4	47	4	52
01:00	*	*	0	41	8	47	4	44
01:15	*	*	6	45	6	37	6	41
01:30	*	*	2	36	3	33	2	34
01:45	*	*	2	29	3	46	2	38
02:00	*	*	2	49	3	35	2	42
02:15	*	*	2	41	2	50	2	46
02:30	*	*	3	52	4	56	4	54
02:45	*	*	2	51	1	37	2	44
03:00	*	*	1	41	2	53	2	47
03:15	*	*	2	64	2	56	2	60
03:30	*	*	3	74	1	73	2	74
03:45	*	*	3	59	0	71	2	65
04:00	*	*	1	64	0	63	0	64
04:15	*	*	1	67	2	61	2	64
04:30	*	*	3	65	1	68	2	66
04:45	*	*	0	67	1	75	0	71
05:00	*	*	4	101	1	89	2	95
05:15	*	*	4	72	9	81	6	76
05:30	*	*	6	93	5	84	6	88
05:45	*	*	9	73	11	72	10	72
06:00	*	*	10	75	11	87	10	81
06:15	*	*	20	81	15	72	18	76
06:30	*	*	20	72	28	57	24	64
06:45	*	*	42	57	27	54	34	56
07:00	*	*	32	55	36	63	34	59
07:15	*	*	25	64	27	58	26	61
07:30	*	*	39	67	34	54	36	60
07:45	*	*	34	40	45	39	40	40
08:00	*	*	41	37	42	45	42	41
08:15	*	*	32	42	32	36	32	39
08:30	*	*	45	46	32	33	38	40
08:45	*	*	30	45	32	39	31	42
09:00	*	*	37	37	35	59	36	48
09:15	*	*	31	41	40	46	36	44
09:30	*	*	26	24	27	46	26	35
09:45	*	*	39	30	29	40	34	35
10:00	*	*	30	20	20	17	25	18
10:15	*	*	28	34	37	20	32	27
10:30	*	*	32	13	36	20	34	16
10:45	*	*	39	15	24	11	32	13
11:00	*	*	35	9	38	18	36	14
11:15	*	*	40	11	43	15	42	13
11:30	*	*	37	9	36	11	36	10
11:45	*	*	31	11	51	12	41	12
Total	0	0	850	2301	866	2326	855	2312
Combined Total	0		3151		3192		3167	
Peak			07:45	05:00	11:00	04:45	11:00	05:00
Volume			152	339	168	329	155	331
P.H.F.			0.844	0.839	0.824	0.924	0.923	0.871
ADT	Not Calculated							

TRAFFIC RESEARCH & ANALYSIS, INC.
3844 E. INDIAN SCHOOL RD
PHOENIX, AZ 85018
(602) 840-1500 FAX (602) 840-1577

Site Code: 1329527
Latitude: 33' 71466.000 North
Longitude: 112' 11965.000 West
Station ID: 02175
I17 & HAPPY VALLEY RD (SB) OFF RAMP
SB

Start Time	Mon A.M.	03-Mar- P.M.	Tue A.M.	04-Mar- P.M.	Wed A.M.	05-Mar- P.M.	Daily Average A.M.	Daily Average P.M.
12:00	*	*	1	30	1	33	1	32
12:15	*	*	2	27	1	40	2	34
12:30	*	*	2	43	0	35	1	39
12:45	*	*	2	29	1	34	2	32
01:00	*	*	2	28	2	26	2	27
01:15	*	*	0	36	1	40	0	38
01:30	*	*	2	31	1	28	2	30
01:45	*	*	1	36	0	34	0	35
02:00	*	*	0	42	0	37	0	40
02:15	*	*	0	26	0	53	0	40
02:30	*	*	7	32	4	34	6	33
02:45	*	*	1	36	0	31	0	34
03:00	*	*	2	32	1	42	2	37
03:15	*	*	5	39	1	33	3	36
03:30	*	*	0	31	2	45	1	38
03:45	*	*	1	53	1	53	1	53
04:00	*	*	7	49	2	36	4	42
04:15	*	*	2	26	6	31	4	28
04:30	*	*	9	35	3	34	6	34
04:45	*	*	5	26	7	41	6	34
05:00	*	*	6	32	5	21	6	26
05:15	*	*	9	33	10	49	10	41
05:30	*	*	14	26	10	30	12	28
05:45	*	*	19	31	19	25	19	28
06:00	*	*	14	29	18	30	16	30
06:15	*	*	27	24	27	27	27	26
06:30	*	*	32	24	34	26	33	25
06:45	*	*	68	18	60	23	59	20
07:00	*	*	52	15	49	18	50	16
07:15	*	*	71	12	77	19	74	16
07:30	*	*	63	14	67	12	65	13
07:45	*	*	53	8	60	17	56	12
08:00	*	*	55	8	42	11	48	10
08:15	*	*	42	10	39	16	40	13
08:30	*	*	47	4	39	10	43	7
08:45	*	*	44	6	52	10	48	8
09:00	*	*	30	8	28	6	29	7
09:15	*	*	34	12	35	12	34	12
09:30	*	*	24	10	23	14	24	12
09:45	*	*	41	7	24	7	32	7
10:00	*	*	37	5	29	5	33	5
10:15	*	*	47	4	39	10	43	7
10:30	*	*	39	6	31	4	35	5
10:45	*	*	25	0	31	4	28	2
11:00	*	*	25	5	24	2	24	4
11:15	*	*	28	2	36	1	32	2
11:30	*	*	44	1	33	4	38	2
11:45	*	*	26	1	31	0	28	0
Total	0	0	1057	1042	1006	1153	1029	1100
Combined Total	0		2099		2159		2129	
Peak			06:45	03:15	06:45	03:00	06:45	03:15
Volume			244	172	253	173	248	169
P.H.F.			0.859	0.811	0.821	0.816	0.838	0.797
ADT	Not Calculated							

TRAFFIC RESEARCH & ANALYSIS, INC.
3844 E. INDIAN SCHOOL RD
PHOENIX, AZ 85018
(602) 840-1500 FAX (602) 840-1577

Site Code: 1329526
Latitude: 33' 71298.000 North
Longitude: 112' 11838.000 West
Station ID: 02175
HAPPY VALLEY RD W OF I17
WB

Start Time	Mon A.M.	03-Mar- P.M.	Tue A.M.	04-Mar- P.M.	Wed A.M.	05-Mar- P.M.	Daily Average A.M.	Daily Average P.M.
12:00	*	*	9	153	24	162	16	158
12:15	*	*	12	162	28	160	20	161
12:30	*	*	16	158	18	159	17	158
12:45	*	*	17	159	19	161	18	160
01:00	*	*	10	171	16	160	13	166
01:15	*	*	11	146	20	171	16	158
01:30	*	*	7	168	14	155	10	162
01:45	*	*	6	159	14	153	10	156
02:00	*	*	7	175	7	149	7	162
02:15	*	*	10	197	5	171	8	184
02:30	*	*	7	216	11	204	9	210
02:45	*	*	8	207	6	193	7	200
03:00	*	*	2	199	6	235	4	217
03:15	*	*	5	266	9	241	7	254
03:30	*	*	6	367	5	398	6	382
03:45	*	*	8	254	10	267	9	260
04:00	*	*	12	324	6	323	9	324
04:15	*	*	4	392	15	323	10	358
04:30	*	*	22	376	14	369	18	372
04:45	*	*	10	315	17	324	14	320
05:00	*	*	26	396	24	371	25	384
05:15	*	*	23	378	41	347	32	362
05:30	*	*	63	345	35	371	49	358
05:45	*	*	61	351	64	342	62	346
06:00	*	*	88	307	81	290	84	298
06:15	*	*	121	255	121	245	121	250
06:30	*	*	154	264	101	256	128	260
06:45	*	*	166	207	144	208	155	208
07:00	*	*	129	246	135	195	132	220
07:15	*	*	125	170	154	202	140	186
07:30	*	*	191	147	183	138	187	142
07:45	*	*	145	136	164	96	154	116
08:00	*	*	157	100	151	133	154	116
08:15	*	*	151	121	123	136	137	128
08:30	*	*	131	108	121	116	126	112
08:45	*	*	131	114	135	124	133	119
09:00	*	*	126	128	106	164	116	146
09:15	*	*	122	135	99	103	110	119
09:30	*	*	139	106	135	116	137	111
09:45	*	*	154	78	136	119	145	98
10:00	*	*	93	83	95	95	94	89
10:15	*	*	116	92	123	89	120	90
10:30	*	*	150	58	139	60	144	59
10:45	*	*	126	51	130	50	128	50
11:00	*	*	127	52	177	71	152	62
11:15	*	*	169	37	141	42	155	40
11:30	*	*	160	57	138	47	149	52
11:45	*	*	154	36	158	33	156	34
Total	0	0	3687	9122	3618	9037	3653	9077
Combined Total	0		12809		12655		12730	
Peak			07:30	04:15	07:15	05:00	07:15	05:00
Volume			644	1479	652	1431	635	1450
P.H.F.			0.843	0.934	0.891	0.899	0.849	0.944
ADT	Not Calculated							

APPENDIX C
On-Site Vehicle Observation Comments

I-17 HAPPY VALLEY INTERCHANGE RESEARCH

OBSERVATIONS & ERRATIC MANUEVERS – EAST & WEST INTERCHANGE

10/15/02 – 7:00AM to 9:00AM and 4:00 PM to 6:00PM

AM PERIOD

1. Construction on Happy Valley Road (HV) is taking place east of the easterly circle. HV in this area is being widened from 1 lane to two lanes in both directions. Widening and curb work is complete. Although traffic markers are shifting eastbound traffic around work locations, it does not look to be affecting the flow or volume of traffic. Westbound traffic is not being shifted, but the adjacent lane markers may be reducing typical speeds. Improvement to the adjacent intersection (23rd Ave?) toward the east is part of the construction process where a traffic signal installation looks to be taking place.
2. It was identified that the vacant lot in the southeast quadrant of the east circle is planned for development. Also, the USAA building is looking to expand/build new facilities adjacent to their existing property in the northeast quadrant.
3. Two lanes are striped entering the circle at each approach, but the rotary is not striped for 2 lanes. As designed, it is not wide enough for two lanes. Most drivers are aware of this situation and stagger their entrance into the circle.
4. At the east circle, one driver turned onto the frontage road, made a u-turn beyond the concrete median divider, then utilized the frontage road slip ramp to access the I-17 NB on-ramp.
5. At the east circle, westbound HV approach, a heavy truck (empty) locked up its brakes, skidding approximately 100 feet before coming to a stop before the yield bar. No vehicle was in front of him.
6. The west circle had more volume than the east circle in the AM, although total traffic was light. The heaviest movement was from HV EB to I-17 SB. Vehicle queues were minor.
7. There is a high proportion of truck volume at the circles. It is assumed that this is due the amount of new home construction in the area and the landfill located at the northwest quadrant of the westerly circle.
8. From the field enumerators, a small number of vehicles were observed to use the circle to make a right turn, and not utilizing the right turn bypass lane (NB I-17 off-ramp to EB HV).

PM PERIOD

1. From the field enumerators, a 20-vehicle queue was observed at the WB HV approach to the east circle. This occurred for only a short period of time. I observed only minor vehicle queue lengths at all approaches. With additional traffic at the circle, it may be difficult for frontage road traffic to enter the circle, given the near continuous flow of vehicles from either the I-17 NB off-ramp or EB HV movements.
2. The predominant traffic movement in the PM at the east circle is from I-17 NB to HV WB, at the west circle is it from WB HV to WB HV.
3. An elderly man was observed trying to access the west circle from the I-17 SB off-ramp. At the yield bar, proceeded to turn left, clockwise, to access EB HV.

4. Same elderly man was observed in the gore area of the WB HV approach at the east circle. He proceeded to enter the circle and exit onto the I-17 NB on-ramp. Realizing he did not want to do this, made a u-turn and traveled back up the ramp to the circle again. Vehicles within the circle stopped to allow him to make a turn toward the west circle without incident.
5. Sun glare for westbound traffic make reading signs somewhat difficult. Not sure if this condition is true for eastbound drivers in the AM.
6. Some minor vehicle queues were observed at the west circle at the I-17 off-ramp and the frontage road approach (six vehicles, volume from these approaches are light). This is due to a nearly continuous flow of vehicles traveling westbound from the east circle and continuing west or heading to I-17 SB.
7. Even though traffic was nearly continuous, operations were very efficient with only minor traffic queues at the approaches. The use of the right-turn bypass lanes works well.
8. Vehicles that use the right lane at the approaches must wait for the vehicle in the left lane to enter the circle first before entering.
9. Field observers identified that some (1 or 2) vehicles traveled around the circle more than 360 degrees before exiting.

I-17 HAPPY VALLEY INTERCHANGE RESEARCH

OBSERVATIONS & ERRATIC MANUEVERS – WEST INTERCHANGE

11/20/02 – 2:00PM to 5:30PM

Observations:

1. Within the circle, vehicles constantly travel over the inside yellow edge line. This can be further verified by the paint obliterated by tire marks.
2. Large trucks will occasionally put some axles/tires on the roll curb or into the infield to complete their movements.
3. When other vehicles are not present, trucks tend to utilize both approach lanes when entering the circle.
4. Occasionally, truck approach speed from the west, seems to be faster than the 20 mph warning signs indicate. This could be due the grade difference between the bridge and the circle, requiring trucks to accelerate up and over the I-17 bridge. Now in the downgrade section, trucks don't decelerate fast enough or they coast into the approach having better visibility than the average motorists. These trucks are probably empty and there was no observance of trucks locking their brakes.
5. Motorists exiting the circle at first exit location will use the outside approach lane, especially in heavier traffic volume conditions. In lighter volume cases, drivers tend to follow the vehicle in front of them, using either approach lane.
6. Heavy/large trucks tend to use the inside lane for all movements.
7. WB approach vehicles will utilize both approach lanes to enter circle, usually entering in a staggered fashion. If both drivers are comfortable, they will travel 2 abreast, with the outside vehicle exiting at the first exit location. This was mostly observed at the higher volume WB approach, but also observed at the I-17 off ramp approach.
8. Some vehicles tend to come to a complete stop at the yield bar, even if no traffic is present.
9. Two bicyclists (2 observances) were viewed using the roundabout, both used the outside portion of the pavement to complete their movements without incident.
10. Two vehicles from SB Frontage to WBHV were waiting (30+ seconds) to complete their turns. Vehicles couldn't find an acceptable gap in the continuous traffic stream, but entered regardless. Vehicles exiting from circle had to slow to allow the vehicles to enter.
11. Around 4:30P, there was approximately 20 to 25 vehicles per minute entering from WBHB (estimate that 26 vehicles per minute would be continuous flow for one lane). Vehicle queues observed at this time were minimal at the other approaches. A maximum of 7 vehicles at SB Frontage Road and SB I-17 off ramp approaches were observed.
12. Pavement width allows for only one truck to utilize circle at a time, no side by side movement.

Erratic Maneuvers:

1. Vehicle in circle came to a complete stop to allow vehicles waiting at EBHV approach to enter.
2. Truck in the inside lane of the two lane WBHV approach stopped at the yield bar, vehicle in the outside lane did not stop. Collision with vehicle in circle nearly occurred.
3. Older motorist tried to make a turn from WBHV onto the SB I-17 off ramp. Luckily, vehicles in the other approach lane flagged and stopped him. Vehicle backed up into circle and turned onto the NB Frontage Road without incident.
4. Older motorist from SB Frontage, turned left into circle, and traveled in the opposite direction to head EB on HV. Vehicles in circle stopped/slowed to allow motorists to accomplish movement without incident.
5. Vehicle from EBHV slip ramp to NB I-17 did not yield to traffic exiting circle. Vehicle from circle honked horn, applied brakes, and traveled on shoulder to get around vehicle which had slowed.
6. As large (heavy) truck entered the circle, car from behind passed truck on the infield. The entire vehicle was on the infield to pass truck.
7. Vehicle stopped in the circle for a few seconds, confused on which direction they had to go. Vehicles behind also stopped, one honking horn.
8. Two vehicles, appearing to be traveling faster than 20 mph, entered the circle from the WBHV approach. Traveling 2 abreast in circle, both exited toward WBHV. Outside vehicle slowed, one vehicle sounded horn, both vehicles accelerated quickly. Striping allows for two vehicles to exit at same time, but pavement soon narrows to one lane.

I-17 HAPPY VALLEY INTERCHANGE RESEARCH

OBSERVATIONS & ERRATIC MANUEVERS – WEST INTERCHANGE

12/11/02 - 1:30PM to 5:30PM

<u>Observations West Roundabout:</u>

1. At 1:56P. Two vehicles at EBHV approach, a truck at the inside position. Outside vehicle line of sight is blocked. Must wait until trucks enters circle to move.
2. At 2:52P. From the EBHV approach, two vehicles to circle at the same time. Inside vehicle had to brake to avoid sideswipe when both vehicles reached narrow portion of circulatory roadway.
3. At 3:16P. SB off ramp and the SB frontage road approach, both entered circle anticipating the same gap.
4. At 3:17P. At the SB I-17 merge point. Ramp vehicle failed to yield to circulatory vehicle.
5. At 3:19P. Truck is on the infield, don't know how or why.
6. At 3:39P. WBHV exit leg, 2 vehicles exit at same time. Outside vehicle must slow to allow inside vehicle to continue since exit is striped for 2 lanes, but quickly necks down to one lane (only 2 pavement marking stripes, approx 50 feet).
7. At 3:40P and other times. SB Frontage Road. Cars typically use only outside approach lane, but will use the inside lane when first vehicle does not take a perceived acceptable gap, increasing drivers in queue to become frustrated. Vehicle from back will utilize inside lane, blocking outside lanes vision, requiring the inside vehicle to enter first before outside driver can move, further perpetuating delays/frustration.
8. At 3:46P Near collision, SB Frontage to I-17 vs. I-17-off to WBHV.
9. Maximum queue at SB Frontage Road = 6 vehicles. EBHV = 4 vehicles.
10. At 4:00P EBHV right onto SB I-17 on-ramp did not use slip ramp.
11. At 4:01P EBHV right onto SB I-17 on-ramp did not use slip ramp.
12. At 4:08P WB circulating vehicle stopped in road to allow SB I-17 off-ramp truck to enter.
13. At 4:26P. On circulatory roadway, Valley Metro bus had to yield to EBHV who proceeded in front.
14. At 4:34P At the I-17 SB slip ramp merge point, near collision, vehicle honking horn.
15. At 4:50P. Vehicle at frontage road approach pulled into circulatory road in front of a vehicle that entered from the off-ramp. Ramp vehicle had to stop.
16. At 4:52P Silver truck with trailer at the SB Frontage Road entering circulatory road nearly clipped by circulatory road vehicle headed towards Frontage Road.
17. At 4:45P. Vehicle from WBHV entered circle without yielding while a vehicle was in roadway. Vehicle from WBHV slowed to allow inside vehicle to exit towards frontage road.
18. At 5:03P. Motorcycle entering busy circulatory roadway without yielding.

19. At 5:17P. White pick-up stopped at the WBHV exit area knowing he went too far to make turn. Proceeded to back-up, thought better of it, then continued forward around circle to exit correctly.
20. At 5:23P. Vehicle stopped at the WBHV approach for no reason.

Erratic Maneuvers at West Roundabout:

1. At 1:53P. Two vehicles from WBHV approach entered roundabout at same time. Inside vehicle made right turn toward WBHV in front of outside vehicle traveling towards SB I-17 ramp.
2. At 2:05P. From the WBHV approach, a truck and two vehicles enter the circle and exit toward WBHV. Both vehicles behind truck pass on the left in the center two-way left turn lane.
3. At 2:43P. Truck turns from roundabout the wrong way onto the SB I-17 off-ramp. Driver makes u-turn and then proceeds to travel onto the I-17 SB on-ramp.
4. At 2:53P. From the NB Frontage Road approach, a truck enters the circle from the outside position. A car from the inside position, goes through yield sign and enters circle, trying to pass truck. Car must stop within the circle to avoid being sideswiped by truck completing his movement around circle.
5. At 3:11P. At the I-17 SB on-ramp merge point, slip ramp vehicle did not yield to oncoming circulatory vehicles. Ramp vehicle uses shoulder to avoid collision (believed to have occurred off-camera).
6. At 4:15P WBHV exit, vehicle passed using the two-way center left turn lane.

I-17 / HAPPY VALLEY INTERCHANGE RESEARCH

OBSERVATIONS & ERRATIC MANEUVERS –WEST INTERCHANGE

12/12/02 - 7:20AM to 8:30AM

Observations West Roundabout:

1. Yield sign knocked down on Tuesday not reinstalled.
2. At 7:46A. Four vehicles enter circle from the EBHV approach, 3 from inside lane, 1 outside lane. The outside vehicle had to stop to allow the 1st, 2nd and 3rd vehicle to continue circulatory movement.
3. At 7:52A. EBHV truck stopped beyond yield bar. Vehicles in the circulatory road had to stop and allow him to enter.
4. At 8:20A. Slip ramp / circle merge point conflict.
5. Motorist turned onto WBHV, stopped, and made u-turn towards I-17 SB.

Erratic Maneuvers West Roundabout:

1. At 7:28A. Vehicle on slip ramp had to break quickly to allow ROW to vehicle from circulatory road.
2. At 8:03A. Near rear-end collision on slip ramp because front vehicle stopped to allow ROW to circulatory vehicles.

I-17 HAPPY VALLEY INTERCHANGE RESEARCH

OBSERVATIONS & ERRATIC MANEUVERS – EAST INTERCHANGE

12/12/02 - 8:45AM to 10:45AM

Observations East Roundabout:

1. At 8:56A. Car w/trailer stopped in circle at WBHV approach. Truck behind vehicle has to blow horn to get 1st vehicle to move.
2. At 9:20A. Vehicle in circle stopped for vehicle at WBHV approach.
3. At 9:42A. 5 bicyclists were observed traveling through the circle.
4. At 9:56A. Vehicle in circle stopped for vehicle at the frontage road approach.
5. At 10:01A. Vehicle approaching from WBHV made u-turn back towards EBHV before splitter.
6. At 10:05A. WBHV truck stopped past yield bar and into rotary.
7. At 10:12A. Vehicle traveling very slowly around circle.
8. At 10:19A. Vehicle made turn from WBHV approach to Frontage Road.
9. At 10:43A. Vehicle stopped, moving slowly in circle.

Erratic Maneuvers East Roundabout:

1. At 9:24A. Vehicle in circle turned the wrong way onto the WBHV approach to go EBHV.
2. At 9:29A. WBHV vehicle did not yield at the yield bar while vehicles were traveling within the circle. WBHV vehicle had to stop half-way into the circulatory roadway to allow cars to continue, luckily no vehicles were headed toward the NB Frontage Road.
3. At 10:03A. Vehicle turned onto the Frontage Road and made u-turn to access I-17 NB slip ramp.

APPENDIX D
Public Opinion Survey Cover Letter and Questionnaire

Arizona Department of Transportation

Transportation Planning Division

206 South Seventeenth Avenue Phoenix, Arizona 85007-3213

Jane Dee Hull
Governor

Victor M. Mendez
Director

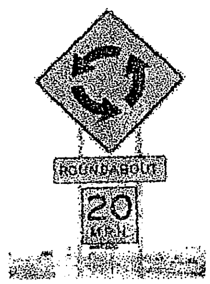
Dale Buskirk
Acting Division Director

December 12, 2002

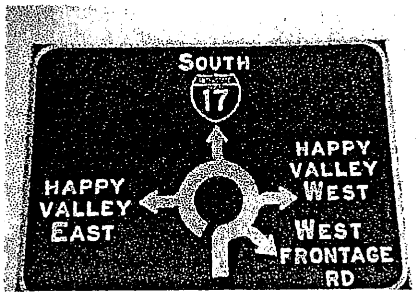
To Whom It May Concern:

The Arizona Transportation Research Center has commissioned Lee Engineering and Kittelson & Associates to study the performance of the traffic roundabouts at the Happy Valley Road interchange on Interstate 17 in north Phoenix. One of their tasks is to survey drivers in north Phoenix who travel through the roundabouts. Your assistance in completing the survey questions and mailing the enclosed prepaid postcard is greatly appreciated. The results will help the Arizona Department of Transportation (ADOT) design and build the safest, most efficient highway system possible in a cost-effective manner.

Roundabouts have been used worldwide for years, but have only been built in the United States during the past few years. Recently, ADOT constructed two roundabouts at the Happy Valley Road Traffic Interchange (TI) on Interstate 17 in northern Phoenix. The results of this survey and the research project will be used to develop a guide for the selection of future roundabout locations and their design.



Roundabout Ahead Sign



Roundabout Directional Guide Sign

Please complete our prepaid survey postcard and return it before December 31st, 2002. If you have any questions on this project, or would like a confirmation of the consulting engineers' role in the research, please call or send me an e-mail. If you have comments or questions related to the survey itself, please contact Brennan Kidd at Lee Engineering, as listed below.

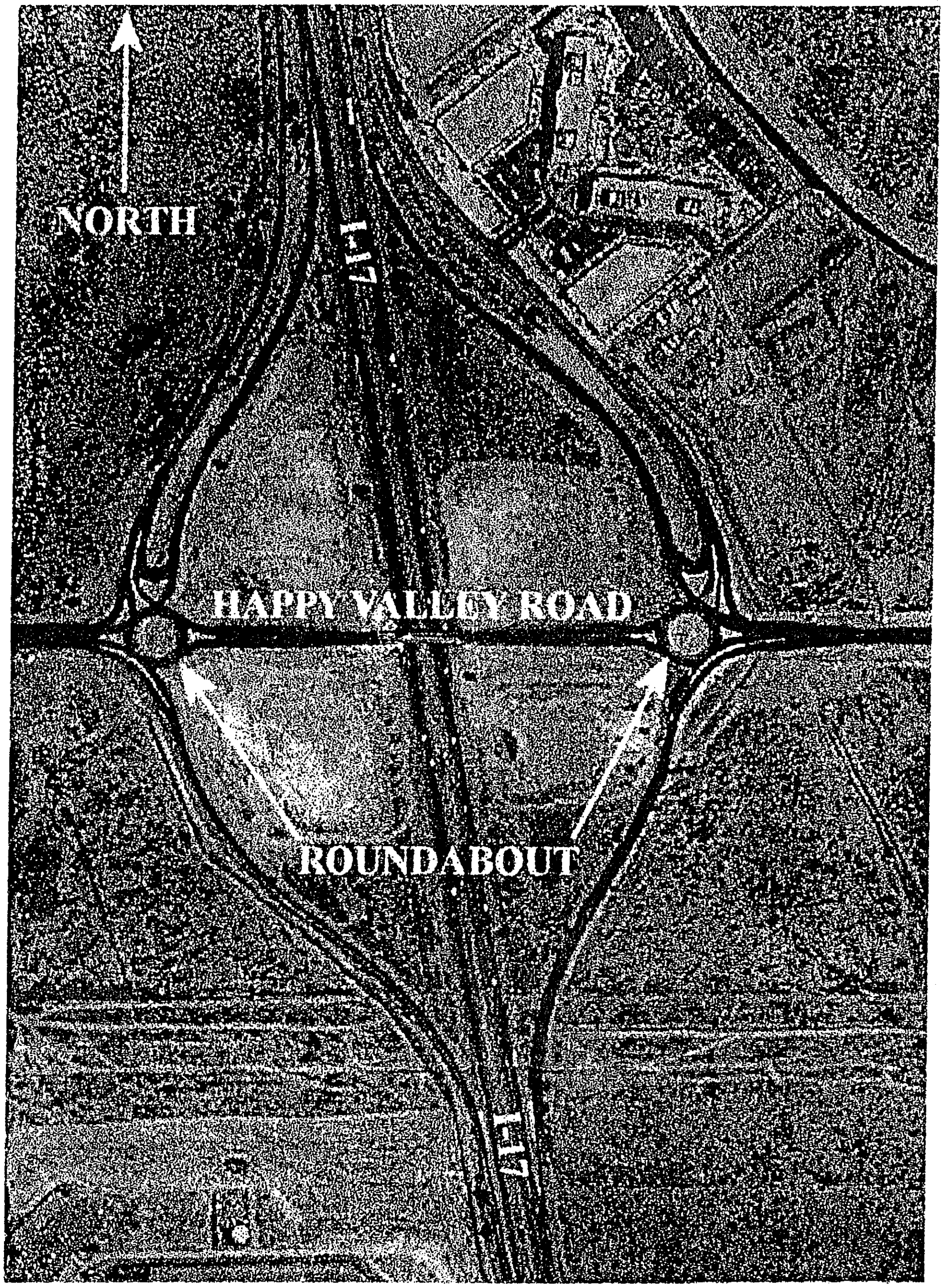
An aerial photograph of the roundabouts at the Happy Valley Road Traffic Interchange is shown on the back of this letter. Thank you very much for your assistance.

Sincerely,

Rosendo Gutierrez, P.E.
ADOT Research Project Manager
Arizona Transportation Research Center
Phone 602-712-6927
Fax 602-712-3400
E-mail: RosendoG@dot.state.az.us

Brennan D. Kidd, E.I.T.
Consultant Team Member
Lee Engineering
Phone 602-955-7206
Fax 602-955-7349
E-mail: BKidd@lee-eng.com

Arizona Governor's Award for Quality
2001 Award Recipient



Aerial Photograph of the Roundabouts at the Happy Valley Road Interchange

Driver Survey - Happy Valley & I-17 Roundabouts

1. Have you ever driven through any other roundabouts anywhere? ❑YES ❑NO ❑NOT SURE
2. About how many times a week, do you use the Happy Valley Road/I-17 roundabouts?

   ❑Zero ❑1 – 5 ❑ 6 – 10 ❑more than 10

3. Compared to typical freeway interchanges, I think the Happy Valley roundabouts are:

   3a. ❑ More efficient (less delay) ❑ Less efficient (more delay) ❑ about the same
   3b. ❑ More safe ❑ Less safe ❑ about the same
   3c. ❑ More confusing ❑ Less confusing ❑ about the same

4. Do you agree or disagree with the following: "When traveling through the Happy Valley roundabouts, I have a clear understanding of where to go and how to get there."

   ❑strongly agree ❑agree ❑neutral ❑disagree ❑strongly disagree

5. Do you feel the directional guide signs are clearly understandable and visible to drivers?

   ❑strongly agree ❑agree ❑neutral ❑disagree ❑strongly disagree

6. Overall, what do you think of these roundabouts? (from 1-poor to 10-great):______
7. Comments? ____

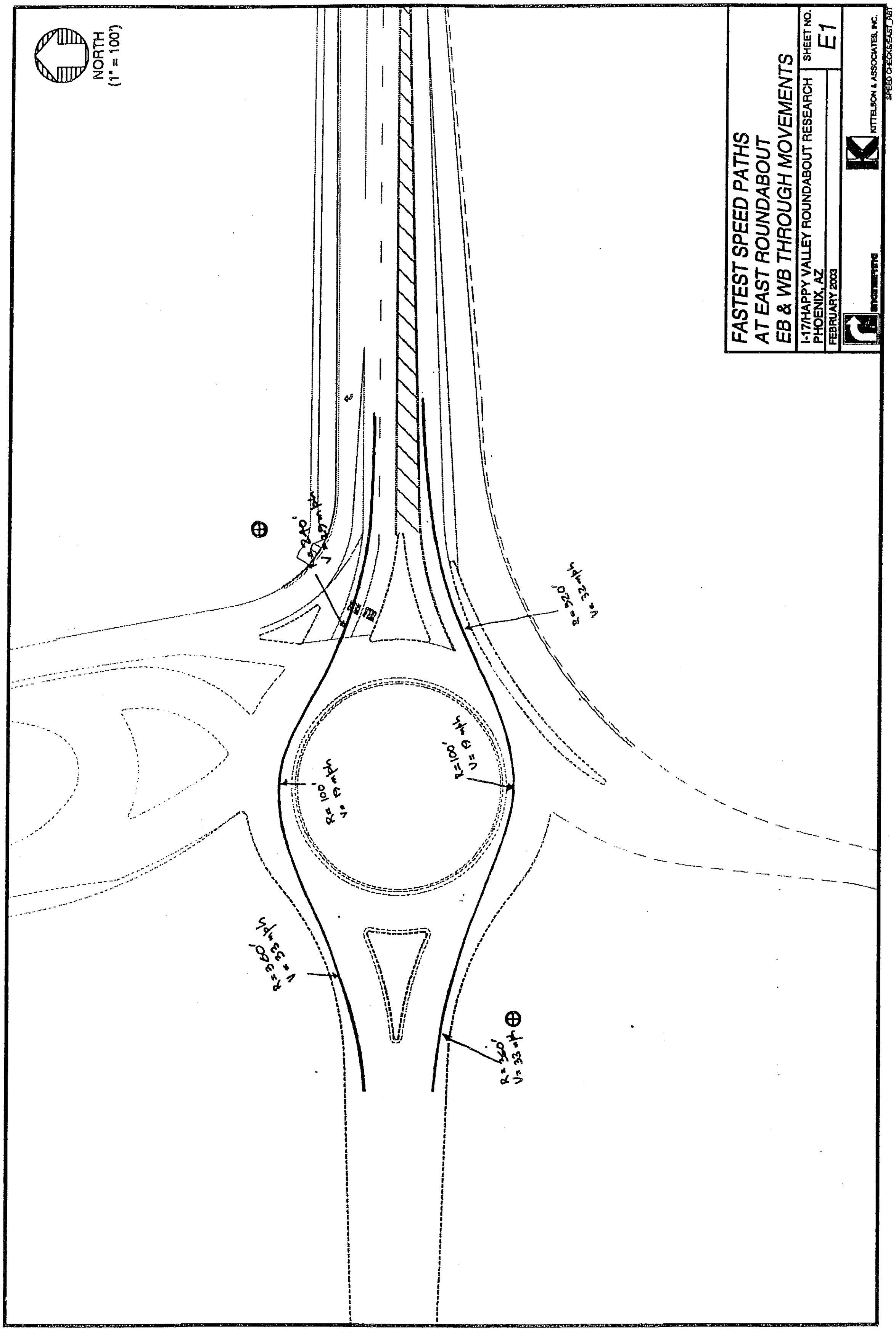
____

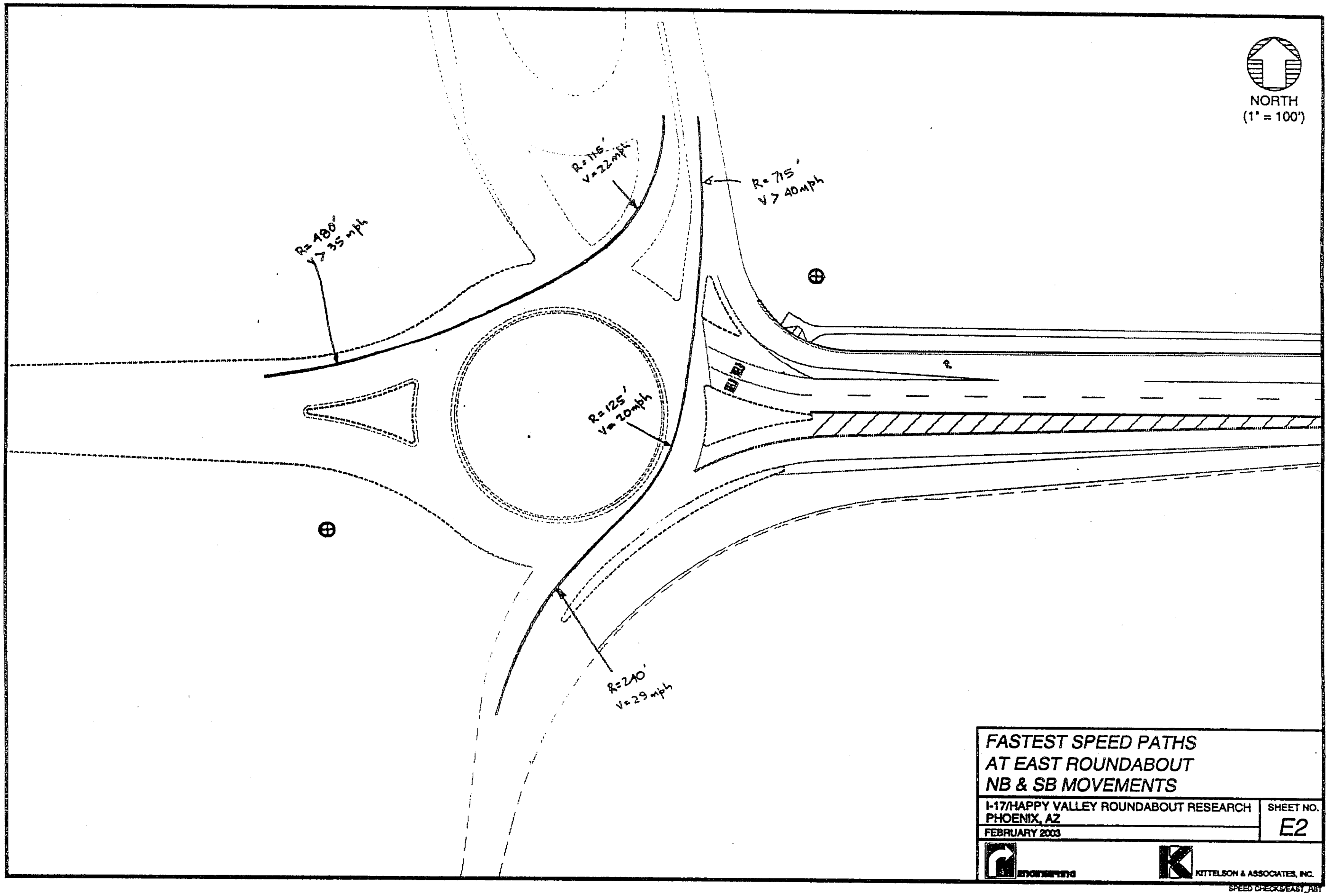
____

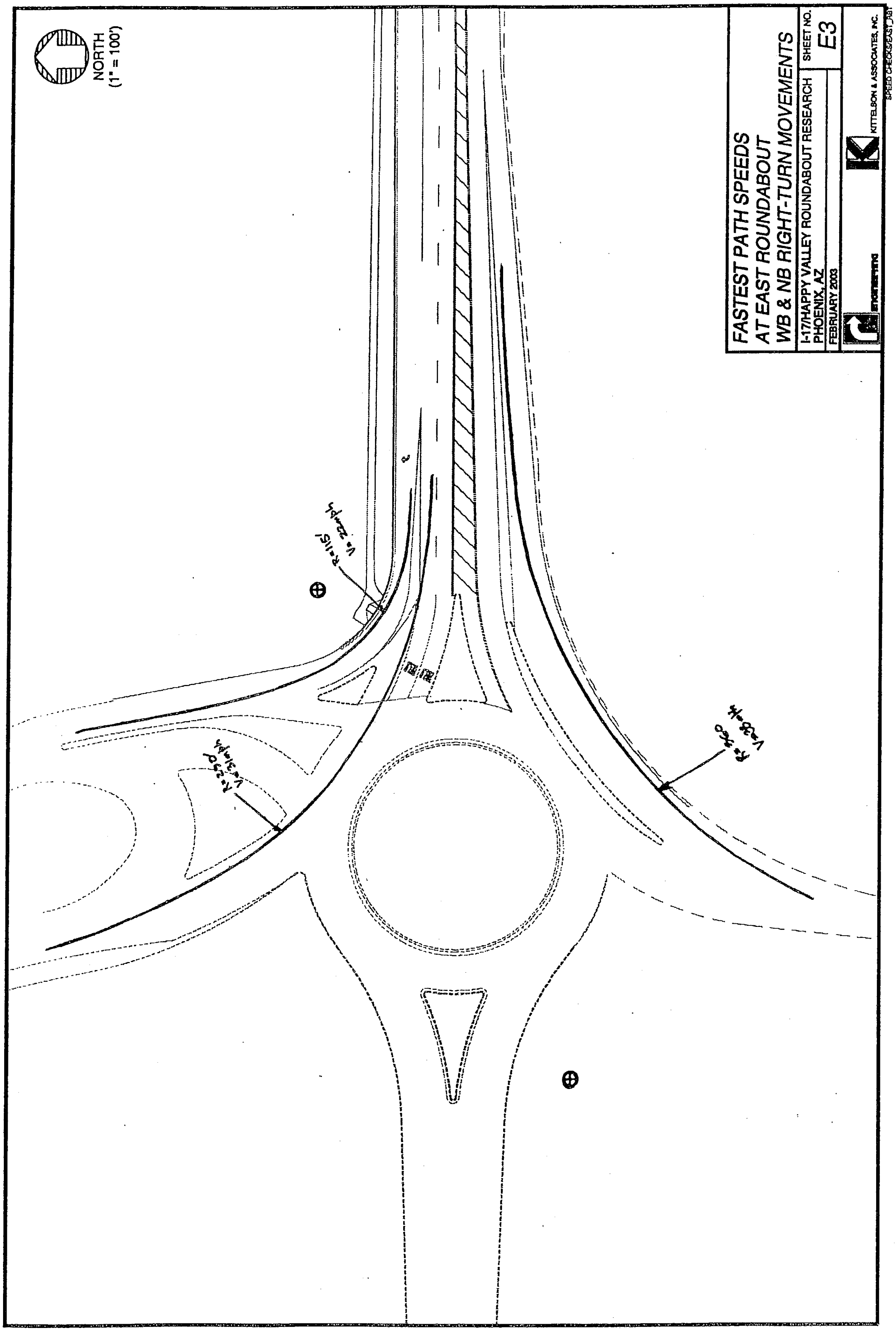
____

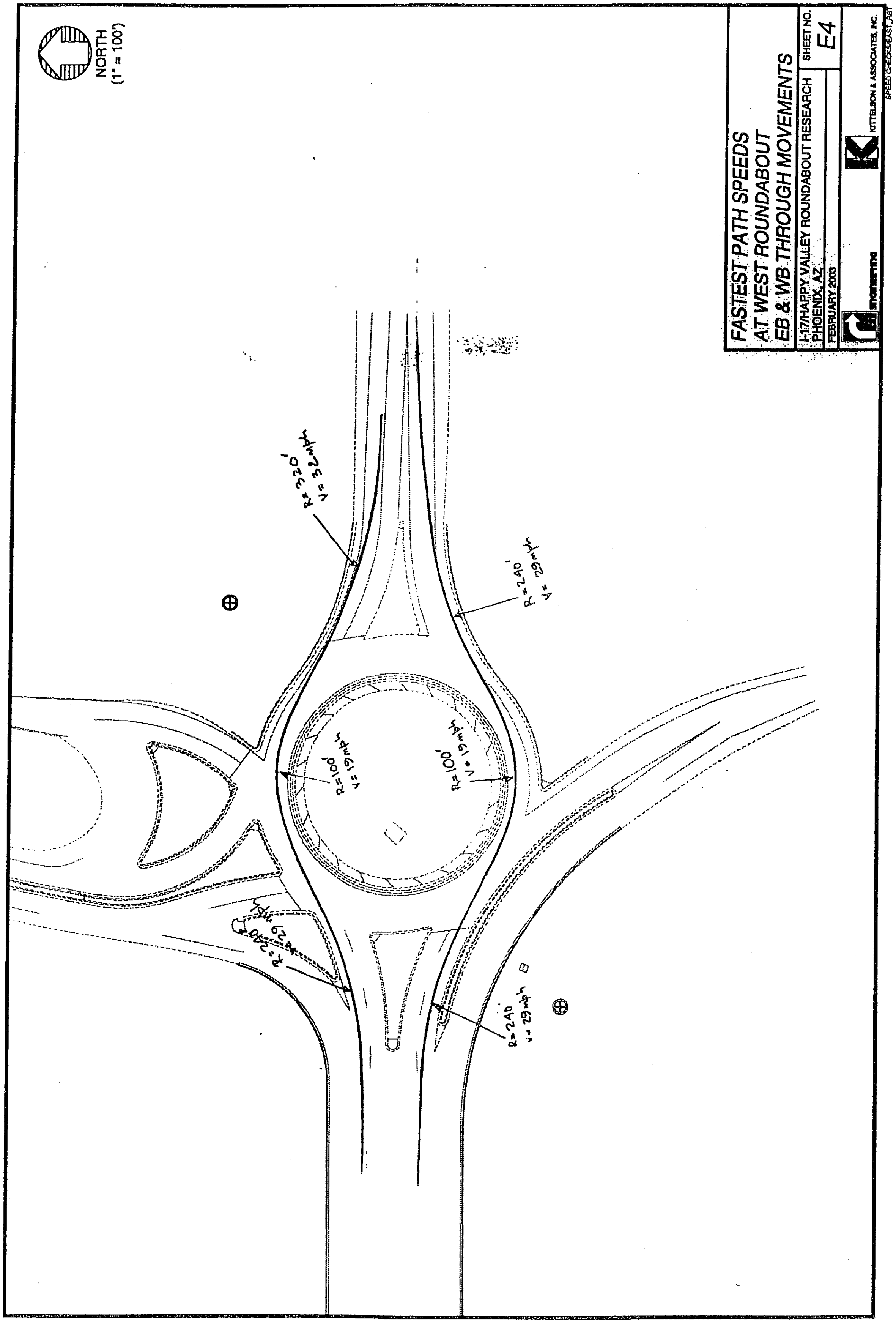
Thank you for your assistance. Please drop this card in any mailbox.

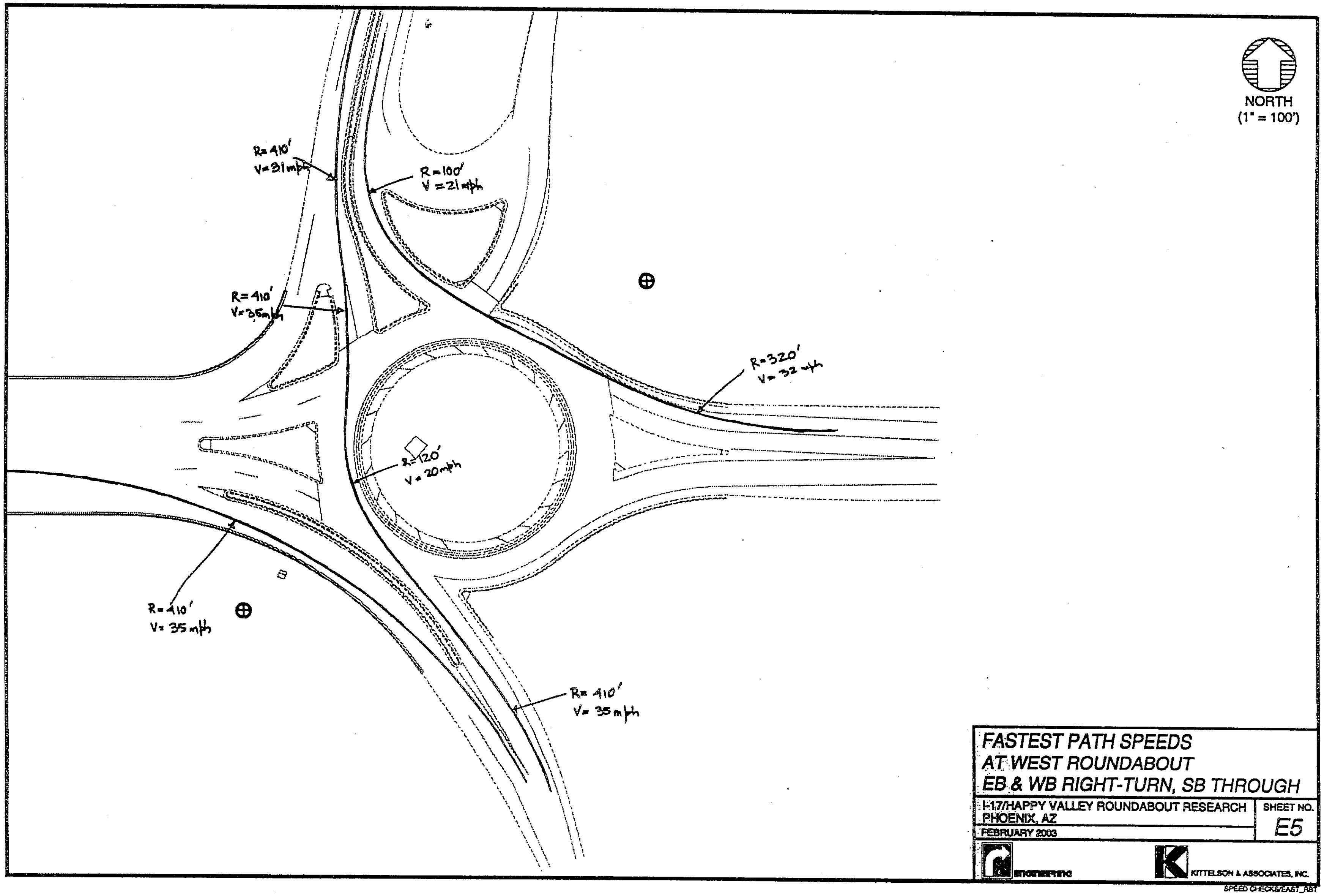
APPENDIX E
Fastest Path Sketches – Existing Conditions


NORTH
(1" = 100')
FASTEST SPEED PATHS
AT EAST ROUNDABOUT
EB & WB THROUGH MOVEMENTS
I-17/HAPPY VALLEY ROUNDABOUT RESEARCH
PHOENIX, AZ
FEBRUARY 2003
SHEET NO.
E1
KITTELSON & ASSOCIATES, INC.

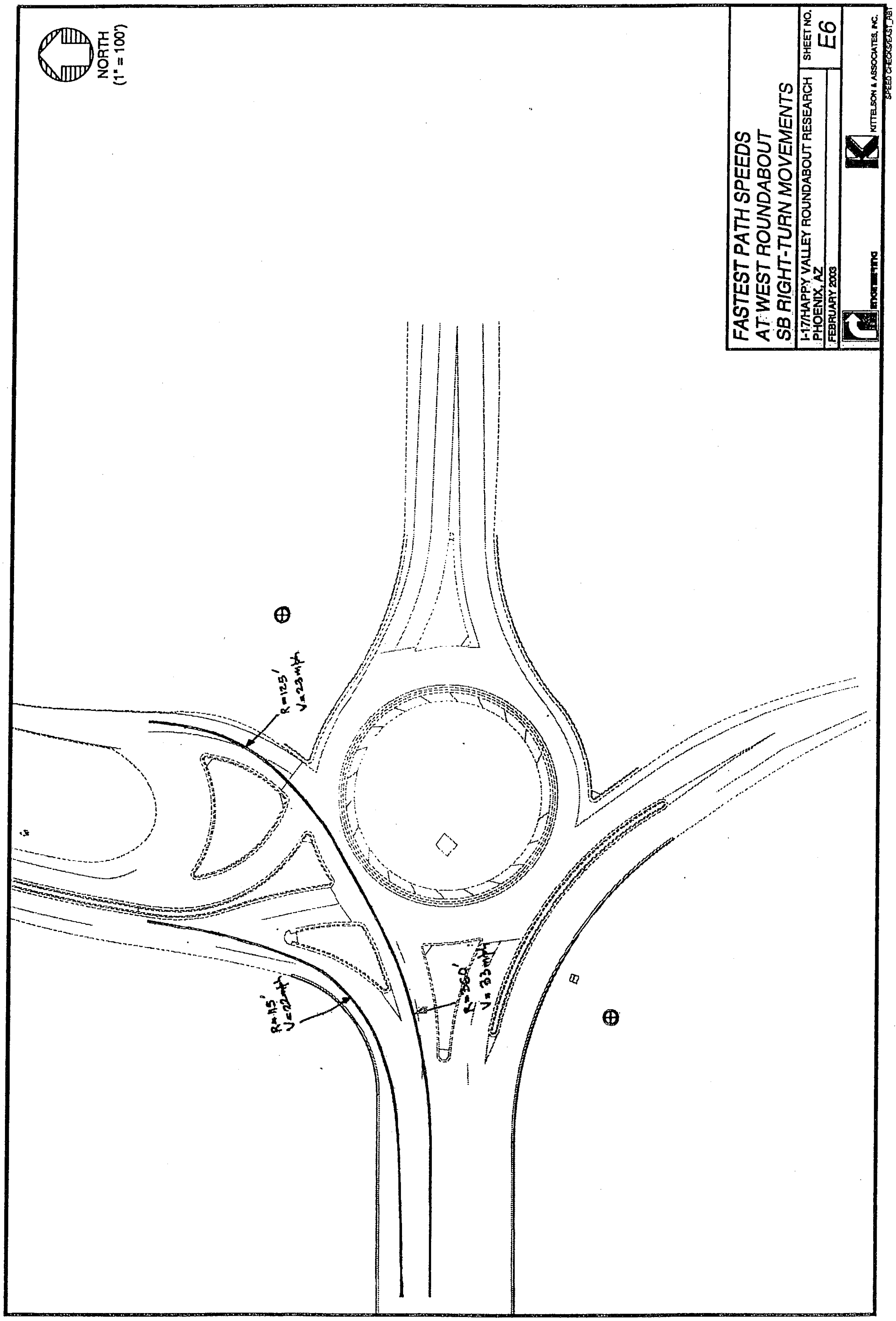

NORTH
(1" = 100')
R=480'
V>35mph
R=115'
V=22mph
R=715'
V>40mph
R=125'
V=20mph
R=240'
V=29mph
FASTEST SPEED PATHS
AT EAST ROUNDABOUT
NB & SB MOVEMENTS
I-17/HAPPY VALLEY ROUNDABOUT RESEARCH
PHOENIX, AZ
FEBRUARY 2003
SHEET NO.
E2
KITTELSON & ASSOCIATES, INC.
SPEED CHECKS/EAST_RBT


NORTH
(1" = 100')
FASTEST PATH SPEEDS
AT EAST ROUNDABOUT
WB & NB RIGHT-TURN MOVEMENTS
I-17/HAPPY VALLEY ROUNDABOUT RESEARCH
PHOENIX, AZ
FEBRUARY 2003
SHEET NO.
E3
KITTELSON & ASSOCIATES, INC.


FASTEST PATH SPEEDS
AT WEST ROUNDABOUT
EB & WB THROUGH MOVEMENTS
I-17/HAPPY VALLEY ROUNDABOUT RESEARCH
PHOENIX, AZ
FEBRUARY 2003
SHEET NO.
E4
KITTELSON & ASSOCIATES, INC.
NORTH
(1" = 100')
R=320'
V=32mph
R=240'
V=29mph
R=100'
V=19mph
R=100'
V=19mph
R=240'
V=29mph
R=240'
V=29mph



R=410'
V=31mph
R=100'
V=21mph
R=410'
V=35mph
R=320'
V=32mph
R=120'
V=20mph
R=410'
V=35mph
R=410'
V=35mph
NORTH
(1" = 100')
FASTEST PATH SPEEDS
AT WEST ROUNDABOUT
EB & WB RIGHT-TURN, SB THROUGH
I-17/HAPPY VALLEY ROUNDABOUT RESEARCH
PHOENIX, AZ
FEBRUARY 2003
SHEET NO.
E5
KITTELSON & ASSOCIATES, INC.
SPEED CHECKS/EAST_RBT


NORTH
(1" = 100')
R=125'
V=23mph
R=115'
V=22mph
R=360'
V=33mph
FASTEST PATH SPEEDS
AT WEST ROUNDABOUT
SB RIGHT-TURN MOVEMENTS
I-17/HAPPY VALLEY ROUNDABOUT RESEARCH
PHOENIX, AZ
FEBRUARY 2003
SHEET NO.
E6
KITTELSON & ASSOCIATES, INC.

APPENDIX F
FHWA Analysis Worksheets – Existing Conditions

Project	Arizona I-17 Interchange Roundabout Research
Location	Phoenix, AZ
Scenario	2002 East Roundabout, Weekday AM Peak Hour

Analyst	SXO	
Date	7-Apr-03	=HWA\[East Roundabout AM Peak Hour.xls]Calcs
Rbt equation to use	S	(C=FHWA compact urban,S=FHWA single,D=FHWA double, B=British approach specific, HCMU=HCM upper, HCML=HCM lowe

Study year	Existing 2002
Time Period	A.M. Peak Hour

Approach		NB I-17 NB Off	SB Frontage Rd	EB Happy Valley	WB Happy Valley
Entering volume (pce)		**482**	**27**	**464**	**249**
Conflicting volume (pce)		**472**	**668**	**8**	**682**
Compact urban capacity		869	724	1212	713
Single-lane capacity		955	848	1208	841
Double-lane capacity		2086	1946	2418	1936
HCM upper bound capacity		955	816	1376	806
HCM lower bound capacity		773	650	1153	642
British approach specific		2086	1946	2418	1936
Rbt equation to use	S				
Ideal capacity (pce)		955	848	1208	841
Capacity reductions					
Short lanes (only valid for D)					
Short lane present?		Y	Y	Y	Y
Length of short lane (veh)		0	0	2	2
Short lane factor		1.000	1.000	1.000	1.000
# of conflicting peds		0	0	0	0
Pedestrian factor		1.000	1.000	1.000	1.000
Adjusted capacity (pce)		**955**	**848**	**1208**	**841**
V/C ratio		**0.50**	**0.03**	**0.38**	**0.30**
T		1	1	1	1
Control delay (sec/veh)		**7.6**	**4.4**	**4.8**	**6.1**
95th %ile approach queue (		**3.0**	**0.1**	**1.9**	**1.3**
Queue Length (feet)		75	2	47	31

Project	Arizona I-17 Interchange Roundabout Research
Location	Phoenix, AZ
Scenario	2002 East Roundabout, Weekday PM Peak Hour

Analyst	SXO	
Date	7-Apr-03	Geometry\FHWA\[East Roundabout PM Peak Hour.xls]Calcs
Rbt equation to use	S	(C=FHWA compact urban,S=FHWA single,D=FHWA double, B=British approach specific, HCMU=HCM upper, HCML=HCM

Study year	Existing 2002
Time Period	P.M. Peak Hour

		NB	**SB**	**EB**	**WB**
Approach		**I-17 NB Off**	**Frontage Rd**	**Happy Valley**	**Happy Valley**
Entering volume (pce)		**920**	**144**	**120**	**318**
Conflicting volume (pce)		**125**	**1256**	**5**	**981**
Compact urban capacity		1126	289	1214	492
Single-lane capacity		1144	528	1209	678
Double-lane capacity		2335	1525	2420	1722
HCM upper bound capacity		1256	504	1379	632
HCM lower bound capacity		1044	382	1156	491
British approach specific		2335	1525	2420	1722
Rbt equation to use	S				
Ideal capacity (pce)		1144	528	1209	678
Capacity reductions					
Short lanes (only valid for D)					
Short lane present?		Y	Y	Y	Y
Length of short lane (veh)		0	0	2	2
Short lane factor		1.000	1.000	1.000	1.000
# of conflicting peds		0	0	0	0
Pedestrian factor		1.000	1.000	1.000	1.000
Adjusted capacity (pce)		**1144**	**528**	**1209**	**678**
V/C ratio		**0.80**	**0.27**	**0.10**	**0.47**
T		1	1	1	1
Control delay (sec/veh)		**15.6**	**9.4**	**3.3**	**10.0**
95th %ile approach queue (veh)		**11.2**	**1.1**	**0.3**	**2.6**
Queue Length (feet)		280	28	8	65

Project	Arizona I-17 Interchange Roundabout Research
Location	Phoenix, AZ
Scenario	2002 West Roundabout, Weekday AM Peak Hour

Analyst	SXO
Date	7-Apr-03 \FHWA Analysis\[West Roundabout AM Peak Hour.xls]Calcs
Rbt equation to use	S (C=FHWA compact urban,S=FHWA single,D=FHWA double, B=British approach specific, HCMU=HCM upper, HCML=HCN
Study year	Existing 2002
Time Period	A.M. Peak Hour

		SB	SB	EB	WB
Approach		I-17 SB Off	Frontage Rd	Happy Valley	Happy Valley
Entering volume (pce)		**212**	**263**	**332**	**453**
Conflicting volume (pce)		**481**	**665**	**493**	**28**
Compact urban capacity		862	726	853	1197
Single-lane capacity		950	850	944	1197
Double-lane capacity		2080	1948	2071	2404
HCM upper bound capacity		948	818	939	1355
HCM lower bound capacity		767	652	759	1134
British approach specific		2080	1948	2071	2404
Rbt equation to use	S				
Ideal capacity (pce)		950	850	944	1197
Capacity reductions					
Short lanes (only valid for D)					
Short lane present?		Y	Y	Y	Y
Length of short lane (veh)		0	0	2	2
Short lane factor		1.000	1.000	1.000	1.000
# of conflicting peds		0	0	0	0
Pedestrian factor		1.000	1.000	1.000	1.000
Adjusted capacity (pce)		**950**	**850**	**944**	**1197**
V/C ratio		**0.22**	**0.31**	**0.35**	**0.38**
T		1	1	1	1
Control delay (sec/veh)		**4.9**	**6.1**	**5.9**	**4.8**
95th %ile approach queue (veh)		**0.9**	**1.3**	**1.6**	**1.8**
Queue Length (feet)		21	33	40	45

Project	Arizona I-17 Interchange Roundabout Research
Location	Phoenix, AZ
Scenario	2002 West Roundabout, Weekday PM Peak Hour

Analyst	SXO
Date	7-Apr-03 /\FHWA Analysis\[West Roundabout PM Peak Hour.xls]Calcs
Rbt equation to use	S (C=FHWA compact urban,S=FHWA single,D=FHWA double, B=British approach specific, HCMU=HCM upper, HCML=HCM
Study year	Existing 2002
Time Period	P.M. Peak Hour

Approach		SB I-17 SB Off	SB Frontage Rd	EB Happy Valley	WB Happy Valley
Entering volume (pce)		**124**	**109**	**120**	**1146**
Conflicting volume (pce)		**1195**	**1270**	**359**	**49**
Compact urban capacity		334	278	952	1182
Single-lane capacity		561	521	1017	1185
Double-lane capacity		1568	1515	2167	2389
HCM upper bound capacity		530	498	1044	1333
HCM lower bound capacity		404	377	853	1114
British approach specific		1568	1515	2167	2389
Rbt equation to use	S				
Ideal capacity (pce)		561	521	1017	1185
Capacity reductions					
Short lanes (only valid for D)					
Short lane present?		Y	Y	Y	Y
Length of short lane (veh)		0	0	2	2
Short lane factor		1.000	1.000	1.000	1.000
# of conflicting peds		0	0	0	0
Pedestrian factor		1.000	1.000	1.000	1.000
Adjusted capacity (pce)		**561**	**521**	**1017**	**1185**
V/C ratio		**0.22**	**0.21**	**0.12**	**0.97**
T		1	1	1	1
Control delay (sec/veh)		**8.2**	**8.7**	**4.0**	**51.8**
95th %ile approach queue (veh)		**0.8**	**0.8**	**0.4**	**32.8**
Queue Length (feet)		21	20	10	820

APPENDIX G
SIDRA Analysis Worksheets – Existing Conditions

Movement Summary

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Arizona I-17 Roundabout Interchange Research #5332

Roundabout

Vehicle Movements

Mov No	Turn	Dem Flow (veh/h)	Cap (veh/h)	Deg of Satn (v/c)	Aver Delay (sec)	Level of Service	95% Back of Queue (ft)	Eff. Stop Rate	Aver Speed (mi/h)	Oper Cost ($/h)
South Approach										
32	L	298	675	0.441	17.6	LOS B	97	0.78	34.1	82
31	T	185	419	0.442	8.1	LOS A	97	0.64	37.9	44
33	R	152	1900	0.080	5.7	LOS A#	3#	0.44	40.6	34
Approach		**635**	**2994**	**0.442**	**12.0**	**LOS B**	**97**	**0.66**	**36.5**	**159**
East Approach										
22	L	249	901	0.276	8.9	LOS A	48	0.68	37.9	60
21	T	57	526	0.108	10.4	LOS B	15	0.69	37.6	14
23	R	13	1900	0.007	6.0	LOS A#	0#	0.45	40.4	3
Approach		**319**	**3328**	**0.276**	**9.1**	**LOS A**	**48**	**0.67**	**37.9**	**76**
North Approach										
42	L	8	869	0.032	13.7	LOS B	6	0.65	35.7	7
42	T	19	869	0.032	13.7	LOS B	6	0.65	35.7	7
42	R	1	869	0.032	13.7	LOS B	6	0.65	35.7	7
Approach		**28**	**869**	**0.032**	**13.7**	**LOS B**	**6**	**0.65**	**35.7**	**7**
West Approach										
12	L	200	1930	0.240	9.4	LOS A	42	0.52	38.2	111
12	T	264	1930	0.240	9.4	LOS A	42	0.52	38.2	111
Approach		**464**	**1930**	**0.240**	**9.4**	**LOS A**	**42**	**0.52**	**38.2**	**111**
All Vehicles		**1446**	**9121**	**0.442**	**10.5**	**LOS B**	**97**	**0.62**	**37.4**	**354**

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Movement Summary

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Arizona I-17 Roundabout Interchange Research #5332

Roundabout

Vehicle Movements

Mov No	Turn	Dem Flow (veh/h)	Cap (veh/h)	Deg of Satn (v/c)	Aver Delay (sec)	Level of Service	95% Back of Queue (ft)	Eff. Stop Rate	Aver Speed (mi/h)	Oper Cost ($/h)
South Approach										
32	L	890	1706	0.522	15.1	LOS B	128	0.66	34.8	239
31	T	31	59	0.525	5.7	LOS A	128	0.43	39.3	7
33	R	80	1900	0.042	5.7	LOS A#	2#	0.44	40.6	18
Approach		**1001**	**3665**	**0.522**	**14.0**	**LOS B**	**128**	**0.63**	**35.3**	**264**
East Approach										
22	L	318	831	0.383	12.3	LOS B	84	0.80	36.6	79
21	T	70	618	0.113	12.4	LOS B	21	0.73	36.5	17
23	R	1	1900	0.001	6.0	LOS A#	0#	0.45	40.4	0
Approach		**389**	**3349**	**0.383**	**12.3**	**LOS B**	**84**	**0.78**	**36.6**	**97**
North Approach										
42	L	5	411	0.353	24.4	LOS C	68	0.99	30.8	41
42	T	139	411	0.353	24.4	LOS C	68	0.99	30.8	41
42	R	1	411	0.353	24.4	LOS C	68	0.99	30.8	41
Approach		**145**	**411**	**0.352**	**24.4**	**LOS C**	**68**	**0.99**	**30.8**	**41**
West Approach										
12	L	61	1914	0.063	10.3	LOS B	10	0.55	37.8	29
12	T	59	1914	0.063	10.3	LOS B	10	0.55	37.8	29
Approach		**120**	**1914**	**0.063**	**10.3**	**LOS B**	**10**	**0.55**	**37.8**	**29**
All Vehicles		**1655**	**9339**	**0.525**	**14.3**	**LOS B**	**128**	**0.69**	**35.3**	**430**

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Movement Summary

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Arizona I-17 Roundabout Interchange Research #5332

Roundabout

Vehicle Movements

Mov No	Turn	Dem Flow (veh/h)	Cap (veh/h)	Deg of Satn (v/c)	Aver Delay (sec)	Level of Service	95% Back of Queue (ft)	Eff. Stop Rate	Aver Speed (mi/h)	Oper Cost ($/h)
East Approach										
22	L	136	571	0.238	14.5	LOS B	42	0.67	35.5	36
21	T	317	1332	0.238	4.9	LOS A	42	0.37	40.7	70
23	R	113	1259	0.090	5.0	LOS A	12	0.37	40.6	25
Approach		**566**	**3162**	**0.238**	**7.2**	**LOS A**	**42**	**0.44**	**39.2**	**131**
North Approach										
42	L	92	960	0.220	13.5	LOS B	44	0.72	35.8	54
42	T	1	960	0.220	13.5	LOS B	44	0.72	35.8	54
42	R	118	960	0.220	13.5	LOS B	44	0.72	35.8	54
Approach		**211**	**960**	**0.220**	**13.5**	**LOS B**	**44**	**0.72**	**35.8**	**54**
North West Approach										
82	L	67	227	0.295	17.5	LOS B	60	0.80	34.0	18
81	T	196	663	0.296	9.4	LOS A	60	0.70	37.7	47
83	R	70	1900	0.037	7.1	LOS A#	2#	0.51	39.7	16
Approach		**333**	**2790**	**0.296**	**10.5**	**LOS B**	**60**	**0.68**	**37.3**	**81**
West Approach										
12	L	28	87	0.322	18.8	LOS B	63	0.77	33.7	8
11	T	304	946	0.321	8.9	LOS A	63	0.66	37.7	73
13	R	1052	1900	0.554	5.8	LOS C#	23#	0.43	40.6	232
Approach		**1384**	**2933**	**0.554**	**6.7**	**LOS A**	**63**	**0.49**	**39.7**	**313**
All Vehicles		**2494**	**9844**	**0.554**	**7.9**	**LOS A**	**63**	**0.52**	**38.9**	**579**

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Movement Summary

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Arizona I-17 Roundabout Interchange Research #5332

Roundabout

Vehicle Movements

Mov No	Turn	Dem Flow (veh/h)	Cap (veh/h)	Deg of Satn (v/c)	Aver Delay (sec)	Level of Service	95% Back of Queue (ft)	Eff. Stop Rate	Aver Speed (mi/h)	Oper Cost ($/h)
East Approach										
22	L	229	376	0.609	14.7	LOS B	172	0.64	35.2	61
21	T	917	1505	0.609	5.1	LOS A	172	0.38	40.0	206
23	R	202	1213	0.167	5.1	LOS A	25	0.38	40.3	45
Approach		**1348**	**3093**	**0.609**	**6.8**	**LOS A**	**172**	**0.42**	**39.1**	**312**
North Approach										
42	L	21	337	0.371	29.5	LOS C	71	1.02	29.0	37
42	T	1	337	0.371	29.5	LOS C	71	1.02	29.0	37
42	R	103	337	0.371	29.5	LOS C	71	1.02	29.0	37
Approach		**125**	**337**	**0.371**	**29.5**	**LOS C**	**71**	**1.02**	**29.0**	**37**
North West Approach										
82	L	25	99	0.253	27.4	LOS C	48	0.95	30.0	7
81	T	84	334	0.251	19.2	LOS B	48	0.92	33.1	22
83	R	58	1900	0.031	7.1	LOS A#	1#	0.51	39.7	13
Approach		**167**	**2334**	**0.251**	**16.2**	**LOS B**	**48**	**0.78**	**34.5**	**43**
West Approach										
12	L	49	460	0.107	17.6	LOS B	19	0.71	34.0	14
11	T	71	667	0.106	7.6	LOS A	19	0.55	38.2	17
13	R	323	1900	0.170	5.7	LOS A#	7#	0.43	40.7	71
Approach		**443**	**3028**	**0.170**	**7.3**	**LOS A**	**19**	**0.48**	**39.4**	**102**
All Vehicles		**2083**	**8792**	**0.609**	**9.0**	**LOS A**	**172**	**0.50**	**38.0**	**494**

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APPENDIX H
Crash Prediction Model Worksheets – Existing Conditions

British Crash Prediction Model

Project Name:	I-17 Roundabout Interchange Research
Project Number:	5332
Location:	East Roundabout
Scenario:	Existing Geometry and volume
units = meters	

	I-17 NB Off Ramp	West bound	SB Frontage Rd	East bound	Total Crashes
Input Data					
Qe :entry flow (1000s ADT)	8.700	4.120	0.910	3.220	
Qc: circulating flow (1000s ADT)	3.200	11.050	11.680	0.100	
Qex: exiting flow (1000s ADT)[1]		1.44	0.48	13.47	
Qp: pedestrian crossing flow (1000s ped/day)[1]					
Re: shortest path radius for entry in meters	73	73	35	110	
Ce: 1/Re	0.014	0.014	0.029	0.009	
Ra: approach radius	5,000.0		325.0		
Ca: 1/Ra	0.000	0	0.003	0	
e: entry width in meters	10.366	7.317	8.537	10.061	
v: approach width in meters	7.622	6.707	7.622	9.146	
R: inscribed diameter/island diameter	1.333	1.333	1.333	1.333	
Pm: proportion of motorbikes	0	0	0	0	
angle: ange to next leg, degrees	108	82	27	71	
Entry-Circulating personal injury/per yr/specific approach	0.078	0.080	0.029	0.015	0.201
Approaching personal injury/per yr/specific approach	0.105	0.040	0.004	0.018	0.167
Single Vehicle personal injury/yr/specifici approach	0.231	0.107	0.048	0.128	0.514
Other (vehicle) personal injury/yr/specific approach	0.037	0.055	0.017	0.001	0.111
Pedestrian personal injury/yr/specific approach	0	0	0	0	0.000
Total Crashes per approach	0.452	0.282	0.098	0.162	0.993

[1] For Pedestrian crash rates only

Based on TRRL Laboratory Report 1120, *"Accidents at 4-Arm Roundabouts"*, G Maycock and RD Hall, 1984

British Crash Prediction Model

Project Name: I-17 Roundabout Interchange Research
Project Number: 5332
Location: West Roundabout
Scenario: Existing Geometry and volume
units = meters

	West bound	I-17 SB Off Ramp	SB Frontage Rd	East bound	Total Crashes
Input Data					
Qe :entry flow (1000s ADT)	12.250	1.960	2.170	2.320	
Qc: circulating flow (1000s ADT)	0.640	12.930	11.260	4.900	
Qex: exiting flow (1000s ADT)[1]	0.46		0.25	10.78	
Qp: pedestrian crossing flow (1000s ped/day)[1]					
Re: shortest path radius for entry in meters	98	38	125	73	
Ce: 1/Re	0.010	0.026	0.008	0.014	
Ra: approach radius			80.0	1,432	
Ca: 1/Ra	0	0	0.013	0.001	
e: entry width in meters	7.317	7.317	7.317	7.317	
v: approach width in meters	7.317	4.573	3.659	7.317	
R: inscribed diameter/island diameter	1.333	1.333	1.333	1.333	
Pm: proportion of mc's	0	0	0	0	
angle: ange to next leg, degrees	87	26	67	105	
Entry-Circulating personal injury/per yr/specific approach	**0.058**	**0.059**	**0.087**	**0.030**	**0.234**
Approaching personal injury/per yr/specific approach	**0.238**	**0.015**	**0.012**	**0.015**	**0.280**
Single Vehicle personal injury/yr/specifici approach	**0.265**	**0.053**	**0.017**	**0.074**	**0.409**
Other (vehicle) personal injury/yr/specific approach	**0.014**	**0.035**	**0.034**	**0.018**	**0.100**
Pedestrian personal injury/yr/specific approach	**0**	**0**	**0**	**0**	**0.000**
Total Crashes per approach	**0.575**	**0.161**	**0.150**	**0.137**	**1.023**

[1] For Pedestrian crash rates only
Based on TRRL Laboratory Report 1120, *"Accidents at 4-Arm Roundabouts"*, G Maycock and RD Hall, 1984

APPENDIX I
FHWA Analysis Worksheets – Recommended Conditions

Project	Arizona I-17 Interchange Roundabout Research
Location	Phoenix, AZ
Scenario	East Roundabout. Recommended Geometry

Analyst	SXO	
Date	7-Apr-03	ast Roundabout AM Peak Hour Recommended Geo.xls]Calcs
Rbt equation to use	D	(C=FHWA compact urban,S=FHWA single,D=FHWA double, B=British approach specific, HCMU=HCM upper, HCML=HCN

Study year	Existing 2002
Time Period	A.M. Peak Hour

	NB	SB	EB	WB
Approach	I-17 NB Off	Frontage Rd	Happy Valley	Happy Valley
Entering volume (pce)	**482**	**27**	**464**	**249**
Conflicting volume (pce)	**472**	**668**	**8**	**682**
Compact urban capacity	869	724	1212	713
Single-lane capacity	955	848	1208	841
Double-lane capacity	2086	1946	2418	1936
HCM upper bound capacity	955	816	1376	806
HCM lower bound capacity	773	650	1153	642
British approach specific	2086	1946	2418	1936
Rbt equation to use D				
Ideal capacity (pce)	2086	1946	2418	1936
Capacity reductions				
Short lanes (only valid for D)				
Short lane present?	Y	Y	Y	N
Length of short lane (veh)	4	0	10	#N/A
Short lane factor	0.871	0.500	0.939	1.000
# of conflicting peds	0	0	0	0
Pedestrian factor	1.000	1.000	1.000	1.000
Adjusted capacity (pce)	**1816**	**973**	**2271**	**1936**
V/C ratio	**0.27**	**0.03**	**0.20**	**0.13**
T	1	1	1	1
Control delay (sec/veh)	**2.7**	**3.8**	**2.0**	**2.1**
95th %ile approach queue (veh)	**1.1**	**0.1**	**0.8**	**0.4**
Queue Length (feet)	27	2	19	11

Project	Arizona I-17 Interchange Roundabout Research
Location	Phoenix, AZ
Scenario	East Roundabout. Recommended Geometry

Analyst	SXO	
Date	7-Apr-03	:ast Roundabout PM Peak Hour Recommended Geo.xls]Calcs
Rbt equation to use	D	(C=FHWA compact urban,S=FHWA single,D=FHWA double, B=British approach specific, HCMU=HCM upper, HCML=HCM

Study year	Existing 2002
Time Period	P.M. Peak Hour

Approach	NB I-17 NB Off	SB Frontage Rd	EB Happy Valley	WB Happy Valley
Entering volume (pce)	**920**	**144**	**120**	**318**
Conflicting volume (pce)	**125**	**1256**	**5**	**981**
Compact urban capacity	1126	289	1214	492
Single-lane capacity	1144	528	1209	678
Double-lane capacity	2335	1525	2420	1722
HCM upper bound capacity	1256	504	1379	632
HCM lower bound capacity	1044	382	1156	491
British approach specific	2335	1525	2420	1722
Rbt equation to use D				
Ideal capacity (pce)	2335	1525	2420	1722
Capacity reductions				
Short lanes (only valid for D)				
Short lane present?	Y	Y	Y	N
Length of short lane (veh)	4	0	10	#N/A
Short lane factor	0.871	0.500	0.939	1.000
# of conflicting peds	0	0	0	0
Pedestrian factor	1.000	1.000	1.000	1.000
Adjusted capacity (pce)	**2032**	**762**	**2273**	**1722**
V/C ratio	**0.45**	**0.19**	**0.05**	**0.18**
T	1	1	1	1
Control delay (sec/veh)	**3.2**	**5.8**	**1.7**	**2.6**
95th %ile approach queue (veh)	**2.5**	**0.7**	**0.2**	**0.7**
Queue Length (feet)	62	17	4	17

Project	Arizona I-17 Interchange Roundabout Research
Location	Phoenix, AZ
Scenario	West Roundabout. Recommended Geometry

Analyst	SXO
Date	7-Apr-03 ɜst Roundabout AM Peak Hour Recommended Geo.xls]Calcs
Rbt equation to use	D (C=FHWA compact urban,S=FHWA single,D=FHWA double, B=British approach specific, HCMU=HCM upper, HCML=HCN
Study year	Existing 2002
Time Period	A.M. Peak Hour

		SB	**SB**	**EB**	**WB**
Approach		**I-17 SB Off**	**Frontage Rd**	**Happy Valley**	**Happy Valley**
Entering volume (pce)		**212**	**263**	**332**	**453**
Conflicting volume (pce)		**481**	**665**	**493**	**28**
Compact urban capacity		862	726	853	1197
Single-lane capacity		950	850	944	1197
Double-lane capacity		2080	1948	2071	2404
HCM upper bound capacity		948	818	939	1355
HCM lower bound capacity		767	652	759	1134
British approach specific		2080	1948	2071	2404
Rbt equation to use	D				
Ideal capacity (pce)		2080	1948	2071	2404
Capacity reductions					
Short lanes (only valid for D)					
Short lane present?		Y	Y	N	Y
Length of short lane (veh)		0	0	#N/A	9
Short lane factor		0.500	0.500	1.000	0.933
# of conflicting peds		0	0	0	0
Pedestrian factor		1.000	1.000	1.000	1.000
Adjusted capacity (pce)		**1040**	**974**	**2071**	**2243**
V/C ratio		**0.20**	**0.27**	**0.16**	**0.20**
T		1	1	1	1
Control delay (sec/veh)		**4.3**	**5.1**	**2.1**	**2.0**
95th %ile approach queue (veh)		**0.8**	**1.1**	**0.6**	**0.8**
Queue Length (feet)		19	28	14	19

Project	Arizona I-17 Interchange Roundabout Research
Location	Phoenix, AZ
Scenario	West Roundabout. Recommended Geometry

Analyst	SXO	
Date	7-Apr-03	ıt Roundabout PM Peak Hour Recommended Geo.xls]Calcs
Rbt equation to use	D	(C=FHWA compact urban,S=FHWA single,D=FHWA double B=British approach specific, HCMU=HCM upper, HCML=HC
Study year	Existing 2002	
Time Period	P.M. Peak Hour	

Approach		**SB** **I-17 SB Off**	**SB** **Frontage Rd**	**EB** **Happy Valley**	**WB** **Happy Valley**
Entering volume (pce)		**124**	**109**	**120**	**1146**
Conflicting volume (pce)		**1195**	**1270**	**359**	**49**
Compact urban capacity		334	278	952	1182
Single-lane capacity		561	521	1017	1185
Double-lane capacity		1568	1515	2167	2389
HCM upper bound capacity		530	498	1044	1333
HCM lower bound capacity		404	377	853	1114
British approach specific		1568	1515	2167	2389
Rbt equation to use	D				
Ideal capacity (pce)		1568	1515	2167	2389
Capacity reductions					
Short lanes (only valid for D)					
Short lane present?		Y	Y	N	Y
Length of short lane (veh)		0	0	#N/A	9
Short lane factor		0.500	0.500	1.000	0.933
# of conflicting peds		0	0	0	0
Pedestrian factor		1.000	1.000	1.000	1.000
Adjusted capacity (pce)		**784**	**757**	**2167**	**2229**
V/C ratio		**0.16**	**0.14**	**0.06**	**0.51**
T		1	1	1	1
Control delay (sec/veh)		**5.5**	**5.6**	**1.8**	**3.3**
95th %ile approach queue (veh)		**0.6**	**0.5**	**0.2**	**3.2**
Queue Length (feet)		14	13	4	79

APPENDIX J
SIDRA Analysis Worksheets – Recommended Conditions

Movement Summary

akcelik & associates
aaTraffic SIDRA

Arizona I-17 Roundabout Interchange Research #5332

Roundabout

Vehicle Movements

Mov No	Turn	Dem Flow (veh/h)	Cap (veh/h)	Deg of Satn (v/c)	Aver Delay (sec)	Level of Service	95% Back of Queue (ft)	Eff. Stop Rate	Aver Speed (mi/h)	Oper Cost ($/h)
South Approach										
32	L	298	1344	0.222	16.0	LOS B	30	0.76	34.6	80
31	T	185	834	0.222	6.2	LOS A	30	0.50	39.0	43
33	R	152	1900	0.080	5.9	LOS A#	3#	0.45	40.5	34
Approach		**635**	**4078**	**0.222**	**10.7**	**LOS B**	**30**	**0.61**	**37.1**	**157**
East Approach										
22	L	249	1595	0.156	7.4	LOS A	22	0.58	38.5	59
21	T	57	365	0.156	7.4	LOS A	21	0.59	38.6	13
23	R	13	1900	0.007	5.9	LOS A#	0#	0.45	40.5	3
Approach		**319**	**3860**	**0.156**	**7.3**	**LOS A**	**22**	**0.58**	**38.6**	**75**
North Approach										
42	L	8	911	0.031	11.7	LOS B	3	0.67	36.5	7
42	T	19	911	0.031	11.7	LOS B	3	0.67	36.5	7
42	R	1	911	0.031	11.7	LOS B	3	0.67	36.5	7
Approach		**28**	**911**	**0.031**	**11.7**	**LOS B**	**3**	**0.67**	**36.5**	**7**
West Approach										
12	L	200	1453	0.138	15.2	LOS B	17	0.71	35.4	54
11	T	264	1919	0.138	4.9	LOS A	17	0.37	40.8	58
Approach		**464**	**3372**	**0.138**	**9.4**	**LOS A**	**17**	**0.52**	**38.2**	**112**
All Vehicles		**1446**	**12220**	**0.222**	**9.6**	**LOS A**	**30**	**0.57**	**37.7**	**350**

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Movement Summary

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Arizona I-17 Roundabout Interchange Research #5332

Roundabout

Vehicle Movements

Mov No	Turn	Dem Flow (veh/h)	Cap (veh/h)	Deg of Satn (v/c)	Aver Delay (sec)	Level of Service	95% Back of Queue (ft)	Eff. Stop Rate	Aver Speed (mi/h)	Oper Cost ($/h)
South Approach										
32	L	890	2831	0.314	14.8	LOS B	46	0.68	35.2	237
31	T	31	99	0.313	5.3	LOS A	46	0.41	40.0	7
33	R	80	1900	0.042	5.9	LOS A#	2#	0.45	40.5	18
Approach		**1001**	**4830**	**0.314**	**13.8**	**LOS B**	**46**	**0.66**	**35.7**	**262**
East Approach										
22	L	318	1435	0.222	8.5	LOS A	32	0.66	38.1	76
21	T	70	316	0.222	8.6	LOS A	30	0.69	38.2	17
23	R	1	1900	0.001	5.9	LOS A#	0#	0.45	40.5	0
Approach		**389**	**3651**	**0.222**	**8.5**	**LOS A**	**32**	**0.67**	**38.1**	**93**
North Approach										
42	L	5	718	0.202	12.8	LOS B	26	0.84	36.2	36
42	T	139	718	0.202	12.8	LOS B	26	0.84	36.2	36
42	R	1	718	0.202	12.8	LOS B	26	0.84	36.2	36
Approach		**145**	**718**	**0.202**	**12.8**	**LOS B**	**26**	**0.84**	**36.2**	**36**
West Approach										
12	L	61	1707	0.036	15.5	LOS B	4	0.72	35.3	16
11	T	59	1651	0.036	4.9	LOS A	4	0.38	41.1	13
Approach		**120**	**3358**	**0.036**	**10.3**	**LOS B**	**4**	**0.55**	**37.8**	**29**
All Vehicles		**1655**	**12556**	**0.314**	**12.2**	**LOS B**	**46**	**0.67**	**36.4**	**420**

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Movement Summary

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Arizona I-17 Roundabout Interchange Research #5332

Roundabout

Vehicle Movements

Mov No	Turn	Dem Flow (veh/h)	Cap (veh/h)	Deg of Satn (v/c)	Aver Delay (sec)	Level of Service	95% Back of Queue (ft)	Eff. Stop Rate	Aver Speed (mi/h)	Oper Cost ($/h)
East Approach										
22	L	136	796	0.171	14.4	LOS B	22	0.68	35.6	36
21	T	317	1855	0.171	4.9	LOS A	22	0.38	40.8	70
23	R	113	661	0.171	4.9	LOS A	20	0.38	40.8	25
Approach		**566**	**3311**	**0.171**	**7.2**	**LOS A**	**22**	**0.45**	**39.4**	**130**
North Approach										
42	L	92	1002	0.211	11.5	LOS B	25	0.68	36.6	53
42	T	1	1002	0.211	11.5	LOS B	25	0.68	36.6	53
42	R	118	1002	0.211	11.5	LOS B	25	0.68	36.6	53
Approach		**211**	**1002**	**0.211**	**11.5**	**LOS B**	**25**	**0.68**	**36.6**	**53**
North West Approach										
82	L	67	224	0.299	16.2	LOS B	45	0.82	34.7	18
81	T	196	654	0.300	8.0	LOS A	45	0.64	38.3	46
83	R	70	1900	0.037	6.9	LOS A#	2#	0.51	39.8	16
Approach		**333**	**2778**	**0.300**	**9.4**	**LOS A**	**45**	**0.65**	**37.8**	**80**
West Approach										
12	L	28	178	0.157	17.8	LOS B	25	0.74	34.0	8
11	T	304	1932	0.157	8.1	LOS A	25	0.60	38.2	72
13	R	1052	1900	0.554	6.1	LOS C#	23#	0.45	40.4	233
Approach		**1384**	**4010**	**0.554**	**6.8**	**LOS A**	**25**	**0.49**	**39.7**	**313**
All Vehicles		**2494**	**11101**	**0.554**	**7.6**	**LOS A**	**45**	**0.52**	**39.1**	**576**

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Movement Summary

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aaTraffic SIDRA

Arizona I-17 Roundabout Interchange Research #5332

Roundabout

Vehicle Movements

Mov No	Turn	Dem Flow (veh/h)	Cap (veh/h)	Deg of Satn (v/c)	Aver Delay (sec)	Level of Service	95% Back of Queue (ft)	Eff. Stop Rate	Aver Speed (mi/h)	Oper Cost ($/h)
East Approach										
22	L	229	559	0.410	14.5	LOS B	67	0.67	35.5	61
21	T	917	2240	0.409	5.0	LOS A	67	0.38	40.3	204
23	R	202	493	0.410	5.1	LOS A	60	0.38	40.1	45
Approach		**1348**	**3293**	**0.409**	**6.7**	**LOS A**	**67**	**0.43**	**39.3**	**310**
North Approach										
42	L	21	700	0.179	12.3	LOS B	23	0.82	36.6	31
42	T	1	700	0.179	12.3	LOS B	23	0.82	36.6	31
42	R	103	700	0.179	12.3	LOS B	23	0.82	36.6	31
Approach		**125**	**700**	**0.179**	**12.3**	**LOS B**	**23**	**0.82**	**36.6**	**31**
North West Approach										
82	L	25	147	0.170	18.9	LOS B	24	0.89	33.4	7
81	T	84	494	0.170	10.7	LOS B	24	0.79	37.5	20
83	R	58	1900	0.031	6.9	LOS A#	1#	0.51	39.8	13
Approach		**167**	**2542**	**0.170**	**10.6**	**LOS B**	**24**	**0.71**	**37.5**	**40**
West Approach										
12	L	49	943	0.052	17.0	LOS B	7	0.70	34.2	14
11	T	71	1366	0.052	7.3	LOS A	7	0.52	38.6	17
13	R	323	1900	0.170	6.0	LOS A#	7#	0.45	40.5	72
Approach		**443**	**4208**	**0.170**	**7.4**	**LOS A**	**7**	**0.49**	**39.3**	**102**
All Vehicles		**2083**	**10743**	**0.410**	**7.5**	**LOS A**	**67**	**0.49**	**39.0**	**483**

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APPENDIX K
Crash Prediction Model Worksheets – Recommended Conditions

British Crash Prediction Model

Project Name:	I-17 Roundabout Interchange Research
Project Number:	5332
Location:	East Roundabout
Scenario:	Recommended Geometry and Existing volume
units = meters	

	I-17 NB Off Ramp	West bound	SB Frontage Rd	East bound	Total Crashes
Input Data					
Qe :entry flow (1000s ADT)	8.700	4.120	0.910	3.220	
Qc: circulating flow (1000s ADT)	3.200	11.050	11.680	0.100	
Qex: exiting flow (1000s ADT)[1]		1.44	0.48	13.47	
Qp: pedestrian crossing flow (1000s ped/day)[1]					
Re: shortest path radius for entry in meters	73	73	40	125	
Ce: 1/Re	0.014	0.014	0.025	0.008	
Ra: approach radius	5,000.0		225.0		
Ca: 1/Ra	0.000		0.004		
e: entry width in meters	8.537	7.927	4.878	10.061	
v: approach width in meters	7.622	6.707	4.878	9.146	
R: inscribed diameter/island diameter	1.400	1.400	1.400	1.400	
Pm: proportion of mc's	0	0	0	0	
angle: ange to next leg, degrees	108	62	38	80	
Entry-Circulating personal injury/per yr/specific approach	0.070	0.107	0.024	0.015	0.216
Approaching personal injury/per yr/specific approach	0.126	0.038	0.005	0.018	0.187
Single Vehicle personal injury/yr/specifici approach	0.231	0.107	0.024	0.124	0.487
Other (vehicle) personal injury/yr/specific approach	0.037	0.055	0.017	0.001	0.111
Pedestrian personal injury/yr/specific approach	0	0	0	0	0.000
Total Crashes per approach	0.464	0.307	0.071	0.158	0.999

[1] For Pedestrian crash rates only

Based on TRRL Laboratory Report 1120, *"Accidents at 4-Arm Roundabouts"*, G Maycock and RD Hall, 1984

British Crash Prediction Model

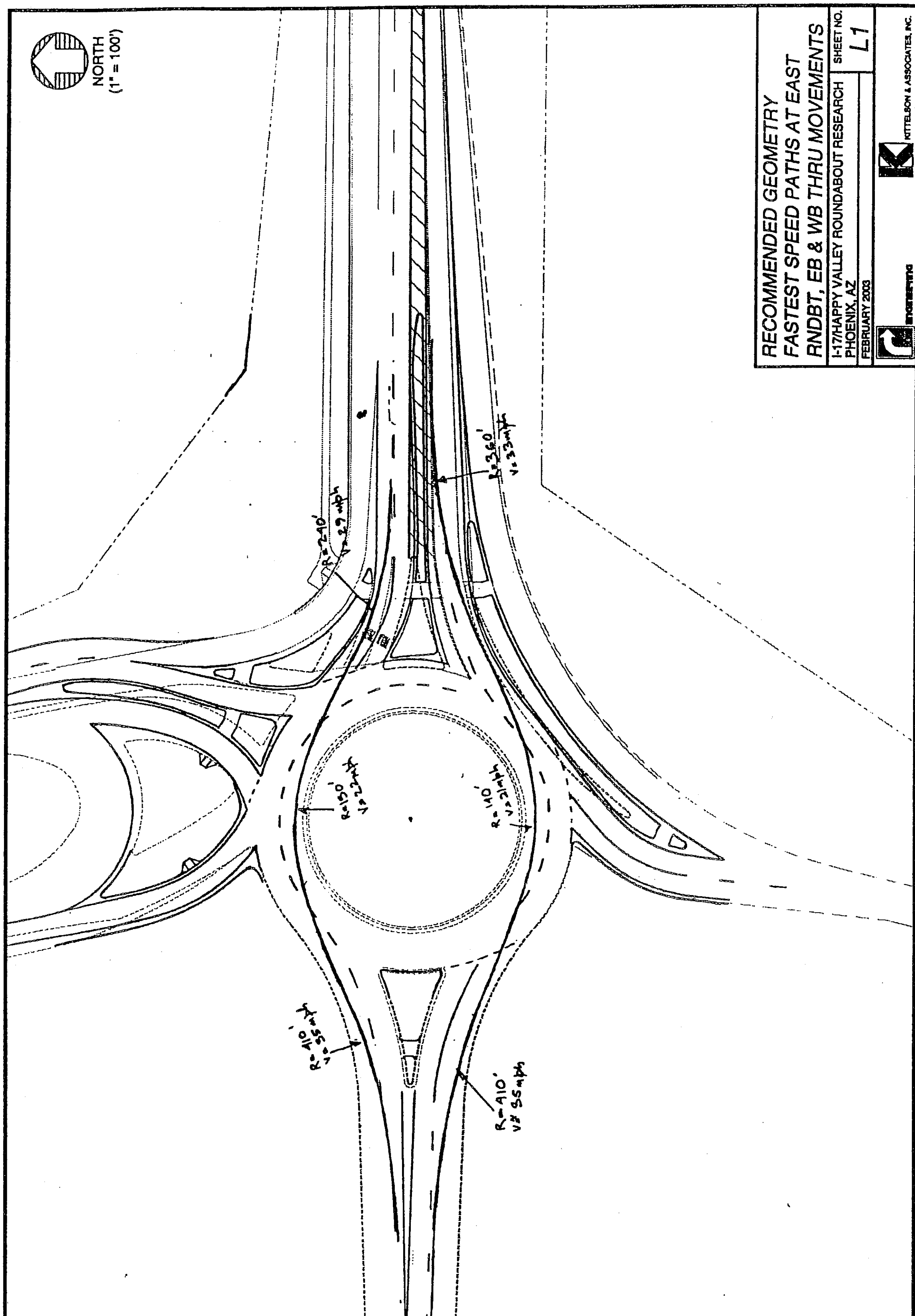
Project Name: I-17 Roundabout Interchange Research
Project Number: 5332
Location: West Roundabout
Scenario: Recommended Geometry and volume
units = meters

	West bound	I-17 SB Off Ramp	SB Frontage Rd	East bound	Total Crashes
Input Data					
Qe :entry flow (1000s ADT)	12.250	1.960	2.170	2.320	
Qc: circulating flow (1000s ADT)	0.640	12.930	11.260	4.900	
Qex: exiting flow (1000s ADT)	0.46		0.25	10.78	
Qp: pedestrian crossing flow (1000s ped/day)					
Re: shortest path radius for entry in meters	73	35	43	55	
Ce: 1/Re	0.014	0.029	0.023	0.018	
Ra: approach radius			160.0	1,432	
Ca: 1/Ra			0.006	0.001	
e: entry width in meters	7.622	5.488	5.183	7.317	
v: approach width in meters	7.317	4.573	4.573	7.317	
R: inscribed diameter/island diameter	1.400	1.400	1.400	1.400	
Pm: proportion of mc's	0	0	0	0	
angle: ange to next leg, degrees	87	29	64	105	
Entry-Circulating personal injury/per yr/specific approach	0.054	0.045	0.038	0.026	0.163
Approaching personal injury/per yr/specific approach	0.247	0.018	0.020	0.017	0.302
Single Vehicle personal injury/yr/specifici approach	0.289	0.056	0.040	0.083	0.468
Other (vehicle) personal injury/yr/specific approach	0.014	0.035	0.034	0.018	0.100
Pedestrian personal injury/yr/specific approach	0	0	0	0	0.000
Total Crashes per approach	0.603	0.154	0.132	0.143	1.032

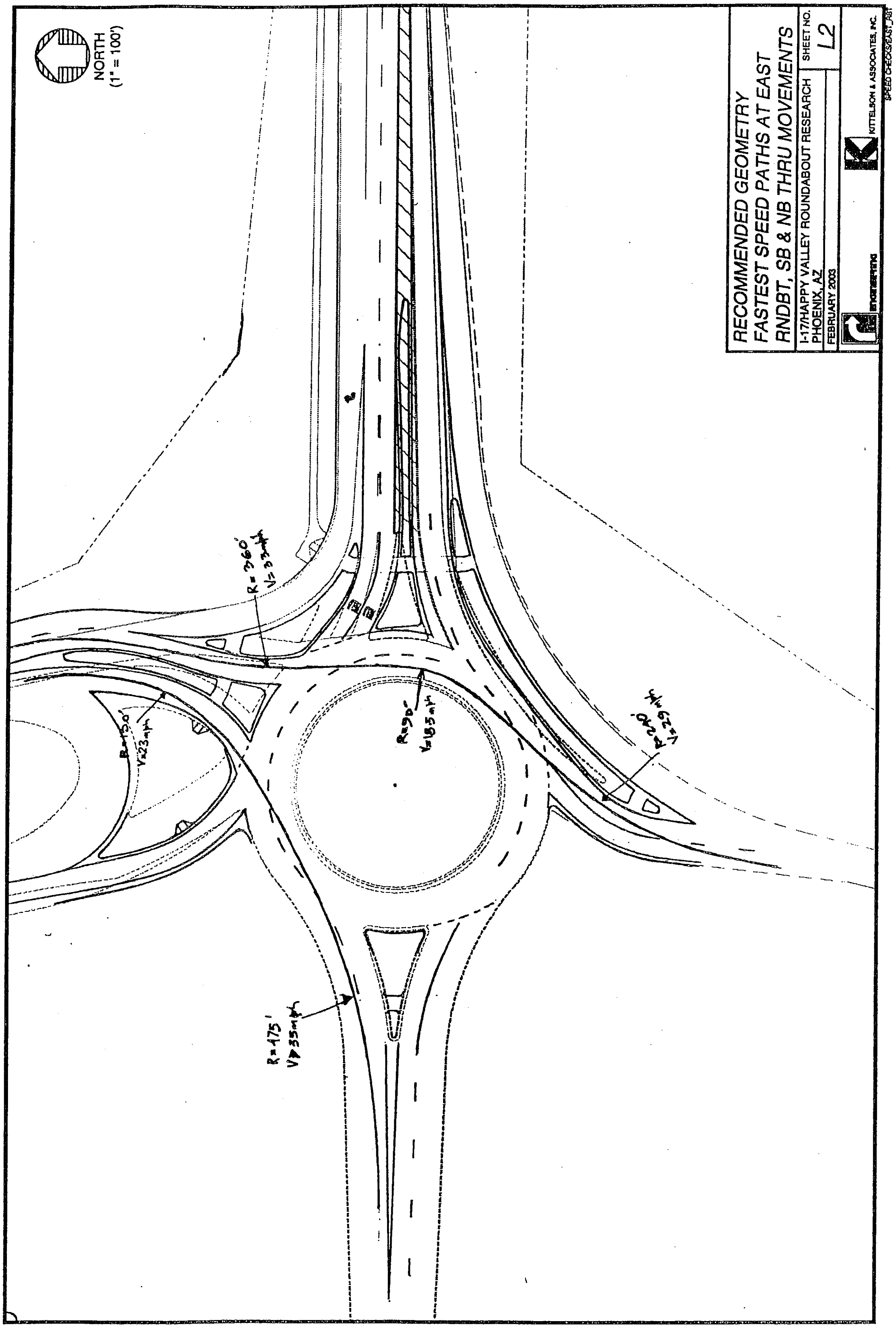
[1] For Pedestrian crash rates only

Based on TRRL Laboratory Report 1120, *"Accidents at 4-Arm Roundabouts"*, G Maycock and RD Hall, 1984

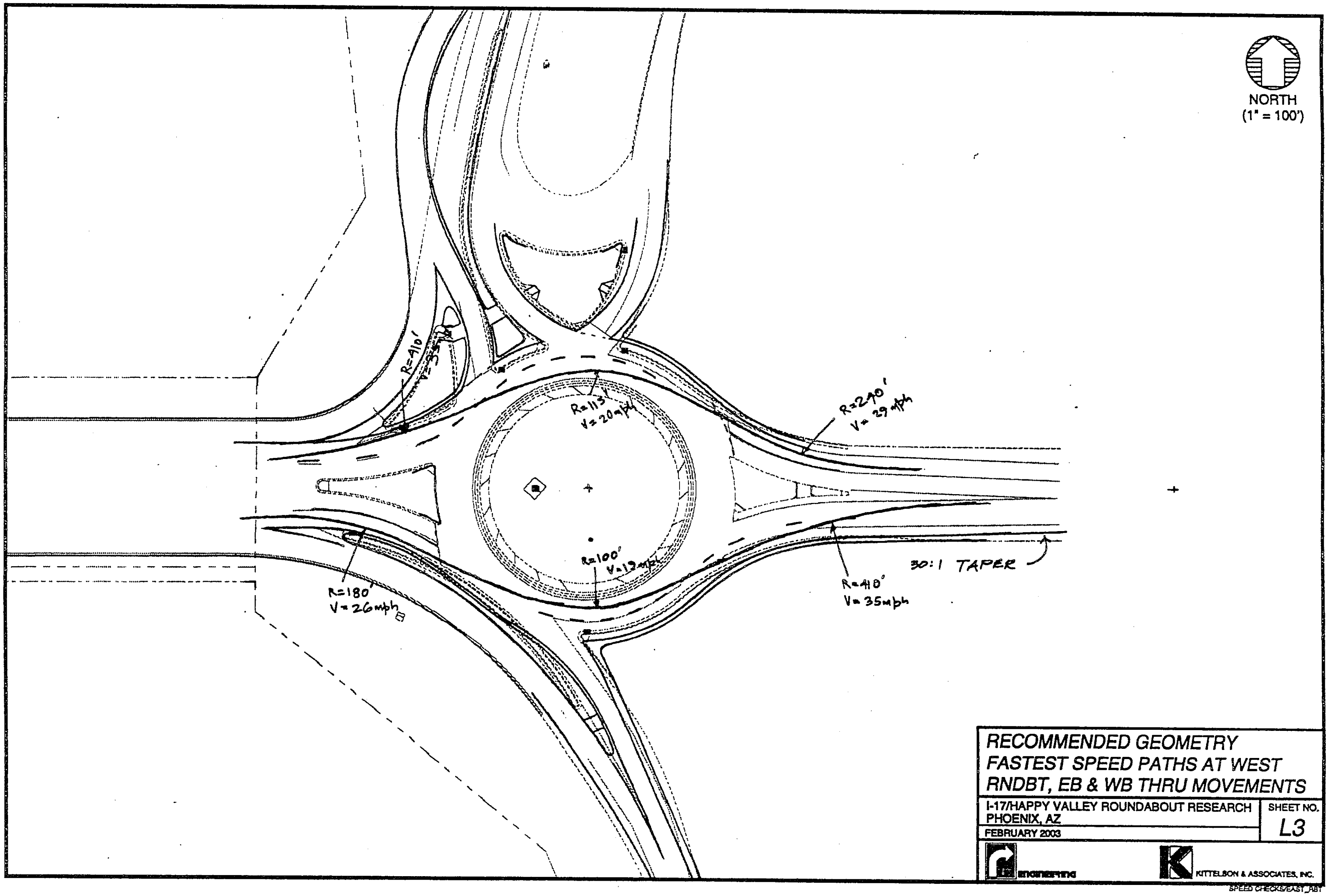
APPENDIX L
Fastest Path Sketches – Recommended Conditions



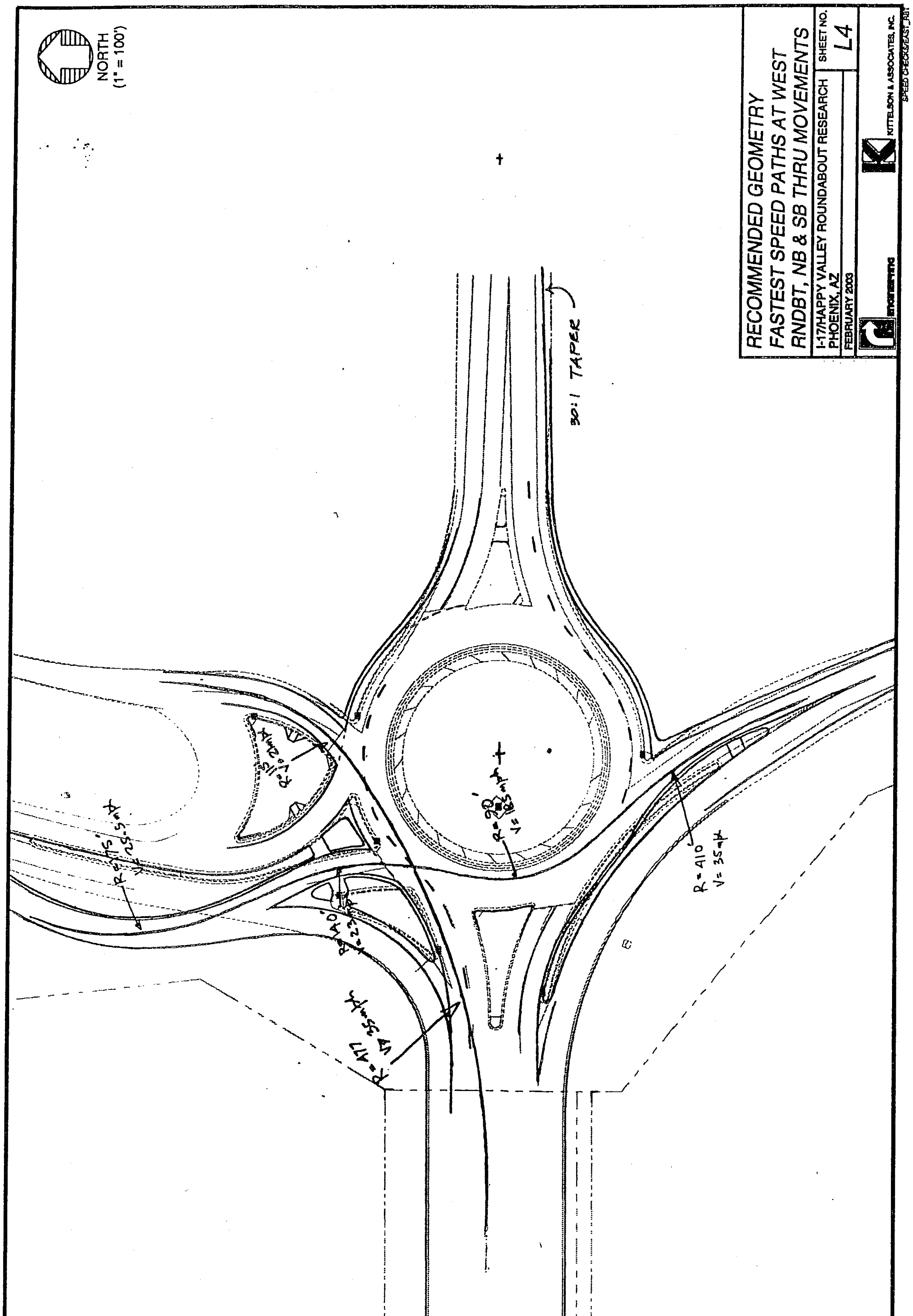
NORTH
(1" = 100')
R=240'
V=29 mph
R=360'
V=33mph
R=150'
V=22mph
R=140'
V=21mph
R=410'
V=35mph
R=410'
V=35mph
RECOMMENDED GEOMETRY
FASTEST SPEED PATHS AT EAST
RNDBT, EB & WB THRU MOVEMENTS
I-17/HAPPY VALLEY ROUNDABOUT RESEARCH
PHOENIX, AZ
FEBRUARY 2003
SHEET NO.
L1
KITTELSON & ASSOCIATES, INC.
SPEED CHECKS/EAST_RBT



NORTH
(1" = 100')
RECOMMENDED GEOMETRY
FASTEST SPEED PATHS AT EAST
RNDBT, SB & NB THRU MOVEMENTS
I-17/HAPPY VALLEY ROUNDABOUT RESEARCH
PHOENIX, AZ
FEBRUARY 2003
SHEET NO.
L2
KITTELSON & ASSOCIATES, INC.
SPEED CHECKS/EAST_RBT
R=175'
V=35mph
R=90'
V=18.5mph
R=130'
V=23mph
R=360'
V=37mph
R=240'
V=29mph



NORTH
(1" = 100')
R=410'
R=113
V=20mph
R=240'
V=29mph
R=100'
R=180'
V=26mph
30:1 TAPER
R=410'
V=35mph
RECOMMENDED GEOMETRY
FASTEST SPEED PATHS AT WEST
RNDBT, EB & WB THRU MOVEMENTS
I-17/HAPPY VALLEY ROUNDABOUT RESEARCH
PHOENIX, AZ
FEBRUARY 2003
SHEET NO.
L3
KITTELSON & ASSOCIATES, INC.


RECOMMENDED GEOMETRY
FASTEST SPEED PATHS AT WEST
RNDBT, NB & SB THRU MOVEMENTS
I-17/HAPPY VALLEY ROUNDABOUT RESEARCH
PHOENIX, AZ
FEBRUARY 2003
SHEET NO.
L4
KITTELSON & ASSOCIATES, INC.
NORTH
(1" = 100')
30:1 TAPER

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