NCRHP 3-65: DATA COLLECTION AND EXTRACTION

Michael Kyte, University of Idaho
Michael Dixon, University of Idaho
George List, Rensselaer Polytechnic Institute
Aimee Flannery, George Mason University
Lee Rodegerdts, Kittelson & Associates, Inc.

National Roundabout Conference

Vail, Colorado
May 22-25, 2005

24 November 2004

1. Overview

In 2002, a team led by Kittelson & Associates, Inc., was selected to lead a study of roundabouts in the United States. One of the primary objectives of this study, funded through the National Cooperative Highway Research Program and noted as NCHRP 3-65, is to develop a new set of predictive models to estimate the safety and operational impacts of roundabouts.

In order to model driver behavior and performance, it is necessary to have information on how drivers behave when using traffic facilities of various designs and characteristics. Thus one of the important elements of this study was to assemble a database of facility operation and safety for a wide variety of roundabout sites in the United States.

In this paper, we describe our process for collecting, extracting, and summarizing data at roundabouts. The data were collected during the spring and summer 2003, and were extracted and summarized during the fall 2003 and winter 2004. This database is now the largest that has ever been assembled for roundabouts in the United States.

Section 2 of this paper provides an overview of the characteristics of the more than 300 modern roundabouts that exist today in the United States. Section 3 describes the process that was used to collect and record data in the field. Section 4 describes how the data were extracted from the field records. Section 5 describes the database that has now been assembled.

The operation of roundabouts results from complex interactions between drivers and between drivers and the roundabout itself. What we have observed, measured, and documented can now be used to better understand what makes roundabouts operate efficiently and safely.

2. Roundabout Characteristics

There are now over 300 modern roundabouts in the United States. Nearly all of these roundabouts were constructed during the past 15 years, with nearly half opened since the year 2000.

Table 1 provides a summary of the database that was compiled by the project team of the 310 known roundabouts that existed in the United States as of 2003. This database was initially developed by a team led by Rensselaer Polytechnic Institute for a project conducted for the New York State Department of Transportation and supplemented by information collected for NCHRP 3-65. Most (94 percent) of these roundabouts are located in urban or suburban areas, with over half located in the western U.S. Over two-thirds of the roundabouts consist of a one lane circulating roadway and four approaches. Over half were converted from some form of stop control, while nearly a third are newly constructed intersections.

Note that while this database is extensive it does not represent an exhaustive list of all roundabouts in the United States that existed at the time the database was developed. Roundabouts that are most likely to be missing from this table fall into one of three categories: (1) no one has taken the time to report or record its existence, (2) the roundabout is not on or near a state-maintained highway (e.g., in a residential development) or (3) the agency responsible for the facility does not regard the facility as being a roundabout even though some people might classify it that way.

Table 1. Characteristics of modern roundabouts located in the U.S.[1]

Characteristics	Number	Percent of total
Total number	310	
Setting		
• Urban	103	36%
• Suburban	164	58%
• Rural	16	6%
Number of approaches		
• 6	4	1%
• 5	16	6%
• 4	197	68%
• 3	70	24%
• 2	4	1%
Number of lanes		
• 3	5	2%
• 2	72	25%
• 1	213	73%
Previous facility		
• One-way stop control	30	19%
• Two-way stop control	49	32%

[1] Not all characteristics are available for all sites; this explains why the totals for each characteristic add up to less than 310, the total number of roundabouts in the database. For example, "setting" data are available for 283 of the 310 roundabouts. The percentages cited for urban, suburban, and rural "settings" add up to 100 percent of the sample of sites for which data for this characteristic is available.

• All-way stop control	16	10%
• Signal control	14	9%
• None	46	30%
Year created		
• 2000 or later	70	46%
• 1995-1999	70	46%
• 1994 or earlier	61	8%
Geographic location (zip code)		
• Northeast (0,1)	24	8%
• Mid-Atlantic (2)	45	15%
• South, Southeast (3,7)	32	12%
• Midwest (4,5,6)	39	13%
• Mountain West (8)	94	30%
• Pacific Coast (9)	76	25%

Figure 1 shows a graphic display of the roundabout sites included in this database.

Figure 1. Geographic distribution of roundabout sites

3. Field Data Collection

3.1 Field sites

The roundabouts described in section 2 of this paper provided a rich source from which potential sites for the project field data collection effort were identified. To narrow down the list, several criteria were considered in the selection of sites at which field data would be collected. These criteria included:

- The likelihood of finding continuous (persistent) queuing on one or more of the roundabout approaches, representing capacity conditions.
- A balance between one lane and multilane sites so that operational characteristics of both kinds of sites could be studied.
- A range of other geometric conditions so that the effect of these conditions on operations and safety could be studied.
- A clustering of sites so that driving time to the sites could be minimized, thus maximizing the number of sites that could be studied.

Table 2 shows a complete list of the 31 sites that were selected for field data collection and that were eventually visited by the project team during the spring and summer 2003.[2] Video recordings were made at each of these sites and other geometric, operations, and safety data were recorded as well. Included in the table are the date of the site visit, the site name[3], the intersection name, and the city and state in which the roundabout is located.

At each site, the field team:

- Made video recordings of traffic flow on at least one roundabout approach.
- Measured and recorded speeds of vehicles at different points entering and within the roundabout.
- Made notes on the geometric characteristics of the roundabout.
- Collected available crash statistics from the relevant jurisdiction.

3.2 Video recording

A video recording system was designed that would allow the team to record the movement of vehicles and pedestrians at each roundabout. The recording system included the following components:

- Two masts, each extendable to 30 feet, that provided the platform for the video cameras.
- Three digital video cameras, each focused on individual approaches at the roundabout.
- Two omni-directional cameras that provided a 360-degree view of the roundabout.
- Four DVD recorders to record the video directly from the digital and omni-directional cameras to DVDs at the site.

A pilot study conducted in April and May 2003 at two sites in Washington State[4] provided the team with experience in using the video recording system that would prove useful for the more extensive field data collection effort. While the team had significant experience in using the masts from earlier projects[5], this was the first time that digital cameras and recording equipment were used. Some of the findings from the pilot study are summarized below.

- The camera setup proved to be suitable.
  - The omni-directional camera provided an excellent overview of the entire roundabout. If the camera was placed on a mast in the center of the roundabout, the entire roundabout and all of the approaches could be observed.

[2] It should be noted that other sites were included in the original field list. Bad weather prevented video recording at these sites.
[3] The site name includes the state in which the roundabout is located and the number of that site within a state. For example, MD03 is the third roundabout in Maryland at which field data were collected.
[4] The sites were located in the cities of Kennewick and Gig Harbor.
[5] For example, NCHRP 3-46, Unsignalized Intersections, conducted between 1993 and 1995.

    - The use of standard video cameras provided clear views of vehicle and pedestrian movements on a specific approach.
- The use of all-digital recording (DVDs and recorders) proved to be satisfactory as the recording medium.

The mast system used for NCHRP 3-46 was well suited for the data collection needs for NCHRP 3-65. However, the amount of equipment and associated personnel needed to instrument a roundabout was more extensive. At least three people were needed to set up and take down the equipment. When combined with other field data collection requirements (speed measurements, safety data, and geometric data), a team of four persons was needed to adequately collect the data needed for project. A four person team was used for the main field data collection effort that took place between June and August 2003.

Table 2. List of data collection sites

Date		Site Name	Intersection name	City and state
June	9	NV01	Hills Center Dr./Village Center Cir./Meadow Hills Dr.	Las Vegas, NV
	10	NV02	Town Center. Dr/Hualapai Way/Far Hills Ave.	Las Vegas, NV
	11	NV03	Town Center Dr./Village Center Cir./Library Hills Dr.	Las Vegas, NV
	12	NV04	Town Center Dr./Banburry Cross Dr.	Las Vegas, NV
	17	CO01	SH-6/I-70 spur	Eagle, CO
	19	CO02	South Golden Road/Johnson Rd/16th Street	Golden, CO
	20	CO03	South Golden Road/Utah St.	Golden, CO
	30	MD01	Tollgate Rd. /Marketplace Dr.	Bel Air, MD
July	1	MD02	MD213 at Leeds Rd/Elk Mills Rd (Lanzi Circle)	Leeds, MD
	2	MD03	MD24 at MD 165 (North Harford)	Jarrettsville, MD
	7	MD04	MD139 (Charles St.) at Bellona Ave	Baltimore County, MD
	8	MD05	MD45 at MD146/Joppa Rd	Towson, MD
	9	MD06	MD 2 at MD 408/MD 422	Lothian, MD
	10	MD07	MD 140/MD 832/Antrim Blvd	Taneytown, MD
	14	VT01	Route 7A/Equinox (Grand Union)	Manchester, VT
	15	VT02	Main St and Spring St (Keck Circle)	Montpelier, VT
	16	VT03	Route 9/Route 5	Brattleboro, VT
	18	ME01	US 202/State Route 237	Gorham, ME
	23	MI01	Hamilton Rd/Marsh Rd	Okemos, MI
	25	KS01	Sheridan St./Rogers Rd	Olathe, KS
	28	CO04	SH 82/ Maroon Crk, Castle Crk	Aspen, CO
	30	UT01	1200 South/400 West	Orem, UT
	31	UT02	1200 South/Sandhill	Orem, UT
August	4	WA01	SR 16 SB Ramp Terminal (near Pioneer at Stinson)	Gig Harbor, WA
	5	WA02	Borgen Blvd/51st	Gig Harbor, WA
	6	WA03	High School Rd/Madison Ave.	Bainbridge Island, WA
	7	WA04	Mile Hill Dr. (Hwy 166)/Bethel Ave	Port Orchard, WA
	11	WA05	NE Inglewood Hill/216th Ave NE	Sammamish, WA
	12	WA06	SR 522 EB Ramps/W. Main St.(164th St SE)/Tester Rd	Monroe, WA
	13	WA07	I-5 off-ramp/Quinault Dr/Galaxy Dr	Lacey, WA
	15	OR01	Colorado/Simpson	Bend, OR

Figure 2 shows one mast set up in the middle of a roundabout located in Kennewick, Washington, one of the pilot study sites. This location provided a view of all traffic entering into and circulating around the roundabout (from the omni-directional camera) as well as all of the vehicle and pedestrian movements on one approach of the roundabout (from the digital camera). The recording equipment was located on the ground to the left of the mast in the figure. Cables provided power to the cameras as well as the connections from the cameras to the recording equipment.

Figure 2. Mast set up in middle of roundabout, Kennewick, Washington

Figure 3 shows a close up of the omni-directional camera (on the left) and digital camera (on the right) located on the top of the mast.

At the beginning of the field data collection both masts were used, with two cameras located on the top of each mast. However, one mast and two digital cameras were destroyed during an unexpected wind storm in Colorado in late June 2003. Modifications were made to the remaining mast so that one omni-directional camera and three digital cameras could be accommodated. While the loss of the mast and cameras was an unexpected and very distressing event for the field data collection team, the use of only one mast greatly reduced the set-up and take-down times for the field team.

Figure 3. Omni-directional camera and digital camera located at top of mast

Figure 4 shows a typical view of one approach taken by one of the digital cameras. This view shows both circulating vehicles and vehicles queued on the approach. All vehicle movements associated with this approach are clearly visible.

Figure 4. View of one approach from digital camera, site WA03-s1

Figure 5 shows a typical view from the omni-directional camera. Vehicles on all four approaches are shown, as well as vehicles circulating on the roundabout. Distances in the field of view are not distorted because of the camera's optics .This omni-directional view provides an excellent record of all vehicle and pedestrian movements, as well as of the intersection geometry and markings.

Figure 5. View from omni-directional camera, site WA03-V1

A total of 262 DVDs were recorded at the 31 sites, including 166 DVDs of individual roundabout approaches. The recordings made for the individual approaches included 474 hours of traffic operations. Twelve of the approaches were for three-lane sites, 58 were for two-lane sites, and 96 were for one-lane sites.

3.3 Field speed measurements

Spot speed data were collected for this project during the summer of 2003 at 34 sites. In addition to the sites listed in

Table 2, the speed data were collected at the following sites:

- Eby Creek Rd/US 6, Eagle, CO
- SH 82/Maroon Crk/Castle Crk, Aspen, CO
- MD 100/Snowden River Pkwy, Howard Co, MD
- MD 94/Old Frederick Rd, Lisbon, MD
- MD 94/MD 144, Lisbon, MD
- Tollgate/Marketplace, Bel Air, MD
- Utah Valley State College, Orem, UT
- Borgen/41st, Gig Harbor, WA

The speed data were collected using a radar gun, recording speeds of free-flow vehicles (i.e. vehicles not influenced by conflicting traffic or vehicles not part of a queue or a platoon) on each approach to the nearest 1 mph (1.6 km/h) at the following locations at the roundabout (see Figure 6):

- Location 1 was well upstream of the roundabout (approximately 250 feet from the entry yield line). Speeds collected at this location, defined as *approach*, were intended to capture vehicles traveling the roadway just before decelerating to navigate the roundabout.
- *Entering* speeds were captured just as vehicles entered the roundabout (location 2). These speeds were recorded just as the front bumper of the vehicle crossed the entry yield line. Again, vehicles were only measured when they were free flowing, that is, when they were not yielding to other vehicles entering the roundabout or circulating around the center island.
- *Circulating* speeds were captured as vehicles traveling the circulating roadway crossed the midpoint of a splitter island (location 3). The purpose of collecting the speed of vehicles within the circulating lane was to learn more about how drivers negotiated a range of inscribed diameters to understand not only the safety implications but also how geometric design elements influence operational performance.
- *Exiting* speeds were recorded as vehicles exiting the roundabout had just completely cleared the circulating roadway (location 4). One area of concern for pedestrians is the exiting path of vehicles. It has been noted[6] that drivers begin to accelerate, in some cases, as they complete their negotiation of the circulating roadway. Since many drivers do not use their turn signals at roundabouts, pedestrians are often at a disadvantage when crossing the exit lanes of an approach.

The number of observations varied by location and approach and depended primarily on the number of free flow vehicles available. Data for entering, circulating, and exiting

[6] Robinson, B. W., Troutbeck, R., Werner, B., Lothar, B., Courage, K., Kyte, M., Mason, J., Flannery, A., Myers, E., Bunker, J., Jacquemart, G. (2000). Roundabouts: an Informational Guide. FHWA-RD-00-067. Federal Highway Administration, McLean, VA.

speeds were differentiated by turning movement (left, through, and right) and vehicle type (passenger cars and trucks[7]).

The data collection team sought to measure 30 speed observations for each directional location (thus a total of 480 measurements at a four-leg roundabout), and, in cases of extremely low traffic volume, *a minimum* of 15 observations. These criteria would ensure that a sufficient number of data points would be available for statistical analysis.

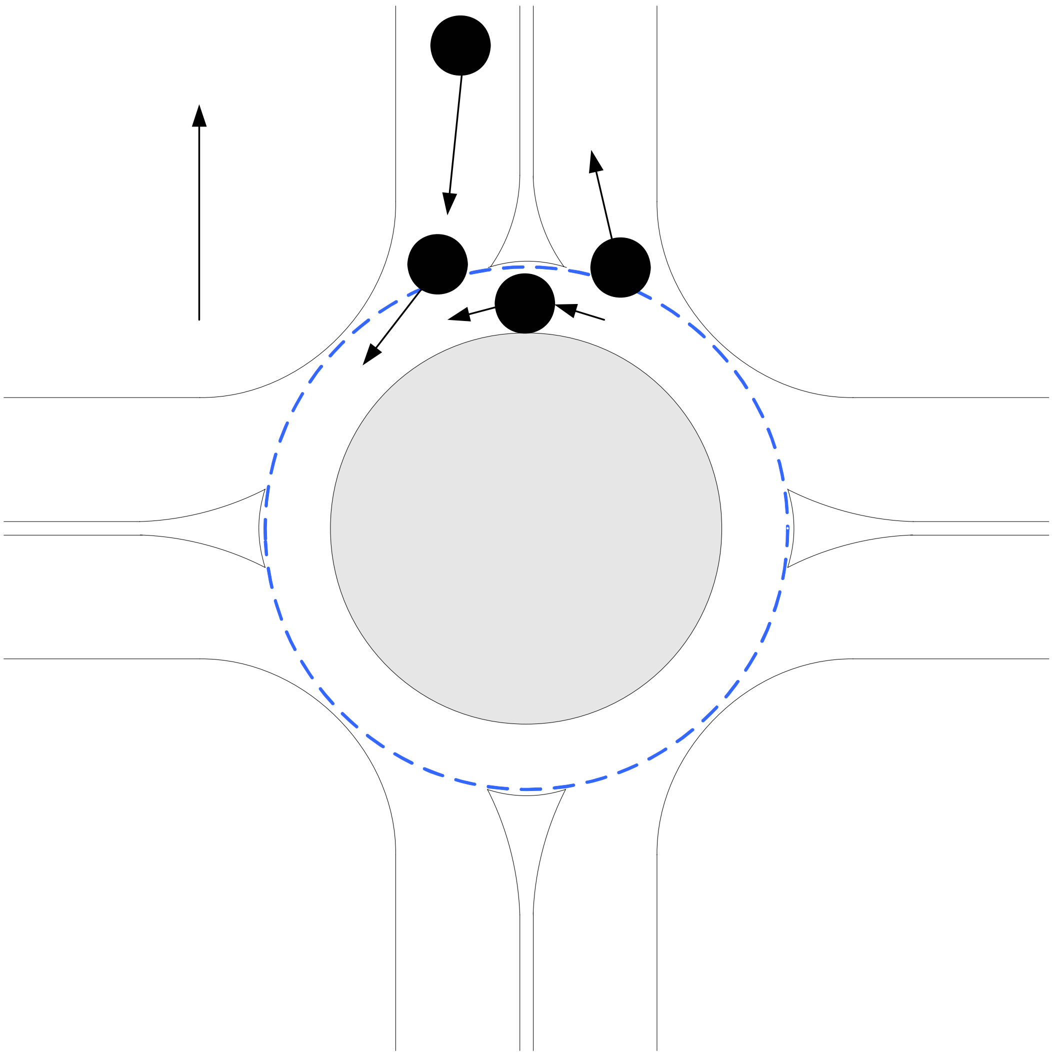


Figure 6. Spot speed data collection locations[8]

3.4 Crash data

Crash data were gathered by two primary means:

[7] There was insufficient data for trucks to conduct a statistical analysis of truck speeds.
[8] Graphic prepared by Hyunwoo Cho, Rensselaer Polytechnic Institute

- Crash records were gathered from local jurisdictions in the vicinity of all field data collection sites.
- Additional data were gathered via phone calls, e-mail and traditional mailings to jurisdictions that might have roundabouts with significant crash histories (i.e., roundabouts that had been in operation for more than one year).

The crash data are of three forms:

- Roundabout level crash data (i.e., number of crashes before and after roundabout installation).
- Roundabout level type specific crash data (i.e., how many of each type of crash before and after roundabout installation)
- Approach specific crash data (i.e., how many, what type, and location of crashes before and after roundabout installation).

Given the needs for roundabout modeling, every effort was made to gather approach/crash specific crash data. As of August 1, 2004, crash data for 117 roundabouts had been collected and synthesized. From these 117 locations, a total of 3,349 crashes and 722 injury crashes occurred before and after roundabout installation. Approach specific information includes 737 crashes at 55 roundabouts. Table 3, Table 4, and Figure 6 contain a breakdown of the information contained in the Safety Database generated as part of NCHRP 3-65.

Table 3. Contents of safety database

	Number	Percent of total
Number of roundabouts	117	
Number of approaches	446	
One-lane roundabouts	79	67.5%
Two-lane roundabouts	36	30.8%
Three-lane roundabouts	2	1.7%

Table 4. Summary of crash records

Crashes	Total crashes		Injury crashes		Ratio of injury crashes to all crashes
	Number	Percent of total	Number	Percent of total	
Before construction	1735	51.8%	507	70.2%	0.29
During construction	104	3.1%	25	3.5%	0.24
After construction	1510	45.1%	190	26.3%	0.13
Total	3349		722		

Table 5. Summary of approach-specific crash records[9]

	Total crashes	Injury crashes	Ratio of injury crashes to all crashes
Entry/rear-end crashes	210	18	0.09
Approach/rear-end crashes	15	0	0.00
Entry/circulating crashes	177	8	0.05
Circulating/exiting	206	12	0.06
Circulating/exiting/rear-end	12	3	0.25
Loss of control crashes	101	25	0.25
Vehicle/pedestrian crashes	7	7	1.00
Vehicle/bike crashes	9	5	0.56
Total	737	78	0.11

Volume data were also gathered as it is useful to understand the changes in crash rates before and after roundabout installation. Table 6 contains information regarding the number of roundabouts for which volume data were available.

Table 6. Summary of approach-specific volume data

	Number	Percent of total
Sites with before volume data	63	53.8%
Sites with after volume data	87	74.4%
Total	150	

[9] The crash-specific records were extracted from 220 approach legs at 55 roundabouts.

4. Extraction of Operations Data

4.1 Time periods of interest

Extraction of data from video recordings is a time-consuming and costly process. The limited project budget required that a strategy be developed to focus only on those time periods that would provide data to meet requirements established by the project team. One of the major requirements was data describing the operation of roundabouts when queues were present, so that measurements of capacity could be made. To identify these periods of continuous or persistent queuing, each of the 166 DVDs recorded for an individual approach was reviewed and the beginning and ending of each persistent queue was noted. In addition, the time that each bicycle and pedestrian event occurred was recorded.

This review identified that queues were present during approximately 61 hours and 24 minutes, or 13 percent of the total of 474 hours of video recording. The maximum continuous queue recorded was 31 minutes and 39 seconds. In addition, a total of 649 bicycle and 1821 pedestrian events were recorded, with maximum values of 42 bicycle and 125 pedestrian events during one DVD recording.

The selection of the time periods for which data would be extracted was based on the following criteria:

- The maximum queue duration, the mean queue duration, and the total duration of all queues computed for each of the approaches. The approaches were ranked according to each of these three factors.
- The time plots of the queues were reviewed to identify persistent periods of queuing in a graphical manner. Figure 7 shows an example plot of the presence and absence of a vehicle at the stop line over a four hour period at site WA03-S3. When a vehicle is present at the stop line the higher value is shown; when there is no vehicle present at the stop line, the lower value is shown. Table 7 shows a summary of the queuing data for site MD07 located in Taneytown, Maryland for the three approaches for which video was recorded as well as a summary of the queuing characteristics for each of the approaches. These graphics helped to visually identify periods of persistent queuing that were in close temporal proximity.

Using these criteria, a total of 33 hours and 3 minutes of operations (at 15 sites) were identified for data extraction. This includes 5 2-lane sites (17 individual approaches) with a total of 17 hours and 18 minutes of near continuous queues and 10 1-lane sites (21 individual approaches) with a total of 15 hours and 15 minutes of near continuous queues. This represents only 7 percent of the total field video recording time, and shows the extent of field recording that must be made to secure a useful amount of data.

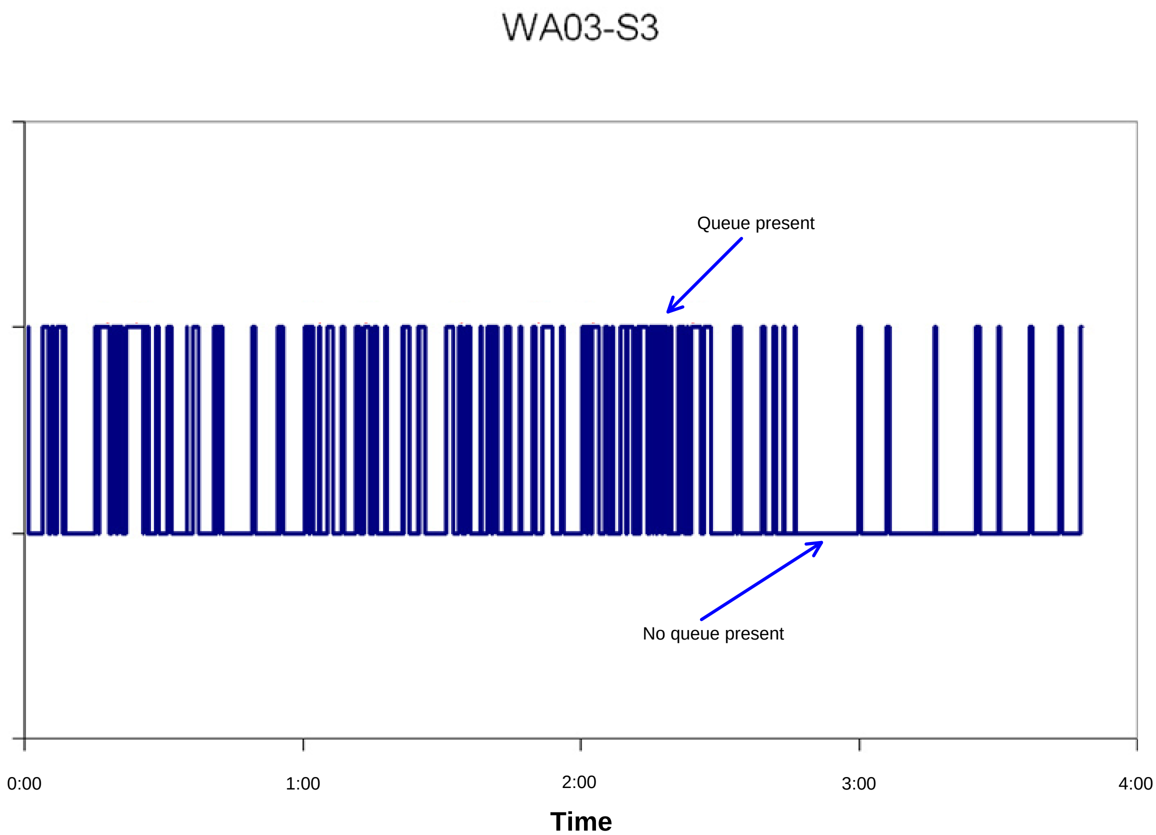
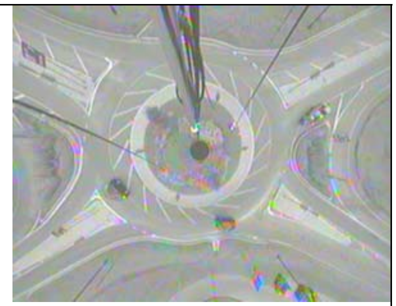
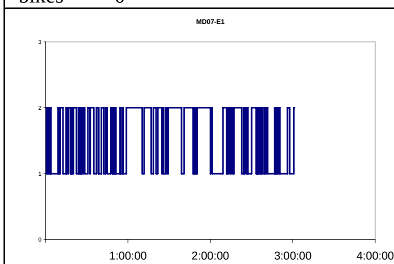
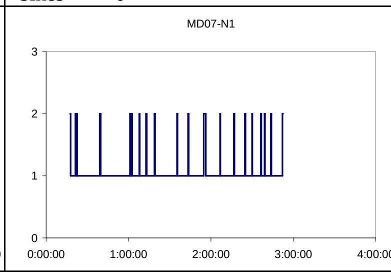
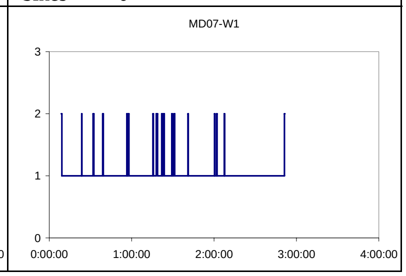


Figure 7. Variation of queue with time, site WA03-S3

Table 7. MD07, MD 140/MD 832/Antrim Blvd, Taneytown, Maryland

Lanes on circulatory roadway Lanes on approaches Number of approaches	1 1 4	
MD07-E1	MD07-N1	MD07-W1
		
max 0:11:28 mean 0:01:43 sum 1:39:42 total 3:01:14 percent 55.0% ped 1 ped-team 1 bikes 0	max 0:01:27 mean 0:00:26 sum 0:08:47 total 2:52:34 percent 5.1% ped 3 ped-team 3 bikes 0	max 0:00:57 mean 0:00:26 sum 0:07:24 total 2:51:33 percent 4.3% ped 2 ped-team 1 bikes 0
		

4.2 Data extraction process

The data extraction process included five steps, including the initial DVD review, the extraction of the raw or event data, error checking, data set merging, and preparation of final data sets.

Table 8 summarizes the data extraction process.

Table 8. Data extraction process

Activity	Purpose	Description
Step 1. Initial DVD review	To identify periods of continuous queuing and pedestrian/bicycle activity	• Each DVD is reviewed for quality of field of view (can all points of interest be clearly observed?). • Each Sony camera DVD is reviewed for periods of continuous queuing. The begin and end times for queuing activity is noted. • Each time period is reviewed for pedestrian and bicycle activity.
Step 2. Raw data (event) extraction	To record the time stamps for all events of interest during periods of continuous queuing	Flow rate data. The following events are extracted for selected DVDs recorded with the omni-directional camera: • EnterTime • Enter approach • ExitTime • Exit approach • Vehicle type (passenger car or other)
		Gap data. The following events are extracted for selected DVDs recorded with the Sony camera: • FirstQTime • EnterTime • ConflictingTime • ExitTime
		Delay data. The following events are extracted for selected DVDs recorded with the Sony camera: • UpstreamTime • FirstQTime • EnterTime
		Pedestrian/bicycle data. The following events are extracted for selected DVDs recorded with the Sony camera: • PedFirstQTime • PedEnterTime • VehYield • PedExitTime • PedType • PedConflictTime
Step 3. Error checking and time corrections	To identify keystroke (event recording) errors and to account for differences in DVD starting times	• Common events (EnterTime, FirstQTime, ExitTime) from the three data sets (flow rate data, gap data, delay data) are compared for consistency. Problems are reviewed and corrected. • Common vehicle events are identified for each DVD covering the same time periods. Time correction factors are computed based on the observation of these common vehicle events. Time stamps are adjusted based on this time correction factor. • One minute summaries are prepared for the common events to further verify the accuracy of the event data sets.
Step 4. Merge event data sets	To merge data sets for each roundabout approach	Data from the three data sets (flow rate data, gap data, delay data) for each approach and time period are merged. The following time/events are included for each vehicle: • UpstreamTime • FirstQTime • EnterTime • ExitTime • Exit approach • Vehicle type The following data (time/events) are also recorded for the circulating vehicles affecting the subject approach: • ConflictingTime • ExitTime
Step 5. Prepare data summaries and compute parameters of interest	To prepare one-minute summaries for each data set and to compute selected parameters	The following data are computed based on the merged data sets prepared in step 4. • Turning movement flow rates, 1-minute summaries • Delays, 1-minute summaries • Follow up times • Critical gaps • Entry and circulating flows during periods of continuous queuing, 1-minute summaries

4.3 Primary (event) data

Five events were extracted from the DVD video using keystroke recording software. When any of these five events occurred, the proper key was pressed and a time stamp was generated in a computer file. These events are listed in Table 9 and illustrated in Figure 8 for the east approach of a roundabout in Maine, ME01-E.

Table 9. Events of interest

Event	Keystroke	Description
Entry time	2	The entry of a vehicle into the roundabout from the approach. The time was recorded when the vehicle crossed the yield line; the lane placement of the vehicle (either left lane or right lane) was recorded for two lane roundabouts. The vehicle type was also recorded.
First-in-queue time	1	The arrival of a vehicle into the server or first in line position on the approach. The time was recorded when the vehicle was about to enter the roundabout (if it did not stop) or the time that it stopped at or near the yield line waiting to enter the roundabout.
Upstream time	z	The passage of a vehicle past a point upstream of the entry point that defines the beginning of the travel time trap.
Conflict time	s	The passage of a vehicle through the conflict point on the roundabout, a point that is adjacent to the point of entry for a minor street vehicle.
Exit time	a	The exiting of a vehicle from the roundabout.

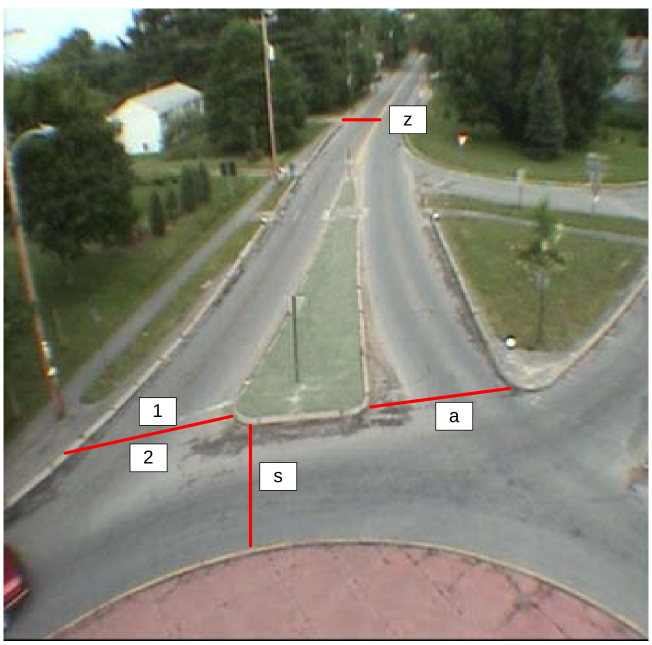


Figure 8. Location of events of interest at roundabout approach, ME01-E

4.4 Secondary data

The event data were used to compute a set of secondary, or derived, data. For example, the number of events that occurred during a specified time interval is the flow rate past the point at which the event was recorded. Or, the time difference between the passing of two vehicles at a given point is the headway between these two vehicles. A complete list of the secondary data is given below:

- The *flow rate* is the number of vehicles passing by a given point during a specified time interval. Flow rates were computed for entry flows, circulating or conflicting flows, and exit flows. Events "2", "s", and "a" were used to compute these flow rates.
- *Delay* is the time spent traveling from the "z" line to the yield line (the "2" event) on a given approach that is in excess of the free flow time for this same path. The free flow time was measured for each approach, considering a sample of vehicles moving unobstructed from the "z" line to the "2" line. The actual travel time for each vehicle was computed for this same pair of events. The difference between these two travel times is the delay for a given vehicle.
- The *turning movement proportion* is the proportion of vehicles entering from one approach and traveling to each of the possible exit points on the roundabout. The "2" and "a" events were used to compute the turning movement data.
- The gaps between vehicles on the circulating roadway that were accepted or rejected by vehicles on the minor approach were recorded. A gap sequence is the sequence of events that define the first circulating vehicle (events "s" or "a"), any intervening entry vehicles (event "2"), and the second circulating vehicle (events "s" or "a"). For multi-lane roundabouts, the lane position of vehicles on the circulating roadway must be considered in this gap sequence.
- The service time is the time difference for a minor approach vehicle between the "1" event and the "2" event. This is the time that a vehicle spends in the server.
- The move up time is the time difference between the entry of one vehicle into the roundabout (the "2" event) and the arrival of the following vehicle at the first in queue position (the "1" event).
- The travel time on the roundabout is the elapsed time from the entry of a vehicle into the roundabout (the "2" event) and the exit of the vehicle from the roundabout (the "a" event).
- The proportion of time that a queue exists on an approach for each minute is the sum of the service times plus the move-up times for that minute divided by sixty seconds.

One-minute summaries were prepared for the following secondary data:

- Entry flow
- Conflicting flow
- Exit flow
- Average delay
- Proportion time queued

The following gap data were computed for each vehicle entering the roundabout:

- The size of the accepted or rejected lag, defined as the time from the arrival of the minor vehicle at the server ("1" event) to the arrival of the next conflicting vehicle ("s" event).
- The size of all gaps that are rejected by the minor vehicle, defined as the time between subsequent vehicles on the circulating roadway ("s" events).
- The size of the gap that is accepted by the minor vehicle, defined as the time between the two consecutive conflicting vehicles on the circulating roadway ("s" events).

4.6 Turning movement data

Turning movement flow rates were determined using the entry flow rate and the turning movement proportions. The entry flow rate was based on the "2" event data, described earlier. Turning movement proportions were estimated by tracking randomly selected vehicles through the roundabout, where the proportion of the sample was assumed to be similar to that of the population.

Vehicle samples were chosen randomly, by following the steps below, while viewing the omni-directional video:

- Step 1. Select a vehicle to sample
- Step 2. Track the selected vehicle to its exit leg
- Step 3. Record the turning movement and times for entry and exit for each vehicle
- Step 4. Repeat steps 1 through 3.

The turning movement proportions were then calculated from the sampled data. Finally, the turning movement flow rate was determined by multiplying the entry flow rate by the turning movement proportion.

5. The Assembled Database

The database that has now been assembled represents a rich resource, not only for the NCHRP 3-65 project team but for other researchers as well. The database consists of operations data, crash data, and geometric data.

5.1 Overall summary

The database includes several levels of data in a variety of formats:

- 262 DVDs recorded at 31 roundabouts, from which primary (event) data and secondary data (processed parameters) describing the operations of the roundabouts
- An additional 29 DVDs recorded at four roundabouts, from which capacity and/or pedestrian/bicycle data were extracted
- 3,349 crash records
- Geometric data for 101 sites

5.2 Overview of the operations database

The operations database includes 15 one-lane approaches and 9 two-lane approaches. The one-lane sites include fifteen unique approaches and a total video time of 15:53:16. The two-lane sites include nine unique approaches and a total video time of 18:30:18. Table 10shows some of the highlights of the data sets that were produced based for the 34 hours of traffic operations:

The database for the one-lane sites includes 884 one-minute time intervals. The maximum entry flow rate is 24 vehicles per minute, while the maximum conflicting flow rate is 18 vehicles per minute. The one-minute average delay ranges from zero to 47.1 seconds per vehicle, while the means range from 4.9 seconds per vehicle at the site/approach MD06-N to 18.9 seconds per vehicle at the site/approach WA01-N. The mean proportion time queued ranges from 0.60 at the site/approach WA01-N to 0.96 at site/approach WA07-S.

The database for the two-lane sites includes 923 one-minute time intervals. The maximum entry flow rate is 19 vehicles per minute, while the maximum conflicting flow rate is 48 vehicles per minute. The one-minute average delay ranges from zero to 121.7 seconds per vehicle, while the means range from 5.1 seconds per vehicle at the site/approach VT03-S to 121.7 seconds per vehicle at the site/approach MD05-SW-NW. The mean proportion time queued ranges from 0.36 to 0.73 for the left lane data and from 0.45 to 0.83 for the right lane data.

For the 1-lane sites, a total of 10,785 gap sequences were measured. A gap sequence is considered to be all of the gaps that must be considered by a given entering vehicle.

- The entry vehicle accepted the lag 77 percent of the time (8,282 gap sequences).
- The entry vehicle rejected the lag but then accepted the first gap 12 percent of the time (1,318 gap sequences).

- The entry vehicle rejected the lag, rejected the first gap, but then accepted a subsequent gap 11 percent of the time (1,151 gap sequences).

For the 2-lane sites, a total of 13,530 gap sequences were measured.

- The entry vehicle accepted the lag 39 percent of the time (5,295 gap sequences).
- The entry vehicle rejected the lag but then accepted the first gap 8 percent of the time (1,067 gap sequences).
- The entry vehicle rejected the lag, rejected the first gap, but then accepted a subsequent gap 53 percent of the time (7,168 gap sequences).

Table 10. Data set highlights

Parameter	One-lane sites	Two-lane sites
Summary		
• Number of sites	10	6
• Number of unique approaches	16	10
• Total video time	15:53:16	18:30:18
Number of one-minute data points		
• Total	884	923
• Number in which proportion time queued exceeded 0.90	344	135 (left lane) 218 (right lane)
Ranges, one minute measurements		
• Entry flow, veh/min	2 – 24	0 – 19
• Conflicting flow, veh/min	0 – 18	0 – 48
• Delay, sec/veh	0.0 – 47.1	0 – 121.7
Mean proportion time queued	0.78	0.55 (left lane) 0.65 (right lane)
Gap sequences		
• Total	10,785	13,530
• Number involving an accepted gap	8,282	5,295
• Number involving a rejected lag followed by an accepted gap	1,318	1,067
• Number involving a rejected lag, followed by one or more rejected gaps, followed by an accepted gap	1,151	7,168
Turning movement proportions, means for sites		
• Left turns	0.28	0.35[10]
• Through movements	0.46	0.35
• Right turns	0.31	0.29
Travel time through roundabout (sec)		
• Left turns	10.8	11.8
• Through movements	6.6	7.4
• Right turns	3.1	2.7
• U-turns	16.2	18.8

[10] Data were not available for all multi-lane roundabouts. The data shown here are averaged over all four approaches for two different roundabouts (MD04 and VT03), a total of eight approaches.

5.3 Overview of safety database

Table 11 summarizes the data that were gathered in the data search, including intersection and approach specific crash data.

Table 11. Overview of safety database

Data	Number of sites
Intersection Crash Data Collected	117
Approach-Specific Crash Data Collected	55
Approach Data Collected/Extracted	
• Geometric Data Collected	133
• Geometric Data Extracted	93
• Video Data Collected/Received	38
• Operational Data Extracted	16
• Speed Data Collected	34

5.4 Overview of the speed database

The speed database includes measurements from 16 single-lane and 11 multi-lane sites. These sites represent a range of geometry, surrounding land use, and volumes found at the roundabouts studied as part of NCHRP 3-65. Table 12 includes the range of measured speeds and related data for the following locations:

- Through movement entry speed, V_1
- Through movement circulating speed, V_2
- Through movement exit speed, V_3
- Left-turn circulating speed, V_4

5.5 Overview of geometric data set

A database of geometric features was developed for NCHRP 3-65 that now includes 101 U.S. roundabouts. The data are principally distance measurements, radii, and angles that may affect the way in which drivers traverse the roundabout. The extraction process was relatively straightforward. The data source was a set of plans, either in hard copy or machine-readable format. In many cases, the parameters could be read directly from the plans (as with a width or a radius), while in other cases the data were directly measured. The radii for the vehicle trajectories were extracted from 1 inch = 50 feet scale copies created by enlarging or reducing the original drawing(s) as necessary and then sketching fastest paths using the techniques described in FHWA's *Roundabouts: An Informational Guide*. The other data were extracted from the original plans.
shows the data that were extracted for each approach, while Figure 9 shows a portion of the geometric worksheet for a four-leg, single-lane roundabout in Lisbon, MD.

Figure 10**Error! Reference source not found.** shows the physical parameters that were obtained while Figure 11 **Error! Reference source not found.**shows the trajectory radii that were measured. The definitions of the trajectory radii in **Error! Reference source not found.** for which data were obtained are as follows:

- R1 (Through entry path radius): the minimum radius on the fastest through path prior to the yield line
- R2 (Through circulating path radius): the minimum radius on the fastest through path around the central island
- R3 (Through exit path radius): the minimum radius on the fastest through path into the exit
- R4 (Left-turn circulating path radius): the minimum radius on the path of the conflicting left-turn movement
- R5 (Right-turn path radius): the minimum radius on the fastest path of a right-turning vehicle
- R6 (Left-turn exit path radius): the minimum radius on the fastest path into the exit from a left-turn (R4)

Table 12. Summary of speed database

Speed	Data type	Single-lane sites	Multi-lane sites
V_1	Range of measured speeds	8 – 27 mph	10 – 35 mph
	Total number of approaches	41	23
	Total number of observations	653	342
	Number of approaches with 15+ observations	25	12
	Number of observations at approaches with 15+ observations	540	266
V_2	Range of measured speeds	7 – 23 mph	12 – 29 mph
	Total number of approaches	33	19
	Total number of observations	617	236
	Number of approaches with 15+ observations	21	7
	Number of observations at approaches with 15+ observations	516	165
V_3	Range of measured speeds	8 – 33 mph	10 – 28 mph
	Total number of approaches	43	8
	Total number of observations	780	190
	Number of approaches with 15+ observations	27	6
	Number of observations at approaches with 15+ observations	661	185
V_4	Range of measured speeds	7 – 22 mph	9 – 28 mph
	Total number of approaches	38	21
	Total number of observations	582	384
	Number of approaches with 15+ observations	19	14
	Number of observations at approaches with 15+ observations	413	331

Table 13. Sample of geometric database

Inscribed circle diameter
Entry width
Approach half width
Effective flare length
Entry radius
Entry angle
Exit width
Departure width
Exit radius
Angle to the next entry leg
Type of pedestrian crosswalk
Splitter island width
Splitter island length
Circulating roadway width
Truck apron width
Central island diameter
Striping on the circulating roadway
Lane configuration (lane 1, lane 2, lane 3, bypass lane)
Type of vertical geometry (entering, exiting, circulating)
R0: The approach radius, including its uncertainty, and superelevation
R1: The entry path radius, including its uncertainty, and superelevation
R2: The circulating radius, including its uncertainty, and superelevation
R3: The exit path radius, including its uncertainty, and superelevation
R4: The left-turn path radius, including its uncertainty, and superelevation
R5: The right-turn path radius, including its uncertainty, and superelevation
R6: The left-turn exit path radius, including its uncertainty, and superelevation

State	**MD**	**Lisbon, MD 94 & MD 144**
Type of plan	**Hardcopy**	
Scale	**1:30**	

Measuring uncertainty	
Linear	**± 1**
Angle	**± 2**
Radius	**± 3**

Apron type (1=Raised, 2=Painted)	**1**

(yellow)	6 input geometric parameters in Rodel
(orange)	Hard to get from the plan
(grey)	N/A in the plan

	Basic parameters												Splitter Island											(+) (
															R0: Approach		R1: Entry path radius			R2: Circulating path		
	Inscribed circle diameter	Entry width	Approach half width	Effective flare length	Entry radius	Entry angle	Circulating width	Exit width	Departure width	Exit radius	Truck apron	Central island diameter	Width	Length	Radius	Uncertainty	Radius	Uncertainty	Superelevation	Radius	Uncertainty	Superelevation
	(D) feet	(e) feet	(v) feet	(l') feet	(r) feet	(∅) degree	feet	feet	feet	feet	feet	feet	feet	feet	feet	(±)	feet	(±)	(+ or -)	feet	(±)	(+ or -)
North Approch on MD RTE 94	100	13	10	40	60	17	19	14	12	78	12	40	12	23.5	9999	0	210	10	+	-80	5	-
West Approach on MD RTE 144	100	13	10	50	78	13	19	14		60	12	40	12	23	9999	0	180	10	+	-70	5	-
South Approach on MD RTE 94	100	14	12	64	60	18	19	14	10	78	12	40	12	23	9999	0	185	15	+	-70	5	-
East Approach on MD RTE 144	100	14	10	68	78	17	19	14		60	12	40	12	23	9999	0	230	10	+	-85	5	-

Figure 9. Example geometric worksheet for Lisbon, MD

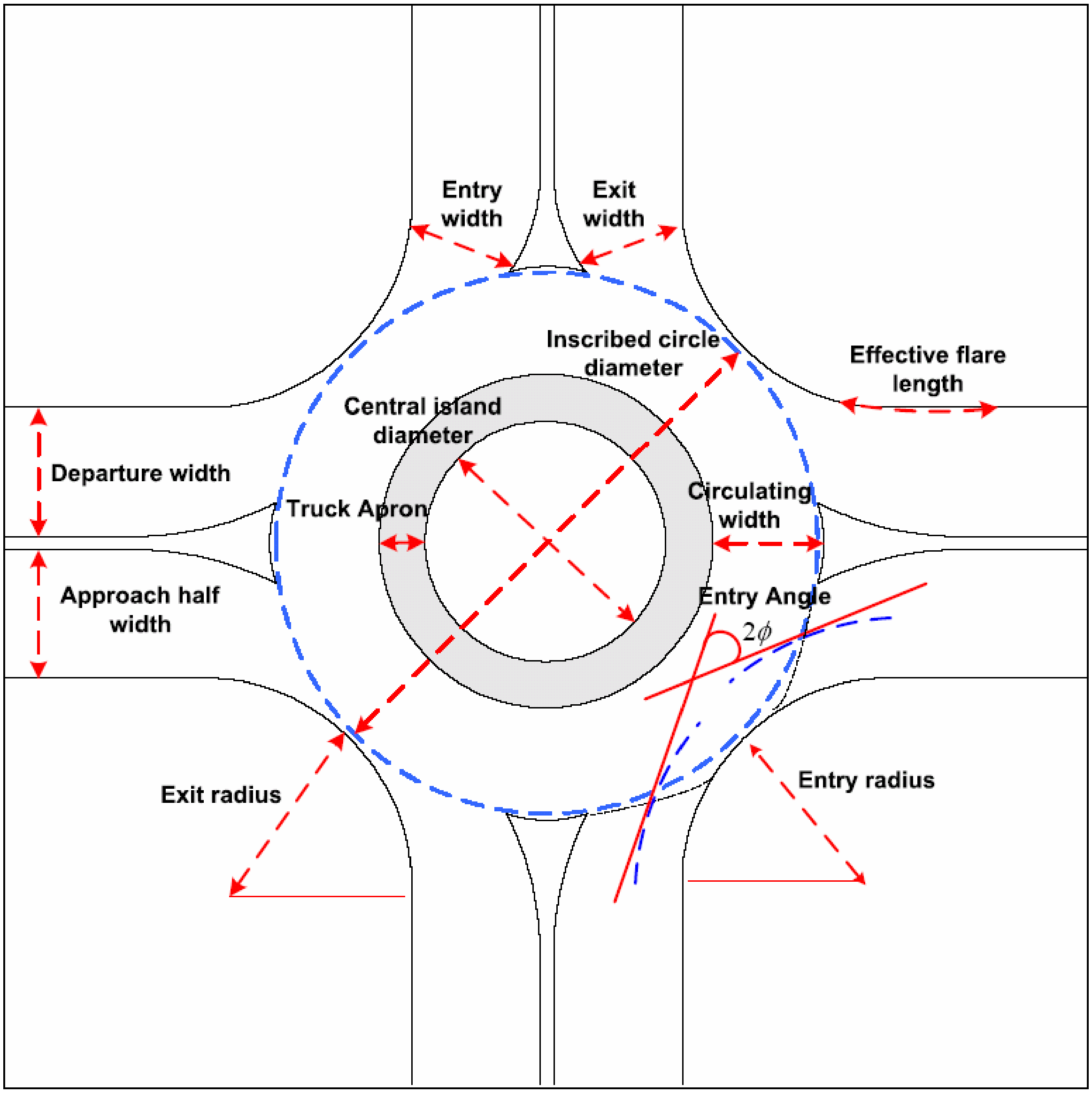


Figure 10. Geometric data extracted for each roundabout

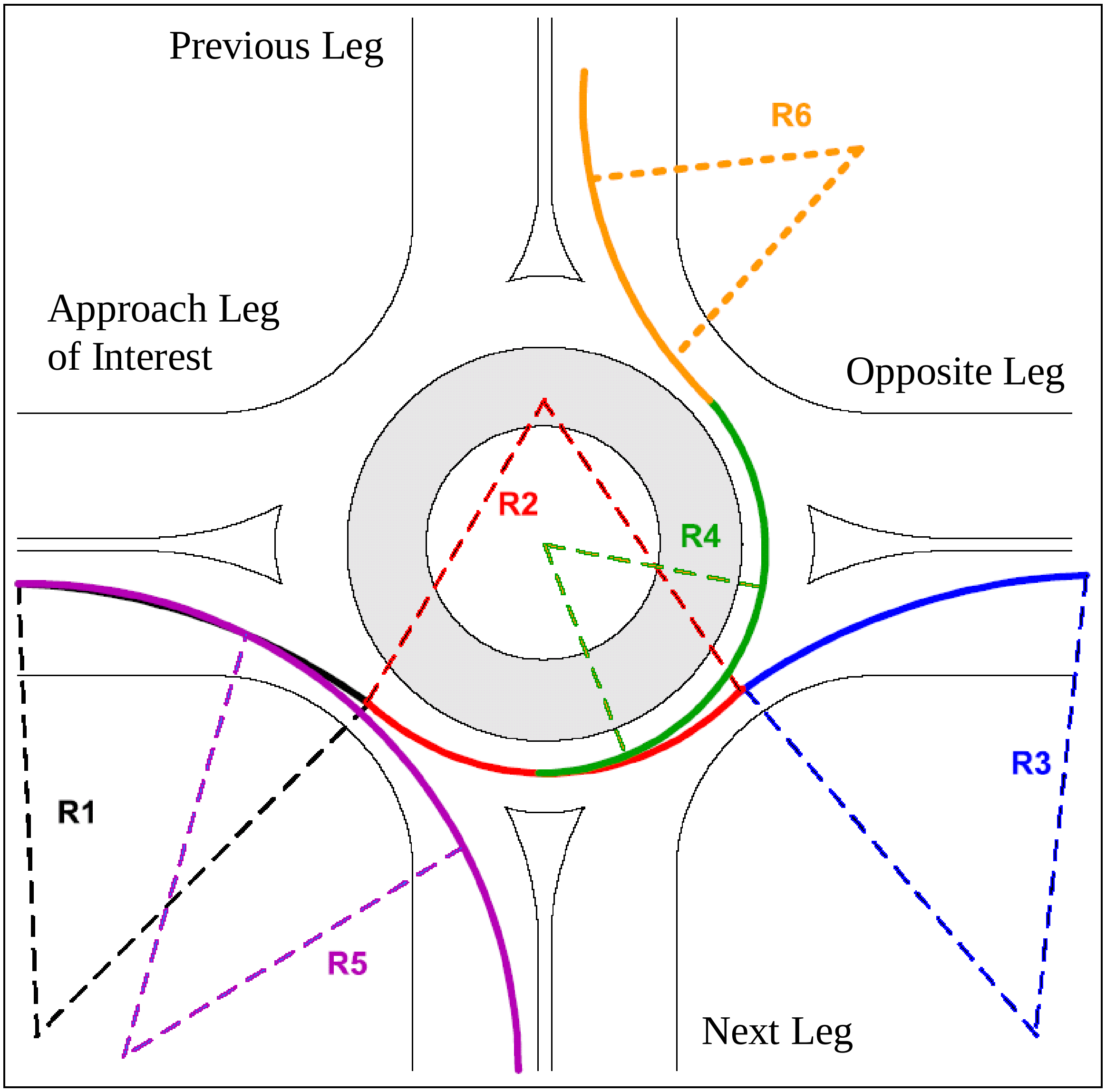


Figure 11. Trajectory radii

Appendix. Guide To Operations Data Set

The operations data set has been summarized on a CD-ROM, and is organized in a web-like structure, so that navigation from one data set to another is efficient. Three data sets are included on the CD.

- *Raw data*. All of the original keystroke/time event data are stored in files with a .csv file extension. These files have not been processed or corrected in any way. Each file is named according to the scheme used in this document. These files can be directly read by a text editor or spreadsheet software.
- *Summary data.* These raw data have been processed into summary files for each site. Included in these summary files are the flow rate, delay, and other similar data into a set of files, one per roundabout approach. Another set of data were processed for the gap data and the turning movement data.
- *Final data.* The final data includes the one minute summaries that were assembled in a small number of spreadsheet files that can be processed by the modeling team.

Figure 12 shows how the three data sets are presented on the CD-ROM.

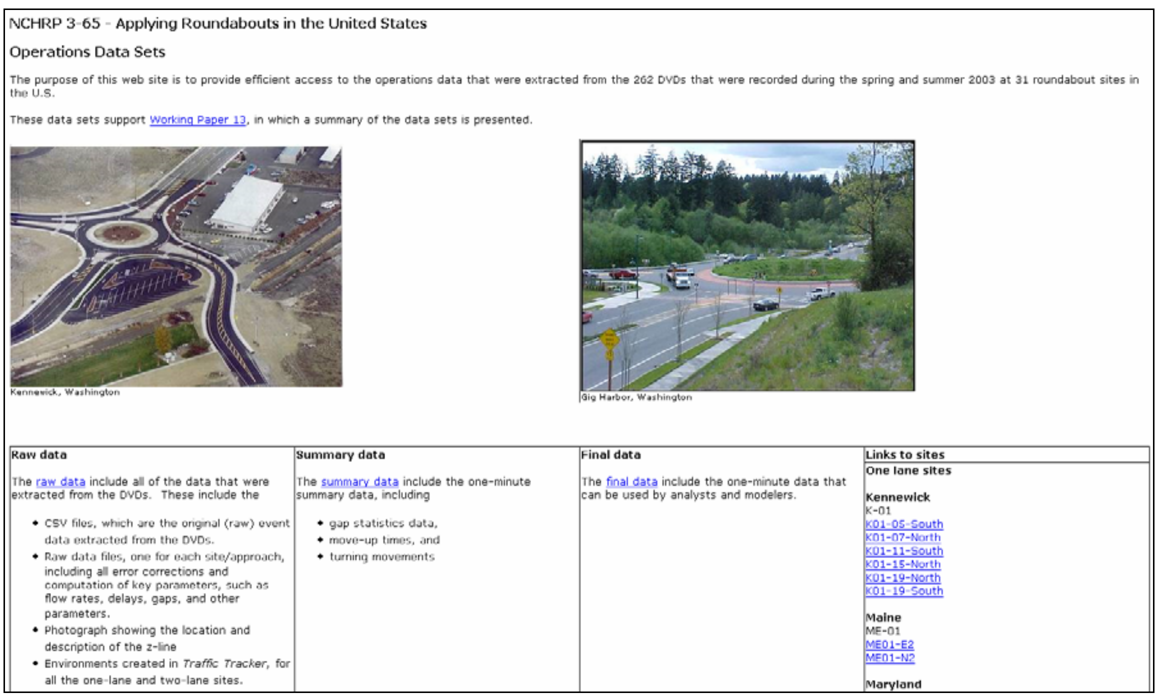


Figure 12. Entry screen for CD-ROM data set

A set of raw data files are included for each site. Figure 13 shows the data sets that are included for each site.

Raw Data Files

The raw data files include ***CSV files***, ***raw data*** files, *a **z-line*** description, and ***environments*** created in *Traffic Tracker*.

Access the data sets:
Site inventory
One lane sites
Two lane sites

Learn more about:
CSV files and description of events
Description of raw data spreadsheets for one lane sites
Description of raw data spreadsheets for two lane sites
Z-line descriptions
Traffic Tracker environments

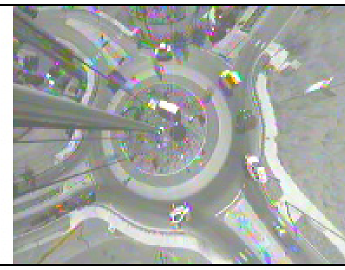
Home

Figure 13. Data sets for each site

Figure 14 shows the data that are available for each site. The data shown here are for a site in Bend, Oregon, numbered OR01-S1 (indicating the first site in Oregon,, the south approach, and the first DVD recorded for this approach).

OR01-S1

Colorado/Simpson, Bend, Oregon

Lanes on circulatory roadway Lanes on approaches Number of approaches	1 1 1	
OR01-N1	OR01-S1	OR01-W1
		

CSV files
OR01-S-freeflow.csv
OR01-S1-D-1.11.00.csv
OR01-S1-G-1.11.00.csv

Raw data files
OR01-S1-1.11.00.xls

Z-Line
OR01-S-Z-Line.doc

Environments for Traffic Tracker
OR01-S-Delay.tdp
OR01-S-Gap.tdp

Figure 14. Site data

Figure 15 shows an example of the data set structure for the MD06-N data. In part 1 of the figure, the list of the fifteen one-lane approach data sets is given. For MD06-N, there are three individual time periods that make up this data set. These are shown in part 2 of the figure, and include MD06-N1-2:08:00, MD06-N1-2:44:00, and MD06-N1-3:06:00. In addition to the data for each of these three time periods, there are also data for the Traffic Tracker configuration files (noted with the extensions .tdp) and a file indicating the specific points at which the events were collected for this approach (the word file, with a .doc extension). These files are shown in part 3 of the figure. In part 4, the two raw data sets that were produced by Traffic Tracker, one for delay and one for gaps (noted as "D" and "G", respectively, in the file names, are shown. Finally, also in part 4, the spreadsheet with much of the summarized data is shown, with an .xls file extension.

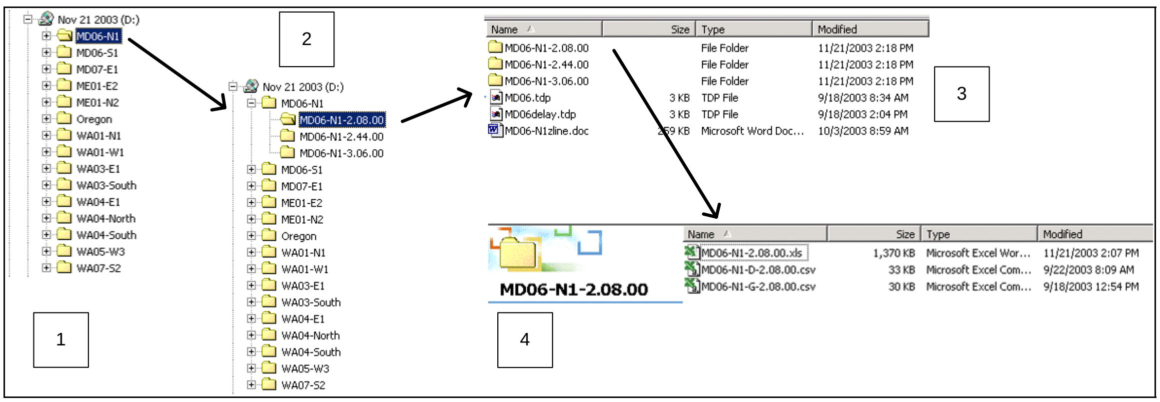


Figure 15. Example file structure, raw and summary data sets