Analysis of Bicycle, Pedestrian, and Auto Interaction at Multilane Roundabouts in the US

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Abstract

This research paper will highlight the findings of a two year study conducted for the California Department of Transportation on the topic of the use of multilane roundabouts and their effect on pedestrian and bicycle behavior. The study involved several methods of data collection including: in-field surveys of pedestrians and bicyclists at multilane roundabouts; video observation of vehicle/pedestrian/bicycle interaction at multilane roundabouts; crash analysis; and vehicular speed analysis. Multilane roundabouts were studied in the states of Maryland, Delaware, Michigan, and California. In addition, focus groups were held in the states of Maryland and California to gather opinions of the perceived safety and operational performance of multilane roundabouts by drivers/pedestrians/bicyclists that use such roundabouts.

The study develops a series of recommendations to planners and designers regarding the use of multilane roundabouts in a manner that does not deter bicycle and pedestrian traffic from using roundabouts. The recommendations are based in part on guidance gathered from existing design documents in addition to the data gathered through field observations and survey data. Field observations included the positioning of bicyclists within the circulating roadway and also the choice of bicyclists to traverse the multilane roundabouts as a pedestrian. Focus group findings included the perceived safety of pedestrians at multilane roundabouts with varying designs.

The research paper and overall guidance document is intended to address not only the geometric challenges of including pedestrian and bicyclists at multilane roundabouts, but also to assist planners and designers better understand the opinions of non-vehicle users of these roundabouts. While many studies have attempted to understand the best methods to incorporate non-vehicle users at multilane roundabouts through passive means (for example accident analysis), this study sought to understand the implications of various design elements at multilane roundabouts on pedestrian and bicycle behavior and perceived safety.

Introduction

Roundabout studies in the United States have followed the approach of understanding the potential safety impact of roundabouts as compared to traditional at-grade intersection designs; determining vehicle operational performance at single and multiple lane roundabouts; and determining the optimal design combinations to achieve safe and efficient roundabouts in terms of vehicle performance. With the expansion of roundabout usage in the past decade more engineers, planners, and decision makers are considering and installing roundabouts in the US. Much of the research focus has been on vehicle performance and with the completion of the National Cooperative Highway Research Program Project 3-65 (Applying Roundabouts in the United States), additional information is available to professionals on the operational and safety performance of vehicles at roundabouts. One area of research that has not received as much attention in the past is the accommodation of bicyclists and pedestrian movement through roundabouts, in particular, visually impaired pedestrians.

Title II of the Americans with Disabilities Act require that new construction and alterations are accessible to, and useable by, people with disabilities. Over the past several years, the ability of visually impaired persons to travel through roundabouts has become an issue to be addressed. In response to this concern, the Transportation Research Board and the US Access Board have co-sponsored a large scale in-field study to determine the ability of visually impaired persons to negotiate roundabouts (NCHRP 3-78). The study is to be completed in March 2010 and is to provide a range of geometric and operational conditions in which potential solutions are expected to be appropriate.

Yet to be completed in the US is a comprehensive study of bicyclists at roundabouts, single and multilane locations. With the lack of bicycle usage in the US, it is not surprising that the accommodation of bicyclists has not attracted the level of attention as vehicles and pedestrians, however, this does not mean that designers should not consider the need of these users as well.

One state that has cast a light on the topic of bicyclists at roundabouts is the State of California. The California Department of Transportation (Caltrans) has sponsored a research effort to better understand the challenges of bicyclists and pedestrians traversing roundabouts. Of particular concern was to determine if bicyclists and pedestrians would alter their path to avoid roundabouts, thus creating a perceived barrier to non-vehicular travelers when traveling along roadways and streets in which they are not prohibited by law. In addition, Caltrans was interested in understanding the characteristics of roundabouts that best accommodated bicyclists and pedestrians to promote the inclusion of such designs in future roundabouts. It should be noted that it was the desire of the research team to develop guidance for the design of roundabouts, particularly multi-lane roundabouts, that can accommodate pedestrians and bicyclists. Some designers may not agree with this approach, however, providing equal access to all users at all locations in which pedestrians and bicyclists are not restricted was the goal of this study.

The primary purpose of this study was to determine what trends exists with pedestrian and bicyclist behavior at roundabouts; the perceptions of pedestrians and bicyclists at roundabouts; and the design characteristics that are anticipated to better accommodate bicyclists and pedestrians at roundabouts. In particular the study focused on observing bicyclists and pedestrians and multilane roundabouts. Researchers identified multilane roundabouts that had the potential of having bicycle and pedestrian traffic that were within an economical distance from the research team members. The following multilane roundabouts were identified for inclusion in the study:

- Rehoboth Beach, Delaware
- Annapolis, Maryland
- East Lansing, Michigan
- Gaithersburg, Maryland
- Santa Barbara, California

Data were collected and observations made at these roundabouts to better understand the challenges faced by pedestrians and bicyclists at multilane roundabouts. These data and observations are included in this paper along with a brief literature review; an overview of the study methodology and data collection efforts; and design recommendations are presented.

Literature Review

To better understand the challenges concerning the accommodation of bicyclists and pedestrians at roundabouts, a literature review was conducted to address:

- Pedestrian and bicycle behavior in the US,
- Perceived safety of pedestrians and bicyclists in the US,
- Safety performance of roundabouts, and
- Design considerations at roundabouts to accommodate pedestrians and bicyclists

Based on the findings of the literature review, the study methodology was developed.

Pedestrian and Bicycle Behavior and Perception of Risk in the US

As noted previously, bicycle trips in the US are typically fewer than in many industrialized nations. A survey completed in 2008 for the US Department of Transportation's National Highway Traffic Safety Administration and Bureau of Transportation Statistics highlights the perceptions and travel behavior of bicyclists and pedestrians in the US (USDOT, 2008). Researchers surveyed a representative sample of 9,616 US residents over 16 years of age in the summer of 2002 to determine their bicycle usage. It was noted that 43 percent of participants reported making at least one bicycle trip per month and 78 percent of participants reporting walking, jogging, or running outside for more than 5 minutes during the summer months. Of those that reported bicycling in the past month, 13 percent reported feeling that there personal safety was threatened on the most recent day they rode their bike in the past 30 days; while 6 percent

of participants who reported pedestrian behavior in the previous month reported feeling their personal safety was threatened during a pedestrian trip in the past month. Perhaps as anticipated, of those who reported feeling threatened when traveling as a pedestrian or bicyclist, 88 percent of bicyclists and 62 percent of pedestrians felt threatened by motorists. Of particular note, are the reasons bicyclists felt their personal safety was threatened by motorists:

- 40 percent reported motorists following too close to the bicyclist
- 32 percent reported motorists driving too fast
- 16 percent reported motorists not seeing bicyclists

Similar findings were reported from participants who felt threatened by motorists when traveling as a pedestrian. These findings will be compared to the findings of the pedestrian and bicyclist survey conducted in the field at multilane roundabouts as part of this study to determine the level of perceived threat of non-motorists traversing roundabouts.

One of the outstanding issues with the deployment of roundabouts is the impact they have on pedestrian and bicycle route choice. A review of existing studies regarding bicycling and pedestrian behavior revealed that route choice is affected by route directness. However, there is evidence that non-motorized travelers, especially bicyclists, are willing to travel additional distance in exchange for other factors that they find significant (Harvey et al. 2008, Howard & Burns 2001, Aultman-Hall et al. 1998). Some of these significant variables include travel time, safety, and pleasantness. Westerdijk et al. (1990) used a multi-attribute utility model to quantify these tradeoffs. For example, they found that bicyclists were willing to travel an additional 250 meters in exchange for one extra point on a scale for traffic safety. Although none of these studies explicitly address roundabouts, they still give insight into how far out of their way pedestrians and bicyclists will go in order to travel a more comfortable route.

The issue of comfort was also addressed in studies that discuss cyclists' perception of risk. Parkin et al. (2006) studied perceived risk over an entire bike journey and concluded that roundabouts, two-way auto traffic, and the number of parked vehicles on the street are all factors that increase perceived risk. Moller and Hels (2007) developed a model for variation in perceived risk by bicyclists, specifically at roundabouts. They found that the most significant variables were gender, having experienced a near-collision in the past year, auto volume through the roundabout, and the existence of a cycle facility. The existence of a cycle facility in a roundabout decreased perceived risk, although this study did not further attempt to compare perceived risk with measures of actual risk or investigate how this perception affects behavior. However, the route choice studies imply that these perceptions of risk could possibly be a significant variable affecting route choice.

Two reports specifically address how non-motorized users react to roundabouts. One study conducted in New Zealand included a comprehensive survey of bicyclists regarding their attitudes toward multi-lane roundabouts (Campbell et al., 2006). The authors found that even though 85 percent of the survey respondents identified themselves as experienced cyclists, 93 percent of participants felt that multi-lane roundabouts were a

hazard and a deterrent to bike riding. Over 60 percent of participants said they were willing to make some attempt to avoid multi-lane roundabouts. Novice cyclists demonstrated even higher levels of aversion to multi-lane roundabouts.

Safety and Design Considerations for Pedestrians and Bicyclists at Roundabouts

Much of the existing literature on roundabout safety addresses the well-documented conclusion that roundabouts have the potential to increase motor vehicle capacity and safety. However, much information is not available as to the impact of multi-lane roundabouts on pedestrian and bicyclist safety. Most studies, especially in the US, have found that there is too little data to conduct meaningful analyses of bike and pedestrian collisions in roundabouts. However, there have been a few studies conducted in other countries that can shed some light on the topic of pedestrian and bicycle safety at roundabouts.

Generally, the effect of multi-lane roundabouts on pedestrians is unclear, although some studies have found that the roundabouts result in no significant change in the level of pedestrian safety. Observational studies have found that pedestrians are more likely to hesitate at multi-lane roundabouts (Harkey & Carter, 2006) and that visually impaired pedestrians suffer longer waiting times and dangerous crossings at multi-lane roundabouts (Ashmead et al., 2005).

Daniels et al. have conducted some comprehensive studies of the effects of roundabouts on bicyclists in Flanders-Belgium (Daniels et al., 2008). In their 2008 study, they investigated whether a safety effect could be quantified and if this effect was influenced by particular characteristics of the roundabout location. Though their results do not focus on multi-lane roundabouts exclusively, they include both single- and multi-lane roundabouts in their sample. Their before-and-after study revealed that roundabouts increased injury collisions involving bicyclists by 27 percent and severe injury collisions by up to 46 percent.

Several articles were reviewed that specifically address accommodations for pedestrians and bicyclists within roundabouts. Some of the literature consists of general design manuals that note that special considerations need to be made for non-motorized users when designing any roundabout. Several discuss the relatively new practice of roundabout signalization for pedestrian access. Inman and Davis (2007) discovered that roundabout signalization has mainly focused on improving traffic operations and not necessarily benefits to other users. However, it has been shown that many pedestrians, especially disabled users, may require special treatments that allow them to safely and efficiently travel through roundabouts. Rouphail et al. (2005) and Schroeder et al. (2008) both used simulation models to study the effects of pedestrian signalization treatments on roundabout operations. Schroeder et al. found that delays for all users could be mitigated using a two-stage pedestrian signal or a HAWK system, both of which minimize the red time for auto traffic. Rouphail et al. suggest that a mid-block crossing downstream of exiting traffic minimizes the possibility of disruptive queues forming; however, the tradeoffs between traffic operations and increased pedestrian travel distance have not been fully examined.

Three studies propose new ideas for road treatments and roundabout design meant to benefit pedestrians and bicyclists. The first evaluates a new road treatment to audibly alert visually impaired pedestrians of yielding vehicles at multi-lane roundabouts (Inman et al., 2005). Two other papers present new versions of a roundabout design that are more amenable to non-motorized users. Campbell et al. (2006) introduce the concept of a cyclist-roundabout (or C-roundabout) which has very specific geometric guidelines intended to reduce the 85th percentile auto circulating speed to 30 kilometers/hour (which reduces the differential between cars and the typical bicyclist to 10 kilometers per hour). The most distinctive feature of the C-roundabout is the narrow entry lane, which encourages heavy vehicles to travel in a single file. Campbell et al. also suggest using economical vertical deflection devices (such as speed humps) at entry legs, but concede that their use may be opposed by bus, emergency vehicle, and other heavy vehicle drivers. Another novel roundabout design, the turbo-roundabout, was described by Bertus in 2003. The turbo-roundabout is a design that prohibits lane changing among the circulatory traffic and has been implemented in the Netherlands. This design benefits non-motorized users by lowering the circulatory speed and reducing potential conflict points.

Much more research is needed on the best way to accommodate pedestrians and bicyclists at roundabouts. But some valuable work has been done to show that a combination of innovative solutions and efficient use of current treatments may ultimately benefit all users.

Study Methodology

With the focus of the study being to determine what trends exists with pedestrian and bicyclist behavior at roundabouts; the perceptions of safety and operations of pedestrians and bicyclists at roundabouts; and the design characteristics that are anticipated to better accommodate bicyclists and pedestrians at roundabouts, the data collection effort was both qualitative and quantitative in nature. Between January 2007 and February 2009 data were collected including:

- In-field intercept surveys of bicyclists and pedestrians at four case study multi-lane roundabouts;
- Video documentation of bicyclists and pedestrians at three case study multi-lane roundabouts;
- And four focus groups held in communities with multi-lane roundabouts.

Additional data were collecting in an attempt to learn more about route choice of pedestrians and bicyclists but these data are not included here as these data fall outside the purview of this paper.

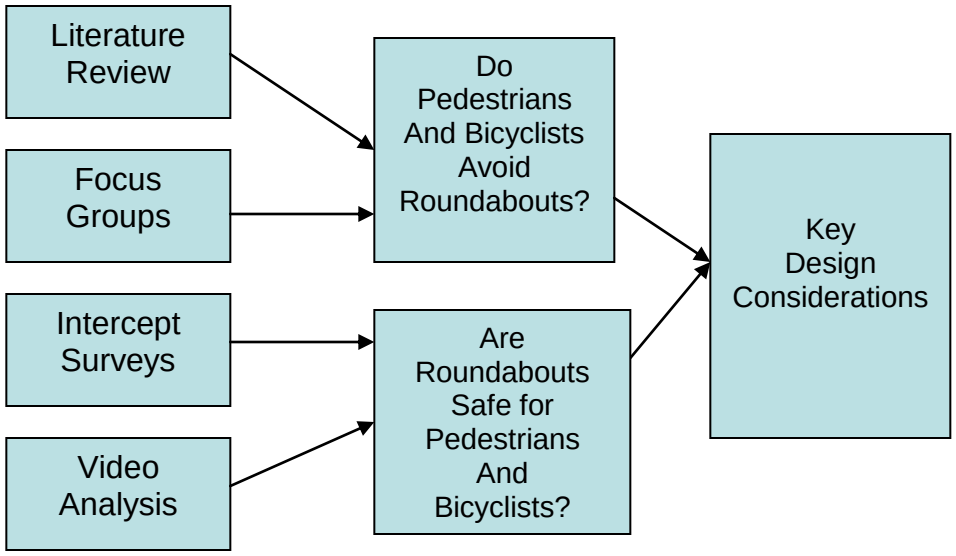
Figure 1 illustrates how the different data collection efforts worked together to answer the three main questions of the study:

1. How do pedestrians and bicyclists perceive multilane roundabouts?

2. What is the safety performance of multilane roundabouts identified for this study?

3. Based on the findings of these questions, what specific design treatments are recommended for accommodating bicyclists and pedestrians at multi-lane roundabouts?

Figure 1 Illustration of Data and Research Questions



Five case study multi-lane roundabouts were used to collect data. Bicyclist and pedestrian counts were conducted at all five locations, while more in-depth analysis (surveys, video documentation, focus groups) were conducted at a subset of the locations.

Data Collection

Video documentation

The video documentation methodology consisted of video-recording pedestrian, bicyclist, and vehicles at the roundabouts for a period of time and reviewing the videos to look for particular behaviors. Videos were recorded at the following three sites:

Maryland—Annapolis, Spa Road/Taylor Avenue/MD 450 Roundabout
Delaware—Rehoboth Beach, Rehoboth Avenue and Grove Street Roundabout
Michigan—East Lansing, Shaw Lane and Bogue Street Roundabout

At each roundabout, a video camera was set up at the center median of the roundabout, facing out, at each of two or three approaches to each roundabout, and allowed to record for a period of time. The locations of the cameras are summarized in Table 1.

Table 1 Camera Locations at Study Roundabouts and Recording Time

Location	Camera Number	Approach	Total Recorded Time (min)
Rehoboth Beach, DE	1	East	186.15
	2	South	209.77
	3	West	125.13
East Lansing, MI	1	South	156.75
	2	North	170.60
Annapolis, MD	1	East	30.56
	2	North	11.87
	3	Northwest	147.69
Total recording time for all locations, minutes:			1,038.52
Total recording time for all locations, hours:			17.31

In-field Surveys

During the summer of 2008, bicyclists and pedestrians were surveyed at three multi-lane roundabouts. The purpose of the surveys was to learn what characteristics attract or detract bicyclists and pedestrians from multi-lane roundabouts and to provide guidance for the placement and design of multilane roundabouts to accommodate all modes. Survey participants were asked to complete a 10-question survey that included questions regarding their comfort level with multilane roundabouts; route choice questions; demographic information; and their travel mode on that particular day. A total of 89 surveys were completed, as shown in Table 2.

Table 2 Survey Responses by Location

Location			
Rehoboth Beach, DE	**Annapolis, MD**	**East Lansing, MI**	**Total**
37	4	48	89

Focus Groups

Focus groups were held to gather insight into the perspectives of travelers on the perceived operations and safety of multi-lane roundabouts. Focus groups are beneficial in that it is possible to gather insight into travelers shared experiences of roundabout performance that can be influenced and evolve in a group situation. The benefits of focus group research include gaining insights into people's shared understandings of everyday life and the ways in which individuals are influenced by others in a group situation. Focus groups are not intended to provide quantitative information on a particular topic for many reasons including, the need to limit the size of focus groups to facilitate a discussion and the desire to allow the topic to evolve with the open discussion format.

A total of four focus groups were held: two in Kentlands, Maryland and two in Santa Barbara, California. Focus groups were held in January 2009 during the weekday

morning and weekday evening and convened in groups of nine participants. Participants ranged in age from 18 to over 65. Slightly more women than men participated in the groups (20 women versus 16 men.) Participants were recruited by posting flyers at local establishments in each community, as well as through ads posted on internet sites. The focus groups were conducted in five sections with each concentrating on a particular topic area:

• Section 1 – Pedestrian and Bicycle Behavior (activity level of participants)
• Section 2 – Understanding of the Operations and Comfort Level with Roundabouts
• Section 3 – Bicycle Design Options for Roundabouts
• Section 4 – Pedestrian Design Options for Roundabouts
• Section 5 – Final Comments/Suggestions

Focus group discussion topics and pre-determined scripts were developed and vetted with a small group of adults prior to the focus groups being convened to ensure a full understanding of the topics and items for discussion in the focus groups.

The groups were conducted by a lead facilitator with the help of an assistant. Comments were recorded using a digital audio recorder and notes were taken by the assistant as well. Participants were paid a $50 cash honorarium for their participation at the end of the focus group. Comments were later transcribed from the digital recordings. In most cases, comments were transcribed word for word as provided by the participants, in some cases, comments were paraphrased to capture the essence of comments. As is with most focus groups, short discussions between participants often arise when a particular topic is addressed and in these cases comments were recorded which reflected the nature of the discussion related to the topic under discussion.

Analysis and Findings of Data Collection

The analysis of the data collection revealed a series of concerns or perceptions of safety by participants which in part are supported by previous international studies. The key concerns that were identified regarding movement of pedestrians and bicyclists at multilane roundabouts included:

- Vehicle speeds are perceived as being too fast by pedestrians and bicyclists
- Pedestrians and bicyclists feel motor vehicle drivers do not see them due to drivers' attention being focused on negotiating multilane roundabouts often leaving pedestrians and bicyclists to feel venerable
- Materials used in some roundabouts on crosswalks and truck aprons are perceived as dangerous by pedestrians and can confuse pedestrian route choice through the roundabout.

Each of the identified concerns will be discussed individually here along with a discussion of the supporting data and recommended design approaches to reduce or eliminate these concerns.

Concern #1: Vehicle speeds are perceived as being too fast by pedestrians and bicyclists.

The concern over vehicle speeds was noted as part of the focus groups held in Santa Barbara, California and in Gaithersburg, Maryland. Study participants were asked to comment on a number of issues including:

- Their bicycle and walking habits,
- Their familiarity with the operations of roundabouts (as a driver, pedestrian, and bicyclists),
- Their comfort level as a pedestrian and bicyclist at a nearby multilane roundabout, and
- Their perceptions of the usefulness of various design options in accommodating pedestrians and bicyclists at multilane roundabouts.

Efforts were made to record the comments made by participants as the focus groups progressed from topic to topic. Some of the comments received by participants highlighted their desire to slow vehicle traffic at multilane roundabouts to improve their sense of safety. Below are a few example comments made by the participants (not direct quotes in all cases however, the bullets capture the essence of the comments):

- Raised crosswalks will also help to greatly reduce speeds, might help to improve bike interaction with cars as well. (Raised crosswalks) might help to improve visibility of pedestrians; they shouldn't be a high speed bump, but give the impression of one to slow down vehicles.
- Rumble strips would be useful on the approach to help draw attention to drivers that they should slow down.
- Vehicles come around like the Indianapolis 500; I just stand there till the coast is clear.
- I'm not intimidated by roundabouts at all; but if I was a mom with young child or older person I might find it more difficult. Traffic comes fast.
- It would make me feel better as a bicyclist if the speed in the roundabout was very slow (10-15mph); if the bike speed is the same as vehicle speed, then I feel comfortable. It will also improve conditions for the vehicle because bicyclists will be traveling at the same speed.

Pedestrian and bicyclist behavior was also documented at three study locations to better understand the interaction between non-vehicular and vehicle traffic at multilane roundabouts. Table 3 contains a breakdown of bicyclists who rode with vehicle traffic on the roadway and those that choose to utilize sidewalks or crosswalks (walking bikes as pedestrians). It is interesting to note that the bicyclist behavior at the East Lansing, Michigan roundabout echoes the reported feelings of comfort by survey participants with the roundabout as gathered through the in-field survey. As shown in Figure 2, 62 percent of non-vehicular travelers at the East Lansing roundabout reported being comfortable as a pedestrian or bicyclists at the roundabout, the most of any of the study locations. However, if one digs a bit further into the video data from East Lansing, one can see that only 15 percent of bicyclists actually travel on the road with vehicles while 85 percent of bicyclists opt to utilize the combination cycle path/pedestrian path that is available. Figure 3 contains an aerial view of the East Lansing roundabout and the pedestrian/cycle

path. This information may suggest that the presence of a shared use bicycle and pedestrian path is a desirable feature of roundabout design.

Additional information regarding bicycle comfort was obtained when observing placement of bicyclists that chose to travel through the roundabout as a vehicle (within a travel lane). As shown in Table 3, in most locations where data were available, the bicyclist tended to ride on the edge of the lane and did not commit to taking the lane by riding in the center of the lane. This behavior provides additional information regarding bicyclists' comfort level in being able to maintain the same speed as other vehicles on the roadway. When bicyclists feel they cannot maintain enough speed to stay ahead of vehicles, they will often drift to the edge of the roadway to allow vehicles to pass them. This behavior, however, in multilane roundabouts can be a safety hazard to bicyclists placing them in a venerable position in which they may be cut off by exiting vehicles.

Table 3 Bicyclist Behavior by Location/Camera

Location	**Total # Bikes**	**On the Road**				**On the Crosswalk/Sidewalk**	
		With Traffic	Against Traffic	Total	% on Road	Total	% on CW/SW
Delaware 1	32	28	0	28	88	4	12.5
Delaware 2	9	8	0	8	89	1	11.1
Delaware 3	186	132	4	136	73	50	27
Total	227	168	4	172	76	55	24
Michigan 1	44	14	0	14	32	30	68
Michigan 2	100	8	0	8	8	92	92
Total	144	22	0	22	15	122	85
Maryland 1	7	4	1	5	71	2	29
Maryland 2	11	5	0	5	46	6	54
Maryland 3	17	9	2	11	65	6	35
Total	35	18	3	21	60	14	40
Grand Total	406	208	7	215	53	191	47

Figure 2 Non-vehicular Traveler Comfort Level by Location

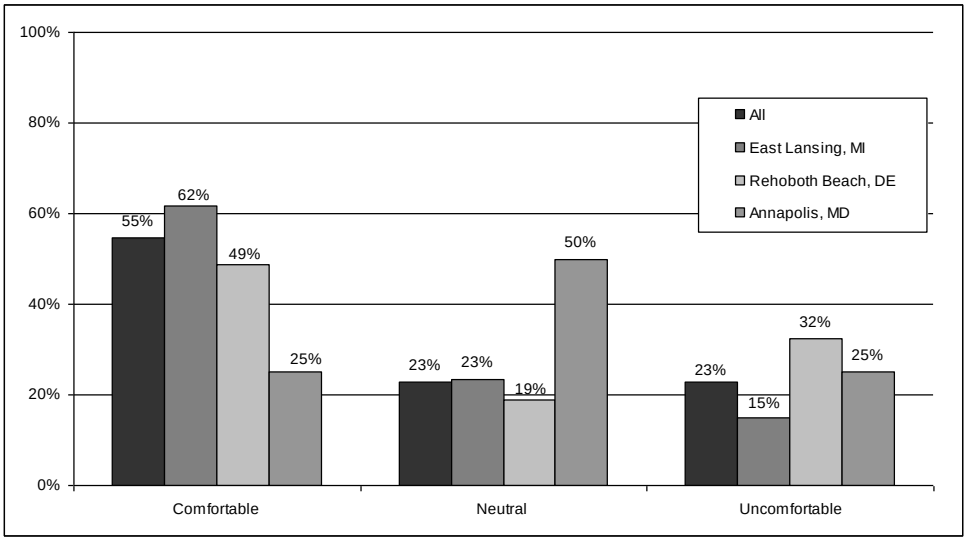


Figure 3 Aerial Image of East Lansing Roundabout (source: Google Earth)

Table 4 Bicycle Lane Position at Study Roundabouts by Video Camera

Location/	Bicyclist Lane Position						
Camera #	Total	Edge	Center	Unknown	% Edge	% Center	% Unknown
Delaware 1	28	25	2	1	89	7	4
Delaware 2	8	3	5	0	37.5	62.5	0
Delaware 3	136	122	10	4	90	7	3
Total/Avg %	*172*	*150*	*17*	*5*	*72*	*25.5*	*2.3*
Michigan 1	14	7	2	5	50	14	36
Michigan 2	8	2	3	3	25	37.5	37.5
Total/Avg %	*22*	*9*	*5*	*8*	*37.5*	*25.75*	*36.75*
Maryland 1	6	4	0	2	66.7	0	33.3
Maryland 2	11	1	0	10	9	0	91
Maryland 3	14	7	0	7	50	0	50
Total/Avg %	*31*	*12*	*0*	*19*	*42*	*0*	*58*
Grand Total	225	171	22	32	52	16	32

Recommended Design Consideration

Considering the hesitancy expressed by pedestrians and bicyclists at multilane roundabouts, it is recommended that roundabout entries and circulating roadways be designed for vehicle speeds of 32 km/hr (20mph) in locations where bicyclists are expected to utilize the travel lanes. This approach to roundabout design may not be possible in all cases, especially when truck traffic is high. The swept path of large

vehicles are often in conflict with the reduced radii which promote slower speeds which are more desirable to bicyclists. Considerations need to be taken to evaluate the operational effects of a reduced radius which may require large vehicles to utilize both entry, circulating, and exiting lanes in order to negotiate. Typically bicyclists can be expected to enter roundabouts at speeds between 19 to 24 km/hr (12 and 15 mph) in addition, research shows that survival rates of pedestrians struck by vehicles is highly correlated to the speed at which the vehicle was traveling when the pedestrian was struck. Fatality rates grow from 5 percent to 45 to 85 percent when impact speeds increase from 32km/hr (20 mph); 48km/hr (30 mph); and 64 km/hr (40 mph) respectively (Tian, UK Dept of Transport, 1997). Research has also revealed a positive relationship between the differential of speed, between the predicted entry speed and the predicted left turning circulating speed around the center island, and the 'entering-circulating' vehicle crash rate (Tian). As the difference in predicted entering and circulating speeds increases, "entering-circulating" vehicle crash rates were also found to increase.

Concern #2: Pedestrians and bicyclists feel motor vehicle drivers do not see them due to driver attention being taxed by negotiating multilane roundabouts.

Focus group participants noted that both as a pedestrian or a bicyclist they often feel that drivers are too focused on negotiating multilane roundabouts in terms of where to exit and also avoiding other vehicles to note their presence and yield properly. In addition, when focus group participants reflected on their experience as drivers of multilane roundabouts, they noted that additional signage and markings may help them better negotiate roundabouts. The following comments were gathered through the focus groups:

- As a driver, I am not as comfortable because I can't easily determine what directions mean by "take third exit"; difficult to traverse easily; if I was a pedestrian I would wait until absolutely all traffic clear before crossing.
- As a pedestrian I find it most difficult to determine if auto drivers can see me; I think that auto drivers are more focused on looking for other vehicles not looking for pedestrians.
- Roundabouts are a lot for drivers to watch so I just wait until all vehicle traffic is gone before I move.
- As a driver, one lane is good, two lanes there is too much going on.
- It feels like a lot of people just try to drive into the circle and hope that no one hits them.
- I always assume that the people coming into the circle are not going to yield to me when I'm in the circle so I always yield (as a driver).
- More signs to tell you where to exit would be better. (I) would feel more comfortable as a pedestrian if the drivers were more aware of where they should exit.

- In Hilton Head, SC they have small concrete borders between the lanes that help you know where to go as a driver; very well signed; I'm very comfortable there.
- Better signage to help drivers know what lane to be in and what exit to take.

Further information regarding the comfort level of pedestrians and bicyclists can be gleaned from the surveys gathered from study participants at multilane roundabouts located in Rehoboth Beach, DE; East Lansing, MI; and Annapolis, MD.

The data shown in Table 2 demonstrate the effect of mode choice on the comfort level of non-vehicular travelers. While 14 percent of overall travelers reported that they would not change their route to avoid a roundabout, 25 percent of travelers reported that if they were biking they would change their route to avoid a roundabout.

Table 5 Route Choice Behavior Data From In-Field Surveys

	All Data		East Lansing, MI		Rehoboth Beach, DE		Annapolis, MD	
if I am walking…	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**
I would change my route	12	14%	3	7%	8	22%	1	25%
I would not change my route	75	86%	43	93%	29	78%	3	75%
Total	87		46		37		4	
if I am biking…	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**
I would change my route	22	25%	7	15%	14	38%	1	25%
I would not change my route	65	75%	39	85%	23	62%	3	75%
Total	87		46		37		4	

Two interesting notes regarding the in-field survey can be made regarding the East Lansing, Michigan roundabout (shown in Figure 3). First, 85 percent of those surveyed at the East Lansing roundabout said they would not change their route to avoid a roundabout if biking. Figure 3 shows the availability of a shared bicycle/pedestrian track which runs around the roundabout. Second, the average age of survey participants were lower than other survey locations due to the fact that the multi-lane roundabout studied is located on the Michigan State University campus. These two facts compound the data to make it difficult to ascertain if it is the presence of younger participants or the shared use pedestrian/bicycle track that is leading to an increased comfort level with the roundabout in East Lansing as compared to other locations.

Therefore, while participants of the focus groups expressed concern over the ability of drivers to easily negotiate multilane roundabouts, the data do not suggest that many are willing to alter their routes to avoid crossing roundabouts when traveling as a pedestrian or bicyclist. In addition, field data collected through the video documentation suggest that pedestrians are fairly aggressive at multilane roundabouts with very few stopping before crossing crosswalks as shown in Table 6, though nearly all pedestrians do cross at crosswalks should improve their visibility to drivers.

Table 6 Pedestrian Behavior, Level of Assertion, and In-Crosswalk or Not

Camera Station	Total # Peds	# Peds Assert 0 or 1	% Peds Assert 0 or 1	# Peds Assert 2 or 3	% Peds Assert 2 or 3	In Crosswalk	% Peds in Crosswalk	Not in Crosswalk	% Peds Not in Crosswalk
Delaware 1	10	3	30	7	70	10	100	0	0
Delaware 2	13	0	0	13	100	10	77	3	23
Delaware 3	40	23	58	17	43	40	100	0	0
Michigan 1	135	15	11	120	89	134	99	1	1
Michigan 2	288	21	7	266	92	285	99	3	1
Maryland 1	5	0	0	5	100	4	80	1	20
Maryland 2	40	5	15	35	85	40	100	0	0
Maryland 3	23	3	13	20	87	23	100	0	0
Total	554	70	13	482	87	546	99	8	1

In general, pedestrians did not stop before crossing streets at roundabouts at all locations. The only exception is station 3 at the Delaware site, where slightly over half of pedestrians did stop before crossing. Note, however, that the sample at that location is relatively small.

Level of assertion 0 or 1 means that the pedestrian stopped either on the sidewalk or on the road before crossing. Level of assertion 2 or 3 means that the pedestrian did not stop, but rather kept walking and possibly forced a vehicle to yield as he/she crossed the street.

Recommended Design Considerations

Many participants in the focus groups felt that drivers had difficultly determining when to exit multi-lane roundabouts. Recently, the *Manual on Uniform Traffic Control Devices* for the inclusion of fishhook markings and curved-stem arrow advance guide signs on the approach to multi-lane roundabouts were further supported by a laboratory study by Hanscome which found that participants had the highest percentage of correct lane choice with this combination of markings and signage (75.0 percent left turn correct choice in lane placement; 99.1 percent correct lane choice for through movements) (FHWA, 2009, Hanscome, 2009). Findings from the focus groups held as part of this study the support of the use of directional signs and fishhook markings to help drivers better negotiate multi-lane roundabouts. With the improved guidance on the approach to the roundabout, drivers should be more comfortable and less distracted with the entry task and thus more aware of pedestrian and bicycle presence and movement. Drivers should be able to choose the appropriate entry and circulating lane, reducing unexpected and prohibited lane changes within the roundabout. This combination of markings and advance guide signs will improve navigation of the roundabout for bicyclists as well.

In addition, the use of directional guide signs on the approach to the roundabout and exit guide signs on splitter islands should be considered, but only if the benefits outweigh the costs of decreased driver awareness due to sign clutter.

Concern #3: Materials used in some roundabouts on crosswalks and truck aprons are perceived as dangerous by pedestrians and can confuse pedestrian route choice through the roundabout.

A few interesting observations and comments were made regarding material choice on truck aprons and crosswalks during the focus groups held during the study. Participants noted their confusion regarding intended paths for them to use while traveling as

pedestrians through multilane roundabouts and their experience with some materials used on crosswalks:

- The pedestrian crosswalks in the roundabout are brick pavers and have faded to the color of the roadway; I'm not sure drivers are aware that the crosswalks are there; perhaps different color pavement to help drivers see the crosswalks.
- The paint markings can be very slippery and should be treated to be less slippery. I've fallen in the roadway when trying to cross the street.
- Pavers are slippery when wet.
- I don't see the point of having the middle island (center island) side walked but there isn't a way for pedestrians to cut through to the roundabout.

These comments may be helpful to designers and engineers when planning and selecting materials for roundabouts. In particular, the comments regarding the traction provided to pedestrians by brick pavers and some heavily stripped crosswalks were raised by older participants. Given the reduced walking speed of older pedestrians and their expressed hesitancy with the perceived slippery nature of brick pavers and ladder crosswalk markings; a situation could be created in which older pedestrians reduce their walking speed even further when faced with the situation of having to cross on such materials at multilane roundabouts. Extra care should be given to the selection of materials at crosswalks to reduce such conflicts.

Another interesting comment was made by a focus group participant regarding the use of the same material on crosswalks as is used on truck aprons. A few participants did not understand why designers chose to use brick pavers on the "middle island" when there was not a path for pedestrians to cut through the roundabout. Meaning, the participants thought that the truck apron was intended to be a sidewalk used by pedestrians to shorten their route around the roundabout. The use of similar materials on sidewalks and truck aprons appears to be confusing for pedestrians and should be avoided to deter pedestrian crossing through the center island.

Recommended Design Considerations

In recognition of the concerns raised by elderly participants, engineers and designers should avoid the use of materials that do not provide good traction to pedestrians, in particular during rainy or wet conditions. In addition, the use of similar materials, pavers for example, to designate crosswalks and truck aprons is not recommended to avoid confusing pedestrian's and their route selection.

Conclusions and Future Research

A number of interesting observations were made through both qualitative and quantitative data collection methods in this study to better understand the perceptions and behaviors of bicyclists and pedestrians who travel multilane roundabouts. Findings from this type of study allow engineers and planners to make changes to multilane roundabout design in the near term as compared to more passive methods of analysis which requires the passage of time and the accumulation of quantitative data. Bicyclists and pedestrians

expressed a desire to slow vehicular traffic; improve navigational information for vehicular traffic; and reduce the use of materials perceived as slippery on crosswalks. Bicyclists appear to be more comfortable traveling as vehicles when vehicle speeds are reduced to speeds near bicycle cruising speed. Pedestrians expressed their vulnerability at multilane roundabouts when vehicular traffic appeared confused as to their desired travel path. The recommended design considerations in this paper are also expected to help improve vehicle operations and safety as well.

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