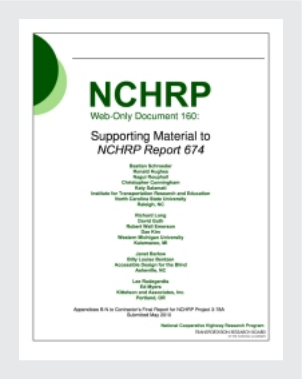


NCHRP

Web-Only Document 160:

Supporting Material to
NCHRP Report 674

Supporting Material to NCHRP Report 674

DETAILS

0 pages | null | PAPERBACK
ISBN 978-0-309-43029-6 | DOI 10.17226/22900

AUTHORS

ACKNOWLEDGMENT

This work was sponsored by the American Association of State Highway and Transportation Officials (AASHTO), in cooperation with the Federal Highway Administration, and was conducted in the National Cooperative Highway Research Program (NCHRP), which is administered by the Transportation Research Board (TRB) of the National Academies.

COPYRIGHT INFORMATION

Authors herein are responsible for the authenticity of their materials and for obtaining written permissions from publishers or persons who own the copyright to any previously published or copyrighted material used herein.

Cooperative Research Programs (CRP) grants permission to reproduce material in this publication for classroom and not-for-profit purposes. Permission is given with the understanding that none of the material will be used to imply TRB, AASHTO, FAA, FHWA, FMCSA, FTA, Transit Development Corporation, or AOC endorsement of a particular product, method, or practice. It is expected that those reproducing the material in this document for educational and not-for-profit uses will give appropriate acknowledgment of the source of any reprinted or reproduced material. For other uses of the material, request permission from CRP.

DISCLAIMER

The opinions and conclusions expressed or implied in this report are those of the researchers who performed the research. They are not necessarily those of the Transportation Research Board, the National Research Council, or the program sponsors.

The information contained in this document was taken directly from the submission of the author(s). This material has not been edited by TRB.

Copyright National Academy of Sciences. All rights reserved.

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

CONTENTS

APPENDIX B: Long List of Treatments

This Appendix contains detailed information about the long list of treatments considered in project NCHRP 3-78a.

State-of-the-Art Pedestrian Crossings

Over the years, a number of various types of pedestrian crossing treatments have been developed to help accommodate safe crossings at various facility types. The team identified a long list of treatments that may be considered for any type of pedestrian crossing, and later identified (through an internal survey) the treatments likely to have the most positive impact on visually impaired pedestrians ability to detect available yields and gaps. This appendix describes the available list of pedestrian crossing treatments that were considered as part of this research project in six basic categories:

1) Driver Information Treatments
2) Traffic Calming Treatments
3) Pedestrian Information Treatments
4) Crosswalk Geometry Modification
5) Signalization with APS
6) Grade Separation

The categories function is to group like treatments based on their intended effect on vehicle operations. Each category and the included treatments are described in more detail below.

Driver Information Treatments

Recent research conducted by Fitzpatrick et al indicates that the use of static pedestrian signs alone is not likely to generate a high frequency of yielding drivers. This is even more likely when low levels of pedestrian volume are present at a crosswalk. This is not to say that signing is ineffective and should not be required. Instead, several recommendations for improvement are possible over static signs, each summarized below.

Continuous Flasher. Flashing amber lights are installed on overhead signs, in advance of the crosswalk, or on signs at the entrance of a crosswalk to make it more visible to drivers. The continuous flasher is a static device that operates in a flashing mode independent of whether a pedestrian is at the crosswalk or not. They can utilize a single beacon, or even use multiple beacons in a ‘wig-wag’ configuration. An example of a single solar powered flashing beacon application is shown in Exhibit 1.

Flashing beacons are typically installed at uncontrolled intersections when used for pedestrian crossings; however, they are frequently used for signalized intersection applications with horizontal or vertical curve sight distance issues. If medium to high pedestrian volumes are not present at a crosswalk, this treatments effectiveness likely reduces as drivers ignore the beacon because its warning is typically communicating unreliable information. This could lead to driver inattention and insensitivity to the treatment over time. The costs of flashing beacons, including labor, can run approximately $10,000 to $40,000 per crossing dependent on the placement and type of application (Fitzpatrick et al., 2006).

s

Exhibit 1 – Solar Powered Flashing Beacon (courtesy of PTL Solar, http://www.ptlsolar.com/)

In-Roadway Warning Sign. Warning signs placed in the street are becoming increasingly popular where sign visibility along the roadside is particularly problematic or when existing signage is ignored. The signs specified by in the Manual of Uniform Traffic Control Devices (MUTCD 2003) and shown in Exhibit 2 read “State Law, Yield to Pedestrians” or “State Law, Stop for Pedestrians.” The sign should be placed in an island if possible to reduce the need for ongoing maintenance as the sign is struck by cars passing over the solid line or snowplows during winter months. Breakaway supports are used if the sign is placed directly in the roadway, and many signs are actually able to be traversed at slow moderate speeds. Speed reductions associated with slight increases in driver compliance are expected with this type of treatment. The costs of the treatment and labor are minimal at best compared to many other treatments.

Exhibit 2 – In-Road Pedestrian Crossing Signs (MUTCD 2003)

Active When Present Flasher. This treatment is similar to the continuous flasher; however, it is dynamically operated by activation of a pedestrian push button or via automated (passive) means such as infrared, microwave, video, or tactile detection. The dynamic push button activated beacon serves to increase conspicuity of the static pedestrian sign. The treatment typically takes the form of a flashing beacon on the roadside, mounted overhead, or imbedded in the pavement (Exhibit 3).

Exhibit 3 – Active When Present Flasher and In-Roadway Flashers (Fitzpatrick et al., 2006)

Adding language (displayed to the driver) to the sign could be considered. Beacons with detection devices are slightly more costly than the static continuous flashers described previously and include additional costs of approximately $2000 per unit for an APS device. Other automated detection could cost significantly more depending on the complexity of the detection devices used. In addition, if in-roadway warning lights are imbedded in the pavement instead of flashing beacons on the side of the road, these are more expensive and may require significantly more effort to install. In-roadway flashers could be considered if sight obstructions to the side of the roadway are problematic or if flashers are ignored all together.

Traffic Calming Treatments

Traffic calming is a method of designing streets using visual or physical cues to encourage drivers to reduce speeds. Traffic calming is largely self-enforcing in that the design of the roadway should result in the desired outcome of reduced speeds and aggressive driving behavior. Traffic calming can be a very effective tool at reducing the severity and frequency of crashes, and even noise levels. In addition, studies suggest (Geruschat and Hassan, 2005) that drivers are more likely to yield to pedestrians when traveling at slower speeds. Three possible treatment alternatives aimed at reducing vehicle speeds are described below.

Posting Lower Speeds (15 and 25 mph). Reducing regulatory posted speed limits significantly at roundabout and CTLs was a consideration of the team. The primary advantage of this treatment is that it is a low cost traffic calming treatment which is highly dependent on the upon driver compliance. If the design of the roundabout does not encourage slower speeds (i.e. poor geometry), the driver compliance of speeds can only be achieved through heavy enforcement of the crosswalk. Posting lower speeds is typically not advisable since the roadway should operate at the design speed intended for the facility. A lower posted speed for a CTL is impractical since it would also apply to the mainline.

Raised Crosswalk. A raised crosswalk will reduce vehicle speeds as a function of its height relative to pavement surface and the transitional slope. A low and a gently sloping raised crosswalk would likely have higher speeds as vehicles easily maneuver over the crosswalk. An example of a raised crosswalk in Golden, CO is provided in Exhibit 4. Likewise, a steep incline to a high raised crosswalk could have significant speed reductions; however, the reduced lane capacity may outweigh the benefit of the reduction in speed. Raised crosswalks also introduce vertical obstructions for ambulances and snow plows that need to be considered.

Exhibit 4 – Raised Crosswalk in Golden, CO

Pedestrian Information Treatments

This functional category utilizes treatments that provide pedestrians with audible information that can be used to make more informed decisions about when to safely cross using available yields and/or gaps. It should be noted that some treatments in this functional category have not been fully developed at this time, but were still considered as a possibility as the team developed the research plan. The four possible treatment categories are:

Surface Alterations/Rumble Strips. Roadway surface alterations, such as rumble strips, generate auditory cues of approaching and/or yielding vehicles (Inman, Davis, and Sauerburger, 2005). The treatment can also have the added benefit of providing information on the availability of crossable gaps. As an added benefit, the driver may be more cautious when approaching the crosswalk due to the additional sound cue provided by the treatment. Rumble strips can be adhered to the pavement or milled into the pavement. Exhibit 5 shows a rumble strip application in Charlotte, NC.

Exhibit 5 – Rumble Strip Application in Charlotte, NC

Yield Detection System. The use of in-road sensors or video image processing to detect whether vehicles have yielded (stopped or slowly rolling) has shown promise in initial tests completed under a related NIH grant (NIH 2010). An auditory signal provides a speech message to the pedestrian indicating when a vehicle has yielded. The functional problems of such a system are primarily based on reliability of detecting yields that roll very slowly, queued vehicles stopped over the crosswalk (at the entry for instance), and providing an instantaneous cancelling detector in the event a yielded vehicle begins moving again. Work is still underway to improve the system in these three areas. The equipment needed to utilize such a system includes multiple video detection cameras, a signal controller, and APS devices. Such a system would cost approximately \$50,000 to \$60,000 to implement an entire roundabout or intersection. Alternatively, inductive loops could be utilized if done appropriately; however, there is still work underway to learn the best placement of loops for such a system.

Gap Detection System. It is possible to use in-road sensors or video image processing to detect if there is an approaching vehicle (or no vehicle) within some predetermined safe crossing time or distance from the crosswalk. As with yield detection, the use of an auditory signal via an audible device is imperative to provide a speech message to the pedestrian indicating when it is safe to cross. The ability to sufficiently or accurately detect such gaps at roundabout (especially the exit approach) and channelized turn lanes is not known at this time, but is under development (NIH 2010).

Yield + Gap Detection System. This treatment would combine the two previous treatments to take advantage of the yield and gap detection capability that could ultimately be possible. It is not known at this time whether such a system is even plausible since there has been no development of gap detection for pedestrian crossing treatments completed at this time.

Crosswalk Geometric Modification

There is the possibility of a modified crosswalk location or an alternative crossing location at roundabouts. This approach would displace all or parts of the crosswalk further away from the circulating lane to separate pedestrian-vehicle interaction from vehicle-vehicle interaction at the roundabout. Supplemental treatments such as static signing, pedestrian-activated signs, and traffic calming techniques can all be applied in the distal crosswalk situation to further enhance accessibility. Four variations of the concept of a re-located crosswalk are presented:

Distal Crosswalk. This treatment would relocate the crosswalk to a distance of approximately 100 feet from the circulating lane of the roundabout. The (presumed) benefit is the lower level of ambient noise at the crosswalk that is associated with moving the crosswalk further from the circulatory roadway. Driver benefits include reduced queue spillback issues in the roundabout with added storage capacity for the exit lane(s). Drawbacks of this treatment include potentially longer pedestrian walking distances, depending on the origin-destination patterns at the site. An additional drawback is that sighted pedestrians may ignore the distal crosswalk and cross closer to the roundabout unless physically restricted from doing so.

Traffic Calming at Distal Location. The distal crosswalk can be combined with other treatments to provide some traffic calming measures to reduce speeds, and to increase the likelihood of drivers yielding and reduce the risk of collisions. Potential treatments considered include lowering regulatory speeds and the installation of a raised crosswalk.

Median Island at Distal Location. The distal crossing location would no longer have the benefit of a pedestrian refuge island, since the roadway at that point is most likely undivided. Therefore, a distal crossing would require a one-stage crossing of both directions vehicular traffic. A median island would provide pedestrian refuge and re-establish a two-stage crossing.

Offset Exit Crossing. The potential effectiveness of this treatment rests on the premise that pedestrians (in particular, blind pedestrians) experience more difficulty crossing exit lanes than entry lanes. By offsetting the exit-lane portion of the crosswalk and creating a zig-zag crossing, gap selection ability may be facilitated if ambient noise levels are in fact reduced relative to the typical crosswalk location. The zig-zag configuration would further maintain and even enforce a two-stage crossing strategy and would provide supplemental queue storage for vehicles at the exit lane. Exhibit 6 shows an example of an offset crosswalk.

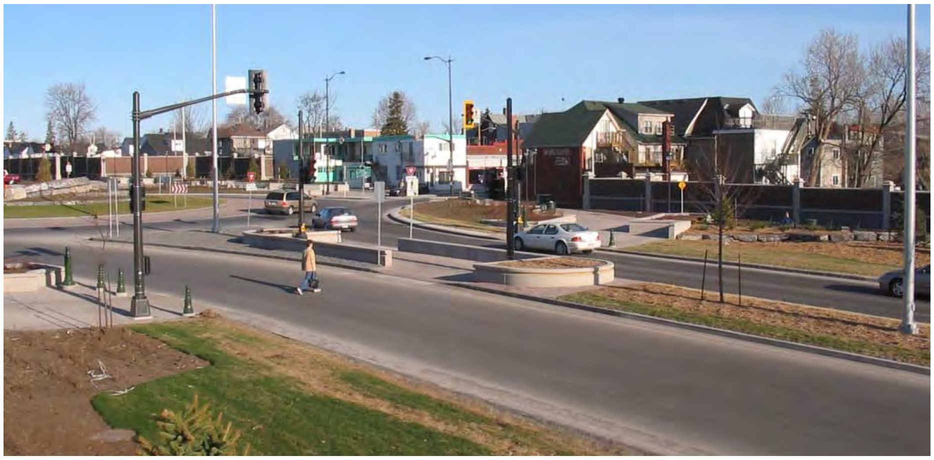


Exhibit 6 – Offset ("Zig-Zag") Crosswalk Design

The crosswalk modification treatments primarily apply to roundabout crossing. Some special considerations for geometric design at channelized turn lanes include:

Deceleration Lanes. The use of deceleration lanes for traffic using the channelized turn lane has several potential advantages: (1) if vehicles, in fact, slow down in the deceleration lane, slower vehicle speeds can increase the likelihood of drivers yielding to pedestrians, and (2) when used in conjunction with some type of audible surface treatment, such a cue may facilitate crossing decision-making.

Acceleration Lanes. While facilitating the movement of traffic exiting the channelized turn lane, acceleration lanes are often associated with higher vehicle speeds. Higher vehicle speeds are associated with a decreased likelihood of drivers yielding and an increased injury rate in the event of a collision. Adoption of a midpoint crosswalk standard serves to move the point at which pedestrian and vehicle paths intersect at a point where the speed of the turning/exiting vehicle is likely to be minimized, before speeding up in the acceleration lane.

Signalization Treatments with APS

Signals at roundabouts and channelized turn lanes represent a more costly and intrusive treatment for providing a safe crossing environment for pedestrians. Traffic signals may introduce delays to both pedestrians and vehicles. Additionally, depending on signal timing and placement, vehicle queues can spill-back in roundabout exit from the signal to affect roundabout circulating flow or CTL through movements. CTL signal impacts can be reduced through coordination with phasing at the main intersection and to avoid the likelihood of queue spillbacks onto the through lanes. Pedestrian signals with a WALK indication can and should be outfitted with an Accessible Pedestrian Signals (APS) to provide auditory cues in addition to the visual signal display. The signalization category considers the use of traditional signals and pedestrian hybrid beacons. Note: Signals that do not provide a hot (almost immediate) response can frustrate pedestrians and lead them to cross away from the signal or begin crossing as soon as there is a gap in traffic, potentially making motorist stop for no reason and lead to future non-compliance; thus a hot response should be provided whenever feasible and practical. If signal coordination is necessary, this may not be possible because this would cause unexpected stopping of vehicles traveling in progression.

Pedestrian Scramble Phase: This signal strategy stops all vehicular traffic at the roundabout intersection to allow pedestrian movements in any and all directions (along marked crosswalks). Pedestrian activation at any approach of the facility would (following some minimum green time for vehicles) produce a red signal at all entry lanes. Following a clearance interval designed to allow all vehicles in the circulatory lane to exit the roundabout, a pedestrian 'WALK' signal would be presented to all pedestrians waiting to cross. This treatment alternative enables pedestrians to cross in a single stage. Following the pedestrian walk phase, vehicles at all entry lanes would be given a green signal to proceed. The effectiveness of such a signalization strategy, while simple in concept and in operation, has yet to be determined. This strategy has no application to CTLs because the pedestrian movements do not conflict with any other vehicles outside the CTL approach. Exhibit 7 shows a time lapsed picture of a pedestrian scramble phase over an entire day.

Exhibit 7 – Time lapse of a pedestrian scramble phase over a 24-hour period in Toronto, Canada (www.spacing.ca).

Pedestrian Actuated Traditional Signal – One or Two Stage: This treatment utilizes a traditional traffic signal for pedestrians at (typically) unsignalized locations such as a roundabout or channelized turn lanes. The signals are standard red-yellow-green traffic signal heads that rest in green when no push button activations are in place. The treatment is particularly useful for blind pedestrians because the signal provides auditory information about phase indication via APS, much like they are accustomed to from a conventional intersection. In areas with high traffic and/or pedestrian volumes, delay and queue spillback at roundabouts could be problematic, especially with false (unused) pedestrian actuations. Also, because the signals rest in green the majority of the time, it is possible that drivers may react slowly (or not at all) to the red stop indication.

Pedestrian Hybrid Beacon (PHB) – One or Two Stage: The Pedestrian Hybrid Beacon (or HAWK signal) aims to be more efficient than a conventional signal by allowing vehicular traffic to move during the pedestrian flashing don't walk phase. When the push button is pushed a flashing yellow starts followed by a solid yellow and solid red. The solid red phase is the beginning of the WALK phase, which last approximately 4 to 7 seconds before a flashing red indication is shown. The flashing red indication for drivers allows traffic to proceed after stopping if the no pedestrian is in the crosswalk. This phasing scheme allows for less vehicular delay while providing similar pedestrian related benefits of a regular signal. A photo of a PHB installation from Tucson, AZ is provided in Exhibit 8.

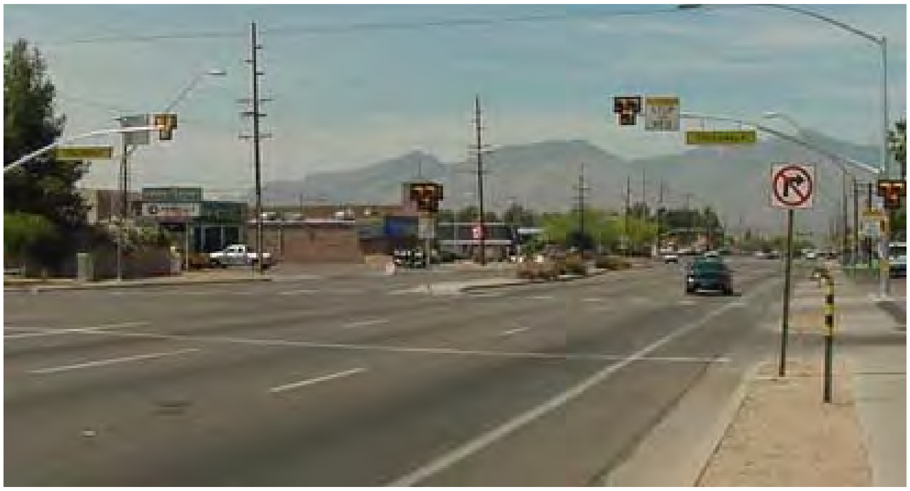


Exhibit 8 – Pedestrian Hybrid Beacon – Note the reverse dog-house signal head that houses the two red indications and the yellow indication. The two lenses at the top of the signal head are red and flash back and forth during the clearance interval. The yellow lens is located on the bottom of the signal head. (Tucson, DOT)

The cost of PHB signals is high, costing approximately $75,000 - $100,000 per crosswalk, depending on the width of the street and the length of mast-arm poles. Operation costs are estimated to be $2,000 per year. Driver education may be required for the alternating flashing red signals; drivers are more likely to stop for a familiar control device such as a traffic signal. Most state laws require drivers to treat dark signals other than ramp meters like a four-way stop, so drivers may stop unnecessarily when the signal is dark. A re-configured signal is currently in development to reduce driver confusion about dark signals. However, HAWK signals seem to be effective. According to an eight-month study conducted by the City of Tucson, the HAWK Signals increased driver compliance from 30 to 93 percent.

Distal Pedestrian Actuated Signal – One or Two Stage: Entry lane and exit lane pedestrian-activated signals used at a distal crosswalk location or in a zig-zag configuration could be used to establish a one or two-phased pedestrian crossing that maximizes the storage capacity of the exit lane during a vehicle red phase. If a two-phase crossing is utilized, a median refuge island would be necessary. Depending on pedestrian route patterns, these configurations may result in an increase in the travel time for pedestrians compared to a crossing at the traditional splitter island.

Distal/Zig-Zag PHB – One or Two Stage: The PHB could also be utilized at a distal location or in a zig-zag arrangement, combining advantage of the extra queue storage capacity at the exiting approach of the roundabout with more efficient signal phasing. Depending on pedestrian route patterns, these configurations may result in an increase in the travel time for pedestrians compared to a crossing at the traditional splitter island. The location of the distal crosswalk requires a median refuge island to be utilized if a two stage crossing is necessary.

Grade Separated Crossing

Grade separation allows pedestrians to operate in an uninterrupted flow without affecting the movement of vehicles. Grade separated facilities must accommodate all persons, including those with vision and mobility impairments. To accommodate all users, these treatments may require very long ramps or elevators. Because of the nature of grade separation, it should only be used as a last resort effort because of the high costs associated with construction of the facilities. Grade separation is typically used in extreme cases where pedestrian must cross very busy streets or freeways, and where pedestrian volumes are extraordinarily high. Grade separated facilities should not be considered where opportunities for crossing at the street level are available on a regular basis because it discourages use of the facility.

Pedestrian Overpass. An overpass is typically used where the topography allows for a smooth transition such that stairs, ramps, and other various facilities must be installed to make them accessible to all pedestrians. Overpasses should be designed so that they provide the ability for multiple users to pass by or around each other. This treatment is only reserved for ‘extreme’ pedestrian and vehicle volumes due to the high cost of constructing such a facility. This treatments primary advantage is the elimination of conflicts between vehicles and pedestrians through grade separation. However, it is not a very realistic treatment for roundabouts and CTLs being implemented in the US. Exhibit 9 shows an example of a pedestrian overpass over a heavily traveled roadway.

Exhibit 9 – Offset (“Zig-Zag”) Crosswalk Design

Pedestrian Underpass. A pedestrian underpass is a rare treatment that is typically used when a smooth transition is not possible at an overpass, or when it is thought of ahead of time during the design and construction process. Underpasses installed as a retrofit require costly underground construction by tunneling. Underpasses may be difficult to keep clean and safe, but with proper design and lighting these preconceptions can be overcome. Some countries such as Germany use this design more than others. An example of a German underpass at a roundabout facility is provided in Exhibit 10.

Exhibit 10 – Pedestrian Underpass Facility - Germany (Photo by Werner Brilon)

APPENDIX C: Team Treatment Survey

This Appendix contains details about the team-internal treatment survey used to reduce the long list of treatments to a recommended short list.

Appendix C: Team Treatment Survey

Due to the limited financial resources and time constraints imposed by the project, the research team conducted an internal survey aimed at identifying candidate treatments to be installed at the sites described later in the report. A scale of 1 to 5 was used with 5 indicating the treatment as being very effective. The following tables show the median and average ratings from nine team members for each possible treatment. Following the tables, individual comments made on treatments are provided to document team member thought processes during the actual evaluation. The following bullets summarize the findings from the tables:

- Base Case: Sighted pedestrians have better yield and gap detection, some drivers yield. Delay and risk are very high (low numbers) for blind pedestrians and are NOT perfect for sighted pedestrians either.
- Driver Information Treatments: don't affect pedestrian behavior, but may help increase yielding. TTI Research has shown some very significant improvements in yielding behavior for some treatments – most notably in-roadway signs and 'active when present' flashers.

  It seems natural to pair these with a yield detection treatment so they actually have a chance of helping blind pedestrians
- Traffic Calming Treatments: help increase yielding and reduce risk for all pedestrians. Further reduce delay for sighted pedestrians, but increase vehicle delay. People seem to agree that dropping the speed limit to 15mph is less feasible.
- Pedestrian Information Treatments: Rumble strips seem less effective and less applicable at 2-lane RABs and CTLs. Yield and Gap detection systems have the anticipated effect of improving the respective parameters for blind pedestrians. Both mechanisms help reduce pedestrian risk and delay and are most effective if combined.

  These treatments don't affect driver behavior (i.e. yielding) so it seems intuitive to combine these high-cost technologies with a low-cost treatment to increase yielding!
- Unsignalized Distal/Midblock Crosswalk: Seems to have a slight effect on Gap Detection for Blind pedestrians if combined with lower speeds or a median island. Driver yielding is also improved under those conditions. Marginal benefits may not justify the cost and inconvenience of this treatment group – the anticipated effects on delay and risk are marginal.
- Signalization: As expected, signals drastically improve yield detection, gap detection and yielding (i.e. compliance with the signal). Signals are expected to make the crossing safer and reduce pedestrian delay, with the tradeoff of added vehicle delay.
- There appears to be consensus that vehicle delay from signals is worst for one-stage crossings at the splitter island (HAWK or regular). Two-stage crossings generally result in lower vehicle delay, without any significant drawbacks for pedestrians. These are applicable for one-lane and two-lane roundabouts, not for CTLs.
- Distal/Midblock signals are less applicable (less desirable??) than signals at the splitter island.
- Grade separated crossings result in safe and undelayed operations but are not applicable at most sites.

Appendix C: Team Treatment Survey

Table 4: Team Estimates of Treatment Effectiveness: Median Ratings by Research Team

TREATMENT FUNCTIONALITY*			BEHAVIORAL PARAMETERS					PERFORMANCE MEASURES					APPLICABILITY		
			BLIND PEDESTRIANS		SIGHTED PEDESTRIANS		VEHICLES	BLIND PEDESTRIANS		SIGHTED PEDESTRIANS		VEHICLES			
			P(YD)	P(GD)	P(YD)	P(GD)	P(Y)	DELAY	RISK	DELAY	RISK	DELAY	1-LANE RAB	2-LANE RAB	CTL
UA	Base Case, Unassisted X-ing, Static Signs	UA	1.5	2.0	5.0	4.0	2.0	1.5	1.0	3.0	2.5	4.0	4.0	4.0	4.0
DRIVER INFORMATION TREATMENTS															
DI	Continuous Flasher	DI_CF	1.0	2.0	5.0	4.0	2.0	1.5	1.0	3.0	3.0	3.8	5.0	5.0	5.0
	In-roadway warning sign	DI_IRW	1.0	2.0	5.0	4.0	2.0	2.0	2.0	3.0	3.0	3.5	3.0	3.0	2.0
	In-road flashing crosswalk	DI_IRFC	1.8	2.0	4.5	4.0	3.3	2.0	2.0	3.0	3.0	4.0	4.0	4.0	3.5
	'Active When Present'	DI_AWP	2.0	2.0	4.5	4.0	3.0	2.0	2.0	3.3	3.0	4.0	4.5	4.0	4.5
	Advanced Yield Line	DI_AYL	1.5	2.0	4.5	4.0	2.5	2.0	2.0	3.5	3.8	3.0	2.5	3.0	2.5
TRAFFIC CALMING TREATMENTS															
TC	Lower Speed (25)	TC_LS25	2.0	2.0	5.0	4.0	3.0	2.5	3.0	4.0	3.0	3.0	4.5	4.0	5.0
	Lower Speed (15)	TC_LS15	2.0	2.0	5.0	4.0	4.0	2.0	3.0	4.0	4.0	3.0	3.5	2.5	3.0
	Raised Crosswalk	TC_RC	1.8	1.8	5.0	4.0	4.0	2.0	3.0	4.0	3.8	3.0	5.0	4.0	4.5
PEDESTRIAN INFO. TREATMENTS															
PI	Surface Alterations / Rumble Str.	PI_SA	3.0	3.0	5.0	4.0	3.0	3.0	3.0	3.0	3.0	4.0	5.0	2.0	3.0
	Gap Detection System	PI_GD	2.0	4.0	5.0	4.0	2.0	3.0	3.5	4.0	3.5	4.3	4.0	3.0	3.0
	Yield Detection System	PI_YD	4.0	2.0	5.0	4.0	2.8	3.0	3.5	4.0	3.8	4.0	5.0	3.5	3.5
	Yield + Gap Detect	PI_YG	4.0	4.0	5.0	4.0	2.8	4.0	4.0	4.0	4.0	4.5	5.0	4.5	4.0
UNSIGNALIZED DISTAL CW															
UD	Set back XX feet BOTH CROSS.	UD_XX	2.0	2.0	5.0	4.0	2.0	1.5	2.0	3.0	2.0	4.0	4.0	3.0	2.0
	Lower Speed at Distal CW	UD_LS	2.0	3.0	5.0	4.0	3.0	2.0	3.0	3.0	3.0	3.5	3.0	3.0	1.0
	Median Island for two-stage crossing	UD_MI	2.0	2.8	5.0	4.0	3.0	2.5	2.5	3.5	3.5	4.0	2.5	3.3	1.0
	Off-Set Exit Crossing	UD_EX	2.0	2.0	4.5	4.0	2.5	2.0	2.0	3.0	3.8	4.0	3.0	3.3	1.0
SIGNALIZATION TREATMENTS w APS															
S	Ped Scramble	S_PS	4.5	4.5	5.0	5.0	4.3	3.0	4.0	3.0	5.0	1.3	2.0	1.0	1.0
	Half-Signal	S_HS	4.0	5.0	5.0	4.0	4.5	3.5	4.0	3.5	4.5	3.0	4.5	4.5	5.0
	HAWK Signal at Splitter Island - One Stage	S_HS1	4.0	4.0	5.0	5.0	4.5	3.8	4.0	3.8	5.0	2.0	4.5	4.0	5.0
	HAWK Signal at Splitter Island - Two Stage	S_HS2	4.0	4.0	5.0	5.0	4.0	4.0	4.3	3.8	4.8	3.0	4.3	4.3	2.0
	Ped. Actuated Trad. Signal at Splitter - One-Stage	S_PA1	5.0	4.0	5.0	5.0	4.0	4.0	4.0	3.8	4.3	1.8	4.0	3.0	5.0
	Ped. Actuated Trad. Signal at Splitter - Two-Stage	S_PA2	5.0	4.5	5.0	5.0	4.0	3.3	4.5	3.8	4.8	3.0	4.3	4.0	2.0
	Distal HAWK Signal - One Stage	S_DHS1	4.0	4.0	5.0	5.0	4.0	3.0	4.0	3.8	4.3	3.0	4.0	4.0	4.0
	Distal HAWK Signal - Two Stage	S_DHS2	5.0	4.5	5.0	5.0	4.0	3.3	4.3	3.8	4.3	3.0	3.5	4.0	3.0
	Distal Ped. Actuated Signal - One Stage	S_DPA1	5.0	4.0	5.0	5.0	4.0	3.0	4.3	3.0	4.0	3.0	3.8	3.3	3.0
	Distal Ped. Actuated Signal - Two Stage	S_DPA2	5.0	4.5	5.0	5.0	4.0	3.3	4.5	3.5	4.0	3.0	3.0	3.5	1.0
GRADE SEPARATED CROSSING															
GS	Pedstrian Overpass	GS_OP	5.0	5.0	5.0	5.0	3.0	4.0	5.0	4.0	5.0	5.0	1.0	2.0	1.0
	Pedestrian Underpass	GS_UP	5.0	5.0	5.0	5.0	3.0	3.0	5.0	4.0	5.0	5.0	1.0	2.0	1.0

Appendix C: Team Treatment Survey

Table 5: Team Estimates of Treatment Effectiveness: AVERAGE Ratings by Research Team

TREATMENT FUNCTIONALITY*			BEHAVIORAL PARAMETERS					PERFORMANCE MEASURES					APPLICABILITY		
			BLIND PEDESTRIANS		SIGHTED PEDESTRIANS		VEHICLES	BLIND PEDESTRIANS		SIGHTED PEDESTRIANS		VEHICLES			
			P(YD)	P(GD)	P(YD)	P(GD)	P(Y)	DELAY	RISK	DELAY	RISK	DELAY	1-LANE RAB	2-LANE RAB	CTL
UA	Base Case, Unassisted X-ing, Static Signs	UA	1.5	1.7	4.3	3.7	2.2	2.0	1.8	3.5	2.9	3.6	3.8	3.5	3.8
DRIVER INFORMATION TREATMENTS															
DI	Continuous Flasher	DI_CF	1.4	1.6	4.3	3.7	2.1	1.9	1.9	3.0	2.8	3.8	4.0	3.6	3.7
	In-roadway warning sign	DI_IRW	1.4	1.6	4.3	3.7	2.6	2.0	2.0	3.6	3.1	3.7	2.8	3.1	2.4
	In-road flashing crosswalk	DI_IRFC	1.6	1.7	4.3	3.8	3.2	2.2	2.3	3.5	3.2	3.6	4.0	3.5	3.8
	'Active When Present'	DI_AWP	1.8	1.8	4.3	3.8	3.3	2.3	2.4	3.6	3.2	3.6	4.0	3.5	4.0
	Advanced Yield Line	DI_AYL	1.5	1.8	4.4	3.9	2.4	1.6	1.8	3.6	3.4	3.6	2.5	3.0	2.5
TRAFFIC CALMING TREATMENTS															
TC	Lower Speed (25)	TC_LS25	1.9	1.7	4.3	3.9	3.1	2.5	2.7	4.0	3.4	3.2	4.2	3.3	4.1
	Lower Speed (15)	TC_LS15	2.0	1.9	4.4	4.1	3.9	2.6	2.9	4.1	3.6	3.2	3.7	2.5	3.6
	Raised Crosswalk	TC_RC	1.7	1.7	4.4	3.9	4.3	2.2	2.7	4.1	3.4	3.6	4.3	3.5	4.0
PEDESTRIAN INFO. TREATMENTS															
PI	Surface Alterations / Rumble Str.	PI_SA	2.9	2.6	4.4	4.0	2.6	3.1	2.9	3.7	3.1	4.1	4.0	2.4	3.1
	Gap Detection System	PI_GD	1.8	4.4	4.4	4.0	2.3	3.3	3.5	3.9	3.5	4.1	4.0	3.1	3.6
	Yield Detection System	PI_YD	4.1	2.0	4.4	3.9	2.5	3.2	3.3	3.9	3.6	3.9	4.4	3.9	3.9
	Yield + Gap Detect	PI_YG	3.9	4.3	4.6	4.3	2.4	3.7	3.9	4.0	3.8	4.1	4.5	4.1	3.9
UNSIGNALIZED DISTAL CW															
UD	Set back XX feet BOTH CROSS.	UD_XX	2.1	2.3	4.3	3.7	2.1	2.1	2.2	3.1	2.9	3.8	4.0	3.1	1.8
	Lower Speed at Distal CW	UD_LS	2.1	2.6	4.3	4.1	2.7	2.2	2.8	3.5	3.3	3.5	3.6	3.1	1.6
	Median Island for two-stage crossing	UD_MI	2.3	2.6	4.5	4.3	2.8	2.4	2.7	3.5	3.2	3.6	2.6	3.4	1.5
	Off-Set Exit Crossing	UD_EX	2.3	2.1	4.3	4.1	2.6	2.0	2.6	2.9	3.1	3.6	3.1	3.3	1.5
SIGNALIZATION TREATMENTS w APS															
S	Ped Scramble	S_PS	4.2	4.2	4.8	4.7	3.8	2.9	3.7	3.5	4.1	2.4	2.1	1.9	1.4
	Half-Signal	S_HS	4.4	4.2	4.8	4.0	4.1	3.0	4.2	3.4	3.7	2.9	3.8	3.8	4.0
	HAWK Signal at Splitter Island - One Stage	S_HS1	4.4	4.1	4.9	4.7	3.9	3.2	3.9	3.6	4.2	2.7	4.1	3.6	4.3
	HAWK Signal at Splitter Island - Two Stage	S_HS2	4.2	4.0	4.8	4.6	3.6	3.3	4.0	3.9	4.1	3.2	3.9	4.2	2.7
	Ped. Actuated Trad. Signal at Splitter - One-Stage	S_PA1	4.6	4.1	4.8	4.6	3.6	3.6	4.1	3.6	3.9	2.1	3.8	3.1	4.3
	Ped. Actuated Trad. Signal at Splitter - Two-Stage	S_PA2	4.6	4.2	4.4	4.8	3.7	3.3	4.1	3.6	4.1	3.1	4.1	4.1	2.7
	Distal HAWK Signal - One Stage	S_DHS1	4.4	4.0	4.4	4.8	3.9	3.1	4.1	3.4	4.0	2.9	3.6	3.7	3.2
	Distal HAWK Signal - Two Stage	S_DHS2	4.6	4.2	4.8	4.6	3.9	3.3	4.2	3.6	4.0	3.1	3.6	3.8	2.9
	Distal Ped. Actuated Signal - One Stage	S_DPA1	4.6	4.1	4.7	4.6	3.5	3.1	4.3	3.1	4.0	2.8	3.6	3.3	2.8
	Distal Ped. Actuated Signal - Two Stage	S_DPA2	4.7	4.3	4.8	4.6	3.6	3.1	4.3	3.3	4.0	3.2	3.2	3.5	2.2
GRADE SEPARATED CROSSING															
GS	Pedstrian Overpass	GS_OP	5.0	5.0	5.0	4.8	3.0	3.9	4.1	3.9	4.1	5.0	2.6	2.7	2.6
	Pedestrian Underpass	GS_UP	5.0	5.0	5.0	4.8	3.0	3.6	4.0	3.9	4.0	5.0	2.6	2.7	2.6

COMMENTS

Base Case, Unassisted X-ing, Static Signs

REVIEWER #1

REVIEWER #2

REVIEWER #3 - There will be great differences in yield and gap detection depending on the geometry of the baseline roundabout or channelized turn lane. I'm assuming a 2-land RAB with no particular traffic calming other than what is expected in good RAB design.

REVIEWER #4

REVIEWER #5

REVIEWER #6

REVIEWER #7 - To me the driver yielding probability changes depending on the width of the lane, speed, and whether it's one lane or multiple lanes, so I've put a number there, but don't really feel very comfortable with the fact that we're rating single lane and multi-lane roundabouts the same; Also, these ratings for sighted pedestrians, in my mind, don't consider those who are elderly or who have cognitive disabilities; I'd rate those populations more like blind peds, needing more time to make the decision and making more risky decisions

REVIEWER #8

REVIEWER #9 - Easiest to install, so applicable to all treatments. Vehicle delay is as low as possible, provided that ped volumes are low (no need to contain peds into platoons).

DRIVER INFORMATION TREATMENTS

Continuous Flasher

REVIEWER #1 - Not effective for blind peds unless paired with a yield detection system of some sort. Not in favor of continuous intervention as drivers will get used to it.

REVIEWER #2

REVIEWER #3 - This treatment resulted in <50% yield rate in the TTI study. Results better on smaller, slower traffic crossings. Not expected to improve yield or gap detection. If considered, consider only for 1-lane RAB.

REVIEWER #4 - This treatment resulted in <50% yield rate in the TTI study. Results better on smaller, slower traffic crossings. Not expected to improve yield or gap detection. If considered, consider only for 1-lane RAB.

REVIEWER #5

REVIEWER #6 - Not likely to have much impact over base case - which I used as a benchmark

REVIEWER #7

REVIEWER #8 - While this is applicable to all locations, I would strongly discourage its use. If using a flasher, it should ALWAYS be 'active when present'!!

REVIEWER #9 - Easy to install, but not expected to be effective in promoting vehicular yielding.

Appendix C: Team Treatment Survey

In-roadway warning sign

REVIEWER #1 - Not effective for blind peds unless paired with a yield detection system of some sort. I think an active intervention will be more effective than passive.

REVIEWER #2

REVIEWER #3 - This treatment resulted in <50% yield rate in the TTI study. Results better on smaller, slower traffic crossings. Not expected to improve yield or gap detection. If considered, consider only for 1-lane RAB.

REVIEWER #4 - This treatment resulted in <50% yield rate in the TTI study. Results better on smaller, slower traffic crossings. Not expected to improve yield or gap detection. If considered, consider only for 1-lane RAB.

REVIEWER #5

REVIEWER #6 - No improvement over base case

REVIEWER #7 - Inman's results indicated that drivers' yielding went from 11% to 16% with the signs, but drivers stopped for less time when they stopped in response to in-street signs and that the signs may possibly be a negative for blind pedestrians. Drivers only stopped for an average of 4 seconds, I think, while without signs, they averaged more like 10 seconds. I wouldn't really expect much effect at one lane if they aren't actually in the roadway.

REVIEWER #8- Ped Delay performance measures seem to be directly related to driver yielding behavior - more yielding, less delay (assuming yield detection)

REVIEWER #9 - Better suited for multilane crossings where sign is located between lanes.

In-road flashing crosswalk

REVIEWER #1 - Not effective for blind peds unless paired with a yield detection system of some sort. This is good for catching driver attention.

REVIEWER #2

REVIEWER #3 - This treatment, if combined with accessible information to bind peds when the lights come on, could result in better gap/yield detection. I would not expect it to improve gap or yield detection without accessible information. I am concerned that risky behavior would increase, however.

REVIEWER #4 - This treatment, if combined with accessible information to bind peds when the lights come on, could result in better gap/yield detection. I would not expect it to improve gap or yield detection without accessible information. I am concerned that risky behavior would increase, however.

REVIEWER #5 - I had assumed that a 'flashing crosswalk' treatment would be pedestrian actuated.

REVIEWER #6 - If flashing continuously - not much impact

REVIEWER #7 - If accompanied by accessible information, (which I think is necessary), it could increase risky behavior by blind peds. Could also increase risky behavior by sighted peds, but they could monitor cars reaction more easily

REVIEWER #8 - Ped Delay performance measures seem to be directly related to driver yielding behavior - more yielding, less delay (assuming yield detection)

REVIEWER #9 - Potential maintenance challenges

'Active When Present'

REVIEWER #1 - Not effective for blind peds unless paired with a yield detection system of some sort. Also good for getting attention only when attention is needed.

REVIEWER #2

REVIEWER #3 - This treatment also resulted in <50% yield rate in the TTI study. If combined with accessible information there is some possibility that gap/yield detection would increase for blind peds when used at 1-lane RAB or CTL, but risky behavior might also increase.

REVIEWER #4 - This treatment also resulted in <50% yield rate in the TTI study. If combined with accessible information there is some possibility that gap/yield detection would increase for blind peds when used at 1-lane RAB or CTL, but risky behavior might also increase.

REVIEWER #5 - What kind of sign/display is being referred to here. Active when present implies that it is pedestrian-actuated, but does not say what type of sign/display

REVIEWER #6 - If lights are activated when peds are present, presumably this will increase yielding modestly - the key question is whether the yields can be detected - without yield detect considered in the ratings of the various treatments - the ratings are of limited usefulness I've rated this without yield detect considered, with increased yielding alone rated in the fifth column P(Y)

REVIEWER #7 - ditto on above comments

REVIEWER #8 - Ped Delay performance measures seem to be directly related to driver yielding behavior - more yielding, less delay (assuming yield detection)

REVIEWER #9

Advanced Yield Line

REVIEWER #1 - Not effective for blind peds unless paired with a yield detection system of some sort. Particularly useful for one lane roundabouts where yielding culture is good (too good?)

REVIEWER #2

REVIEWER #3 - It is possible that AYL would resulting greater yielding because drivers could have greater distance in which to react to ped. However, in the absence of GD, YD, or YG, it might be even more difficult for blind peds to detect gaps/yields.

REVIEWER #4 - It is possible that AYL would resulting greater yielding because drivers could have greater distance in which to react to ped. However, in the absence of GD, YD, or YG, it might be even more difficult for blind peds to detect gaps/yields.

REVIEWER #5 Applicable only to 2-lane facility type. Under applicability to CTL, are you assuming only a single CTL?

REVIEWER #6 - I don't see much benefit here - and it certainly would increased the likelihood of missed yields on the part of blind folk

REVIEWER #7 - Would negatively affect blind pedestrians' ability to detect yielding vehicles, because cars would be further away; don't know that it would affect drivers' probability of yielding at all. Where do you put an advanced yield line for the exit crossings? Doesn't seem like it would really apply well to roundabouts or CTL's

REVIEWER #8 - The advanced yield line only makes sense at 2-lane approaches (reduce multiple threat crashes). That said, I think it makes sense to paint a solid yield line on all approaches to let drivers know where to yield (and let pedestrians and yield detection devices know where to look)

REVIEWER #9 - Not practical for rbt exits - not enough room unless crosswalk is located much further away from rbt. Only useful for multilane rbt entries. Blind peds may have difficulty hearing vehicles yield at advanced yield line.

TRAFFIC CALMING TREATMENTS

Lower Speed (25)

REVIEWER #1 - Likely to increase yield rate, may result in a small amount of improvement in gap/yield detection for blind peds. May reduce delay if yield rate increases, and if gap/yield detection increases. Reduced delay could lead to taking less risky gaps by blind peds.

REVIEWER #2

REVIEWER #3 - Likely to increase yield rate, may result in a small amount of improvement in gap/yield detection for blind peds. May reduce delay if yield rate increases, and if gap/yield detection increases. Reduced delay could lead to taking less risky gaps by blind peds.

REVIEWER #4 - Likely to increase yield rate, may result in a small amount of improvement in gap/yield detection for blind peds. May reduce delay if yield rate increases, and if gap/yield detection increases. Reduced delay could lead to taking less risky gaps by blind peds.

REVIEWER #5 - Lower vehicle speed will not by itself guarantee lower risk unless one assumes it increases the likelihood of drivers yielding (both voluntarily and upon ped taking risky gap)

REVIEWER #6 - Will increase yields - with beneficial result if detectable

REVIEWER #7 - I'm not really sure how we test this. What traffic calming treatments are we envisioning working at an exit lane crosswalk? And lower speed is not really a treatment, so how do we get lower speed reliably at multilane roundabout, particularly at the exits; seems the speed can vary greatly depending on geometry and volume.

REVIEWER #8 - Speeds at most single-lane roundabouts and CTLs are probably (hopefully) lower then this anyways

REVIEWER #9 - Geometric delay is less likely to be perceived by drivers than control (e.g., signal) delay.

Lower Speed (15)

REVIEWER #1 - More likely to increase yield rate than 25 mph; may result in a small amount of improvement in gap/yield detection for blind peds. May reduce delay if yield rate increases, and if gap/yield detection increases. Reduced delay could lead to taking less risky gaps by blind

REVIEWER #2

REVIEWER #3 - More likely to increase yield rate than 25 mph; may result in a small amount of improvement in gap/yield detection for blind peds. May reduce delay if yield rate increases, and if gap/yield detection increases. Reduced delay could lead to taking less risky gaps by blind

REVIEWER #4 - More likely to increase yield rate than 25 mph; may result in a small amount of improvement in gap/yield detection for blind peds. May reduce delay if yield rate increases, and if gap/yield detection increases. Reduced delay could lead to taking less risky gaps by blind

REVIEWER #5 - Lower speed may increase likelihood of driver yielding; may be associated with an increase in perceived risk on part of pedestrian, but not necessarily likelihood of his/her taking risky gap

REVIEWER #6

REVIEWER #7 - lower speed doesn't affect probability of yield or gap detection; might actually be disadvantage because vehicle is quieter; could improve chance for vehicles to stop for pedestrians and decrease risk, but I'm not sure that we can get that at exits, except by installing raised crosswalks and we have that listed separately

REVIEWER #8 - Speed Limit 15 is like a general traffic calming strategy. Probably more applicable to downtown areas

REVIEWER #9 - Difficult to achieve with design vehicle constraints. Serious path overlap problems can occur at multilane entries and exits if too slow. Lower speed means quieter environment - may be difficult to hear gaps.

Raised Crosswalk

REVIEWER #1 - Should have higher yield creation rates than lowering speeds. Should also help blind peds stay in crosswalk.

REVIEWER #2

REVIEWER #3 - Expected to improve yield rate. May result in slightly improved gap/yield detection. If it results in improved gap/yield detection, could result in slightly decreased delay, but may not reduce risk decisions. Expected to have considerable benefit for wayfinding--staying within crosswalk.

REVIEWER #4 - Expected to improve yield rate. May result in slightly improved gap/yield detection. If it results in improved gap/yield detection, could result in slightly decreased delay, but may not reduce risk decisions. Expected to have considerable benefit for wayfinding--staying within crosswalk.

REVIEWER #5 - Perception of raised crosswalk may prompt vehicles to reduce speed increasing the likelihood of yielding (all assumptions). If there are increased yields ped travel time, on average, will be reduced

REVIEWER #6 - I don't think any of these treatments above will work very effectively at a multilane roundabout

REVIEWER #7 - Assuming that raised crosswalk gets speeds down?

REVIEWER #8

REVIEWER #9

Appendix C: Team Treatment Survey

PEDESTRIAN INFORMATION TREATMENTS

Surface Alterations / Rumble Str.

REVIEWER #1 - If rumble strips are present primarily to give auditory info, there are problems with placement that are tough to overcome.

REVIEWER #2

REVIEWER #3 - May improve yield rate slightly. Expected to improve yield detect, and possibly gap detect at 1-lane RAB and possibly CTL with deceleration lane.

REVIEWER #4 - May improve yield rate slightly. Expected to improve yield detect, and possibly gap detect at 1-lane RAB and possibly CTL with deceleration lane.

REVIEWER #5 - Ped delay is reduced IF treatment improves ped ability to detect gaps and yielded vehicles. Likewise risk will be reduced IF treatment improves gap and yield detection on ped's part; and likelihood of yielding on drivers part.

REVIEWER #6 - N help, really, over baseline

REVIEWER #7 - AT one lane roundabout only or separated channelized lane only; no effect on yielding; it's a variation of a yield and gap detection systems, but needs more testing to see if it's feasible; If individuals reliably detect yields, it could have a positive effect on vehicle delay; need to offset the exit crosswalk?

REVIEWER #8

REVIEWER #9

Gap Detection System

REVIEWER #1 - If the technology works, and we can figure out where to put it, I assume GD will improve gap detection. Probably not as beneficial as yield detection.

REVIEWER #2

REVIEWER #3 - If the technology works, and we can figure out where to put it, I assume GD will improve gap detection. Probably not as beneficial as yield detection.

REVIEWER #4 - If the technology works, and we can figure out where to put it, I assume GD will improve gap detection. Probably not as beneficial as yield detection.

REVIEWER #5

REVIEWER #6 - Will be challenging to configure and potentially expensive - but it has potential - must be error free!!

REVIEWER #7 - only works if there are adequate gaps! Entry probably easier to do than exit lane and not sure how easy it is to implement on multi-lane facility or on ctl, since vehicles might change lanes at the last minute

REVIEWER #8 - Gap Detection System is probably only applicable on the entry leg to roundabouts and CTLs with deceleration lanes. Honestly, I am less and less convinced that this makes any sense. You are spending a lot on technology and then rely on the device to make decisions for you. Worst part about it, the drivers have no idea that this thing is in place and are therefore oblivious to how it may guide pedestrian behavior. It also doesn't make sense to install this at the entry and not the exit leg. I also don't see how you could ever justify installing this over a signal. If you think about it, the system will only give you a 'crossable gap' indication, if there is no traffic - well if there isn't any traffic than you don't really have to worry about a signal causing vehicle delay! So why not spend the money on a HAWK?

REVIEWER #9 - Detection of gaps on exit will be difficult to configure if crosswalk is in splitter island - lack of space.

Yield Detection System

REVIEWER #1 - This seems most beneficial to me, as long as it is placed to fit the culture and environment properly.

REVIEWER #2

REVIEWER #3 - If the technology works, and we can figure out where to put it, I assume YD will improve yield detection. Consider on 2-lane RAB. Try combining with AYL as well as standard yield line location.

REVIEWER #4 - If the technology works, and we can figure out where to put it, I assume YD will improve yield detection. Consider on 2-lane RAB. Try combining with AYL as well as standard yield line location.

REVIEWER #5

REVIEWER #6 - This one has real potential at a one laner

REVIEWER #7 - only works if there are adequate yields

REVIEWER #8 - This makes a lot more sense, because the detection area is a lot better defined. Impact on delay depends on the amount of drivers yielding - so it would make intuitive sense to combine this with a low-cost treatment to increase driver yielding (in-roadway cones, raised CW, 'active when present')

REVIEWER #9

Yield + Gap Detect

REVIEWER #1 -Not sure how this would play out logistically, but it seems enticing to try.

REVIEWER #2

REVIEWER #3 - If the technology works, and we can figure out where to put it, I assume YG may improve both yield and gap detection. However, I wouldn't expect it to be much better than YD alone.

REVIEWER #4 - If the technology works, and we can figure out where to put it, I assume YG may improve both yield and gap detection. However, I wouldn't expect it to be much better than YD alone.

REVIEWER #5

REVIEWER #6 - If the technology works, and we can figure out where to put it, I assume YG may improve both yield and gap detection. However, I wouldn't expect it to be much better than YD alone.

REVIEWER #7 - only works if there are adequate gaps and yields; no effect at all if there are high volumes and low yielding

REVIEWER #8 - This makes more sense than GD alone - but I am still hesitant of the effectiveness and reliability of the gap detect component of the system

REVIEWER #9

DISTAL/MIDBLOCK CROSSING

Set back XX feet BOTH CROSS.

REVIEWER #1 - This logically seems to provide some useful effect but I don't think the effect is that great. Certain constraint remain.

REVIEWER #2

REVIEWER #3 - It would be of some interest to determine whether, particularly on exit lane crossings, there would be improved performance in gap/yield detection for bind peds. I wouldn't expect it to be much, however. If vehicle storage is the issue, I expect this can be modeled without human factors testing.

REVIEWER #4 - It would be of some interest to determine whether, particularly on exit lane crossings, there would be improved performance in gap/yield detection for bind peds. I wouldn't expect it to be much, however. If vehicle storage is the issue, I expect this can be modeled without human factors testing. REVIEWER #5 - Estimated vehicle delay at distal CW assumed to derive from increased likelihood of vehicles yielding to pedestrians

REVIEWER #6

REVIEWER #7 - I think the distance from the roundabout could make a lot of difference in my answers.

REVIEWER #8 - This really has two potential benefits: removing the crosswalk from the noise of the roundabout and separating decisions for drivers. I can see the danger though, that a distal CW without speed treatments may actually make crossing more difficult. At the roundabout, entering drivers are already prepared to stop and exiting drivers should still be at a relatively low speed - at a distal location, people may be less willing to delay their trip a second time and yield to a pedestrian. The delay for pedestrians does not incorporate added travel time from the main intersection

REVIEWER #9 - Infeasible for CTL, assuming intersection is signalized - midblock xwalk will need to be quite distant to clear signal queues. Not likely to be practical in most cases. Midblock xwalk easier to distinguish exiting vehicles.

Lower Speed at Distal CW

REVIEWER #1 - Lower speeds anywhere are going to increase yield and perhaps gaps but need to marry this with a detect system.

REVIEWER #2

REVIEWER #3 - Not expected to result in much, if any, improvement in gap/yield detection. I think TTI data may be useful for modeling the effect of different speeds and widths on yielding.

REVIEWER #4 - Not expected to result in much, if any, improvement in gap/yield detection. I think TTI data may be useful for modeling the effect of different speeds and widths on yielding.
REVIEWER #5 - Associated with increased likelihood of yielding at distal location combined with increased likelihood of yielding associated with lower speed
REVIEWER #6
REVIEWER #7 - lower speed than what?
REVIEWER #8
REVIEWER #9

Median Island for two-stage crossing

REVIEWER #1 - Median island are generally a good idea, if possible. They make the crossing task easier to perform overall.
REVIEWER #2 - maybe it helps a bit as peds need to focus one direction at a time.. Questions… how would blind peds know this is 1 vs. 2 stage crossing??
REVIEWER #3 - The median island would be required for a two-stage crossing. I don't think this requires human factors research, but modeling could tell us something about delay for both peds and vehicles.
REVIEWER #4 - The median island would be required for a two-stage crossing. I don't think this requires human factors research, but modeling could tell us something about delay for both peds and vehicles. We'd also want to consider out-of-direction travel.
REVIEWER #5
REVIEWER #6 - Improves yield detect because you don't have to detect both ways simultaneously
REVIEWER #7
REVIEWER #8
REVIEWER #9 - Depends on space to accomplish this.

Off-Set Exit Crossing

REVIEWER #1 - The off-set crossing idea is intriguing. What has been the experience of England in using this?
REVIEWER #2
REVIEWER #3 - May result in modest improvement in gap and yield detection at 1-lane RAB. I think it would be more informative to test off-set crossings at conventional distance from the circular roadway.
REVIEWER #4 - May result in modest improvement in gap and yield detection at 1-lane RAB. I think it would be more informative to test off-set crossings at conventional distance from the circular roadway.
REVIEWER #5
REVIEWER #6 - Not sure what you mean here, exactly
REVIEWER #7

REVIEWER #8 - The added benefits are obviously only at the exit leg to a roundabout - but they should be quite significant here.

REVIEWER #9 - Depends on space to accomplish this.

SIGNALIZATION TREATMENTS

Ped Scramble

REVIEWER #1 - No reason to test. Unlikely to be implemented except in rare instances. Not informative to blind peds without APS.

REVIEWER #2

REVIEWER #3 - No reason to test. Unlikely to be implemented except in rare instances. Not informative to blind peds without APS.

REVIEWER #4 - No reason to test. Unlikely to be implemented except in rare instances. Not informative to blind peds without APS.

REVIEWER #5 - Detection of gaps and yields are n/a if signal is present (or a 5.0 in terms of elimination of requirement). When signal is present, key issue is locating call button and presence of APS

REVIEWER #6 - I wouldn't go here

REVIEWER #7 - Delay really depends on the volume and minimum gap settings, doesn't it?? Only reasonable to install at locations with very high pedestrian volumes; seems to have high potential for sighted peds to ignore because it's likely to increase their delay; don't see it applying to CTL

REVIEWER #8 - The high pedestrian delay is due to a higher vehicle clearance time (vehicle green indication). I think if the approach signals are independent that you can get away with shorter 'min green times' for vehicles and thus have lower ped delays

REVIEWER #9 - Inappropriate for most scenarios - recommend dropping.

Half-Signal

REVIEWER #1 - Ratings are based on trad. Signal with flashing green. I am thinking that the flashing green may not only increase the yield rate, when not actuated, but may also decrease the likelihood of rear-end collisions. Useless to blind peds unless an APS is provided. Ratings assume presence of APS.

REVIEWER #2

REVIEWER #3 - Ratings are based on trad. Signal with flashing green. I am thinking that the flashing green may not only increase the yield rate, when not actuated, but may also decrease the likelihood of rear-end collisions. Useless to blind peds unless an APS is provided. Ratings assume presence of APS.

REVIEWER #4 - Ratings are based on trad. Signal with flashing green. I am thinking that the flashing green may not only increase the yield rate, when not actuated, but may also decrease the likelihood of rear-end collisions. Useless to blind peds unless an APS is provided. Ratings assume presence of APS.

REVIEWER #5 - Detection of gaps and yields are n/a if signal is present (or a 5.0 in terms of elimination of requirement). When signal is present, key issue is locating call button and presence of APS

REVIEWER #6 - APS assumed

REVIEWER #7 - Really flashing green, to yellow to red?? Then no different from ped activated traditional

REVIEWER #8 - I don't see how this is applicable for any of the sites - seems to make most sense at a midblock. Not sure how this affects the performance measures

REVIEWER #9 - N/A for rbts and CTL.

Appendix C: Team Treatment Survey

HAWK Signal at Splitter Island - One Stage

REVIEWER #1 - Ratings assume presence of an APS. With that, will provide excellent crossing info, testing done in Raleigh seemed to support this, but placement needs to be investigated.

REVIEWER #2

REVIEWER #3 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. Especially important to test at CTL.

REVIEWER #4 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. Especially important to test at CTL.

REVIEWER #5 - Detection of gaps and yields are n/a if signal is present (or a 5.0 in terms of elimination of requirement). When signal is present, key issue is locating call button and presence of APS

REVIEWER #6

REVIEWER #7 - I really don't see the usefulness of not splitting the crossing into two stages; maybe a small one lane roundabout and CTL

REVIEWER #8

REVIEWER #9 - Highly feasible at CTL at signalized intersection - hardware already in place, can time ped signal current with vehicle phases to minimize overall delay. Requires hardware not typically present at roundabout.

HAWK Signal at Splitter Island - Two Stage

REVIEWER #1 Ratings assume presence of an APS. With that, will provide excellent crossing info, testing done in Raleigh seemed to support this, but placement needs to be investigated.

REVIEWER #2

REVIEWER #3 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. Especially important to test at 2-lane RAB.

REVIEWER #4 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. Especially important to test at 2-lane RAB.

REVIEWER #5 - Detection of gaps and yields are n/a if signal is present (or a 5.0 in terms of elimination of requirement). When signal is present, key issue is locating call button and presence of APS

REVIEWER #6

REVIEWER #7 - wouldn't use two stages at CTL

REVIEWER #8 - Slightly longer delay times, because phases are longer

REVIEWER #9 - N/A for CTL. Requires hardware not typically present at roundabout.

Ped. Actuated Trad. Signal at Splitter - One-Stage

REVIEWER #1 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. Important to test at CTL.

REVIEWER #2

REVIEWER #3 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. Important to test at CTL.

REVIEWER #4 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. Important to test at CTL.

REVIEWER #5 - Detection of gaps and yields are n/a if signal is present (or a 5.0 in terms of elimination of requirement). When signal is present, key issue is locating call button and presence of APS

REVIEWER #6

REVIEWER #7 - ditto on the one stage with HAWK

REVIEWER #8

REVIEWER #9 - Highly feasible at CTL at signalized intersection - hardware already in place, can time ped signal current with vehicle phases to minimize overall delay. Requires hardware not typically present at roundabout.

Ped. Actuated Trad. Signal at Splitter - Two-Stage

REVIEWER #1 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. Important to test at 2-lane RAB.

REVIEWER #2

REVIEWER #3 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. Important to test at 2-lane RAB.

REVIEWER #4 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. Important to test at 2-lane RAB.

REVIEWER #5 - Detection of gaps and yields are n/a if signal is present (or a 5.0 in terms of elimination of requirement). When signal is present, key issue is locating call button and presence of APS

REVIEWER #6

REVIEWER #7 - what kind of timing are we talking about? I'd like to try a very short WALK for these or for the HAWK. Could peds do ok with a 2 second WALK, particularly since they'll have the APS cue too?

REVIEWER #8

REVIEWER #9 - N/A for CTL. Requires hardware not typically present at roundabout

Distal HAWK Signal - One Stage

REVIEWER #1 - Ratings assume presence of an APS. With that, will provide excellent crossing info, testing done in Raleigh seemed to settle this.

REVIEWER #2

REVIEWER #3 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. No good reason to test.

REVIEWER #4 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. No good reason to test.

REVIEWER #5 - Detection of gaps and yields are n/a if signal is present (or a 5.0 in terms of elimination of requirement). When signal is present, key issue is locating call button and presence of APS

REVIEWER #6 - Ratings assume presence of an APS. It'll work, I suspect

REVIEWER #7 - If peds use the crosswalk! But, my expectation is that they won't unless there are strong measures to keep them from crossing closer to the roundabout, or the main ped desire lines are away from the roundabout anyway. I don't see a lot of value that we won't get with the signal closer to the roundabout

REVIEWER #8

REVIEWER #9 - Not practical for CTLs at signalized intersections due to queues at signal unless midblock crossing is 250+ ft away - doesn't qualify as treatment of intersection.

<u>Distal HAWK Signal - Two Stage</u>

REVIEWER #1 - Ratings assume presence of an APS. With that, will provide excellent crossing info, testing done in Raleigh seemed to settle this.

REVIEWER #2

REVIEWER #3 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. No good reason to test.

REVIEWER #4 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. No good reason to test.

REVIEWER #5 - Detection of gaps and yields are n/a if signal is present (or a 5.0 in terms of elimination of requirement). When signal is present, key issue is locating call button and presence of APS

REVIEWER #6 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. No good reason to test.

REVIEWER #7

REVIEWER #8

REVIEWER #9 - Not practical for CTLs at signalized intersections due to queues at signal unless midblock crossing is 250+ ft away - doesn't qualify as treatment of intersection.

<u>Distal Ped. Actuated Signal - One Stage</u>

REVIEWER #1 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. No good reason to test.

REVIEWER #2

REVIEWER #3 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. No good reason to test.

REVIEWER #4 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. No good reason to test.

REVIEWER #5 - Detection of gaps and yields are n/a if signal is present (or a 5.0 in terms of elimination of requirement). When signal is present, key issue is locating call button and presence of APS

REVIEWER #6

REVIEWER #7
REVIEWER #8
REVIEWER #9 - Not practical for CTLs at signalized intersections due to queues at signal unless midblock crossing is 250+ ft away - doesn't qualify as treatment of intersection.

Distal Ped. Actuated Signal - Two Stage

REVIEWER #1 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. No good reason to test.
REVIEWER #2
REVIEWER #3 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. No good reason to test.
REVIEWER #4 - Ratings assume presence of an APS. Expected to result in good yield/gap detection as well as yield rate. No good reason to test.
REVIEWER #5 - Detection of gaps and yields are n/a if signal is present (or a 5.0 in terms of elimination of requirement). When signal is present, key issue is locating call button and presence of APS
REVIEWER #6 - For the signals - not sure that distal v conventional location matters a lot - If APS is in place - detection will occur. Increased detection is the main reason for distal if APS is NOT In the scenario
REVIEWER #7
REVIEWER #8
REVIEWER #9 - Not practical for CTLs at signalized intersections due to queues at signal unless midblock crossing is 250+ ft away - doesn't qualify as treatment of intersection.

GRADE SEPARATED CROSSINGS

Pedestrian Overpass

REVIEWER #1 - Unrealistic, expensive, potentially creates more problems than it solves.
REVIEWER #2
REVIEWER #3 - I think the effect of this solution, in addition to its very high cost, will be negative in most regards unless it is made completely impossible for pedestrians to cross at street level. I think risk will increase for both blind and sighted pedestrians unless they are prevented from making street-level crossings.
REVIEWER #4 - I think the effect of this solution, in addition to its very high cost, will be negative in most regards unless it is made completely impossible for pedestrians to cross at street level. I think risk will increase for both blind and sighted pedestrians unless they are prevented from making street-level crossings.
REVIEWER #5 - Detection of gaps and yields n/a given overpass/underpass (or could be considered a 5.0 given elimination of these requirements. Vehicle delay would be decreased compared to baseline
REVIEWER #6 - I'm not really interested in this one
REVIEWER #7

REVIEWER #8 - more difficult at CTL - would have to go across entire intersection to make sense

REVIEWER #9 - Eliminates interaction and therefore delay between vehicles and peds. Completely impractical and undesirable in 99.99% of all cases, plus unnecessary to test - recommend dropping.

Pedestrian Underpass

REVIEWER #1 - Unrealistic, expensive, potentially creates more problems than it solves.

REVIEWER #2

REVIEWER #3 - I think the effect of this solution, in addition to its very high cost, will be negative in most regards unless it is made completely impossible for pedestrians to cross at street level. I think risk will increase for both blind and sighted pedestrians unless they are prevented from making street-level crossings.

REVIEWER #4 - I think the effect of this solution, in addition to its very high cost, will be negative in most regards unless it is made completely impossible for pedestrians to cross at street level. I think risk will increase for both blind and sighted pedestrians unless they are prevented from making street-level crossings.

REVIEWER #5 - Detection of gaps and yields n/a given overpass/underpass (or could be considered a 5.0 given elimination of these requirements. Vehicle delay would be decreased compared to baseline

REVIEWER #6

REVIEWER #7

REVIEWER #8 - more difficult at CTL - would have to go below entire intersection to make sense

REVIEWER #9 - Eliminates interaction and therefore delay between vehicles and peds. Completely impractical and undesirable in 99.99% of all cases, plus unnecessary to test - recommend dropping.

APPENDIX D: Details on Site Selection

This Appendix contains details on the selection of treatment sites in NCHRP 3-78a:

Site Selection Criteria

In this task, the research team will evaluate the potential sites identified in Phase I and select those that are deemed suitable for further field investigation of the proposed treatments. Criteria for site selection include:

- Feasibility of implementing one or more of the desired treatments at a given site within NCHRP project schedule;
- Level of federal, state, and local support and cost-sharing in implementing the proposed treatments;
- Sufficient vehicle and pedestrian demand to enable a meaningful evaluation of the treatment impact on the system performance;
- Proximity of the sites to the data collection team;
- Proximity of the sites to one another;
- Availability of adequate numbers of potential research participants who are blind or visually impaired in reasonable proximity to the sites identified for data collection tasks; and
- Adequate representation of the various geometric conditions to be considered.

Site Selection Short-Listing

The research team used three methods to identify candidate sites. First, we broadcast a request pertaining to interested participants at the 2006 TRB conference and on the Kansas State/TRB sponsored roundabout list serve. The message posted on the list serve read:

The National Academies of Science has an ongoing research project (NCHRP 3-78) titled "Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities". The objective of this research is to recommend a range of geometric designs, traffic control devices, and other treatments that will make pedestrian crossings at roundabouts and channelized turn lanes more useable by pedestrians with vision impairment. These recommendations should be suitable for inclusion in transportation-industry practice and policies, including the AASHTO Policy on Geometric Design of Highways and Streets and the FHWA Manual on Uniform Traffic Control Devices. Exploration of the proper balance among the needs of passenger cars, trucks, pedestrians (including pedestrians with vision impairments), and bicycles is central to achieving the objectives of the research.

We are soliciting your help in identifying potential treatment sites. We are looking for sites where single lane and multilane roundabouts or channelized turn lanes exist, or where they are planned to be constructed in the next year or two. We are especially *interested in sites that may be considering some form of signalization that will permit its possible use now or in the future. Potential treatments include:*

Signing
Pavement markings
Signals (pedestrian actuated, APS, HAWK)
Alternate crosswalk locations
Raised crosswalks
Other geometric treatments

We plan on collecting data at the sites in 2006 or 2007.

Thank you for your consideration.

If you are interested, please contact me via email or at the address/phone number shown below.

The end of this Appendix contains aerial and site photographs taken at the sites identified in the responses to the broadcast request.

In our second method of site identification we contacted agencies and practicing engineers active in the planning, design, and construction of roundabouts. We recognize that roundabouts are not the entire focus of the study, but we were confident that we could easily identify sites for the channelized turn lane located within close proximity to the roundabout sites. Conversations with agency officials confirmed this. The following is a list of agencies/professionals we contacted:

- Maryland State Highway Administration - Tom Hicks/Mike Niederhauser
- Kansas DOT - David Church/Cheryl Lambrecht
- Washington State DOT - Brian Walsh
- New York State DOT - Howard McCulloch (panel member)
- North Carolina DOT - Jim Dunlop (panel member)
- California DOT - Rebecca Mowry/Jerry Champa (3-65 panel member)
- Florida DOT - Beatriz Caicedo-Maddison (3-65 panel chair,)
- City of Clearwater, FL - Ken Sides
- City of Kennewick, WA - Peter Beaudry,
- City of Modesto, CA - Firoz Vohra, (active local roundabout program)
- City of Bend, OR - Robin Lewis, (active local roundabout program)
- City of Portland, OR - Bill Kloos, (active participants in APS and other research projects)
- City of Tucson, AZ - Richard Nassi
- City of Golden, CO
- Town of Vail, CO
- MTJ Engineering - Mark Johnson

- Roundabouts, USA - Bill Baranowski
- Ourston Roundabout Engineering - Leif Ourston/Mark Lenters/Phil Weber
- Alternate Street Design - Michael Wallwork

We had follow-up meetings and/or telephone conversations with the Maryland State Highway Administration, Washington State Department of Transportation, New York State Department of Transportation, and Ourston Roundabout Engineering.

The third method for site selection consisted of reviewing sites studied under NCHRP 3-72: *Lane Widths, Channelized Right Turns, and Right-Turn Deceleration Lanes in Urban and Suburban Areas*, and NCHRP 3-65: *Applying Roundabouts in the United States.*

Table 1, shown on the next page, represents an initial site short-listing compared against the site selection criteria discussed on page one. The sites in the Mid-Atlantic region are generally rated higher based on their proximity to the research team and each respective Department of Transportation's willingness to participate in and/or contribute to the experiment. However, the sites that already have the more expensive treatments (namely signals) should also receive serious consideration.

Table 1 – Sites and Site Selection Criteria

Site	Implementation Feasibility	Local Support	Vehicle / Pedestrian Demand	Proximity to Data Collection Team	Proximity to One Another	Availability of Research Participants	Adequate Geometric Conditions	Total
Double Lane Roundabouts								
1. Towson, MD	2	3	3	2	3	3	1	17
2. Mt. Rainier, MD	2	3	2	2	3	3	1	16
3. Annapolis MD (Alternate Site)	**2**	**3**	**2**	**2**	**3**	**3**	**3**	**18**
4. Winston-Salem, NC	2	3	3	2	3	1	2	16
5. Orem, UT	3	1	3	1	1	2	2	13
6. WA 16 NB/Borgen Boulevard	2	2	1	1	1	2	2	11
7. Golden, CO (Preferred Site)	**3**	**3**	**3**	**2**	**1**	**3**	**3**	**18**

Key : 1 = Poor
2 = Average
3 = Good

Appendix D: Details on Site Selection

Table 1 (Continued) – Sites and Site Selection Criteria

Site	Implementation Feasibility	Local Support	Vehicle/Pedestrian Demand	Proximity to Data Collection Team	Proximity to One Another	Availability of Research Participants	Adequate Geometric Conditions	Total
Single Lane Roundabouts								
1. Brunswick, MD	3	3	2	3	3	1	2	17
2. New Haven, NY	2	2	1	1	2	2	2	12
3. Voorheesville, NY	3	2	2	2	2	3	2	16
4. Pullen/Stimson, Raleigh, NC (Alternate Site)	**2**	**3**	**3**	**3**	**3**	**3**	**3**	**20**
5. UNC Charlotte, NC (Preferred Site)	**3**	**3**	**3**	**3**	**3**	**3**	**2**	**20**
6. Alpine, UT	2	1	2	1	1	2	2	11
7. Salt Lake City, UT	2	1	2	1	1	3	2	12
8. 51st Ave/Borgen Boulevard, Gig Harbor, WA	3	2	2	1	1	2	2	13
9. WA 16 SB/Borgen Blvd, Gig Harbor, WA	2	2	1	1	1	2	2	11
Signalized Roundabouts								
1. Gatineau, Quebec	3	1	2	2	1	2	3	14

Key : 1 = Poor
2 = Average
3 = Good

Table 1 (Continued) – Sites and Site Selection Criteria

Site	Implementation Feasibility	Local Support	Vehicle/ Pedestrian Demand	Proximity to Data Collection Team	Proximity to One Another	Availability of Research Participants	Adequate Geometric Conditions	Total
Channelized Turn Lanes								
1. Loch Raven/Joppa Road, Towson, MD	2	2	2	2	2	3	2	15
2. Dulaney Valley/ Fairmount Avenue, Towson MD	2	2	2	2	2	3	2	15
3. Padonia Road/York Rd, Timonium MD	2	3	1	3	2	2	2	15
4. Sabino Canyon Road/Cloud Rd, Tucson, AZ	3	3	1	1	3	3	2	16
5. Sabino Canyon Road/Klob Road, Tucson, AZ	2	3	2	1	3	3	2	16
6. Martin Way/Sleater Kinney Rd, Lacey WA	2	2	2	1	1	2	2	12
7. Martin Way/College Street, Lacey, WA	2	2	2	1	1	2	2	12
8. Grant Road/ Campbell, Tucson, AZ (Alternate Site)	**3**	**3**	**2**	**1**	**3**	**33**	**3**	**18**
9. Providence Rd/ Pineville–Matthew Rd, Charlotte, NC (Preferred Site)	**3**	**3**	**1**	**3**	**3**	**3**	**2**	**18**

Key : 1 = Poor
2 = Average
3 = Good

Final Site Selection

Our recommended site selection is outlined below. Further descriptions of the sites and treatments installed at each site are found in Appendix E.

Single Lane Roundabout

1. UNC Charlotte – Charlotte, NCPullen Stimson – Raleigh, NC

The UNC Charlotte roundabout is the preferred site for a few reasons. First, the site is close to many of the team members. Second, the team has a great working relationship with engineers the Charlotte DOT, all who are very willing to help purchase and install treatments. Third, the site is in the vicinity of the CTL site in Charlotte. Although is intimately familiar with the Pullen Stinson site, which is even more convenient to team members at ITRE, the team has done many studies at this site in the past. In addition, the pedestrian traffic from the University is so high that drivers can be extremely cautious around crosswalks. However, the site should still be considered a very good alternate site since we would have permission to study and test treatments, not to mention the fact that the NC State team has already modeled this site in VISSIM, which will help to reduce the modeling costs in subsequent phases.

Double Lane Roundabout

1. Golden, CO
2. Spa road/Taylor Avenue, Annapolis, MD

The Golden, CO site is the preferred site because of the range of geometric conditions and the local support for the research effort. Conversations with the City of Golden's representative, Don Hartman, indicated that there is relatively strong community support for roundabouts, and the City is willing to test any of the treatments identified by the research team.

The double-lane roundabout located in Annapolis, MD is the alternate site identified by the team. It is located in an area with a relatively high level of pedestrian activity. Current construction immediately adjacent to the roundabout prevents any testing of treatments at the pedestrian crosswalks; however, the site could be used once the construction activities are completed. SHA would likely be interested in exploring a range of alternatives short of signalization.

Channelized Turn Lanes

1. Providence Road/Pineville-Matthews Road – Charlotte, NC
2. Grant Road/Campbell Ave – Tucson, AZ

The Charlotte, NC site is the preferred candidate for study of channelized turn lanes (CTLs) for multiple reasons. First, the site has CTLs on each of the four legs of the intersection. The geometric conditions are fairly good here, with minor skew angles between the two intersecting roadways. The choice between which two CTLs to use will take into account this skew angle. Second, the site has high volumes of traffic with two heavily traveled intersecting roadways. Third, the site is very close to many of the research team members and is located near the desirable single lane roundabout. Last, the support from local engineering staff to purchase and install treatments is already in place, saving time and money for the project. No APS signals are installed at this time; however, the city has agreed to install those along with any other treatments we deem appropriate.

The alternate site is located in Tucson, AZ. This location is considered advantageous because Tucson has experience using HAWK signals for pedestrian mid-block crossings; therefore, drivers are familiar with their operation. A HAWK signal is one of the treatments that the research team would like to test at channelized turn lanes; however, it is not entirely necessary since it will be tested at the dual lane roundabout. Based on conversations with Richard Nassi, the City of Tucson's representative, the Grant Road/Campbell Avenue intersection would be preferable if Tucson was chosen as the location for CTL treatment testing.

Site Pictures

Double Lane Roundabouts

Figure 8. Towson Roundabout

Figure 9. US 1/34th Street, Mt. Rainier, MD

Figure 10. Spa Road / Taylor Avenue, Annapolis, MD

Figure 11. Spa Road / Taylor Avenue, Annapolis, MD

Figure 12. Winston-Salem, NC

Figure 13. Winston-Salem, NC

Figure 14. Winston-Salem, NC

Figure 15. Winston-Salem, NC

Figure 16. Utah Valley State College, Orem, UT

Figure 17. Utah Valley State College, Orem, UT (zoomed out view)

Figure 18. WA 16 Northbound/Borgen Boulevard, Gig Harbor, WA

Figure 19. Golden, CO

Single Lane Roundabouts

Figure 20. MD 17 / B Street, Brunswick, MD

Figure 21. Ferry Road / Tyndall Road, New Haven, NY (Long Island)

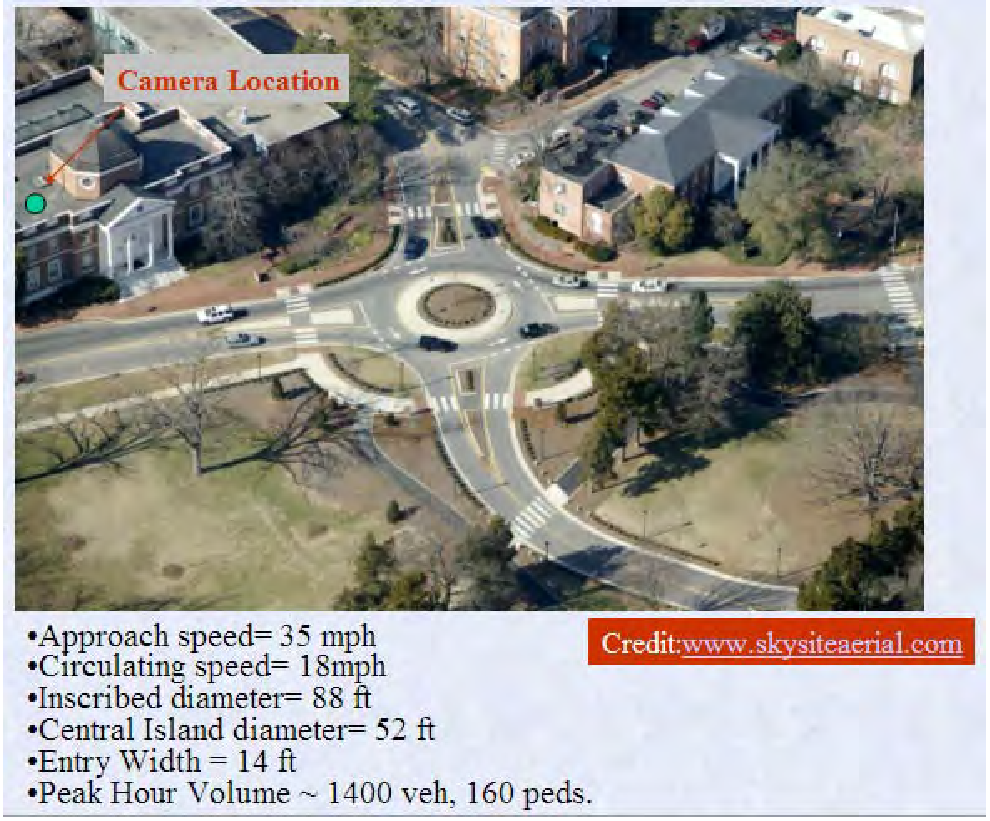
Figure 22. Maple Road / State Farm Road, Voorheesville, NY

Image © 2006 New York GIS

© 2006 Navteq

©2005

Figure 23. Pullen / Stinson, Raleigh, NC



- Approach speed= 35 mph
- Circulating speed= 18mph
- Inscribed diameter= 88 ft
- Central Island diameter= 52 ft
- Entry Width = 14 ft
- Peak Hour Volume ~ 1400 veh, 160 peds.

Credit:www.skysiteaerial.com

Figure 24. N. Davidson / 9^{th} Street, UNC Charlotte, NC

Figure 25. Main Street, Alpine, UT

Figure 26. South Campus Drive / Center Campus Drive, Salt Lake City, UT

Figure 27. 51st Avenue NW / Borgen Boulevard, Gig Harbor, WA

Figure 28. WA 16 Southbound / Borgen Boulevard, Gig Harbor, WA

Signalized Roundabouts

Figure 29. Gatineau, Quebec

Figure 30. Gatineau, Quebec

Channelized Turn Lanes

Figure 31.Loch Raven Boulevard / Joppa Road, Towson, MD

Figure 32. Loch Raven Boulevard / Joppa Road, Towson, MD

Figure 33. Dulaney Valley Road / Fairmount Avenue, Towson, MD

Figure 34. Dulaney Valley Road / Fairmount Avenue, Towson, MD

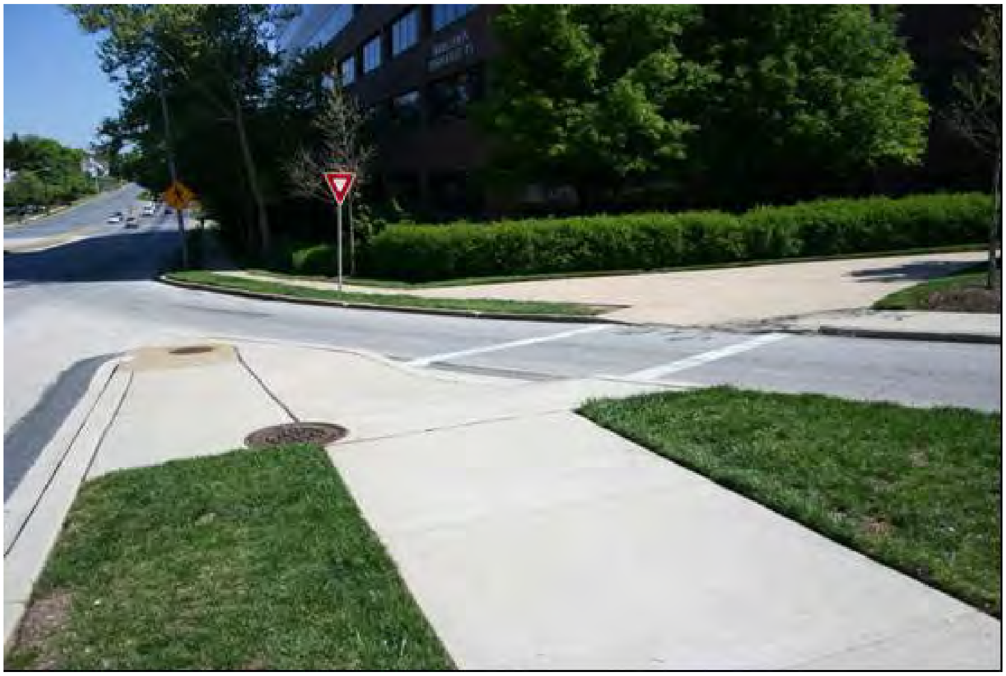


Figure 35. Dulaney Valley Road / Fairmount Avenue, Towson, MD

Figure 36. Padonia Road / York Road, Timonium, MD

Figure 37. Padonia Road / York Road, Timonium, MD

Figure 38. Padonia Road / York Road, Timonium, MD

Figure 39. Sabino Canyon Road / Cloud Road, Tucson, AZ

Figure 40. Sabino Canyon Road / Klob Road, Tucson, AZ

Figure 41. Martin Way / Sleater Kinney Road, Lacey, WA

Figure 42. Martin Way / College Street, Lacey, WA

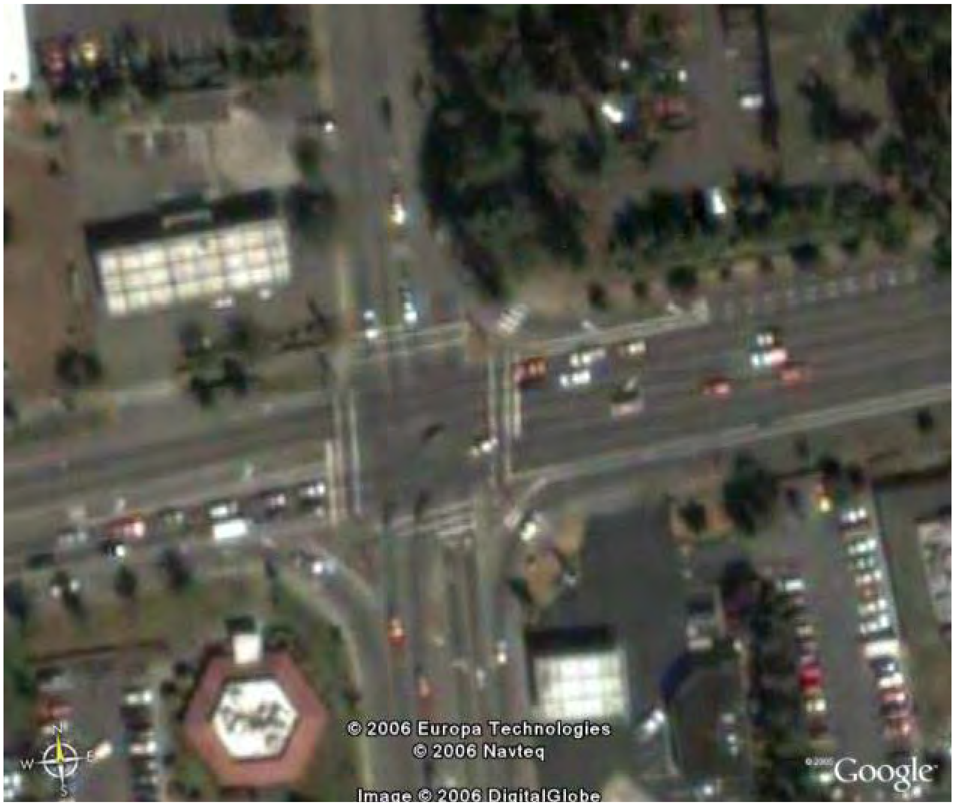


Figure 43. Grant Road / Campbell, Tucson, AZ

Figure 44. Grant Road / Campbell, Tucson, AZ

Figure 45. Grant Road / Campbell, Tucson, AZ

APPENDIX E: Treatment and Site Descriptions

This Appendix contains descriptions of the data collection sites for NCHRP 3-78a and details on treatment installation at these sites.

Appendix E: Treatment and Site Descriptions

This appendix serves to explain specifics of the four treatments installed at two channelized turn lanes (CTL) and a dual lane roundabout as a part of this research effort: sound strips, flashing beacons, raised crosswalk, and a Pedestrian Hybrid Beacon (PHB). The sites are also briefly described.

Sound Strips

Sound strips were considered as a low cost treatment that could provide audible cues about yields or available gaps in traffic. Past research conducted by Fitzpatrick et. al. noted that the treatment was not effective at providing the necessary yield information when using a three strip configuration sounding a "clack…..clack-clack." The single strip was intended to provide the pedestrian with cue that a vehicle was present. The two follow-on sound strips provided a different sound cue which was intended to provide the pedestrian with information that the vehicle did not stop and that they should not cross. Our team hoped to improve on this initial test by providing a series of strips equally spaced starting much further back from the crosswalk, starting at approximately 300 feet before the crosswalk. In addition, the materials used will be much different, utilizing a hard rubber-like material instead of a PVC-based material like that tested earlier. Last, should the sound strip prove insufficient in providing available yield and gap cues, another test of the material was supplemented with flashing beacons is completed and document in a later section.

Site Selection

The CTL at the intersection of Providence Road and NC 51 (Pineville-Matthews Road) in Charlotte, NC was chosen as the test site for sound strip installation. This site was also used to study the push button activated flashing beacon, which allowed economical testing of both treatments under similar traffic conditions with a common set of participants. Staff from the Charlotte Department of Transportation (CDOT) was very supportive of the research effort and were willing to pay for and install both treatments.

Speeds on all approaches were posted at 45 mph. Land uses in the vicinity of the site included a good mix of office buildings, retail, and residential. Volumes at the northwest corner crosswalk are slightly higher than the southeast corner with approximately 6,000 vpd in the CTL and 18,400 vpd in adjacent through traffic. The downstream conflicting through flow was 22,400 vpd and the opposing left turn 2,700 vpd. Low pedestrian activity was observed at the site on the order of 20 pedestrians per day, primarily during the midday off peak period.

The north-west quadrant of the intersection was utilized for the sound strip installation. Sound strips were also installed as a package treatment with the push button activated flashing beacon in the south-east quadrant. This package treatment is discussed further in the next section. An aerial photo of both legs prior to treatment installation is shown in Exhibit 1.

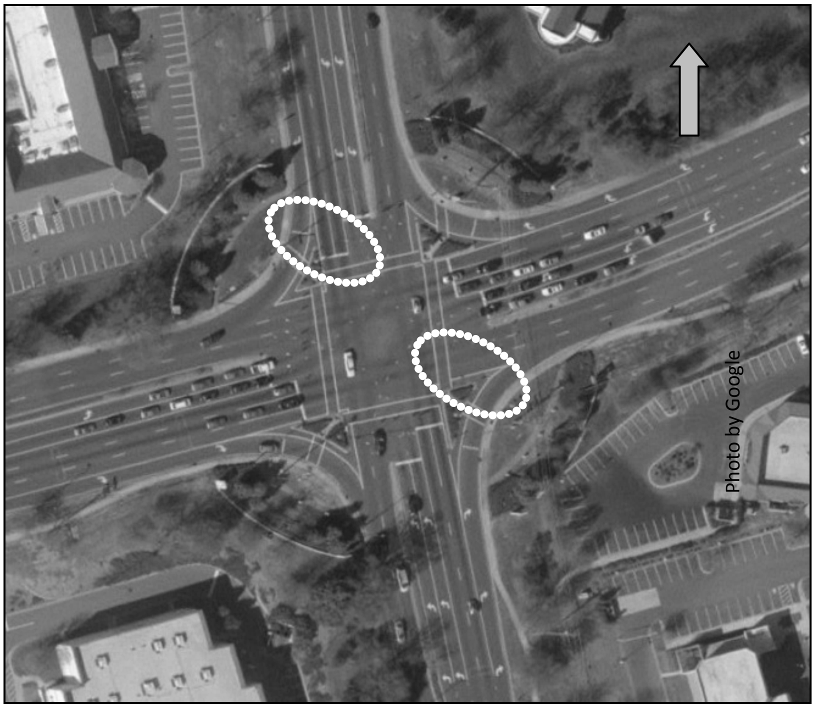


Exhibit 1: Aerial Photo of Charlotte, NC CTL Site

Additionally, lane delineators were installed to prevent late vehicle merges into the CTL. This allowed the pedestrian to utilize audible queues of yielding or available gaps from each of the “clacks” (or lack of clacks) to attempt to make judgments about when it is safe to cross.

Field Setup

The sound-strip treatment was intended to distinguish the auditory pattern of turning vehicles from mainline traffic, thereby facilitating gap and/or yield detection at the crosswalk. To test the audible cues generated by the rumble strips, a pilot test was done by the research team in a nearby parking lot. Many different configurations were tested. In the end, it was decided that a total of six sound strips would be installed at an even spacing of approximately 50'. With constant spacing, the temporal separation of sound cues ("clack" noises) is also constant at a consistent speed (approximately 35 mph yields a 1 second sound cue). However, as vehicles decelerate to a yield, the time between "clacks" increases, thereby giving pedestrians additional auditory information about driver intent. In addition, if no “clacks” are present, this hopefully provides supplemental information about the possibility of a crossable gap. Exhibit2 shows the installation of the six rumble strips along with the delineators at the northwest corner of the intersection.

Exhibit 2: North-west Quadrant - View of Sound Strips and Lane Delineators

The sounds strips tested at the CTL were an off-the-shelf rumble strip used for temporary applications. The strips were raised approximately 0.25 inches and could be cut to the specified length necessary to cover the entire lane width. Exhibit 3 shows a vertical profile of the sound strip used for our test. This height was just high enough to produce audible cues while still allowing safe traversal of all modes of traffic (especially bicycles and motorcycles). Although many colors were available, the team chose white which was consistent with the pavement markings and suggested by team members familiar with MUTCD guidance.

Exhibit 3: Close-Up View of Sound Strip Profile

Costs

The Charlotte Department of Transportation purchased the sound strip material along with the delineators for less than $1000. This treatment is a low cost treatment with the majority of the costs associated with field installation and removal. With a longer installation period, it would be expected that maintenance would need to be done on both the sounds strips and delineators as materials work their way lose or are hit rendering them useless.

Installation Issues Addressed

As discussed earlier, delineators were recommended to facilitate drivers entering the CTL in enough time to cross over all sounds strips. Delineators, while very practical for dividing lanes, are a maintenance issue as they frequently need to be replaced as they are inadvertently hit. Not only are they rendered useless if they are struck, they are not very aesthetically pleasing, especially when they are lying on the ground.

With regards to the sounds strips, the installation of taller sound strips would be more audible; however, they would not be very practical to drivers of motorcycles or bicyclist. In addition, taller sounds strips would likely yield to public outcry to remove them to reduce noise pollution. Installing sounds strips of any sort near residential areas is not advisable.

Flashing Beacon with Audible Pedestrian Signals

Intro

Site Selection

The opposing CTL at the south-east quadrant of Providence Road at NC 51 (Pineville-Matthews Road) in Charlotte, NC was utilized for testing of a solar powered flashing beacon equipped with an audible pedestrian signal. The flashing beacon was supplemented with sound strips in the same pattern as the ones installed in the north-west quadrant. Also, delineators were installed similar to the opposing quadrant. This site was utilized because the Charlotte Department of Transportation was very supportive of our research efforts and even paid for the treatments. Also, by utilizing this site, we were able to use the same pedestrians from the sound strip only test (described previously) in the alternate corner of the intersection, thus allowing the effect of the flashing beacon to be determined on its own (the sound strip only effect could be accounted for directly from the opposing corner of the intersection).

Speeds on all approaches were posted at 45 mph. Land uses in the vicinity of the site included a good mix of office buildings, retail, and residential. Twenty-four hour volumes at the southeast corner were approximately 3,200 vpd in the CTL and 12,400 vpd in adjacent through traffic. The downstream conflicting through flow was 10,600 vpd and the opposing left turn 3,000 vpd. Low pedestrian activity was observed at the site on the order of 20 pedestrians per day, primarily during the midday off peak period.

Field Setup

The flashing beacon treatment was set up to be dynamically activated by an APS device. For our testing purposes, the flashing beacon supplemented sound strips by providing an additional cue to the driver that a pedestrian is attempting to cross the street. Two solar powered flashing beacons with APS devices were installed on each side of the road at the crosswalk. Exhibit4 shows the approach to the flashing beacon along with six rumble strips and the delineators at the south-east corner of the intersection.

Exhibit 4: South-East Quadrant - View of Sound Strips, Delineators, and Flashing Beacons

The flashing beacons tested at the CTL were off-the-shelf devices used for various applications such as advanced traffic signal warnings. They are almost always used as a static device which can often be overlooked by drivers who ignore them; therefore, the team recommended installing them as a package with an APS device. The beacons a pole mounted dual-head, wig-wag display which rested in a dark mode until activated via the push button. The APS message used at the crosswalk said “Cross with caution, cars may not stop” which played concurrently with the wig-wag signal display.

Costs

While the "sound-strip-only" treatment is considered a low-cost solution, the addition of the flashing beacons adds some cost. However, the cost and associated impact to vehicle operations is still less than for a fully signalized crossing. A solar powered flashing beacon unit costs approximately $3000 per unit. The APS device was approximately $1000 per unit. In addition, the materials for the sound strip would also need to be considered if being used in combination with the flashing beacon. .Two units per CTL are necessary, totaling $8,000 for the entire set up at a single CTL.

Installation Issues Addressed

The installation of solar powered flashing beacons is a standard off-the-shelf treatment that is readily available. However, the inclusion of APS devices which have a locator tone every 1 second means more power consumption. For our test purposes, a larger battery and solar unit were necessary to keep the APS device functioning properly. In addition, the APS locator tone frequency was changed from 1 second to 2 seconds to keep battery drain to a minimum.

Raised Crosswalk

Raised crosswalks are sometimes used as a surrogate to standard crosswalks. The standard crosswalk marking is applied to a raised surface approximately 3 to 6 inches above normal road grade. The elevated surface is intended to attract driver attention, thus encouraging lower speeds approaching the crosswalk. The concept of a raised crosswalk is to encourage safe crossings for pedestrians since drivers need to yield prior to crossing the crosswalk.

Site Selection

The raised crosswalk was installed at the south-eastern quadrant of the double-lane roundabout at the intersection of South Golden Road/Jonson Avenue/16th Street in Golden, CO. The south-eastern leg was utilized for installation of the raised crosswalk. This site was also used for the Pedestrian Hybrid Beacon (PHB) installation on the alternate approach, which allowed the team to utilize the same subjects and limited the need for additional travel. Staff from the City of Golden was very supportive of the research effort, helping purchase and install the raised crosswalk.

The raised crosswalk was installed as a low cost treatment in comparison to the PHB, which is quite costly. The raised crosswalk is intended to slow traffic, increasing the likelihood they drivers would yield to pedestrians wishing to cross. This leg was chosen because the geometry was very reasonable, traffic volumes were fairly high, and pedestrian crossings were fairly well established. In addition, a fair number of bicyclists were noted by the team on multiple visits. South Golden Road is the major approach and primarily consists of retail establishments with a small assortment of office and residential locations in the vicinity. Speeds at all the approaches are 45 mph. A photo of the south-east leg prior to installation of the raised crosswalk installation is shown in Exhibit 5.

Exhibit 5: South-East Quadrant - View of Sound Strips, Delineators, and Flashing Beacons

Field Setup

The raised asphalt crosswalk was installed at the south-east quadrant of the two-lane roundabout. In order to avoid drainage concerns, the city did not install the crosswalk flush with the sidewalk (which would have required a drainage pipe under the asphalt), but sloped the raised crosswalk upward from the curb-line. While this doesn't alter driver behavior, it makes for an uncomfortable pedestrian walking environment, as pedestrians have to first walk down the curb-ramp and then back up on the raised crosswalk. The O&M instructor practiced the crossing with all participants so that they would be familiar with the uneven pavement. The raised crosswalk was signed and marked consistent with MUTCD requirements. No other geometric changes were made to the roundabout or its approaches. Exhibits 6 and 7 show photos of the raised crosswalk installed in Golden, CO.

Exhibit 6: South-East Quadrant – View of Raised Crosswalk

Exhibit 7: South-East Quadrant – View of Raised Crosswalk

Costs

The costs associated with retro-fitting a raised crosswalk was minimal compared to the installation of a PHB. It is estimated that a crosswalk such as this could be constructed and painted for less than $5000 in materials and labor for each leg. This assumes that drainage is not really accounted for by installing drainage inlets or a pipe under the crosswalk, but is instead allowed to flow down the original gutter line. In addition, because the crosswalk slopes back down to the gutter line to allow water to drain, the curb cuts were allowed left as-is. If drainage were accounted for, the curb cuts would have been filled in and reinstallation of detectable warnings at the crosswalk.

Installation Issues Addressed

The primary installation issue was how to account for drainage at the crosswalk. Our site was a temporary installation; however, it is recommended that the crosswalk not slope back to the curb cut; but instead be flush to the top of curb. In addition, the slope and height of this particular raised crosswalk were very low. It may be more effective if the crosswalk were installed with larger slope and height to force slower speeds coming into contact with the pedestrian.

Pedestrian Hybrid Beacons

Pedestrian hybrid beacons (commonly known as HAWK signals) have been in use in the United States since 2000, when the first one was installed in Tucson, Arizona (1). They are gaining acceptance nationally, and are proposed to be in the next edition of the MUTCD. Tucson's HAWK signals are primarily installed at mid-block locations on wide arterials as either one-stage or two-stage operations. However, HAWK signals have been identified as a potential pedestrian crossing treatment to improve roundabout crossings for all pedestrians, including those with visual impairments, and appear to fulfill the Access Board's proposed requirement that pedestrian crossings at roundabouts be signalized.

To further examine the viability and benefits of introducing HAWK signals at roundabouts, a temporary one was installed on one leg of a roundabout as part of this project. This was the first installation of a HAWK signal at a roundabout in the United States.

Site Selection

The double-lane roundabout at the intersection of South Golden Road/Johnson Avenue/16th Street in Golden, Colorado was chosen as the test site for a HAWK signal installation. This site was also used for the raised crosswalk treatment on an alternate approach, which allowed economical testing of both treatments under similar traffic conditions and with a common set of participants. Staff from the City of Golden was supportive of the research effort and willing to install both treatments.

Double-lane roundabouts are generally more challenging to pedestrians than single-lane roundabouts. Pedestrian crossing distances are longer, vehicle speeds can be higher, and traffic volume can be higher. In addition, the draft Public Rights-of-Way Accessibility Guidelines require some form of signalization for multilane roundabout entries and exits. For these reasons, a double-lane roundabout was more suitable than a single-lane roundabout as a test site.

The HAWK signal was installed on the northwest leg of the roundabout on South Golden Road. This leg was chosen because of reasonable geometry, moderate pedestrian volume, and physical conditions conducive to installing a temporary signal at reasonable cost. A photo of this leg prior to HAWK signal installation is shown in Exhibit 7.

Entry Crossing

Exit Crossing

Exhibit 7 – HAWK signal test site prior to installation

Field Setup

HAWK signals are not addressed in the current (2003) edition of the MUTCD. The proposed amendments to the MUTCD, prepared in anticipation of the next edition, include a new chapter (4F) on “Pedestrian Hybrid Signals”, or HAWK signals (2). In this proposed MUTCD chapter, it is stated that, except as noted, pedestrian hybrid signals shall meet the provisions of [proposed] Chapters 4D and 4E, which address normal green/yellow/red signals and pedestrian control at such signals, respectively.

Many of these exceptions are related to the signal face and the sign placed next to the signal face explaining when to stop.

There is only one mention of roundabouts in proposed Chapter 4F. It is noted that if a pedestrian hybrid signal is installed at a roundabout to facilitate crossings by visually impaired pedestrians, pedestrian signal heads may rest in dark if an engineering study determines that pedestrians without visual disabilities may cross safely without activating the signal. This is only an option at roundabouts; elsewhere the pedestrian signal shall rest with a steady upraised hand indication.

To install the temporary HAWK signal, the City of Golden submitted and was granted a Request to Experiment to FHWA. This request, provided in Appendix F, includes signal design plans and signal timing plans. The HAWK signal was designed to conform with the 2003 MUTCD and the proposed amendments to the extent possible.

Striping

A 24” solid white stop bar was placed 4 feet prior to the crosswalk on the entry and the exit of the approach. All existing striping was left in place, including the continental-style crosswalk marking and the yield line at the roundabout entry.

Signal Poles and Heads

A total of four signal poles were used: two on each approach (entry and exit). Each pole was used to mount a pedestrian signal head, a pedestrian push button, and a vehicle signal head with 12-inch lenses.

At the Golden roundabout, crosswalks are set back 30 feet from the circulatory roadway. Because of this, the placement of stop bars, poles and traffic signal heads presented challenges.

Under a typical signal design, Section 4D.15 of the 2003 MUTCD specifies a minimum separation of 40 feet between the stop bar and traffic signal heads. On the exit leg, this 40 foot separation could be obtained in one of the following ways:

- If the stop bar were placed 4 feet prior to the crosswalk, the signal heads would be placed approximately 25 feet beyond the far side of the ten foot wide crosswalk. This would result in signal heads being far removed from the pedestrian crossing and the roundabout intersection environment. Drivers might not see the signal.
- If the signal heads were placed at the far side of the ten foot wide crosswalk, the stop bar could be placed approximately 30 feet prior to the crosswalk. This would place the stop bar in the circulatory roadway.

On the entry leg, assuming the signal heads were located on the far side of the crosswalk, the stop bar would need to be located approximately 30 feet in advance of the signal.

The language in proposed MUTCD Chapter 4F on pedestrian hybrid signals treats the entire section on signal head location as guidance, not a standard. In this Golden experiment, the site constraints require a closer separation between the stop bar and signal faces, with the poles located at the far side of the crosswalk and the stop bar located 4 feet in front of the crosswalk. This creates a 14-foot separation between the stop bar and the signal face, which is mitigated by locating the bottom of the signal face 10 feet above the ground, five feet lower than the MUTCD-recommended minimum mounting height of 15 feet.

Signal Timing and Controller Programming

HAWK signals are intended to provide pedestrians with a safe means of crossing a roadway while minimizing the delay to vehicles that is created by doing so. On roundabout leg, this is preferably accomplished with a two-stage crossing. When a pedestrian activates the signal, vehicles are only stopped in one direction of travel. For example, if a pedestrian will be crossing the lanes entering the roundabout, only entering traffic is stopped. After making this crossing, the pedestrian will be in the splitter island, which is designed to be a refuge for pedestrians. The pedestrian can then activate the signal for the second crossing. This allows both the walk time and pedestrian clearance intervals to be as short as possible to minimize both vehicular and pedestrian delay.

In addition to reducing vehicular delay, a two-stage crossing may result in increased vehicular compliance with HAWK signals. If, for example, a pedestrian were crossing the entry approach and the HAWK signal on the exit approach was activated, drivers on the exit approach could be less likely to stop since a pedestrian is not present.

Controller and Timing Plan

A NEMA controller (Econolite ASC2S Type II) was the design controller for the test site and is shown in the plans and specifications provided in Appendix F. This is the same controller used by the City of Tucson at their HAWK signals. Ultimately, the City of Golden installed a spare 170 controller, for which a timing plan was developed. The 170 plan in Appendix F is the initial plan; some changes were made in the field following installation and are discussed below.

NEMA Setup

The NEMA controller plan for the test site in Golden used specifications developed by Tucson staff for two-stage crossings.

Tucson has adapted NEMA controllers and cabinets from control of green/yellow/red signals to control of HAWK signals largely by rewiring the controller cabinet into a custom configuration, with load switches being reassigned through the creative use of jumpers. For example, both the vehicular and pedestrian heads were assigned to pedestrian phases, which enabled the vehicular heads to display both solid and flashing indications. The two red indications were connected to separate load switches to make wig-wag flash possible. Limited software changes were necessary, including a change to the Econolite controller’s write-protected memory to allow flash don’t walk (FDW) intervals of less than seven seconds when FDW was used to flash vehicular signal indications.

A custom conflict monitor schedule was used to accommodate the extensive changes in phase assignments needed to create the HAWK timing plan.

170 Setup

Unlike the hardware-oriented modifications needed for the Econolite NEMA system, the 170 system was modified to control a HAWK signal through use of the Command Box programming within the Wapiti W4IKS software that Golden uses in its 170 controllers. A custom Command Box program was written specifically for this project and tested with a briefcase tester prior to installation on the controller at the test site in Golden.

In the 170 plan developed for this project, phases 3 and 4 are used in the first ring and phases 7 and 8 are used in the second. In the first ring, phase 3 amber is connected to the amber indication, phase 3 red is connected to one of the red indications, and phase 3 green is connected to the second red indication. Phase 4 is connected to the pedestrian signal head. The connections for the second ring are similar. Flashing and steady indications are created by Command Box program.

Signal Timing

HAWK signals operate with three phases – an activation phase, a pedestrian crossing phase, and a “green” time for vehicles. The final timing plan – installed on the 170 controller at the test site in Golden – is described below and shown in Exhibit 8.

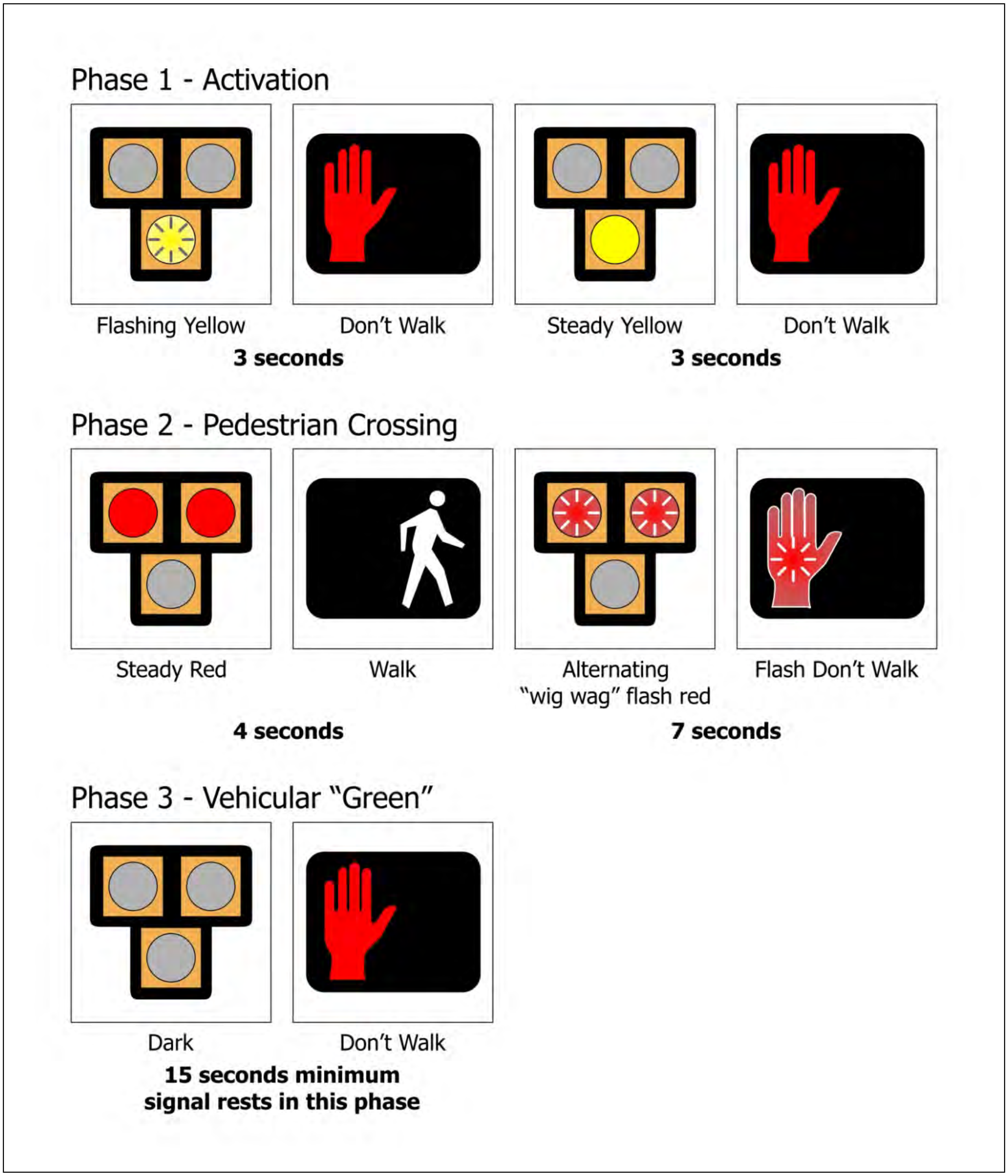


Exhibit 8 - HAWK Signal Phases and Timing

In the first phase, the signal is activated – the vehicular signal flashes yellow, and then displays solid yellow. Both the flashing yellow and solid yellow clearance intervals were set at 3 seconds. Throughout phase 1, the pedestrian signal heads continue to display a steady hand.

In the second phase, the pedestrian signal head displays a walk indication followed by a FDW and the vehicular signal head displays a steady red indication on both red lenses followed by a wig-wag flashing red. The interval for the walk and the solid red indications is 4 seconds, and the interval for the FDW and wig-wag flashing red is 7 seconds. The walk was set to the minimum of 4 seconds to minimize vehicular delay.

The third phase functions as a minimum green time for vehicles. This prevents multiple pedestrian calls from causing excessive vehicular delay. There are no signal heads wired to the third phase, as a dark HAWK signal is “green” for vehicles. The minimum green time is set at 10 seconds and the yellow clearance interval is set at 5 seconds, resulting in an effective minimum “green” time of 15 seconds. The pedestrian signal heads display a don’t walk indication. If no pedestrian calls are placed, the signal will rest in this phase.

The timing plan described above differs from the implementation designed for the Econolite NEMA controller in several ways:

- The yellow flashing interval and the solid yellow clearance interval in the first phase were both decreased from 5 seconds to 3 seconds. These changes were intended to reduce delay and confusion for drivers and pedestrians. Three seconds of flashing was considered to be sufficient time to notify drivers that the signal is being activated, and 3 seconds of clearance time was considered sufficient for the speeds and geometry at the test site. Roundabouts generally limit vehicle speeds to 30 miles per hour, whereas mid-block locations could be much higher. For pedestrians, the shorter intervals decrease the time between placing a call and receiving a walk indication
- The walk interval was shortened from 7 to 4 seconds. The 2003 MUTCD states that a walk interval should be 7 seconds, but that it may be as short as 4 seconds “if pedestrian volumes and characteristics do not require a 7-second walk interval”. At the test site, pedestrian volumes are low enough that persons crossing can be expected to be at the curb and not queued. Also, except when the minimum vehicular “green” has not been served, the walk indication will be given six seconds after a call is placed, when pedestrians will generally be expecting it to appear.

Cost

The City of Golden constructed much of the HAWK signal with spare materials already on hand, greatly reducing the experimental cost. If the signal had been built with new materials purchased specifically for this project, it is estimated that the cost would be about $53,000, as detailed in Appendix F. Approximately half of the estimated cost is for the controller cabinet and associated cabinet hardware, including the controller itself. If all crossings of a roundabout were to be signalized, costs could be significantly reduced by using one controller for the entire roundabout instead of one controller per leg.

Installation and Turn On

The HAWK signal was turned on in mid-August of 2008. Photos of the installed signals on the entry and exit approaches are shown below in Exhibit 9. A photo of the two-stage crossing from a pedestrian's viewpoint is shown in Exhibit 10. A photo of the 170 cabinet is shown in Exhibit 11.

Entry Crossing

Exit Crossing

Exhibit 9 – HAWK signal test site following installation

Exhibit 10 - Two stage, signalized pedestrian crossing

Exhibit 11 – 170 cabinet at test site in Golden, Colorado

Lessons Learned and Recommendations for Future Study

The groundbreaking nature of this design revealed several issues that will need to be further studied by the profession if HAWK signals are to be widely used at roundabouts.

Visibility Issues

At the test site, it was not practical to meet the 40-foot minimum separation between the stop bar and the signal heads that is recommended by the MUTCD for visibility purposes. Such a spacing would have either placed a stop bar in the circulatory roadway or placed signal heads far beyond the crosswalk. At the test site, a shorter spacing was used. Signal heads were pole mounted 10 feet off of the ground, making them visible to a design driver in a design vehicle stopped only 14 feet away.

One way of obtaining a 40 or more feet of separation between the stop bar and signal heads would be to move the crosswalk further away from the circulatory roadway. The current recommendation of 25-foot spacing between the crosswalk and the circulatory roadway is primarily indented to create the safest possible unsignalized crossing. With a HAWK signal, a greater crosswalk setback, such as 50 feet, might be beneficial. Vehicle speeds and pedestrian visibility are less of a concern since the signal will be stopping vehicles. On the exit, the stop bar could be placed well in advance of the crosswalk and there could still be a space for at least one vehicle to stop and be fully out of the circulatory roadway. On the entry, a queue of two vehicles could be stopped and waiting to enter the roundabout without blocking the crosswalk.

Both of these designs should be further studied. Even if a 50-foot crosswalk setback was found to be optimal in most situations, a 25-foot setback (and shorter stop bar to signal head distance than currently recommended in the MUTCD) might still be optimal in some circumstances. These circumstances could include retrofits of existing roundabouts and locations where expanding the footprint of the roundabout would be prohibitively expensive.

Moving crosswalks, and thus signal heads, further back from the circulatory roadway will help to mitigate this issue. It will not, however, entirely eliminate it. Modifications to the design and placement of the signal heads on the exiting lanes should be studied. One possibility would be to shield lenses. Another would be to change the mounting position of the signal heads. Different heights or angles should also be explored to see if visibility to vehicles entering on the opposite approach can be decreased while maintaining or increasing visibility to exiting vehicles (i.e. those being controlled by the HAWK signal).

Obtrusiveness Issues

HAWK signals are intended to provide pedestrians with a safe, controlled crossing of a roadway while minimizing vehicular delay. At the test site, a four second walk interval (the minimum allowed by the MUTCD) and a vehicle “green” time of 15 seconds were used. At a normal signalized intersection, it is common for pedestrians to wait much longer than 15 seconds to receive a walk indication after placing a call. At a congested roundabout, a minimum green time of more than 15 seconds may be appropriate and should be investigated. Clearance intervals and other aspects of the signal plan should be further investigated as well.

Intersection-Wide Application Issues

This experiment was limited in that a HAWK signal was only installed on one leg of the roundabout. If HAWK signals are adopted into the next edition of the MUTCD and become widely used at roundabouts, they would be installed on all legs at many locations. At a typical four-leg intersection, this would result in eight signalized crossings – one for each entry and one for each exit. Optimally, each of these crossings should operate independently to minimize vehicular delay.

As previously noted, the controller cabinet and related hardware are estimated to comprise half the cost of signalizing a single leg. To minimize costs at a roundabout where crossings on all legs are signalized, a single controller should be used. This would require eight rings – more than are available on any commercial traffic signal controller software. Creating software capable of handling eight rings (or more, for cases of unusual geometry) should be a priority, as it will significantly reduce the cost of HAWK signals at roundabouts. Such software should also be designed specifically for HAWK signals. Currently, using software and controllers designed for normal green-yellow-red signals at HAWK signals requires extensive customization to do things such as display flashing and steady indications on the same signal head.

Off-the-shelf HAWK signal software, with eight or more rings and the ability to display all necessary flashing and steady indications should be developed for both NEMA, 170, and 2070 controllers. This would eliminate the need for extensive manual rewiring and/or reprogramming.

References:

1. Nassi, Richard B., City of Tucson (retired). Presentation to Kittelson & Associates, Inc. staff, December 11, 2008.
2. Proposed Amendments to the MUTCD. <http://mutcd.fhwa.dot.gov/resources/proposed_amend/index.htm>. Accessed April 1, 2009.

APPENDIX F: Details on Pedestrian Hybrid Beacon (PHB) Installation

This Appendix contains details on the installation of the pedestrian hybrid beacon treatment at the two-lane roundabout in Golden, CO. The appendix is presented in three parts:

Part 1: Request for Experimentation Submittal to FHWA

Part 2: 170 Controller and Cabinet Configuration

Part 3: Preliminary Cost Estimates

City of Golden

PLANNING & DEVELOPMENT
TEL: 303-384-8097

PUBLIC WORKS
TEL: 303-384-8151

1445 10TH ST. GOLDEN, CO 80401
FAX: 303-384-8161
www.cityofgolden.net

June 30, 2008

Mr. Scott Wainwright, P.E.
Federal Highway Administration
Office of Transportation Operations
1200 New Jersey Avenue, S.E., HOTO-1
Washington, DC 20590

MUTCDofficialrequest@dot.gov

RE: City of Golden, Colorado, Request to Experiment with Pedestrian Hybrid Beacon

Dear Mr. Wainwright:

Enclosed is our request to approve experimentation by the City of Golden, Colorado, with a pedestrian hybrid beacon. The City of Golden understands the responsibilities as a requestor for experimental use of new traffic control devices as outlined in the MUTCD.

We believe that the proposed pedestrian hybrid beacon will have a positive effect in improving the accessibility of pedestrian crossings across multilane entries and exits at roundabouts. This tool is expected to be of value in helping practitioners meet the requirements for accessibility of all users at roundabouts as required by the provisions of the Americans with Disabilities Act as administered by the United States Access Board.

The draft proposal is consistent with the language in the current Notice for Proposed Amendments for inclusion in the next MUTCD and is consistent with other experiments currently in use in Tucson, Arizona, and other communities around the United States. We will be happy to consider any changes recommended by FHWA.

Thank you in advance for your consideration.

Sincerely,

Vince Auriemma, P.E.
Deputy Director of Public Works/City Engineer

cc: Mr. Lee A. Rodegerdts, P.E. (Kittelson & Associates, Inc.)
Dr. Ronald Hughes, Ph. D. (North Carolina State University)

KITTELSON & ASSOCIATES, INC.
TRANSPORTATION ENGINEERING / PLANNING
610 SW Alder Street, Suite 700, Portland, OR 97205 P 503.228.5230 F 503.273.8169

MEMORANDUM

Date: June 30, 2008 Project #: 6317

To: Vince Auriemma
City of Golden, Colorado

From: Lee A. Rodegerdts, P.E.

Project: NCHRP 3-78: Crossing Solutions for Pedestrians with Vision Impairments at Roundabouts and Channelized Turn Lanes

Subject: Request for Experimentation for Pedestrian Hybrid Signal/Beacon

---

This memorandum describes the proposed pedestrian hybrid signal/beacon proposed for the northwest crosswalk at the multilane roundabout at South Golden Road/Johnson Rd. in Golden, Colorado. This documentation is being prepared to support an official Request for Experiementation as required by FHWA for new application of a traffic control device under Section 1A.10 of the 2003 MUTCD.

NATURE OF THE PROBLEM

Traffic operations at roundabouts create different auditory environments than traditional intersections. The different environments are challenging for visually impaired pedestrians to identify and use crossable gaps and/or to create and identify opportunities when drivers yield. When vehicles are present at a roundabout, noise in multiple directions is created simultaneously as vehicles circulate in the intersection, enter via the yield control entry and exit via the free flow exit. The continuous noise can mask the traditional auditory cues discussed above. Because of these challenges, the United States Access Board has issued draft rule making language that will require some form of signalization at all multilane entries and exits at roundabouts.

The proposed pedestrian hybrid beacon is intended to serve as a possible satisfaction of the U. S. Access Board's draft rulemaking, particularly in cases that do not meet warrants for traditional pedestrian signals. In the case of a roundabout, the dark indications for vehicles used in the pedestrian hybrid beacon are seen as preferable to the green indications used at conventional pedestrian signals because they minimize confusion with the Yield sign at the roundabout entry. In addition, the operation of the pedestrian hybrid beacon in a two-stage operation with flashing red operation during the pedestrian clearance interval is seen as a way to provide pedestrian access while providing the minimum amount of delay possible to motorists.

DESCRIPTION OF THE PROPOSED CHANGE

This proposal is being conducted in conjunction with NCHRP Project 3-78, Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Visual Disabilities, led by Ron Hughes of North Carolina State University. As part of this study, the research term would like to test the use of a pedestrian hybrid beacon (historically known as a HAWK signal) on a two-lane roundabout entry and exit to facilitate pedestrian crossings. The research team intends to collect before-and-after data to assess the effectiveness of a pedestrian hybrid signal as a means to facilitate crossings for pedestrians, as well as the impacts on traffic operations at the roundabout due to the pedestrian hybrid signal. The final report generated from NCHRP 3-78 is intended to serve as a resource for the Access Board's standards related to accessibility and usability requirements at roundabouts.

The proposed change would allow the use of a pedestrian hybrid signal/beacon as described in Chapter 4F of the 2007 Notice of Proposed Amendments for the Manual on Uniform Traffic Control Devices, December 2007. The proposed experimental installation has been designed in accordance with these provisions as proposed with the exception that the device will rest in DON'T WALK (indicated by Upraised Hand) for pedestrians. This is consistent with applications at other locations currently under experimentation in Tucson, Arizona, and elsewhere and was approved by the National Committee on Uniform Traffic Control Devices in June 2006.

Details of the proposed installation are included in the attached plans and specifications.

PROPOSED WORK AND RESEARCH PLAN

The proposed installation is on the crosswalk at the northwest corner of the South Golden Road/Johnson Street roundabout as illustrated in the attached plans. Installation is planned for July 2008. Testing of "before" conditions using the protocol identified above was conducted in June 2008, and testing of "after" conditions is planned for approximately three months after turn-on. A public information campaign is planned in conjunction with signal turn-on.

The basic form of the research plan is a controlled before-after study. Before and after tests will be conducted using selected pedestrians with vision impairments under the supervision of certified Orientation & Mobility (O&M) instructors. The research team will videotape all tests for further evaluation.

For pedestrians, the testing protocol will examine the following parameters: availability and utilization of crossable gaps, availability and utilization of driver yields, pedestrian delay, delay beyond first crossing opportunity (yield or gap), and frequency of O&M interventions. In addition, the research plan is anticipated to examine a measure for crossing opportunity and utilization due to a WALK signal phase, as well as monitoring of jaywalking behavior if the participants cross against the signal.

For drivers, the primary parameter being collected is driver compliance with the signal indication. The research team will keep track of the specific vehicle phase and relate vehicles entering the crosswalk to the active phase. This will allow us to keep track of red-light running events, and more importantly, driver behavior during the flashing red. The type of driver yield—soft yield (slowing to allow pedestrian to cross) or hard yield (coming to a complete stop for a pedestrian)—will also be recorded.

LENGTH OF EXPERIMENTATION

The purpose of this experimentation is to focus specifically on the potential change in accessibility the device provides to pedestrians with vision disabilities. Therefore, the proposed experiment is intended to be operated for approximately four months: three months to allow driver adjustment to the device, followed by one month for "after" field experimentation with blind subjects. The device will be installed using temporary construction techniques (e.g., wood poles, aerial cabling, etc.) to minimize testing cost while providing full functionality for the duration of the experiment.

Other experiments currently in operation by the City of Tucson, Arizona, the City of Portland, Oregon, and others are examining other elements of this device's operation, including crash experience, variations on signal indications (flashing yellow versus solid yellow, resting the pedestrian head dark versus in DON'T WALK, etc.).

SUPPORTING DOCUMENTS

This device was tested and reported in NCHRP Report 562/TCRP Report 112 and was found along with other red-indication devices to have the highest driver compliance rate among the devices tested (Reference 1). The success of the pedestrian hybrid signal to date has led to its recommendation for inclusion in the MUTCD by the National Committee on Uniform Traffic Control Devices in June 2006 and its incorporation into the current Notice of Proposed Amendments.

REFERENCES

1. Fitzpatrick, K., S. Turner, M. Brewer, P. Carlson, B. Ullman, N. Trout, E. S. Park, J. Whitacre, N. Lalani, and D. Lord. *NCHRP Report 562/TCRP Report 112: Improving Pedestrian Safety at Unsignalized Crossings.* National Cooperative Highway Research Program/Transit Cooperative Research Program, Transportation Research Board, National Academies of Science, Washington, D.C., 2006.

SPECIAL PROVISIONS

TEMPORARY PEDESTRIAN HYBRID BEACON SYSTEM

S. Golden Rd./Johnson Rd./16th St.

Golden, Colorado

6/30/08

COLORADO REGISTERED PROFESSIONAL ENGINEER
LEE A. RODEGERDTS
41057

Prepared for:

City of Golden, Colorado

Prepared by:

Kittelson & Associates, Inc.
610 SW Alder St., Suite 700
Portland, OR 97205
(503) 228-5230

June 30, 2008

TEMPORARY PEDESTRIAN HYBRID BEACON SYSTEM

DESCRIPTION

This work consists of the construction of temporary pedestrian hybrid beacon system at the crosswalk on the northwest quadrant of the roundabout at South Golden Road/Johnson Road in Golden, Colorado. It shall be done in accordance with these project special provisions, the latest revision of the *Manual on Uniform Traffic Control Devices for Streets and Highways* published by the FHWA and adopted by CDOT, the latest revision of the Colorado Supplement thereto, and in conformity with the details shown on the plans or established.

MATERIALS

Sign Posts and Sign Structures. Sign Posts and Sign Structures shall conform to the requirements of Section 614.02 and to the details shown on the plans.

Sign Panels. Sign panel materials shall conform to Section 614.04 and to the details shown on the plans.

Traffic Signal Materials. Except as noted in these project special provisions, traffic signal materials shall conform to Section 614.08 and to the details shown on the plans.

(a) **Pedestrian Beacons.** Pedestrian beacons shall conform to the details shown on the plans and consist of three signal sections, with a CIRCULAR YELLOW signal lens centered below two horizontally aligned CIRCULAR RED signal lenses.

OPERATION

Signal Timings. Signal heads to be assigned to the phases shown on the plans. Phase times to be programmed into controller according to the table below. Details are based on City of Tucson, Arizona, specification; for additional clarification, contact John Ramos, City of Tucson, (520) 791-0857 ext. 257, or Paul Burton, City of Tucson, (520) 791-3191.

Timing Function	Ø1	Ø2	Ø4	Ø5	Ø6	Ø7
Minimum Green[1]			10			10
Solid Yellow Clearance		5	5		5	5
Dual Red Clearance		8			8	
Alternating Red Clearance		7			7	
Walk[2]	4	1		4	1	
Ped Clearance/ Flashing Yellow Clearance[3]	7	5		7	5	
Dual Entry		Off			Off	
Non-Actuated I[4]		On			On	
Overlaps[5]		A	A		B	B
Recall		Min			Min	

Notes:

1. Ø4 Minimum Green and/or Ø7 Minimum Green required to provide minimum time for vehicular traffic.
2. Set Ø2 Walk and Ø6 Walk = 1 to avoid vehicle indications from skipping flashing yellow operation.

3. Flash Yellow (Ped Clearance) less than 7 seconds is set in write protected memory. Phase 2 is set at memory location 0x055. Phase 6 is set at memory location 0x069. Set to 03 for 3 seconds.
4. Ø2 Non-Actuated I and Ø6 Non-Actuated I must be selected for yellow to flash.
5. Overlap A (2 & 4) and Overlap B (6 & 7) required to provide improved conflict monitor functionality.

WIRING

Load Switches. The back panel of the controller cabinet to include a Siemans ITS TS2, Type 2, 12 position load bay. Load switches to be used are 1, 2, 3 & 4. Ring, channel, and field wire terminal assignment to be performed according to the table below.

Ring	Load Switch	Channel	Field Wire Terminals
1	1R	1R	Don't Walk
1	1Y	7Y	Left Red
1	1G	1G	Walk
1	2R	8Y	Right Red
1	2Y	5Y	Yellow
1	2G	6Y, 7R, 8R	Load Resistor
2	3R	3R	Don't Walk
2	3Y	11Y	Left Red
2	3G	3G	Walk
2	4R	12Y	Right Red
2	4Y	9Y	Yellow
2	4G	10Y, 11R, 12R	Load Resistor

Notes:

1. Lift and tag LS2G and LS4G monitor wires off of field terminals to prevent false failures.
2. Overlap A G and Overlap A Y to power LS2 Green and Overlap B G and Overlap B Y to power LS4 Green

Wiring Details. Channel 2, 4, 5, 6, 9 and 10 to be wired to AC buss on the back panel. These channels must see a red at all times.

LS2 Green to be jumpered to LS6Y (on the field wire terminal panel). LS6Y to be jumpered to Ch6Y, Ch7R and Ch8R on back panel. When signals are dark (OK for traffic), LS2 Green to be monitored by Ch6Y, Ch7R and Ch8R.

LS4 Green is jumpered to LS10Y (on the field wire terminal panel). LS10Y is jumpered to Ch10Y, Ch11R and Ch12R on back panel. When signals are dark (OK for traffic), LS4 Green to be monitored by Ch10Y, Ch11R and Ch12R.

Back panel to be jumpered according to the following schedule.

02Y * LS2YC (197------198)
02DW * LS9RC (201------202)
02W * LS9GC (207------208)
04Y * LS4YC (219------220)
04DW * LS10RC (223------224)
04W * LS10GC (229------230)
05R * LS7RC (233------234)

05Y * LS5YC (235------236)
05G * LS5GC (237------238)
06R * LS6RC (239------240)
06Y * LS6YC (241------242)
06G * LS6GC (243------244)
06DW * LS11RC (245------246)
06W * LS11GC (251------252)

07R * LS7RC (255------256)
07Y * LS7YC (257------258)
07G * LS7GC (259------260)
08R * LS8RC (261------262)
08Y * LSYRC (263------264)
08G * LS8GC (265------266)
08DW * LS12RC (267------268)
08W * LS12GC (273------274)
+24CM - +24VDC
(277------278------279 (24V))
IN#41 * IN#2 (299------300)
CM2M * SDRM * LOGIC COMMON
(303------304------305------306 (LogCom))
SDRO * IN #4 (308------309)
Vmon * Cvm (310------311)
CH1R * LS1R (321------322)
CH1Y * LS1Y (333------334)
CH3R * LS3R (343------344)
CH10R * LS10Y (353------354)
CH10G * LS10G (355------356)
CH6Y * LS6Y (371------372)
CH11G * LS11G (377------378)
CH12G * LS12G (399------400)
CU AC+ - AM AC+ (405------406)
01PD * 02PD (102------110)
I/O Bit B * LOG COM(121------305)
01DW * LS1RC (117------190)
01W * LS1GC (119------194)
03DW * LS3RC (139------212)
03W * LS3GC (141------216)
05PD * 06PD (146------154)
01R * 01RC (189------192)
01G * LS2RC (193------196)
LS2GC * OLAY * OLAG
(200------206------209)
03R * LS3YC (211------214)
03G * LS4RC (215------218)
LS4GC * OLBY * OLBG
(222------228------231)
LS5RC * CH7Y (324------389)
LS2R * CH8Y (326------393)
LS2Y * CH5Y (328------367)
CH9Y * LS4Y (331------350)
LS3Y * CH11Y (346------375)
LS4R * CH12Y (348------397)
CH6Y * CH7R * CH8R
(371------387------391)
CH10Y * CH11R * CH12R
(353------373------395)

CONTROLLER PROGRAMMING

Sequence. The sequence of Ring 1 phases shall be 2 1 4 with no barriers and the sequence of Ring 2 phases shall be 6 5 7 with no barriers.

Phases. The phases used are 1,2,4,5,6,and 7 with phases 1 and 5 as exclusive peds. Phase to load switch assignments to be all zero.

Start-up. Power start to include Phase 2 & Phase 6 green, all red = 5 seconds, and minimum flash time = 5 seconds. External start = green.

Flash. Remote flash = blank. Flash relays used + 1 & 2. Flash Relay 2 pin 4: Move wire from Power Buss 1-5B to Power Buss 1-7B to utilize both flasher outputs.

MALFUNCTION MONITORING UNIT (MMU)

MMU. MMU to be a model number 16LE and to be disabled. MMU program to be blank. MMU dip switches 7, 8, 11 & 12 to be set to on.

Conflict Monitor Card Configuration. Suggested conflict Monitor Card configuration is as follows.

1- 3,4, 7,8,9,10,11,12 (conflicts with 2, 5, and 6)
2-
3- 5,6,7,8, 11,12 (conflicts with 4, 9, and10)
4-
5- 6, 9,10,11,12 (conflicts with 7 and 8)
6- 9,10,11,12 (conflicts with 7 and 8)
7- 8,9,10,11,12

8- 9,10,11,12
9- 10 (conflicts with 11,and12)
10- (conflicts with 11 and 12)
11- 12

Configured traffic signal controller and MMU to be provided to the City of Golden's Engineering Department for shop testing and final configuration.

Monitor Front Switch Settings. Monitor front switches 1,2,3,4,5,6,9,10to be set off and Monitor front switches 7,8,11,12 to be set to on.

Yellow Inhibits. All yellow inhibits to be jumpered on monitor board.

Conflict Schedule. Conflicts to be defined according to the following schedule.

Ring 1
If vehicle yellow comes on with Walk, Ch1 conflicts with Ch5.
If Walk comes on while signals are dark, Ch1 conflicts with Ch6.
If both Walk and Don't Walk fail to come on, Ch1 to get a red fail.
If Left Red sticks on, Ch6 conflicts with Ch7.
If Right Red sticks on, Ch6 conflicts with Ch8.
If Left or Right Red fails during Walk interval, Ch7 or Ch8 to get a red fail.
If yellow sticks on, Ch5 conflicts with either Ch6 or Ch7.

Ring 2
If vehicle yellow comes on with Walk, Ch3 conflicts with Ch9.
If Walk comes on while signals are dark, Ch3 conflicts with Ch10.
If both Walk and Don't Walk fail to come on, Ch3 to get a red fail.
If Left Red sticks on, Ch10 conflicts with Ch11.
If Right Red sticks on, Ch10 conflicts with Ch12.
If Left or Right Red fails during Walk interval, Ch11or Ch12 to get a red fail.
If yellow sticks on, Ch9 conflicts with either Ch11 or Ch12.

CONSTRUCTION REQUIREMENTS

Construction requirements shall conform to Section 614.09.

METHOD OF MEASUREMENT

Except as noted in these project special provisions, all equipment will be measured in accordance with Section 614.13.

Pedestrian beacons will be measured by the number used and shall include all work necessary to complete the item.

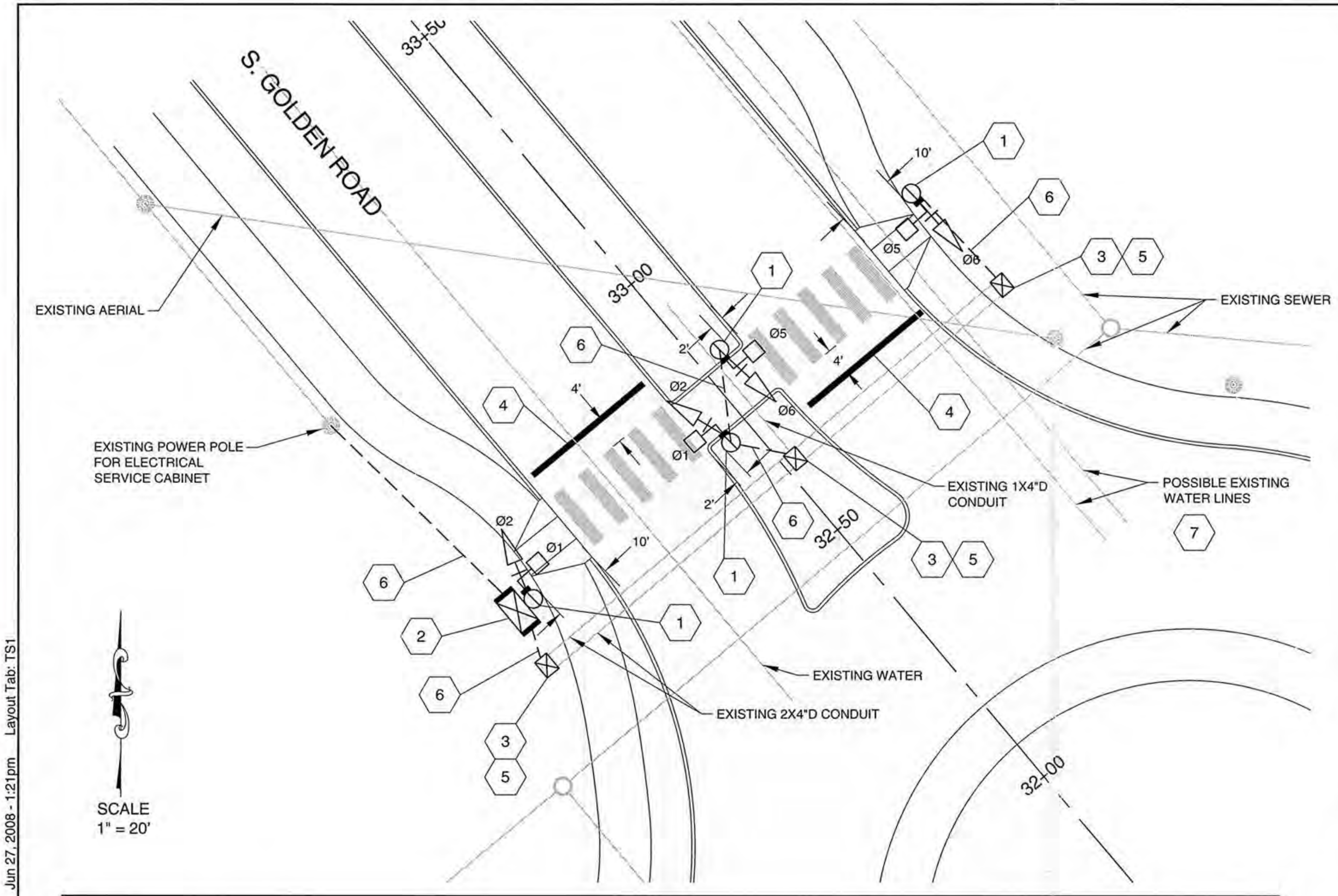
BASIS OF PAYMENT

The accepted quantities will be paid for at the contract price per unit of measurement for each of the pay items listed in Section 614.14 and the project special provision pay items below that appear in the bid schedule.

Project special provision payment will be made under:

Pay Item	**Pay Unit**
Pedestrian Beacon	Each

H:\projfile\6317btm\Ped Beacon\95% submittal\roundabout1_cmb.dwg Jun 27, 2008 - 1:21pm Layout Tab: TS1



CONSTRUCTION NOTES

1. INSTALL 25 FOOT LONG, CLASS 4 TEMPORARY WOOD POLE. AUGER FOUNDATION TO DEPTH SHOWN ON SIGNAL POLE ASSEMBLY DETAIL.
2. INSTALL POLE-MOUNTED CONTROLLER CABINET, SERVICE CABINET, AND METER. SEE SPECIAL PROVISIONS FOR PHASE ASSIGNMENTS, WIRING, CONFLICT MONITOR, AND TIMING NOTES.
3. INSTALL SMALL PULL BOX.
4. INSTALL 24" WHITE STOP BAR.
5. INTERCEPT EXISTING CONDUIT AND EXTEND INTO PULL BOX USING 4" NONMETALLIC CONDUIT.
6. INSTALL CONDUIT AND/OR WIRING PER CONDUIT AND WIRING DETAIL.
7. POSSIBLE CONFLICT WITH WATER LINE - VERIFY LOCATIONS OF UTILITIES.

GENERAL NOTES

1. LOCATION OF POLES, CONDUITS, SIGNAL HEADS, PULL BOXES, AND CONTROLLER (AS SHOWN ON PLAN) ARE APPROXIMATE. ACTUAL LOCATIONS SHALL BE DESIGNATED IN THE FIELD BY THE ENGINEER.
2. ALL MATERIALS AND WORKMANSHIP SHALL CONFORM TO THE COLORADO DEPARTMENT OF TRANSPORTATION (CDOT) STANDARD DRAWINGS, THE CDOT STANDARD SPECIFICATIONS FOR ROAD AND BRIDGE CONSTRUCTION (CDOT 2005), AND THE SPECIAL PROVISIONS FOR THIS CONTRACT.
3. THE LOCATION OF EXISTING UTILITIES SHALL BE VERIFIED. COORDINATE ALL WORK WITH UTILITY COMPANIES TO ELIMINATE CONFLICTS.
4. THE CONTRACTOR SHALL COORDINATE WORK WITH THE POWER COMPANY FOR POWER SERVICE CONNECTION. THE CONTRACTOR SHALL INSTALL WIRING TO POWER SOURCE AS REQUIRED.

BILL OF MATERIALS

ITEM	QUANTITY	UNIT	DESCRIPTION
⊘	4	EA	WOOD VEHICLE PEDESTAL POLE. 25 FT LONG, CLASS 4 TREATED.
▷	4	EA	TRAFFIC SIGNAL FACE, BLACK POLYCARB TUNNEL VISOR (SEE SIGNAL FACE DETAIL ON SHEET TS2).
☐	4	EA	PEDESTRIAN SIGNAL FACE, BLACK POLYCARB.
▮	4	EA	ACCESSIBLE PEDESTRIAN SIGNAL, POLARA NAVIGATOR OR EQUIV.
☒	1	EA	ECONOLITE TS2 CONTROLLER CABINET (TYPE 5, POLE MOUNTED) WITH ECONOLITE ASC2S TYPE II CONTROLLER INCLUDING 32791C8243 MODULE AND 34275G1 REV. B EXPANDED MEMORY, SERVICE CABINET, AND METER.
☒	3	EA	UNDERGROUND PULL BOX.
	8	EA	POLE MOUNTED JUNCTION BOX
⊣	4	EA	R10-23 SIGN
	30	LF	2" DIA UNDERGROUND CONDUIT
	5	LF	3" DIA UNDERGROUND CONDUIT
	40	LF	POLE MOUNTED CONDUIT
	330	LF	7 CONDUCTOR CABLE (14 GA.)
	305	LF	2 CONDUCTOR CABLE (18 GA. SHIELDED)
	48	LF	24" WHITE STOP BAR
	40	LF	POWER CABLE

LEE A. RODEGERDTS
41057
6/30/08

KITTELSON & ASSOCIATES, INC.
TRANSPORTATION ENGINEERING/PLANNING

TEMPORARY PEDESTRIAN HYBRID BEACON PLAN
S. GOLDEN RD/JOHNSON RD/16TH ST
GOLDEN, COLORADO

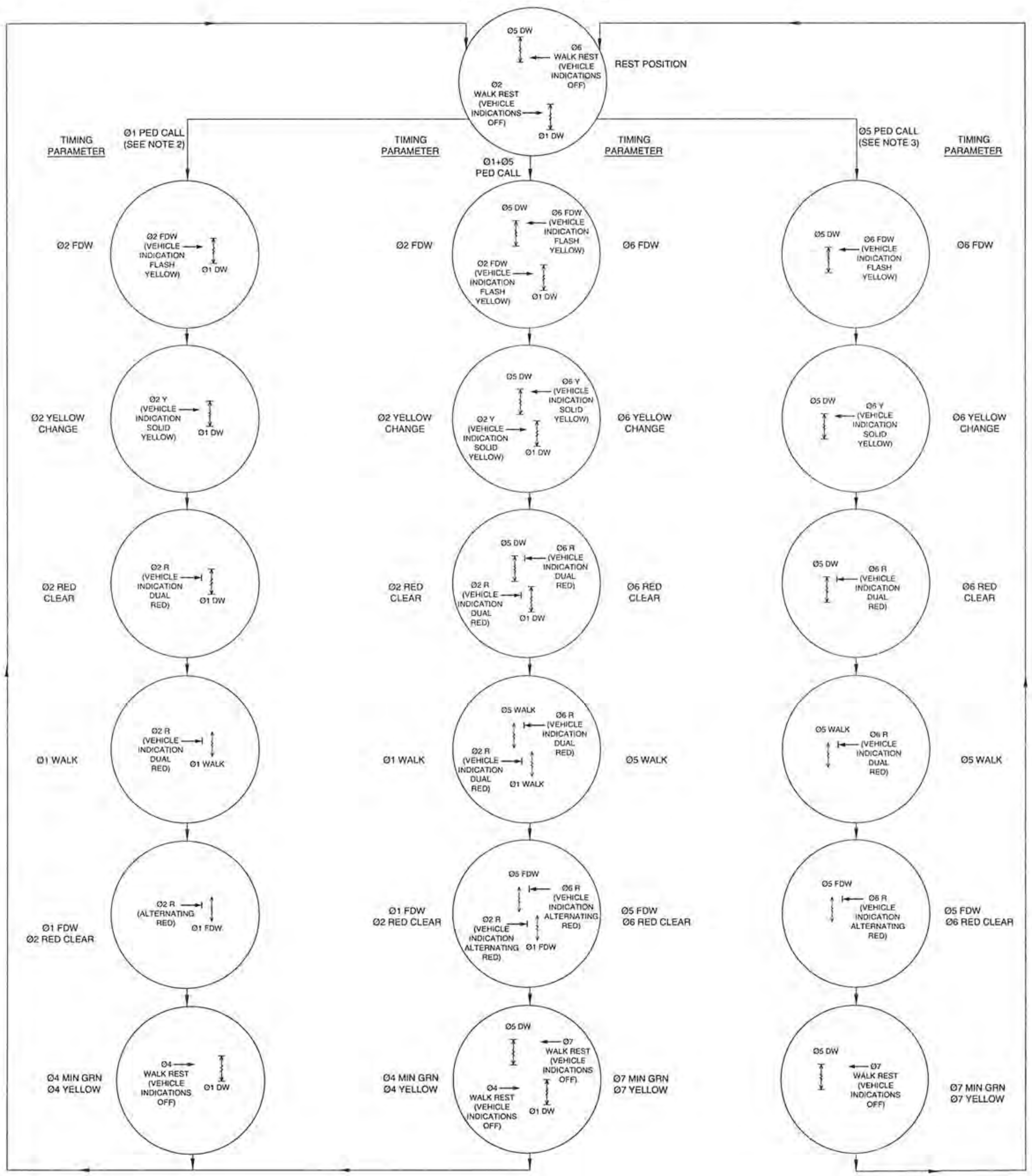
DATE *JUNE 2008*
DESIGNED BY: *LAR*
CHECKED BY: *JFR*
DRAWN BY: *JCH*

ACCOMPANIED BY DWGS. ______

SHEET NO. TS-1

C:\DOCUME~1\JHENRI~1\LOCALS~1\Temp\AcPublish_6008\roundabout1_cmb.dwg Jun 27, 2008 - 1:16pm Layout Tab: TS2

PHASING SEQUENCE

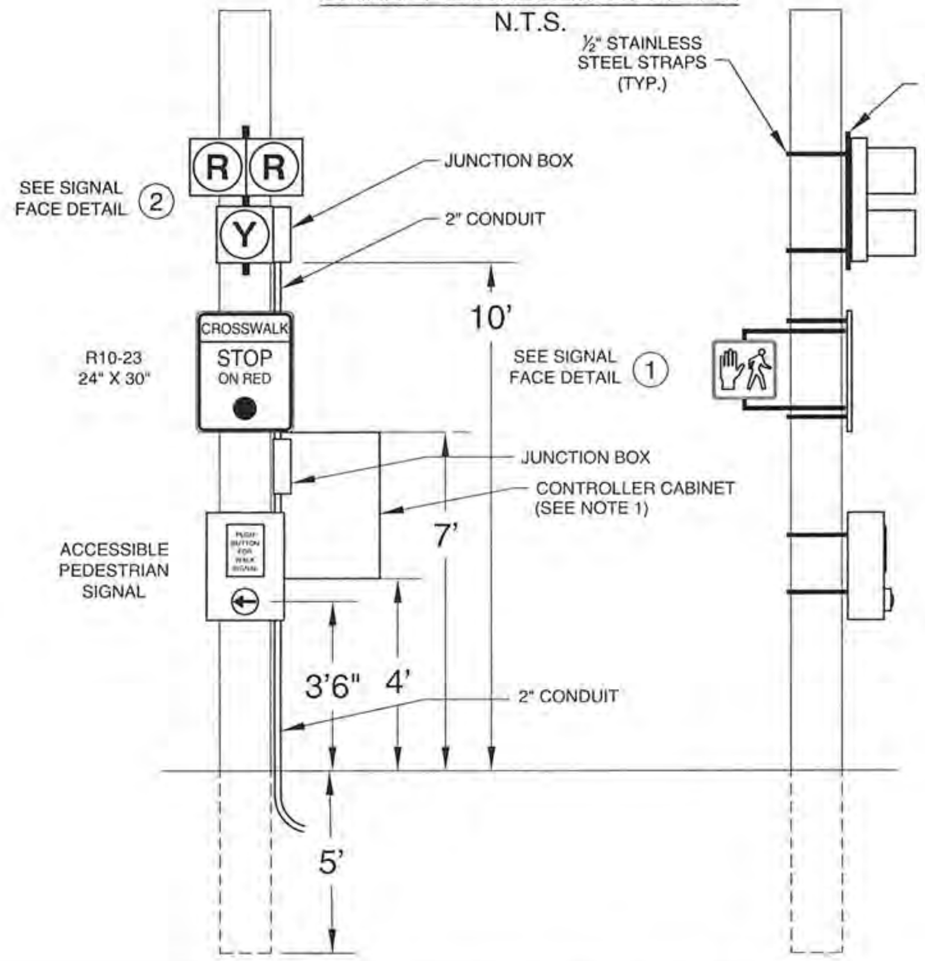


NOTES

1. SEE TS1 FOR APPLICABLE SIGNAL POLE.
2. DURING Ø1 PED CALL, Ø6 VEHICLE INDICATIONS REMAIN IN OFF POSITION AND Ø5 PEDESTRIAN INDICATIONS REMAIN IN DON'T WALK.
3. DURING Ø5 PED CALL, Ø2 VEHICLE INDICATIONS REMAIN IN OFF POSITION AND Ø1 PEDESTRIAN INDICATIONS REMAIN IN DON'T WALK.

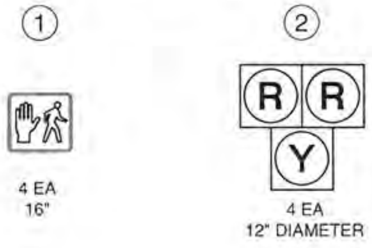
SIGNAL POLE ASSEMBLY DETAIL

N.T.S.



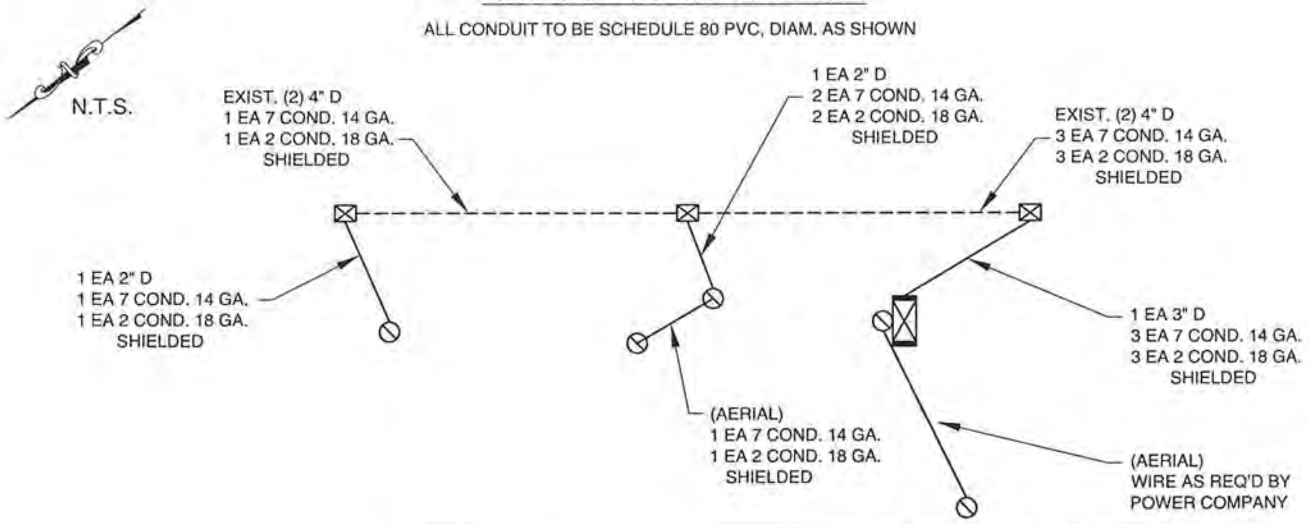
SIGNAL FACE DETAIL

SIGNAL FACE TO BE BLACK POLYCARB WITH TUNNEL VISORS.



CONDUIT AND WIRING DETAIL

ALL CONDUIT TO BE SCHEDULE 80 PVC, DIAM. AS SHOWN



6/30/08

LEE A. RODEGERDTS 41057

KITTELSON & ASSOCIATES, INC.
TRANSPORTATION ENGINEERING/PLANNING

TEMPORARY PEDESTRIAN HYBRID BEACON PLAN
S. GOLDEN RD/JOHNSON RD/16TH ST
GOLDEN, COLORADO

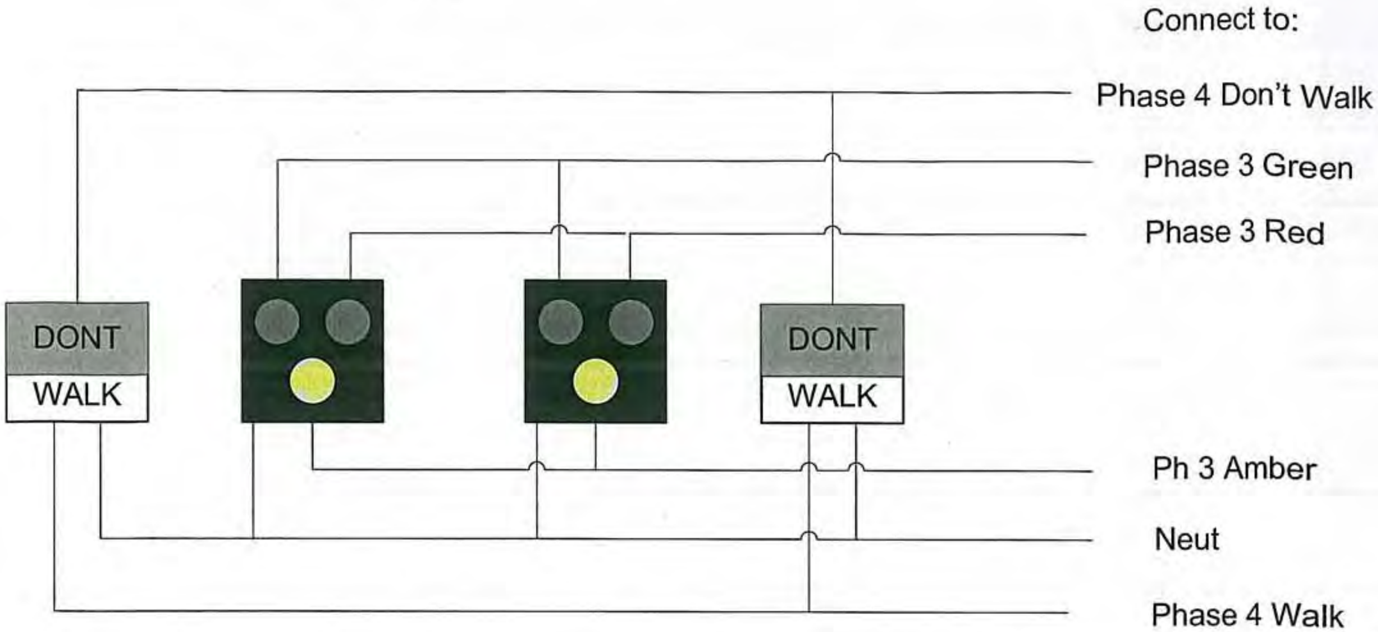
DATE JUNE 2008
DESIGNED BY: LAR
CHECKED BY: JFR
DRAWN BY: JCH

ACCOMPANIED BY DWGS.

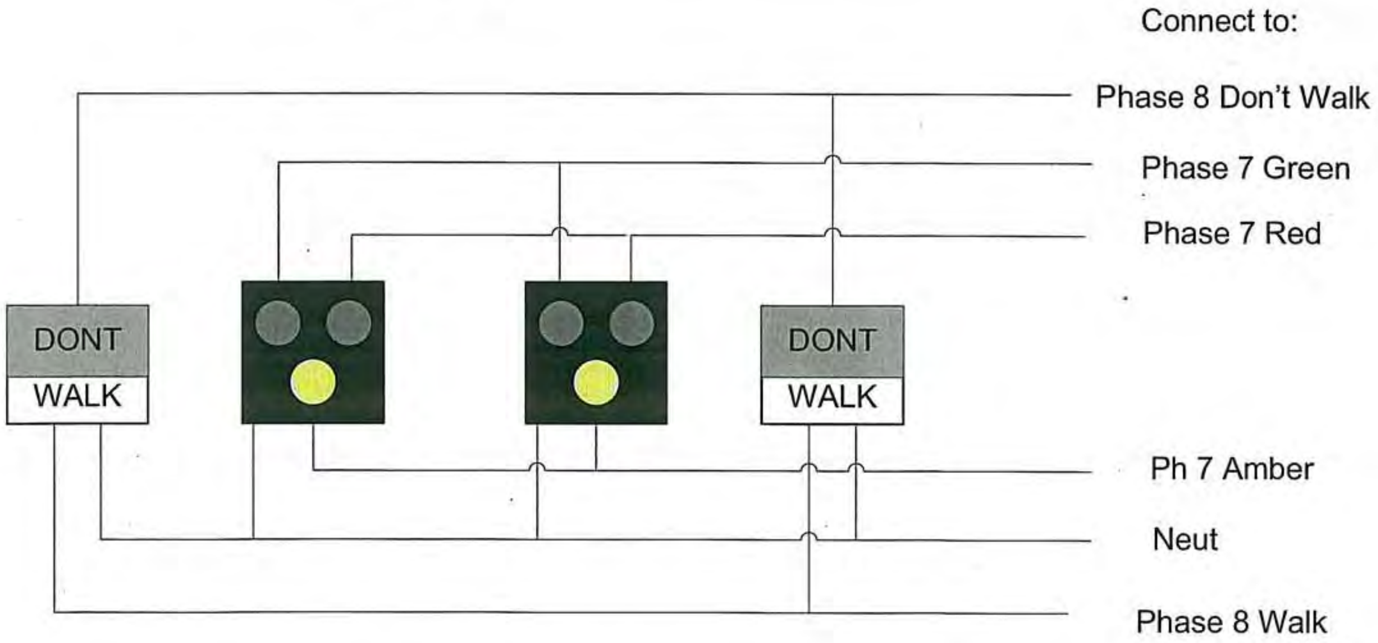
SHEET NO. TS-2

170 Controller and Cabinet Configuration

Hawk 1



Hawk 2



PHASE TIMING PAGE 0

Key	(0 + Key)		(Phase + Key)								
			Phase	1	2	3	4	5	6	7	8
			Phase Direction	Hawk 1	Rest 2			Hawk 5	Rest 6		
0	Veh Recall	-2---6--	Max I	40	2	0	0	40	2	0	0
1	Ped Recall	-2---6--	Max II HFDW	40	2	0	0	40	2	0	0
2	Red Lock	--------	Walk	~~7~~ 4	~~4~~ 15	0	0	~~7~~ 4	~~4~~ 15	0	0
3	Yellow Lock	--------	Flash DW	~~20~~ 7	~~6~~ 3	0	0	20 7	~~6~~ 3	0	0
4	Permit	12--56--	Max Initial	~~27~~ 11	~~2~~ 15	0	0	~~27~~ 11	~~2~~ 15	0	0
5	Ped Phases	12--56--	Min Green	~~27~~ 11	~~2~~ 15	0	0	27 11	~~2~~ 15	0	0
6	Lead Phases	1--45-7-	T B R	0	0	0	0	0	0	0	0
7	Double Entry	--------	T T R	0	0	0	0	0	0	0	0
8	Seq Timing	--------	Observe Gap	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	Start Up Grn	-2---6--	Passage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
A	Overlap A	--------	Min Gap	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B	Overlap B	--------	Added Act	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C	Overlap C	--------	Yellow	3.0	3.0	0.0	0.0	3.0	3.0	0.0	0.0
D	Overlap D	--------	Red Clear	~~1.0~~ 0	~~1.0~~ 0	0.0	0.0	~~1.0~~ 0	~~1.0~~ 0	0.0	0.0
E	Exclusive	--------	Red Revert	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F	Sim Gap	--------	Walk II	0	0	0	0	0	0	0	0

! Change Ped times to suit!

LOCAL TIME AND PREEMPTS

Key	(C + Key) Function		(E + Key) Function	
0	Local Time Year	5	Emer Vehicle A Delay	0
1	Local Time Month	10	Emer Vehicle A Min	0
2	Local Time Day of Month	31	Emer Vehicle B Delay	0
3	Local Time Day of Week	Monday	Emer Vehicle B Min	0
4	Local Time Hour	16	Emer Vehicle C Delay	0
5	Local Time Minute	22	Emer Vehicle C Min	0
6	Local Time Second	46	Emer Vehicle D Delay	0
7	Local Time Timing by	2	Emer Vehicle D Min	0
8	Triggers on in Flash	None	Overlap Red Revert	0.0
9	Start Up Yellow	---------	Railroad Delay	0
A	Emer Vehicle A Phases	---------	Railroad Clear	0
B	Emer Vehicle B Phases	---------	Railroad Clear Phs	--------
C	Emer Vehicle C Phases	---------	Railroad Permit	--------
D	Emer Vehicle D Phases	---------	Railroad Ol Permit	--------
E	Handicap Ped	---------	NEMA Hold Phs	--------

TOD DOW SCHEDULE

(A + xy)	xy		xy		xy		xy	
Event		SMTWTFS Days of week		Hour		Minute		Function
1	80	1 2 3 4 5 6 7	81	0	82	0	83	20
2	84	--------	85	0	86	0	87	0
3	88	--------	89	0	8A	0	8B	0
4	8C	--------	8D	0	8E	0	8F	0
5	90	--------	91	0	92	0	93	0
6	94	--------	95	0	96	0	97	0
7	98	--------	99	0	9A	0	9B	0
8	9C	--------	9D	0	9E	0	9F	0
9	A0	--------	A1	0	A2	0	A3	0
10	A4	--------	A5	0	A6	0	A7	0
11	A8	--------	A9	0	AA	0	AB	0
12	AC	--------	AD	0	AE	0	AF	0
13	B0	--------	B1	0	B2	0	B3	0
14	B4	--------	B5	0	B6	0	B7	0
15	B8	--------	B9	0	BA	0	BB	0
16	BC	--------	BD	0	BE	0	BF	0
17	C0	--------	C1	0	C2	0	C3	0
18	C4	--------	C5	0	C6	0	C7	0
19	C8	--------	C9	0	CA	0	CB	0
20	CC	--------	CD	0	CE	0	CF	0
21	D0	--------	D1	0	D2	0	D3	0
22	D4	--------	D5	0	D6	0	D7	0
23	D8	--------	D9	0	DA	0	DB	0
24	DC	--------	DD	0	DE	0	DF	0
25	E0	--------	E1	0	E2	0	E3	0
26	E4	--------	E5	0	E6	0	E7	0
27	E8	--------	E9	0	EA	0	EB	0
28	EC	--------	ED	0	EE	0	EF	0
29	F0	--------	F1	0	F2	0	F3	0
30	F4	--------	F5	0	F6	0	F7	0
31	F8	--------	F9	0	FA	0	FB	0
32	FC	--------	FD	0	FE	0	FF	0

(D + 8 + xy)	xy		xy		xy		xy	
Event		SMTWTFS Days of week		Hour		Minute		Function
33	80	---------	81	0	82	0	83	0
34	84	---------	85	0	86	0	87	0
35	88	---------	89	0	8A	0	8B	0
36	8C	---------	8D	0	8E	0	8F	0
37	90	---------	91	0	92	0	93	0
38	94	---------	95	0	96	0	97	0
39	98	---------	99	0	9A	0	9B	0
40	9C	---------	9D	0	9E	0	9F	0
41	A0	---------	A1	0	A2	0	A3	0
42	A4	---------	A5	0	A6	0	A7	0
43	A8	---------	A9	0	AA	0	AB	0
44	AC	---------	AD	0	AE	0	AF	0
45	B0	---------	B1	0	B2	0	B3	0
46	B4	---------	B5	0	B6	0	B7	0
47	B8	---------	B9	0	BA	0	BB	0
48	BC	---------	BD	0	BE	0	BF	0
49	C0	---------	C1	0	C2	0	C3	0
50	C4	---------	C5	0	C6	0	C7	0
51	C8	---------	C9	0	CA	0	CB	0
52	CC	---------	CD	0	CE	0	CF	0
53	D0	---------	D1	0	D2	0	D3	0
54	D4	---------	D5	0	D6	0	D7	0
55	D8	---------	D9	0	DA	0	DB	0
56	DC	---------	DD	0	DE	0	DF	0
57	E0	---------	E1	0	E2	0	E3	0
58	E4	---------	E5	0	E6	0	E7	0
59	E8	---------	E9	0	EA	0	EB	0
60	EC	---------	ED	0	EF	0	EF	0
61	F0	---------	F1	0	F2	0	F3	0
62	F4	---------	F5	0	F6	0	F7	0
63	F8	---------	F9	0	FA	0	FB	0
64	FC	---------	FD	0	FE	0	FF	0

CONTROL

Key	*(B + 0 + Key)*		*xy*	*(D + x + y)*	
0	Present Plan	3	2E	Floating Ped	0-DISABLE
1	TOD DOW Plan	3	7D	ID High Digits	[redacted]
2	Hardware Plan	0	2F	ID Low Digits	[redacted]
3	Modem Plan	142	76	Protocol Switch	[redacted]
4	Mode	0-Free	3E	No Cord Ped Rcl	0-ALLOW
5	Master	0-Not a master	3F	Rest in Walk	1-Rest at end of walk
6	Master Clock	52	4E	Adv Warn EoG	0
7	Local Clock	18	4F	Adv Warn SoG	0
8	Dwell Clock	18	5E	Railroad Red Clear	0
9	Reserved 1	0	5F	Railroad Clr Color	0-Green
A	Reserved 2	0	6D	Bus Delay	25.5
B	Reserved 3	0	6E	Bus Free T1	0
C	LRT Clr Phs	- - - - - - - - -	6F	Bus Free T3	0
D	LRT Rtn Phs	- - - - - - - - -	7E	Emer Vehicle Min after C	0-DISABLE
E	Adv Warn Phs	- - - - - - - - -	7F	Emer Vehicle Indicators	0-Off
F	MRI Phs	1 - - - 5 - - -	66	NEMA Inputs	0-DISABLE

INPUT REASSIGNMENT PAGE 0

Key	*(A + 4 + Key)*		*(A + 5 + Key)*		*(A + 6 + Key)*	
	C1 Pin	Code	C1 Pin	Code	C1 Pin	Code
0	39	11	55	31	67	131
1	40	12	56	32	68	133
2	41	13	57	33	69	53
3	42	14	58	34	70	54
4	43	15	59	35	71	55
5	44	16	60	36	72	56
6	45	17	61	37	73	57
7	46	18	62	38	74	58
8	47	21			75	61
9	48	22			76	62
A	49	23			77	63
B	50	24			78	64
C	51	25	63	45	79	65
D	52	26	64	46	80	66
E	53	27	65	47	81	67
F	54	28	66	48	82	68

OUTPUT REASSIGNMENT PAGE 0

Key	*(A + 0 + Key)* Function	Code	*(A + 1 + Key)* Function	Code	*(A + 2 + Key)* Function	Code	*(A + 3 + Key)* Function	Code
0	04 D/W	71	08 D/W	99	02 PED Y	99	01 D/W	11
1	04 WALK	72	08 WALK	99	06 PED Y	52	01 WALK	12
2	04 RED	13	08 RED	33	04 PED Y	53	Overlap B RED	73
3	04 YEL	14	08 YEL	34	08 PED Y	54	Overlap B YEL	74
4	04 GRN	15	08 GRN	35	03 PED Y	55	Overlap B GRN	75
5	03 RED	99	07 RED	99	01 PED Y	56	Overlap A RED	76
6	03 YEL	99	07 YEL	99	FLASH	57	Overlap A YEL	77
7	03 GRN	99	07 GRN	99	WATCHDOG	58	Overlap A GRN	78
8	02 D/W	21	06 D/W	41	03 D/W	61		
9	02 WALK	22	06 WALK	42	03 WALK	62	SD	0
A	02 RED	23	06 RED	43	Overlap D RED	63	LTT	0
B	02 YEL	24	06 YEL	44	Overlap D YEL	64		
C	02 GRN	25	06 GRN	45	Overlap D GRN	65		
D	01 RED	26	05 RED	46	Overlap C RED	66		
E	01 YEL	27	05 YEL	47	Overlap C YEL	67		
F	01 GRN	28	05 GRN	48	Overlap C GRN	68		

EXTENDED OUTPUT REASSIGNMENT PAGE 0

Key	*(D + B + 0 + Key)* Function	Value	*(D + B + 1 + Key)* Function	Value	*(D + B + 2 + Key)* Function	Value
0	05 DW	31	Overlap E Green	0	Cycle 2	0
1	05 Walk	32	Overlap F Green	0	Cycle 3	0
2	Overlap L Red	0	Overlap E Yellow	0	Offset 1	0
3	Overlap L Yellow	0	Overlap F Yellow	0	Offset 2	0
4	Overlap L Green	0	Adv Warning	0	Offset 3	0
5	Overlap K Red	0	Railroad Fl. Yellow	0		
6	Overlap K Yellow	0	Det. Reset	0	Free	0
7	Overlap K Green	0	Railroad ON	0	Flash	0
8	07 DW	0	Emer Vehicle A ON	0	Coord Plan 1 2 3	0
9	07 Walk	0	Emer Vehicle B ON	0	Coord Plan 4 5 6	0
A	Overlap J Red	0	Emer Vehicle C ON	0	Coord Plan 7 8 9	0
B	Overlap J Yellow	0	Emer Vehicle D ON	0	Coord Plan 10 11 12	0
C	Overlap J Green	0	LRT 1 Go	0	Coord Plan 13 14 15	0
D	Overlap H Red	0	LRT 1 Stop	0	Coord Plan 16 17 18	0
E	Overlap H Yellow	0	LRT 2 Go	0		
F	Overlap H Green	0	LRT 2 Stop	0		

EXTENDED OVERLAPS

Key	*(D + 9 + 0 + Key)* Function	Value	*(D + 9 + 3 + Key)* Function	Value	*(E + F + Key)* Function	Value
0	Overlap H	---------	Overlap H Green	0.0	Railroad Max II	0
1	Overlap J	---------	Overlap H Yellow	0.0	Ped Perm Pl 1	0
2	Overlap K	---------	Overlap H Red	0.0	Ped Perm Pl 2	0
3	Overlap L	---------	Overlap J Green	0.0	Ped Perm Pl 3	0
4	Overlap H Switch P	---------	Overlap J Yellow	0.0	Ped Perm Pl 4	0
5	Overlap J Switch P	---------	Overlap J Red	0.0	Ped Perm Pl 5	0
6	Overlap K Switch P	---------	Overlap K Green	0.0	Ped Perm Pl 6	0
7	Overlap L Switch P	---------	Overlap K Yellow	0.0	Ped Perm Pl 7	0
8			Overlap K Red	0.0	Ped Perm Pl 8	0
9			Overlap L Green	0.0	Ped Perm Pl 9	0
A			Overlap L Yellow	0.0	Long Powerouts	6
B			Overlap L Red	0.0	Short Powerouts	6
C					Failed Det.	0
D					Max II On	0-INACTIVE
E					No Daylight Save	0-ENABLE
F					Revision Level	17

COMMAND BOX 1

D+9+8+0	205	D+9+A+0	23	D+9+C+0	21	D+9+E+0	20
D+9+8+1	117	D+9+A+1	51	D+9+C+1	1	D+9+E+1	24
D+9+8+2	21	D+9+A+2	205	D+9+C+2	12	D+9+E+2	21
D+9+8+3	2	D+9+A+3	118	D+9+C+3	20	D+9+E+3	2
D+9+8+4	12	D+9+A+4	21	D+9+C+4	24	D+9+E+4	12
D+9+8+5	205	D+9+A+5	1	D+9+C+5	23	D+9+E+5	205
D+9+8+6	9	D+9+A+6	2	D+9+C+6	51	D+9+E+6	137
D+9+8+7	23	D+9+A+7	205	D+9+C+7	205	D+9+E+7	21
D+9+8+8	73	D+9+A+8	116	D+9+C+8	118	D+9+E+8	6
D+9+8+9	205	D+9+A+9	21	D+9+C+9	21	D+9+E+9	12
D+9+8+A	117	D+9+A+A	1	D+9+C+A	2	D+9+E+A	205
D+9+8+B	21	D+9+A+B	2	D+9+C+B	14	D+9+E+B	137
D+9+8+C	2	D+9+A+C	207	D+9+C+C	20	D+9+E+C	21
D+9+8+D	3	D+9+A+D	207	D+9+C+D	24	D+9+E+D	6
D+9+8+E	20	D+9+A+E	207	D+9+C+E	21	D+9+E+E	3
D+9+8+F	23	D+9+A+F	207	D+9+C+F	2	D+9+E+F	20
D+9+9+0	51	D+9+B+0	207	D+9+D+0	11	D+9+F+0	23
D+9+9+1	205	D+9+B+1	207	D+9+D+1	20	D+9+F+1	51
D+9+9+2	118	D+9+B+2	207	D+9+D+2	24	D+9+F+2	205
D+9+9+3	21	D+9+B+3	207	D+9+D+3	21	D+9+F+3	138
D+9+9+4	1	D+9+B+4	207	D+9+D+4	2	D+9+F+4	21
D+9+9+5	3	D+9+B+5	207	D+9+D+5	12	D+9+F+5	5
D+9+9+6	20	D+9+B+6	205	D+9+D+6	205	D+9+F+6	3
D+9+9+7	23	D+9+B+7	118	D+9+D+7	116	D+9+F+7	20
D+9+9+8	51	D+9+B+8	21	D+9+D+8	21	D+9+F+8	23
D+9+9+9	205	D+9+B+9	1	D+9+D+9	2	D+9+F+9	51
D+9+9+A	116	D+9+B+A	12	D+9+D+A	14	D+9+F+A	205
D+9+9+B	21	D+9+B+B	20	D+9+D+B	20	D+9+F+B	136
D+9+9+C	1	D+9+B+C	23	D+9+D+C	24	D+9+F+C	21
D+9+9+D	3	D+9+B+D	51	D+9+D+D	21	D+9+F+D	5
D+9+9+E	20	D+9+B+E	205	D+9+D+E	2	D+9+F+E	3
D+9+9+F	24	D+9+B+F	116	D+9+D+F	11	D+9+F+F	20

COMMAND BOX 2

D+E+0+0	24	D+E+4+0	11	D+E+8+0	0	D+E+C+0	0
D+E+0+1	23	D+E+4+1	20	D+E+8+1	0	D+E+C+1	0
D+E+0+2	51	D+E+4+2	24	D+E+8+2	0	D+E+C+2	0
D+E+0+3	205	D+E+4+3	21	D+E+8+3	0	D+E+C+3	0
D+E+0+4	138	D+E+4+4	6	D+E+8+4	0	D+E+C+4	0
D+E+0+5	21	D+E+4+5	12	D+E+8+5	0	D+E+C+5	0
D+E+0+6	5	D+E+4+6	0	D+E+8+6	0	D+E+C+6	0
D+E+0+7	2	D+E+4+7	0	D+E+8+7	0	D+E+C+7	0
D+E+0+8	205	D+E+4+8	0	D+E+8+8	0	D+E+C+8	0
D+E+0+9	136	D+E+4+9	0	D+E+8+9	0	D+E+C+9	0
D+E+0+A	21	D+E+4+A	0	D+E+8+A	0	D+E+C+A	0
D+E+0+B	5	D+E+4+B	0	D+E+8+B	0	D+E+C+B	0
D+E+0+C	2	D+E+4+C	0	D+E+8+C	0	D+E+C+C	0
D+E+0+D	207	D+E+4+D	0	D+E+8+D	0	D+E+C+D	0
D+E+0+E	207	D+E+4+E	0	D+E+8+E	0	D+E+C+E	0
D+E+0+F	207	D+E+4+F	0	D+E+8+F	0	D+E+C+F	0
D+E+1+0	207	D+E+5+0	0	D+E+9+0	0	D+E+D+0	0
D+E+1+1	207	D+E+5+1	0	D+E+9+1	0	D+E+D+1	0
D+E+1+2	207	D+E+5+2	0	D+E+9+2	0	D+E+D+2	0
D+E+1+3	207	D+E+5+3	0	D+E+9+3	0	D+E+D+3	0
D+E+1+4	207	D+E+5+4	0	D+E+9+4	0	D+E+D+4	0
D+E+1+5	207	D+E+5+5	0	D+E+9+5	0	D+E+D+5	0
D+E+1+6	207	D+E+5+6	0	D+E+9+6	0	D+E+D+6	0
D+E+1+7	205	D+E+5+7	0	D+E+9+7	0	D+E+D+7	0
D+E+1+8	138	D+E+5+8	0	D+E+9+8	0	D+E+D+8	0
D+E+1+9	21	D+E+5+9	0	D+E+9+9	0	D+E+D+9	0
D+E+1+A	5	D+E+5+A	0	D+E+9+A	0	D+E+D+A	0
D+E+1+B	12	D+E+5+B	0	D+E+9+B	0	D+E+D+B	0
D+E+1+C	20	D+E+5+C	0	D+E+9+C	0	D+E+D+C	0
D+E+1+D	23	D+E+5+D	0	D+E+9+D	0	D+E+D+D	0
D+E+1+E	51	D+E+5+E	0	D+E+9+E	0	D+E+D+E	0
D+E+1+F	205	D+E+5+F	0	D+E+9+F	0	D+E+D+F	0
D+E+2+0	136	D+E+6+0	0	D+E+A+0	0	D+E+E+0	0
D+E+2+1	21	D+E+6+1	0	D+E+A+1	0	D+E+E+1	0
D+E+2+2	5	D+E+6+2	0	D+E+A+2	0	D+E+E+2	0
D+E+2+3	12	D+E+6+3	0	D+E+A+3	0	D+E+E+3	0
D+E+2+4	20	D+E+6+4	0	D+E+A+4	0	D+E+E+4	0
D+E+2+5	24	D+E+6+5	0	D+E+A+5	0	D+E+E+5	0
D+E+2+6	23	D+E+6+6	0	D+E+A+6	0	D+E+E+6	0
D+E+2+7	51	D+E+6+7	0	D+E+A+7	0	D+E+E+7	0
D+E+2+8	205	D+E+6+8	0	D+E+A+8	0	D+E+E+8	0
D+E+2+9	138	D+E+6+9	0	D+E+A+9	0	D+E+E+9	0
D+E+2+A	21	D+E+6+A	0	D+E+A+A	0	D+E+E+A	0
D+E+2+B	6	D+E+6+B	0	D+E+A+B	0	D+E+E+B	0
D+E+2+C	14	D+E+6+C	0	D+E+A+C	0	D+E+E+C	0
D+E+2+D	20	D+E+6+D	0	D+E+A+D	0	D+E+E+D	0
D+E+2+E	24	D+E+6+E	0	D+E+A+E	0	D+E+E+E	0
D+E+2+F	21	D+E+6+F	0	D+E+A+F	0	D+E+E+F	0
D+E+3+0	6	D+E+7+0	0	D+E+B+0	0	D+E+F+0	0
D+E+3+1	11	D+E+7+1	0	D+E+B+1	0	D+E+F+1	0
D+E+3+2	20	D+E+7+2	0	D+E+B+2	0	D+E+F+2	0
D+E+3+3	24	D+E+7+3	0	D+E+B+3	0	D+E+F+3	0
D+E+3+4	21	D+E+7+4	0	D+E+B+4	0	D+E+F+4	0
D+E+3+5	6	D+E+7+5	0	D+E+B+5	0	D+E+F+5	0
D+E+3+6	12	D+E+7+6	0	D+E+B+6	0	D+E+F+6	0
D+E+3+7	205	D+E+7+7	0	D+E+B+7	0	D+E+F+7	0
D+E+3+8	136	D+E+7+8	0	D+E+B+8	0	D+E+F+8	0
D+E+3+9	21	D+E+7+9	0	D+E+B+9	0	D+E+F+9	0
D+E+3+A	6	D+E+7+A	0	D+E+B+A	0	D+E+F+A	0
D+E+3+B	14	D+E+7+B	0	D+E+B+B	0	D+E+F+B	0
D+E+3+C	20	D+E+7+C	0	D+E+B+C	0	D+E+F+C	0
D+E+3+D	24	D+E+7+D	0	D+E+B+D	0	D+E+F+D	0
D+E+3+E	21	D+E+7+E	0	D+E+B+E	0	D+E+F+E	0
D+E+3+F	6	D+E+7+F	0	D+E+B+F	0	D+E+F+F	0

COMMAND BOX OUTPUTS

Key		(D + B + 3 + Key) Page 0	(D + B + 7 + Key) Page 1	(D + B + B + Key) Page 2
0	CB output 1	0	0	0
1	CB output 2	0	0	0
2	CB output 3	0	0	0
3	CB output 4	0	0	0
4	CB output 5	0	0	0
5	CB output 6	0	0	0
6	CB output 7	0	0	0
7	CB output 8	0	0	0
8	CB FIH op 9	51	0	0
9	CB FIH op 10	0	0	0
A	CB FIH op 11	0	0	0
B	CB FIH op 12	0	0	0

Double Hawk Signal
Command Box Modules

Sept 12 2008
PZ

Hawk 1

Hawk 2

Outputs

3G	Left Red	7G
3R	Right red	7R
3A	Amber	7A
4DW	Don't Walk	8DW
4W	Walk	8W

Inputs

C1-67	Ped PB	C1-68

Command Box Outputs

P2 Amber	# 9

Command Box

		Control the solid amber of Hawk 1
0	205	Turn on output
1	117	Phase 3 Amber
2	21	When the phase condition
3	2	of phase 2
4	12	is any amber

		Create a utility flasher on ped 2 amber
5	205	Turn on output
6	9	that flashes
7	23	when the output
8	73	that controls OLB red is active (always on)

		Control the flashing amber for Hawk 1
9	205	Turn on output
A	117	Phase 3 amber
B	21	when the phase condition
C	2	of phase 2
D	3	is flashing don't Walk
E	20	AND
F	23	the output
0	51	that flashes is on

		Control the Dual WigWag intervals
1	**205**	Turn on output
2	**118**	Of phase 3
3	**21**	when the phase condition
4	**1**	of phase 1
5	**3**	is flashing don't walk
6	**20**	AND
7	**23**	The output
8	**51**	that is flashing is active
9	**205**	Turn on output
A	**116**	of phase 3
B	**21**	when the phase condition
C	**1**	of phase 1
D	**3**	is flashing don't walk
E	**20**	AND
F	**24**	it is NOT the case that
0	**23**	The output
1	**51**	of the utility flasher is on

		Display Solid Red interval during walk
2	**205**	Turn on output
3	**118**	of phase 3
4	**21**	When the phase condition
5	**1**	of phase 1
6	**2**	is walk
7	**205**	Turn on output
8	**116**	of phase 3
9	**21**	when th phase condition
A	**1**	of phase 1
B	**2**	is Walk

C-5	**207**	**NOPS**

		WigWag during the ped amber
6	**205**	Turn on output
7	**118**	of phase 3
8	**21**	when the phase condition
9	**1**	of phase 1
A	**12**	is amber
B	**20**	AND
C	**23**	the output
D	**51**	that flashes is active
E	**205**	Turn on output
F	**116**	of phase 3
0	**21**	when the phase condition
1	**1**	of phase 1
2	**12**	is amber
3	**20**	AND
4	**24**	it is NOT the case
5	**23**	that the output
6	**51**	that flashes is active

		Display solid red during red clearance
7	**205**	Turn on output
8	**118**	of phase 3
9	**21**	when the phase condition
A	**2**	of phase 2
B	**14**	indicates that the phase is active
C	**20**	AND
D	**24**	it is NOT the case
E	**21**	that the phase condition
F	**2**	of phase 2
0	**11**	is green
1	**20**	AND
2	**24**	it is NOT the case
3	**21**	that the phase condition
4	**2**	of phase 2
5	**12**	is amber
6	**205**	Trun on output
7	**116**	phase 3
8	**21**	when the phase condition
9	**2**	of phase 2
A	**14**	indicates that the phase is active
B	**20**	AND
C	**24**	it is NOT the case
D	**21**	that the phase condition
E	**2**	of phase 2
F	**11**	is green
0	**20**	AND
1	**24**	it is NOT the case
2	**21**	that the phase condition
3	**2**	of phase 2
4	**12**	is Amber

Now do the other Hawk

5	**205**	Turn on output
6	**137**	Phase 7 Amber
7	**21**	When the phase condition
8	**6**	of phase 6
9	**12**	is any amber

		Control the flashing amber for Hawk 2
A	**205**	Turn on output
B	**137**	Phase 7 amber
C	**21**	when the phase condition
D	**6**	of phase 6
E	**3**	is flashing don't Walk
F	**20**	AND
0	**23**	the output
1	**51**	that flashes is on

		Control the Dual WigWag intervals
2	**205**	Turn on output
3	**138**	Of phase 7
4	**21**	when the phase condition
5	**5**	of phase 5
6	**3**	is flashing don't walk
7	**20**	AND
8	**23**	The output
9	**51**	that is flashing is active
A	**205**	Turn on output
B	**136**	of phase 7
C	**21**	when the phase condition
D	**5**	of phase 5
E	**3**	is flashing don't walk
F	**20**	AND
0	**24**	it is NOT the case that
1	**23**	The output
2	**51**	of the utility flasher is on

		Display Solid Red interval during walk
3	**205**	Turn on output
4	**138**	of phase 7
5	**21**	When the phase condition
6	**5**	of phase 5
7	**2**	is walk
8	**205**	Turn on output
9	**136**	of phase 7
A	**21**	when th phase condition
B	**5**	of phase 5
C	**2**	is Walk

D-6	**205**	**NOPS**

		WigWag during the ped amber
7	**205**	Turn on output
8	**138**	of phase 7
9	**21**	when the phase condition
A	**5**	of phase 5
B	**12**	is amber
C	**20**	AND
D	**23**	the output
E	**51**	that flashes is active
F	**205**	Turn on output
0	**136**	of phase 7
1	**21**	when the phase condition
2	**5**	of phase 5
3	**12**	is amber
4	**20**	AND
5	**24**	it is NOT the case
6	**23**	that the output
7	**51**	that flashes is active

		Display solid red during red clearance
8	**205**	Turn on output
9	**138**	of phase 7
A	**21**	when the phase condition
B	**6**	of phase 6
C	**14**	indicates that the phase is active
D	**20**	AND
E	**24**	it is NOT the case
F	**21**	that the phase condition
0	**6**	of phase 6
1	**11**	is green
2	**20**	AND
3	**24**	it is NOT the case
4	**21**	that the phase condition
5	**6**	of phase 6
6	**12**	is amber
7	**205**	Trun on output
8	**136**	phase 7
9	**21**	when the phase condition
A	**6**	of phase 6
B	**14**	indicates that the phase is active
C	**20**	AND
D	**24**	it is NOT the case
E	**21**	that the phase condition
F	**6**	of phase 6
0	**11**	is green
1	**20**	AND
2	**24**	it is NOT the case
3	**21**	that the phase condition
4	**6**	of phase 6
5	**12**	is Amber

TRAFFIC DESIGN

PRELIMINARY COST ESTIMATES

Intersection: **Temp. Roundabout Ped. Signal**
Designer: **Paul W .Ward/Cade M. Braud**
Engineer in Responsible Charge: **Lee Rodegerdts**
Date: 1/9/2008 **Project No.** 6317

ITEM	UNITS	UNIT PRICE	QUANTITY	COST PER ITEM
Temporary Wood Pole	Each	$ 1,000.00	4	$ 4,000.00
2 Inch Electrical Conduit	Lin Foot	$ 7.40	30	$ 222.00
3 Inch Electrical Conduit	Lin Foot	$ 9.02	5	$ 45.10
Pole mounted junction box	Each	$ 150.00	8	$ 1,200.00
Pull Box (16"x14"x6")	Each	$ 350.00	3	$ 1,050.00
Sign Panel (Class I)	Sq Foot	$ 16.50	20	$ 330.00
Pedestrian Signal Face (16) (Countdown)	Each	$ 610.00	4	$ 2,440.00
Traffic Signal Face (12-12-12)	Each	$ 767.37	4	$ 3,069.48
Traffic Signal Controller Cabinet	Each	$ 22,000.00	1	$22,000.00
Pedestrian Push Button	Each	$ 1,250.00	4	$ 5,000.00
Signal Cable	Lin Foot	$ 4.93	635	$ 3,130.55
Thermoplastic Pavement Marking (Xwalk-Stopline)	Sq Foot	$ 10.05	96	$ 964.80
			Project Subtotal	$39,500.00
			Plus 20% Contingency	$ 7,900.00
			Plus 15% Construction Engineering	$ 5,900.00
			Total Cost Estimate	**$53,300.00**

APPENDIX G: Participant Survey Forms

This Appendix includes the participant survey questions used during debriefing after each of the studies. Forms included are:

1. **Debriefing Questions for Channelized Turn Lane Study - Pretest**
2. **Debriefing Questions for Channelized Turn Lane Study - Posttest**
3. **Debriefing Questions for Charlotte, NC Roundabout Study - Pretest**
4. **Debriefing Questions for Golden, CO Roundabout Study - Pretest**
5. **Debriefing Questions for Golden, CO Roundabout Study - Posttest**

Appendix G: Participant Survey Forms

1. Debriefing Questions for Channelized Turn Lane Study - Pretest

Date _____________ Time____________

Subject # ______ Starting leg: NW SE Starting Location: Curb Island

1. Have you ever crossed at this intersection before?

2. Have you ever crossed a channelized turn lane before?

3. Do you cross streets at locations where there is no signal or other traffic control provided? (describe)

4. What made you decide to cross? What cues were you using?

5. Did it matter whether you were crossing to or from island?

6. How would you rate your confidence in your ability to cross here safely on a scale of 1 –5 with 1 being not at all and 5 very confident?

7. Would you cross these channelized turn lanes if they were on your route home from work?

8. Do these crossings need anything to increase safety and usability? If so, what would you suggest?

Appendix G: Participant Survey Forms

2. Debriefing Questions for Channelized Turn Lane Study - Posttest

Date _____________ Time____________

Subject # ______ Starting leg: NW SE Starting Location: Curb Island

1. Have you ever crossed at this particular intersection, besides during our earlier data collection?

2. Have you crossed channelized turn lanes before, except for our previous data collection?

You made crossings at two locations, but I want to first ask about the crossings you made with the sound strips alone [remind P if those were at the first or second set of crossings]

Sound strips alone (NW corner)

3. **(NW)** What made you decide to cross? What cues were you using? (ask why if they waved yielding vehicles on).

4. **(NW)** (If not mentioned) Were you using the sound from the strips to help you decide? How?

5. **(NW)** Did it matter whether you were crossing from the curb or from the island?

6. **(NW)** How would you rate your confidence in your ability to cross here safely on a scale of 1 –5 with 1 being not at all and 5 very confident?

7. **(NW)** Would you use this crossings if it was on the most direct route home from work?

Now, about the crossings at the corner with both the sound strips and beacon [the first, or second, set of crossings you made]

8. **(SE)** What made you decide to cross? What cues were you using? (ask why if they waved yielding vehicles on).

9. **(SE)** (If not mentioned) Were you using the sound from the strips to help you decide? How?

10. **(SE)** Were you using the speech message to help you decide to cross?

11. **(SE)** Did you think the beacon made a difference in the drivers' behavior? How?

12. **(SE)** Did it matter whether you were crossing from the curb or from the island?

13. **(SE)** How would you rate your confidence in your ability to cross here safely on a scale of 1 –5 with 1 being not at all and 5 very confident?

14. **(SE)** Would you use this crossing if it was on the most direct route home from work?

Now to a slightly different type of question…these are rating questions and we want you to rate the extent of your agreement with each statement with 1 strongly disagree and 5 strongly agree so 3 would be 'neutral'. *There were two kinds of treatments here …sound strips on both corners, and beacons with voice message on one. In thinking about the beacon with the speech message and locator tone…*

15. Where there were beacons installed, I'd push the button each time I wanted to cross.

16. Knowing the beacon was flashing made me more confident that I was starting to cross at a safe time.

17. The speech message didn't interfere with my ability to hear traffic.

18. The locator tone on the beacon helped me know I was coming to the crosswalk.

19. The locator tone helped me go straight across the crosswalk.

20. The locator tone helped me know I was approaching the end of the crosswalk.

Thinking about the sound strips….

21. The sound strips helped me know when vehicles were approaching.

22. The sound strips helped me know when vehicles were slowing down.

23. The sound strips helped me know when vehicles had yielded.

24. The sound strips made me confident that I was starting to cross at a safe time.

OVERALL, at end:

25. Was anything about the sound strips different on the two corners?

26. Do you think sound strips alone, or beacon and sound strips, or just the beacon would help most and why?

27. Do you think these crossings need anything to increase safety and usability? If so, what else would you suggest?

3. Debriefing Questions for Charlotte, NC Roundabout Study - Pretest

Date _____________ Time____________

Subject # ______ Starting leg: N S Starting Lane: Entry Exit

1. Have you ever crossed at this intersection before?

2. Have you every crossed a roundabout before?

3. Do you cross streets at locations where there is no signal or other traffic control provided? (describe)

4. You had the opportunity to cross both the 'entry' lane (when vehicles were entering the circle) as well as the 'exit' lane (when vehicles were leaving the circle). Which as more difficult and why?

5. How would you rate your confidence in your ability to cross here safely on a scale of 1 –5 with 1 being not at all and 5 very confident?

6. Would you cross at this intersection if it was on your route home from work, or would you find another way home from work?

7. How do you think this type of crossing situation could be made more accessible and less risky to people who are blind and visually impaired?

8. When a vehicle yielded, you crossed sometimes and not other times (or maybe 'never crossed'). What made you decide to cross? What cues were you using? (or why not?)

4. Debriefing Questions for Golden Roundabout Study - Pretest

Date _____________ Time____________

Subject # ______ Starting leg: N S Starting Lane: Entry Exit

1. Have you ever crossed at these particular intersections before?

2. Have you every crossed at a roundabout before?

3. Do you cross streets at locations where there is no signal or other traffic control provided? (describe)

Single lane roundabout

4. What made you decide to cross? What cues were you using? (ask why if they waved yielding vehicles on)

5. Did it matter whether you were crossing an entry lane or an exit lane?

6. How would you rate your confidence in your ability to cross here safely on a scale of 1 –5 with 1 being not at all and 5 very confident?

7. Would you use these crossings if they were on the most direct route home from work?

8. Overall, do you think crossing here is more risky, less risky, or about the same risk as crossing at an intersection with two lanes of traffic and a traffic signal?

9. If there was an unsignalized, mid-block crossing nearby, would you be more likely to use it than to attempt to cross where you crossed in the study?

10. If there was a signalized mid-block crossing nearby, would you be more likely to use it than to attempt to cross where you crossed in the study?

11. How do you think this type of crossing situation could be made more accessible and less risky to people who are blind and visually impaired?

Double lane roundabout

12. What made you decide to cross? What cues were you using? (ask why if they waved yielding vehicles on)

13. Did it matter whether you were crossing an entry lane or an exit lane?

14. How would you rate your confidence in your ability to cross here safely on a scale of 1 –5 with 1 being not at all and 5 very confident?

15. Would you use these crossings if they were on the most direct route home from work?

16. Overall, do you think crossing here is more risky, less risky, or about the same risk as crossing at an intersection with four lanes of traffic and a traffic signal?

17. If there was an unsignalized, mid-block crossing nearby, would you be more likely to use it than to attempt to cross where you crossed in the study?

18. If there was a signalized mid-block crossing nearby, would you be more likely to use it than to attempt to cross where you crossed in the study?

19. How do you think this type of crossing situation could be made more accessible and less risky to people who are blind and visually impaired?

5. Debriefing Questions for Golden Roundabout Study - Posttest

Date _____________ Time____________

Subject # ______ Starting leg: N S Starting Lane: Entry Exit

1. Have you ever crossed at these particular intersections, besides during our earlier data collection?

2. Have you crossed at a roundabout since the last time we were here?

3. Do you cross streets at locations where there is no signal or other traffic control provided? (describe)

Single lane roundabout

4. What made you decide to cross? What cues were you using? (ask why if they waved yielding vehicles on)

5. Did it matter whether you were crossing an entry lane or an exit lane?

6. Did it matter whether you were crossing from the curb or the median (island)?

7. How would you rate your confidence in your ability to cross here safely on a scale of 1 –5 with 1 being not at all and 5 very confident?

8. Would you use these crossings if they were on the most direct route home from work?

9. Overall, do you think crossing here is more risky, less risky, or about the same risk as crossing at an intersection with two lanes of traffic and a traffic signal?

10. How do you think this type of crossing situation could be made more accessible and less risky to people who are blind and visually impaired?

Double lane roundabout

HAWK signal

11. What made you decide to cross? What cues were you using? (ask why if they waved yielding vehicles on)

12. Did it matter whether you were crossing an entry lane or an exit lane?

13. Did it matter whether you were crossing from the curb or the median (island)?

14. How would you rate your confidence in your ability to cross this crosswalk safely on a scale of 1 –5 with 1 being not at all and 5 very confident?

15. Would you use these crossings if they were on the most direct route home from work?

16. Overall, do you think crossing with the HAWK signal is more risky, less risky, or about the same risk as crossing at an intersection with four lanes of traffic and a traffic signal?

Rate the extent of your agreement with this statement with 1 strongly disagree and 5 strongly agree.

17. If there were signals like these, I'd push the button each time I wanted to cross.

18. If there were signals like these, I would always wait to cross until I hear "walk sign is on".

19. These signals helped me know I was coming to the crosswalk.

20. These signals helped me align to cross.

21. These signals helped me go straight across the crosswalk.

22. These signals helped me know I was approaching the end of the crosswalk.

Double lane, Raised crosswalk:

23. What made you decide to cross? What cues were you using? (ask why if they waved yielding vehicles on)

24. Did it matter whether you were crossing an entry lane or an exit lane?

25. Did it matter whether you were crossing from the curb or the median (island)?

26. How would you rate your confidence in your ability to cross this crosswalk safely on a scale of 1 –5 with 1 being not at all and 5 very confident?

27. Would you use these crossings if they were on the most direct route home from work?

28. Overall, do you think crossing at the raised crosswalk is more risky, less risky, or about the same risk as crossing at an intersection with four lanes of traffic and a traffic signal?

OVERALL, at end:

29. How do you think this type of crossing situation could be made more accessible and less risky to people who are blind and visually impaired?

APPENDIX H: Team Conflict Survey Results

This Appendix contains the results of the team-internal conflict survey to test the validity of the O&M Intervention measure used in NCHRP 3-78a.

NCHRP 3-78a Conflict Survey Results
Providence Road at NC51, Charlotte, NC - PRE Condition
February 2009

Instructions

These were the instructions given to the team members:

Dear NCHRP 3-78a Team Member,

Please use the spreadsheet on the next tab labeled 'Conflict Log' to record your ratings of the clips on the conflict DVD mailed to you. The DVD contains 86 short video clips (~30 seconds each) of the PRE study at the intersection of Providence Road and NC51 in Charlotte, NC. These clips include all experimenter interventions, other events that we would consider risky, as well as, events that we consider safe. The clips are in random order, so you won't know which one is which.

In rating the clips, please focus your assessment on the FIRST CROSSING DECISION shown in the video. Some clips may contain "rejected gaps" prior to crossing which should be ignored for this exercise. Note also, that not all "first crossing decisions" result in an actual crossing, since the Orientation & Mobility Specialist may have intervened. For example, an intervention may result in a forced yield which is then utilized for a crossing. Your rating should focus on the FIRST CROSSING DECISION, which in this case is the O&M intervention, not the crossing after the forced yield.

On the rating sheet, please rate each clip using the following 1-5 rating scale:

1:	**Perfectly Safe**	- I believe that the **initial crossing decision by the pedestrian** was perfectly safe and that no emminent risk from approaching cars was visible
2:		- I believe that the **initial crossing decision by the pedestrian** was somewhere inbetween ratings 1 and 3
3:	**Marginal Risk**	- I believe that the **initial crossing decision by the pedestrian** was tolerable and that the risk for a crash with an approaching vehicle was low
4:		- I believe that the **initial crossing decision by the pedestrian** was somewhere inbetween ratings 3 and 5
5:	**Clearly Risky**	- I believe that the **initial crossing decision by the pedestrian** was clearly risky and that a crash with an approaching vehicle was very likely

The DVD can be played on any DVD player or computer with DVD drive. If using a home DVD player, you can "skip" chapters as you would when watching a movie to access different clips. If using a computer, Windows Media Player allows you to select chapters directly. NOTE: Other DVD playback programs such as Power DVD may not recognize the chapters and will only allow you to play the first clip.

The goal of this exercise is to expand our analysis of crossing safety beyond the O&M-Interventions measure. If you have any questions, please contact Bastian Schroeder at Bastian_Schroeder@ncsu.edu or 919-515-8565

Thank you for your assistance!

Observations

- Twelve team members completed the conflict survey of the 86 clips, resulting in 1032 ratings.
- The 86 clips consisted of a total of 35 O&M interventions, 27 other 'risky' events, and 24 'safe' events that were included to benchmark the test. The intervention category was based on field-coded intervention events by team member Wall Emerson. The 'risky' clips were selected by ITRE staff based on video observations. The 'safe' clips were included to benchmark this experiment and were selected because of the perceived low risk (based on ITRE assumptions).
- Figure 1 shows the distribution of ratings for all intervention clips in three categories: SAFE (rating 1 or 2), MIDDLE (rating 3), and RISKY (rating 4 or 5).

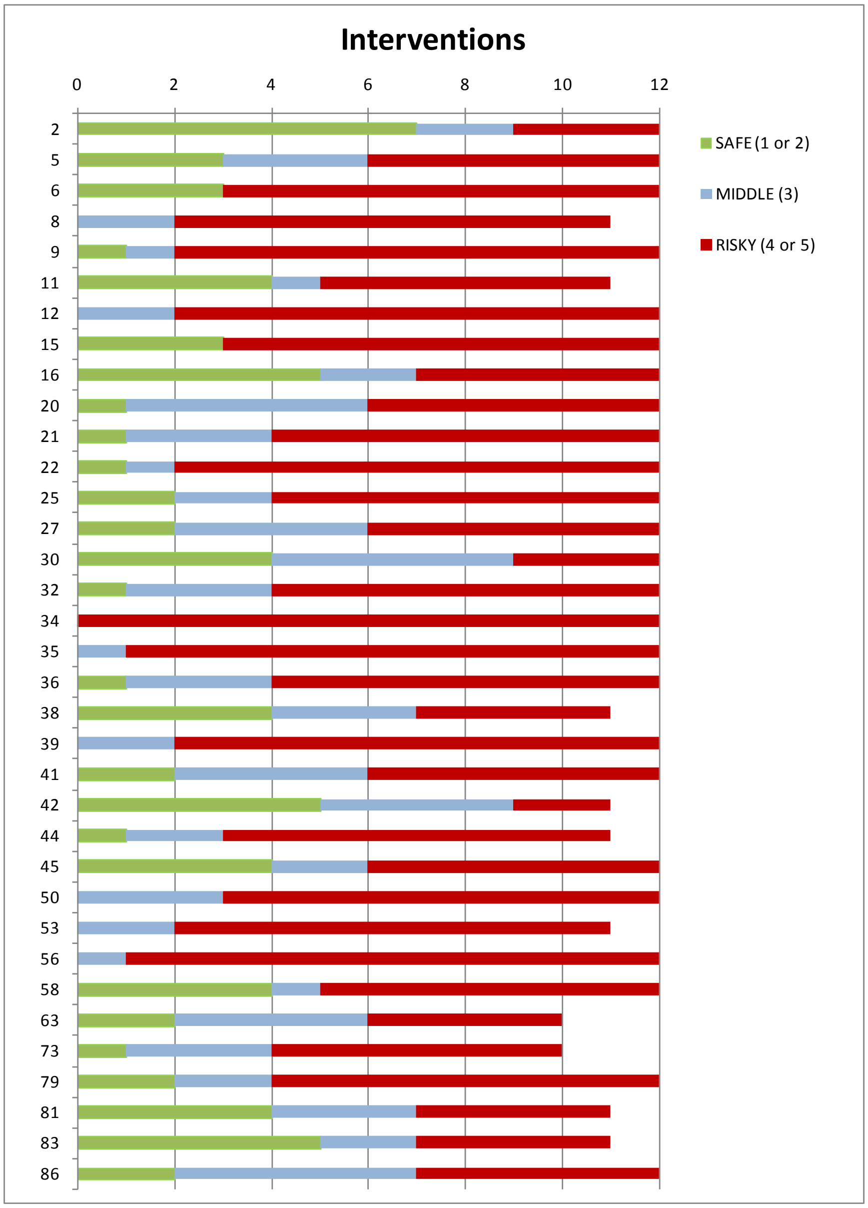


Figure 1: Distribution of Ratings for Intervention Clips

- The intervention clips (Figure 1) generally received high (risky) rating. However, almost all intervention clips (27 of 35) received at least one 'safe' rating on the "1-2" category. The two possible reasons are:

1) The intervention was difficult to see and was missed.
2) The observer disagreed with the need for the intervention.

- The figure makes evident that most interventions tended to get risky ratings, but with some exceptions. The arguably riskiest clips were clips 8, 12, 34, 35, 39, 50, 53, and 56, all of which got no 'safe' ratings. Clip 34 was the only clip with consistent 4-5 ratings by all observers.
- The average rating for intervention clips was 3.66, with 31 of 35 clips above a 3.0 average and 10 intervention clips with average rating above 4.0. The highest average rating was for clip 34 with a 4.92 average rating.

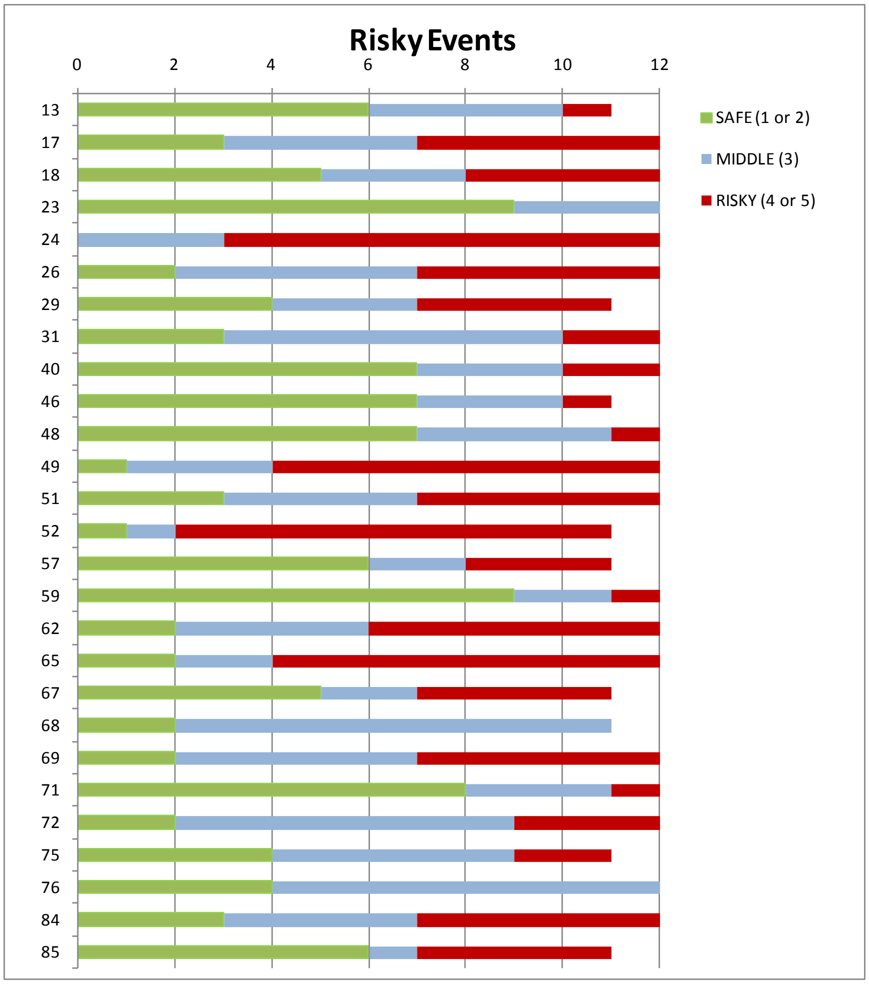


Figure 2: Distribution of Ratings for Risky Clips

- The <u>risky clips</u> (Figure 2) were included based on reviewing video at ITRE. This category of clips showed the greatest amount of variability among observers. Figure 2 shows the resulting distributions for the 27 clips in this category. The results make evident that all clips tended to get some 4-5 ratings, but many also received 1-2 ratings, indicating that the observer did not perceive a great amount of risk in the crossing.
- The average rating for risky clips was 2.99, with 12 of 27 clips above a 3.0 average and 2 clips with average rating above 4.0. One of the 'risky' clips received an average rating less than 2 (clip 23)

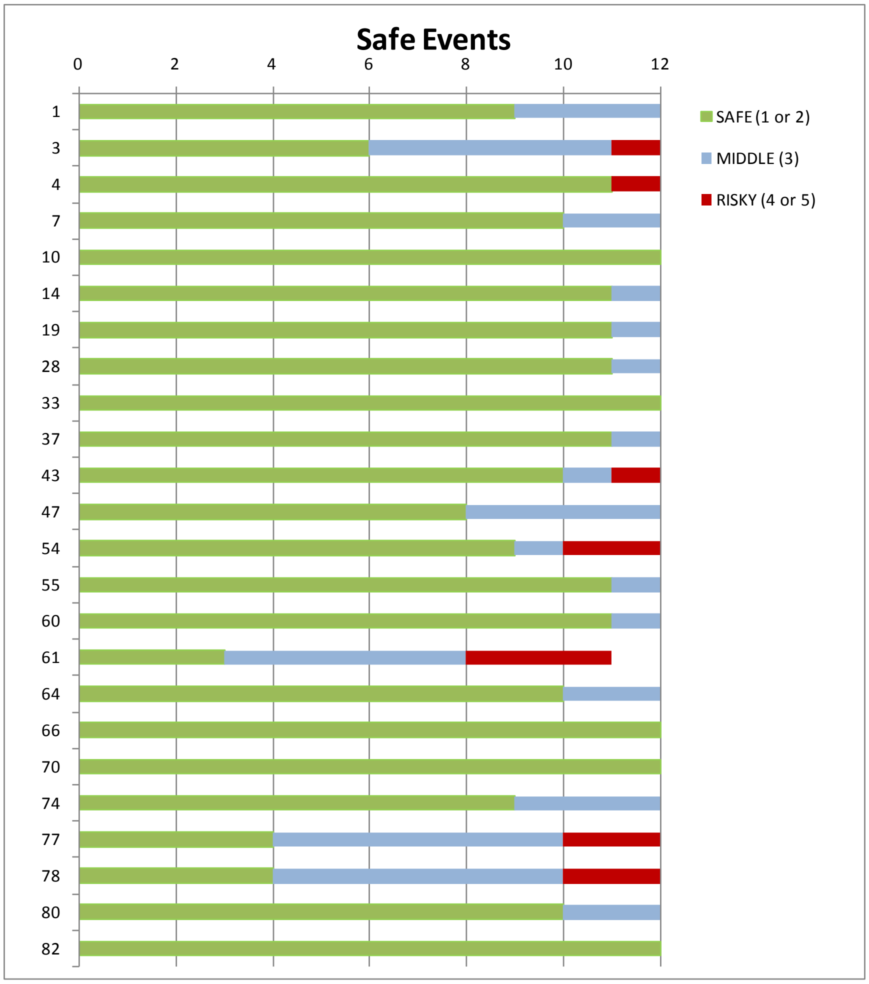


Figure 3: Distribution of Ratings for Safe Clips

- The safe clips (Figure 3) were included to benchmark the test results. Overall, pedestrians crossed the CTL facility about 800 times in the 'pre' condition. The 'safe' clips were included on the conflict DVD as a representative sample of the approximately 750 crossing events that were not capture by the 'intervention' or 'risky' categories. The underlying hypothesis is that these clips would generally get 'safe' ratings, thereby validating the selection process (for 'risky' clips) conducted by ITRE staff. Figure 3 shows the resulting distributions for the 24 clips in this category.

- The average rating for 'safe' clips was 1.69, with none of the 24 clips above a 3.0 average. The majority received an average rating less than 2.0 (19 of 24) and the highest average rating in this category was a 2.79. The results suggest that while these clips received occasional high ratings (4=5), observers predominantly agreed that no eminent risk was present in these crossings.

- In a general observation, some clips were poorly chosen because multiple events were shown in the short video segment. In all five of these clips, an O&M intervention was followed by other pedestrian-vehicle interaction events. In some cases, the pedestrian actually crossed after the intervention, creating ambiguity among observers about which event they should rate. These clips were numbers 22, 32, 44, 62, and 63.

- Looking at the 'safe', 'middle', and 'risky' categories (i.e. a three-category simplification of the 1-5 scale) many clips had significant disagreement among observers. Of the 86 clips, only six had unanimous agreement among all observers (Clips 10, 33, 34, 66, 70, and 82). Another nine had one disagreement (Clips 4, 14, 19, 28, 35, 37, 55, 56, and 59), and eight addition clips had two disagreements from the mode (Clips 7, 9, 12, 22, 39, 43, 64 and 80). The remaining 59 clips had more disagreement.

- Continuing to look at the variability amongst observers, people tend to differ in their perception of risk. Of the 86 rated clips, only 6 had a standard deviation of less than 0.5 on the 1-5 scale. The majority of the clip ratings had a standard deviation between 0.5 and 1.0 (50), with the remaining 30 clips having a standard deviation greater than 1.0.

APPENDIX I: Details on Simulation Analysis Framework

This Appendix was previously published as conference proceedings at the 86th Annual Meeting of the Transportation Research Board, January 21-25, 2007. The citation for this work is:

Schroeder, Bastian J. and Nagui M. Rouphail. *A Framework for Evaluating Pedestrian-Vehicle Interactions at Unsignalized Crossing Facilities in a Microscopic Modeling Environment* 86th Annual Meeting of the Transportation Research Board. 2007

A Framework for Evaluating Pedestrian-Vehicle Interactions at Unsignalized Crossing Facilities in a Microscopic Modeling Environment

By

Bastian Jonathan Schroeder, E.I.*
Graduate Research Assistant
Institute of Transportation Research and Education (ITRE)
North Carolina State University
Centennial Campus, Box 8601
Raleigh, NC 27695-8601
Tel.: (919) 515-8565
Fax: (919) 515-8898
Email: Bastian_Schroeder@ncsu.edu

Nagui M. Rouphail, Ph.D.
Director, Institute for Transportation Research and Education (ITRE)
Professor of Civil Engineering
North Carolina State University
Centennial Campus, Box 8601
Raleigh, NC 27695-8601
Tel.: (919) 515-1154
Fax: (919) 515-8898
Email: rouphail@eos.ncsu.edu

November 2006

Submitted for presentation at the 86th Annual Meeting of the Transportation Research Board, January 21-25, 2007

Word Count: 5,982 text words plus 1,500 for figures/tables (6*250) = 7,482 total

* Corresponding Author

ABSTRACT

This paper proposes a framework for evaluating the interaction of pedestrians and vehicles at pedestrian crossing facilities in a microscopic modeling environment. The paper discusses modeling parameters for the interaction of pedestrian and vehicle traffic that should be included in a microscopic simulation analysis of unsignalized pedestrian crossing facilities. The paper lists the requirements for stochastic input data in the model and discusses performance measures including pedestrian delay, vehicle delay and the likelihood of pedestrian-vehicle conflicts. The paper further describes how a calibrated microsimulation model can be used to simulate a range of pedestrian crossing treatments by modifying a limited number of input parameters. The analysis will include nuances of pedestrian-vehicle interaction that are frequently neglected in existing microsimulation software. The paper concludes by demonstrating the application of the framework for an unsignalized crosswalk example in the simulation model VISSIM.

ACKNOWLEDGMENT

The research leading up to this document was supported by the NCHRP 3-78 project, 'Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Visual Disabilities'. The authors would like to thank the National Academies for the opportunity to be involved in the project and for permission to share the proposed modeling framework with the Transportation Research Board Community. The authors would also like to thank the members of the project panel, who have provided continuous feedback to the research efforts and the proposed methodology. Finally, the authors would like to thank the other members of the project team, who have been invaluable in discussing the application of microsimulation models to the project.

INTRODUCTION

This paper proposes a framework for describing pedestrian-vehicle interaction at unsignalized pedestrian crossing facilities in a microscopic modeling environment. While some of the commercially available microsimulation packages are theoretically able to simulate pedestrians, the primary purpose of these models clearly lies in simulating motorized traffic. There is currently not a great amount of guidance in the literature on how to represent pedestrians in a microscopic environment and how to model their interaction with motorized traffic at pedestrian crossings. This paper attempts to summarize the characteristics that distinguish pedestrians from motorized traffic and discusses ways of implementing these pedestrian-specific attributes in microsimulation.

BACKGROUND

Microsimulation models are used frequently in transportation research applications due to their ability to evaluate a great range of geometric and operational configurations in a non-intrusive manner. They are also seeing increasing use in public and private traffic engineering practice to simulate complex geometries, intelligent transportation systems (ITS) solutions and for numerous other applications. The *Next Generation Microsimulation (NGSIM)* effort by the Federal Highway Administration (FHWA) has taken on the challenge of developing new and improved algorithms, working towards the goal of standardized application of microsimulation models in the US. With limited resources, the initial focus of the NGSIM effort is in areas with high degrees of applicability, such as the freeway lane selection algorithm and cooperative freeway merge behavior. The area of pedestrian simulation is much lower on the list of priorities on the national scale and won't be addressed until these other 'high-impact' algorithms have been completed.

Nonetheless, the field of microsimulation has a lot of potential applications in the area of pedestrian-vehicle interaction, especially in light of evaluating delay and safety impacts of different pedestrian crossing treatments. A lot of research in recent years has focused on proposing new and improved treatments for safe pedestrian crossings and most communities are including pedestrian-safety initiatives in transportation planning. While it is possible to a certain extent to conduct 'before and after studies' for testing pedestrian crossing treatments, there is clearly a benefit to performing some treatment evaluation in a microsimulation environment.

The discussion that led to the development of this proposed framework originated in the NCHRP 3-78 research effort. Motivated by budget considerations and a very broad range of potential crossing treatments, the project team decided early-on to include microsimulation analysis in the process of screening and evaluating proposed treatments a priori to field implementation. Following the actual experiments in the field, calibrated microsimulation models will further be used to assess treatment effectiveness under a range of operational and geometric configurations. Due to authors' involvement in NCHRP 3-78, most examples in this paper include behavioral comparisons between blind and sighted pedestrians. These are intended as illustrative examples and are easily transferable to other applications with varying driver and pedestrian populations.

THE CROSSING TASK

The movement of pedestrians is principally different from that of motorized traffic and therefore warrants a separate assessment of associated behavioral attributes. Blue and Adler (2001) compiled the following list of principal differences between pedestrian and vehicular traffic:

- Pedestrians are not officially channelized
- Pedestrians can vary their speed
- Pedestrians can occupy any part of the walkway
- Pedestrians can bump into each other
- Pedestrians have almost instantaneous acceleration/deceleration profiles

In this paper, the authors will transfer some of these pedestrian attributes to the pedestrian crossing task and discuss implications on the crossing performance at unsignalized crosswalks.

The authors will define an 'unsignalized' crossing as one at which the crossing task is not explicitly regulated by a traffic signal. Assuming compliance and proper timing, a signalized crossing can be evaluated with existing capacity equations and theoretically does not pose risks to the pedestrians. The issue of non-compliance at signals and misunderstanding of signal indications will be deferred to future human factors research. At an unsignalized crossing the priority regulation is usually less rigid. Such crossings can also be outfitted with various pedestrian crossing treatments such as signage, flashing beacons or auditory pavement treatment. In fact, the principal purpose of this framework is the evaluation of such non-signal treatments in a microscopic environment.

Conceptually, the process of pedestrians crossing at an unsignalized facility can be represented by a *dual gap acceptance* process: pedestrians accepting gaps in the vehicle stream, and vehicles accepting gaps in the pedestrian stream. Pedestrians waiting to cross the road screen the conflicting vehicle stream for crossable gaps or a yield situation. Drivers, in turn, observe the pedestrian crosswalk to decide whether to yield to a pedestrian. At the majority of unsignalized pedestrian crossings it is oftentimes not clearly defined, whether pedestrians or vehicles have the right-of-way. Legislative language commonly states that 'drivers shall yield to pedestrians in the crosswalk', but in observing any given crosswalk it quickly becomes evident that drivers are frequently non-compliant or over-compliant with this legislation; not stopping for pedestrians or yielding to pedestrians who have yet to arrive at the crosswalk. This apparent ambivalence makes any definition of this interaction challenging.

The variability on the willingness of drivers to yield has been linked to vehicle speeds (Geruschat et al., 2005), the difference of entry and exit leg at roundabouts (Ashmead et al., 2005) and different roundabout geometries (Guth et al., 2005). Other research has identified relationships between yielding behavior and pedestrians attributes, including bright clothing and 'assertiveness' of pedestrians (Harrell, 2001), and the number of pedestrians waiting at the curb (Sun et al., 2002). The same researchers found that older drivers were more likely to yield than younger drivers.

Research with blind pedestrians has further shown that it can be challenging for this group of pedestrians to successfully detect a yield. Due to auditory interference from background traffic, pedestrians with vision impairments oftentimes cannot distinguish if a vehicle has in fact yielded for them. Successful detection of driver yielding and the acceptance of such yield can also be complicated for older pedestrians, children and other individuals displaying extraordinary caution when crossing an unsignalized roadway. These findings suggest the need to link gap acceptance and yielding behavior in a generalized pedestrian crossing framework.

GAP ACCEPTANCE APPROACHES

In a review of gap acceptance approaches, most analytical software tools (including HCM2000 and aaSIDRA) and microsimulation models (VISSIM and others) use *deterministic* critical gap models when estimating unsignalized intersection capacity. The models use capacity equations that can be calibrated to local conditions by adjusting the 'critical gap' and 'follow-up' time parameters. By definition, the 'critical gap' is the gap time between two vehicles in the conflicting stream at which a pedestrian waiting to cross (or a vehicle waiting to merge) is equally likely to accept or reject that gap, i.e. enter the crosswalk or remain standing. In theory, any gap greater than the critical gap will be accepted, while shorter gaps will be rejected. The 'follow-up time' is the minimum additional time (beyond the initial critical gap for the first vehicle) needed for the next following vehicle to enter the conflict section within the same gap.

Deterministic critical gap models assume constant values for critical gap and follow-up time, which are applied across the entire population of drivers. The use of deterministic gap acceptance parameters assumes that the driver population is both *homogeneous* and *consistent*. In a homogeneous driver population, all drivers have the same critical gap. Under consistency assumption, the same gap acceptance situation will always cause a driver to make the same (consistent) decision. Although these assumptions are not realistic, Troutbeck and Brilon (2002) justify their use because inconsistencies in driver behavior tend to increase capacity while a heterogeneous driver population will decrease capacity, thereby offsetting the previous effect.

The HCM2000 pedestrian chapter offers a method for estimating a deterministic critical gap time for pedestrians as a function of crosswalk length, walking speed and a start-up time. Similarly, Rouphail et al (2005) described pedestrian gap acceptance using actual field observations to compare crossing attributes in a heterogeneous population of blind and sighted pedestrians. However, the HCM pedestrian methodology excludes 'zebra-striped' crossings, because pedestrians have the right-of-way and recommends applying the unsignalized intersection concepts in those cases. For any crossing with ambivalent priority regulations, arguably the majority of crossings, both methods fall short. For these conditions, microsimulation can provide a way to combine driver yielding and pedestrian gap acceptance characteristics.

PEDESTRIAN CROSSING ATTRIBUTES

A population of pedestrians in most applications is *heterogeneous*. At any given time or location, the pedestrian stream is made up of a mix of students, retirees, children, blind individuals, business people, wheelchair users, and parents with baby strollers. Building on the authors' background in blind pedestrian research, people with vision impairments for example waited three times longer than sighted pedestrians when attempting to cross at a two-lane roundabout and also made 6% 'risky' decisions (Ashmead et al., 2005). Research by Sun et al. (2002) supports the notion of heterogeneity, showing that both the minimum and average accepted gaps at an unsignalized midblock crossing were longer for younger than for older pedestrians.

Literature on pedestrian walking speeds in the Highway Capacity Manual (HCM, 2000) and in Bennett et al. (2001) further acknowledge that pedestrian attributes vary as a function of pedestrian age, and crosswalk location, respectively. Assuming consistency of pedestrians also doesn't seem intuitive, because the nature of a walking trip ranges from exercising, to strolling, to shopping to rushing to a lecture. From a human factors perspective it appears intuitive that the same pedestrian will make very *inconsistent* crossing decisions in different situations. For modeling applications this suggests that a deterministic gap acceptance model may not be appropriate, because the distribution of pedestrian critical gap times is expected to have a much larger variance than for vehicle traffic.

Pedestrians are also likely to become impatient and lower their critical gap time as a function of delay, which results in *decaying critical gap times*. Research at pedestrian mid-block crossings by Dunn and Pretty (1984) found that pedestrians tend to exhibit more risky behavior when waiting 30 or more seconds at a crossing. Accordingly, the HCM2000 predicts an increasing likelihood of non-compliance with pedestrian signals as pedestrian delay increases. On the other hand, Sun et al. (2002) actually found an increase in the average accepted gap as the waiting time of pedestrians increased. The authors explained this trend because pedestrians who still wait at the crosswalk after long waiting times tend to be careful in nature and therefore would never accept a short or risky gap; an argument in support of the heterogeneity discussion above.

Inconsistent and impatient behavior eventually results in the occurrence of 'forced gaps' or 'forced yields'. In a forced situation, a pedestrian's accepting of a short gap in traffic, forces the oncoming motorist to decelerate or even come to a stop. The frequency of forced situations will intuitively vary across the pedestrian population and is likely to show significant differences as the degree of urbanization increases in a region. Ultimately, the range of pedestrian attributes and the variability of behavior call for a more sophisticated pedestrian crossing framework that relates these parameters to delay and risk performance measures for motorized and non-motorized modes.

TOWARDS A PEDESTRIAN CROSSING MODEL

Troutbeck and Brilon (2002) suggest that vehicle gap acceptance involves the two basic elements of gap acceptance and gap distribution (a function of the arrival patterns of major stream traffic). In the case of pedestrian gap acceptance, it can be argued from above literature that two additional factors are of importance: The willingness of drivers to yield to a pedestrian (or accepting a gap in the pedestrian stream) and the possibility of the pedestrian to detect that yield. The process of pedestrians crossing the road then becomes a function of four behavioral probability parameters:

P[G] – the probability of a crossable gap occurring in the traffic stream, or gap distribution (exclusive of yields), P[Gap]
P[GD] – the probability that a pedestrian detects a crossable gap, P[Gap Detection]
P[Y] – the probability of drivers yielding to a pedestrian at the crosswalk, P[Yield]
P[YD] – the probability that a pedestrian detects a yield, P[Yield Detection]

In the case of a yielding vehicle, it needs to be determined what fraction of drivers yield when a pedestrian is present, and what fraction of those yields are detected by different types of pedestrians. In the absence of such *potential yielders*, the crossing task becomes a pure gap acceptance process, dependent on headway characteristics of the traffic stream and the attributes of the waiting pedestrian. While actual parameters for these probabilities need to be estimated directly from field observations, it is possible to make certain assumptions to allow for a preliminary sensitivity analysis.

Pedestrian Delay

Mathematically, the probability of crossing in a yield= P[Y]*P[YD]. One can reasonably assume that P[YD] =1.0 for the majority of pedestrians, but is expectedly less than 1.0 for blind and maybe others.

In the case of a crossable gap, methods from traffic flow theory and empirical observations can be used to relate the conflicting traffic volume with the probability of safe crossable gaps P[G]. The particular duration of a "safe" crossable gap is based on the crossing distance and an assumed "safe" crossing speed, accounting for the clearance time between completing the crossing and the arrival of the next vehicle. Following above discussion, the correct detection of a crossable gap, P[GD] follows a probabilistic distribution for a heterogeneous population, may differ across situations (inconsistency) and may change as a function of waiting time (decay).

The probability of a pedestrian incurring delay upon arrival, P[pd] at the crossing can then be estimated as a function of the four parameters.

Equation 1: Probability of Pedestrian Delay at Unsignalized Crosswalk

$$P[pd] = 1 - \{P[G] * P[GD] + (1 - P[G]) * P[Y] * P[YD])\}$$

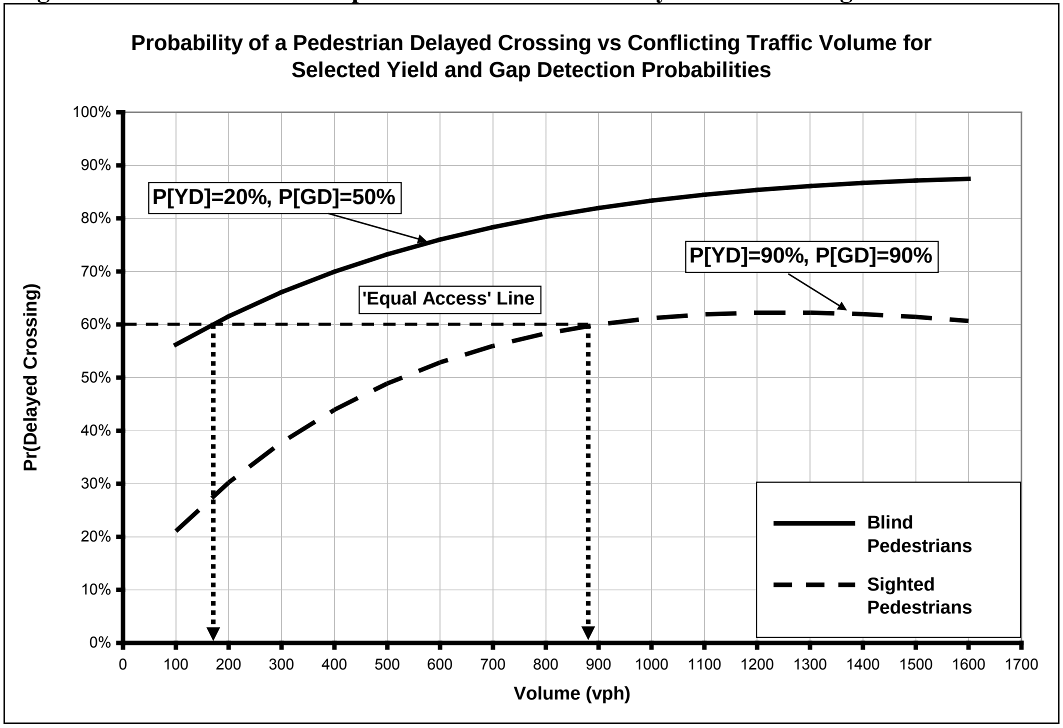
As an illustrative example, if 55% of the drivers yielded, but only 20% of those yields are detected by the pedestrian and the traffic flow is such that it contains 40% crossable gaps, 80%

of which are detected, then P[pd]= 1- [0.40*0.8+0.60*0.55*.20]= 0.614. So, there is a ~ 39% chance of crossing immediately, and a 61% chance of waiting for a yield or a crossable gap.

It should be noted that these 4 probabilities are not necessarily independent. As traffic volume increases, one would expect that P[G] decreases, as would possibly be the case for P[GD] and P[YD] for blind pedestrians – due to increased ambient noise. On the other hand, heavier traffic will result in lower overall speeds, and probably higher P[Y]. Thus, there is a tradeoff between the frequency of crossable gaps and the amount of driver yielding. This points to a non-linear relationship between variables - indicating that intermediate volumes may be more challenging than either the high or low volume cases.

A chart depicting the effect of yield and gap detection percentages on the probability of pedestrian delay at various volume levels is shown below (Figure 1). The two curves can be viewed as reflecting the abilities of sighted (solid curve) and blind (dashed curve) pedestrians, respectively to initiate an immediate crossing. In this diagram, a crossable gap of 5 sec is assumed, average speed is assumed to be decreasing with traffic volume, P[Y] is assumed to be inversely correlated with speed, and the P[G > 5sec] assumes a volume-based exponential distribution of gaps in traffic.

Figure 1: Possible Relationship Between Pedestrian Delay and Conflicting Vehicle Volumes



While these relationships need calibration, the integration of the concepts of yield and gap detection directly into a model of crossing performance is crucial. It is evident that poor gap judgment will have a strong influence on pedestrian delay, both at high and low volumes. It is also clear that training or technological treatments intended to increase the yield and gap detection capabilities for blind or low vision pedestrians could simplify the crossing process. An interesting sidebar of the curves is the ability to define traffic volumes that provide '*Equal*

Access'. For example, a horizontal line drawn at 60% shows that a blind pedestrian negotiating a facility with conflicting volumes of 180 vehicles per hour (vph) is exposed to the same likelihood of delay as a sighted pedestrian negotiating the same facility at a much higher flow rate of 890 vph.

While above graphic and discussion deal with the issue of pedestrian delay, similar thought processes may be applied to derive relationships between the four interaction parameters and vehicle delay, as well as, the likelihood of pedestrian-vehicle conflicts.

Evaluating Conflicts

The discussion above ignores the challenge of assessing the risk posed by a pedestrian making an incorrect decision, such as incorrectly assuming that a crossable gap or a vehicle yield has occurred (false positives). For the purpose of discussion, we will assume that upon arrival at the crossing location, the pedestrian is exposed to two types of gaps, safe or unsafe. Safe gaps can be thought of as a combination of large gaps in moving traffic as well as gaps due to yielding drivers. The pedestrian then makes a decision to accept or reject the gap. For the following discussion it will be assumed that all pedestrians can accurately detect a yielding vehicle, as not to deal with too many parameters at once.

It will further be assumed that a pedestrian's crossing decision can be described as a function of the pedestrian's *critical lag time*. A 'lag' will be defined as the time between a pedestrian's arrival at the crosswalk (or the point he/she makes a decision to cross or not) and the arrival of the next conflicting vehicle. The pedestrian will cross if the lag time to the next vehicle arrival is greater or equal to the critical lag time, where the vehicle arrival time is a function of that vehicle's speed and distance to the crosswalk. It can be reasoned that the average pedestrian will have a 'safe' critical lag time; one that allows a sufficient safety margin to the next vehicle arrival. However, there are also cases where pedestrians will make 'risky' decisions, or 'conservative decisions', which will be represented by shorter and longer critical lag values, respectively. Conceptually, a *conflict* will occur when a 'risky' pedestrian decision coincides with a vehicle arrival; especially if that particular vehicle happens to move fast or has slow reaction time parameters. The section on model implementation below will discuss this in more detail.

THE ROLE OF TREATMENTS

The NCHRP 3-78 research effort is principally interested in identifying treatments that will assist blind pedestrians to cross at certain facility types safely and efficiently. Based on the framework described above, the purpose of these or any other pedestrian crossing treatment is to enhance or minimize delay and risk for pedestrians, without unduly impacting traffic flow. This can be done in one of four ways:

- Increasing the probability of driver yielding, P[Y]: Previous research implies that slower speeds, increased driver awareness and education/enforcement may be able to achieve that. Some natural speed reduction also occurs at high flows. Treatments addressing P[Y] could include warning signs, flashing lights, or raised crosswalks.

- Increasing the occurrence of crossable gaps, P[G]: It is unclear if there are treatments whose sole purpose is an increase in P[G], but a number of situations will have an impact, including upstream signals or more conservative driver behavior.
- Increasing the probability of yield detection, P[YD]: This is particularly important for blind pedestrians, but others may benefit from such treatments. Pavement sound strips, surface treatments or automated yield detection tools can be applied.
- Increasing the occurrence of gap detection, P[GD]: There may be treatments that enable pedestrians to perform better gap judgment, as to decrease the frequency of risky, as well as, overly conservative decisions. Examples include improved lighting conditions or automated gap detection technology.

Testing Treatment Functionality

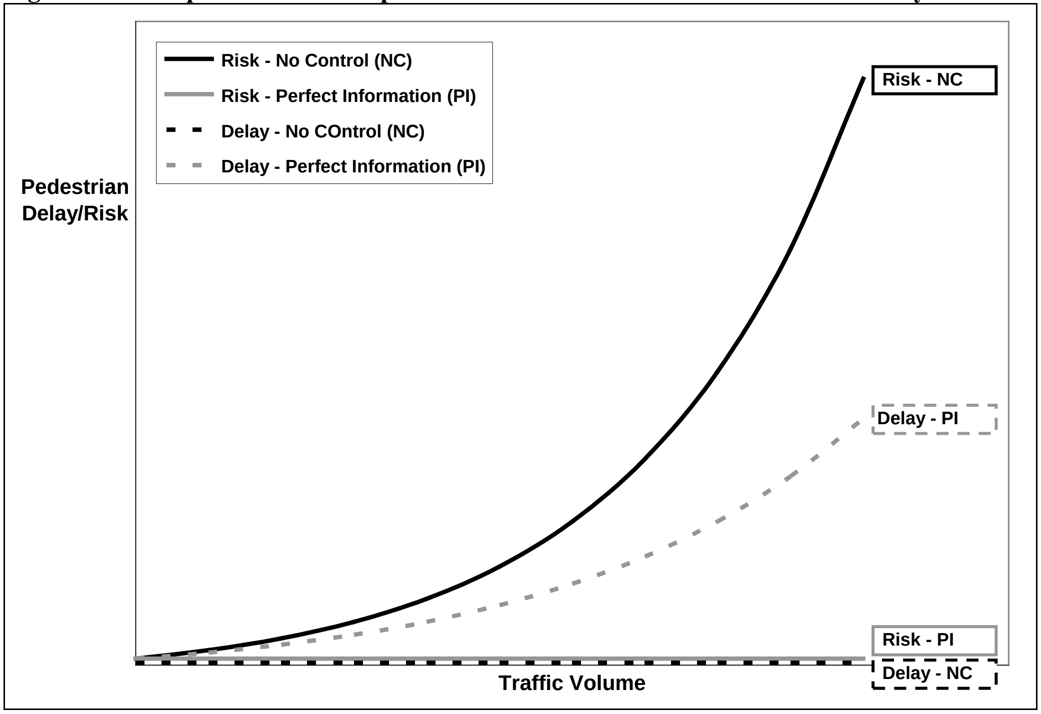
For purpose of exploring these concepts, the authors used the VISSIM (PTV, 2005) simulation package to define a modeling test-bed. Other models such as AIMSUN or Paramics may have similar capabilities, but were beyond the scope of this preliminary evaluation. For a comparison of these software tools, refer to the referenced NGSIM document (Cambridge Systematics, 2004).

In the default vehicle-pedestrian interaction model in VISSIM, no information is imparted by either vehicles or pedestrians! Barring the use of ‘priority rules’, vehicles and pedestrian will flow perpendicular to each other at the crosswalk with no consideration of potential conflicts. This will be referred to as the ‘No Control’ (NC) case. By tracking ‘risky’ vehicle-pedestrian events, we can measure the frequency of pedestrian-vehicle conflicts for random arrivals of both classes and across a range of traffic and pedestrian volumes. Interestingly enough, ‘delay’ to pedestrians and pedestrian-induced delay to vehicles in this case is zero, independent of conflicting volumes (vehicles may still experience some delay due to car-following algorithms and site geometry). This scenario represents the ‘base’ maximum conflicts condition that behavioral parameters, and ultimately treatments, are intended to remedy. Conceptually, as pedestrian-vehicle interaction ‘improves’, the number of conflicts tend to decrease, while driver and pedestrian delay tend to increase.

On the other extreme, if ‘Perfect Information (PI)’ is imparted, as in the case of all drivers yielding to pedestrians and pedestrians accepting only safe gaps or yields, conflicts are eliminated at the expense of added delay to both pedestrian and vehicles.

It is clear that there are trade-offs between risk and delay. Not every wrong decision (by pedestrians or drivers) will result in a conflict, but as vehicle and pedestrian volumes increase, both delay and conflicts are likely to increase in some fashion. Figure 2 shows a conceptual schematic of the conflict-delay tradeoff from the pedestrian perspective.

Figure 2: Conceptual Relationship between Traffic Volume and Pedestrian Delay/Conflicts



The relationship in the figure suggests that pedestrian delay for the NC case (black lines) will remain zero as traffic volume increases, because there is no interaction between modes. The likelihood of conflicts is expected to increase exponentially as a function of random arrivals at the crosswalk. In the PI case (gray lines), there won't ever be any conflicts as a result of the strictly controlled interaction between modes. In this case it is the pedestrian delay that will increase in a non-linear fashion as a function of traffic volume.

In reality, most operating scenarios will lie somewhere between the two extremes defined above, which will include some combination of risk and delay. The implementation of pedestrian crossing treatments will change model input parameters (more yielding, less risky decisions …) and will impact risk, as well as, pedestrian and driver delay in some fashion.

MODEL IMPLEMENTATION

In a microscopic implementation of pedestrian-vehicle interaction, the modeler has to account for the driver and pedestrian behavioral attributes that are captured by these four parameters.

Deterministic models assume driver consistency and driver homogeneity, within each vehicle class. By defining multiple vehicle classes and estimating separate critical gaps for each, the homogeneity assumption can be partly overcome. In the following, this approach will be referred to as a *quasi-heterogeneous* driver population, because the homogeneity assumption still holds within each vehicle class.

Gap acceptance in VISSIM is achieved through 'priority rules', which define where a minor movement has to screen conflicting traffic for certain conditions before continuing. By applying different 'priority rules' to different entities and at different geometries, VISSIM can model quasi-heterogeneous populations of drivers and pedestrians. This allows the user to code a certain percentage of drivers as 'potential yielders' P[Y]. The gap distribution, P[G], is automatically determined from the headway distribution of traffic upon entering the system. It is important to note that the authors worked with existing modules in the software and did not employ any external code.

Conflicts

To extract conflict data from the model, we will define a spatial boundary for the pedestrian path and track the crossing times of *all vehicles and pedestrians at that boundary within a prescribed time window*. For example, we could identify the passage time of all vehicles that occur at a *lead time* of X seconds *before* and a *lag time* of Y seconds *after* the pedestrian appears at that boundary.

Hence, a simulated (one-way, one stage) pedestrian crossing would be defined as "risky", if one or more vehicles appear at the spatial boundary within the (X, Y) time window. Thus, the percentage of risky crossings would be the number of crossings defined as risky divided by the total number of crossings. The values for X and Y to define the cut-offs for critical leads and lags can be user-defined.

The spatial boundary in this example takes the form of two overlapping data collection points; one on the vehicle link and one on the pedestrian link. The two data collection points can be configured to output raw data of pedestrian and vehicle arrival and departure events at the defined location. Using Visual Basic script, this data can be formatted as necessary to calculate the *lead time since the last vehicle* (rear bumper) and the *lag time to the next vehicle* (front bumper) for each pedestrian arriving at the conflict point. A spreadsheet was configured to compare each lead and lag time to user-defined *critical values* and to keep track of all *risky leads* and *risky lags*.

The pedestrian-vehicle conflict approach presented is similar to the method discussed in a recent FHWA publication on using microsimulation for conflict analysis (FHWA, 2003). That document describes two measures of effectiveness, *Post Encroachment Time* (PET) and *Time to Collision* (TTC), which are similar in concept to the lead and lag terminology used in this document. The FHWA document also points to the big potential advantage of performing conflict analyses in microsimulation, because a range of treatments and traffic intensity can be tested. The document does not go into detail on modeling pedestrian-vehicle conflicts.

Modeling Example

To illustrate the use of multiple vehicle and pedestrian classes, the two populations are divided into several groups. Vehicles are categorized as either *Yielding* or *Non-Yielding* Drivers, P[Y]. Pedestrians are divided into *blind* and *sighted* pedestrians and within those groups in categories with different gap acceptance parameters; *risky*, *typical* and *conservative* – where critical lag times are increasing in that order.

It will generally be assumed that most sighted pedestrians will make 'typical' decisions, while blind pedestrians will be more strongly represented at either extreme. As crossing treatments are implemented at a facility, more pedestrians will shift away from ‘risky’ and ‘conservative’ decisions, thereby reducing conflicts and delay, respectively. In the following, we will assess the operational impacts of six treatment functionalities:

- No Control, NC: This configuration represents the default interaction in the VISSIM model without any interaction between modes. Delay is a function of car-following parameters only and risk is the result of random arrivals at the conflict point
- Unassisted Crossing, UA: Pedestrian and drivers are assigned 'priority rules', which govern the interaction. Pedestrians have different gap acceptance parameters and some drivers will yield if encountering a pedestrian. No further treatments are implemented.
- Yield Sign for Drivers, YS: The likelihood of drivers yielding is increased through treatments such as a raised crosswalk, warning signs, pedestrian flashers, enforcement, or education measures. It is assumed that the treatment has no effect on pedestrian behavior.
- Vehicle Detection, VD: Some treatments will help blind pedestrians to more effectively detect the arrival of a vehicle. The assumption is that this will enable them to make better (safer and more efficient) crossing decisions. Examples include a gap-detection system, or noise-generating rumble strips. It is assumed that driver behavior is not affected.
- Yield Sign and Vehicle Detect, YSVD: This treatment category combines YS and VD treatments to increase driver yielding and improve vehicle detection capabilities of blind pedestrians. Examples include a combination of automated vehicle detection with a pedestrian flasher or rumble strips in the approach of a raised crosswalk.
- Perfect Information, PI: This configuration represents perfect unsignalized crossing conditions from a pedestrian perspective. 100% of Vehicles yield to pedestrians, thereby minimizing pedestrian delay and risk. This form of driver behavior might represent a strictly enforced right-of-way law.

The six treatment scenarios are implemented in VISSIM at a one-way, one-lane pedestrian crossing, using assumed run-specific pedestrian and driver attributes (Table 1).

Table 1: VISSIM Input Parameters for Simulation Scenarios

Treatment Functionality (assume 100% Yield Detection)		**Run-Specific Attributes**						
		Pedestrians						**Drivers**
		50 'Sighted' Pedestrians per hour			**50 Blind 'Pedestrians' per hour**			**300 Vehicles per hour**
		P(C)	**P(T)**	**P(R)**	**P(C)**	**P(T)**	**P(R)**	**P(Y)**
NC	**No Information**	n/a	n/a	n/a	n/a	n/a	n/a	0%
UA	**Unassisted Crossing**	5	90	5	10	70	20	20%
YS	**Yield Sign for Drivers**	5	90	5	10	70	20	50%
VD	**Vehicle Detect for Pedestrians**	5	90	5	0	90	10	20%
YSVD	**Yield Sign and Vehicle Detect**	5	90	5	0	90	10	50%
PI	**Perfect Information, Everybody Yields**	0	100	0	0	100	0	100%

P(C) Probability of **Conservative** Pedestrian Crossing Behavior. Pedestrian will accept gaps of **12 seconds or more.**
P(T) Probability of **Typical** Pedestrian Crossing Behavior. Pedestrian will accept gaps of **6 seconds or more.**
P(R) Probability of **Risky** Pedestrian Crossing Behavior. Pedestrian will accept gaps of **3 seconds or more.**
P(Y) Probability of Drivers Yielding to Pedestrians (Percentage of **Potential Yielders**)

It was assumed that the *typical* pedestrian has a critical lag of 6 seconds, which is considered safe compared to the actual crossing time of about 5 seconds at a walking speed of 4 ft/second.

Accordingly, *conservative* pedestrians are assigned a longer critical lag value (12 seconds) and *risky* pedestrians have a short critical lag of only 3 seconds.

Defining Conflicts

Before analyzing the event data and extracting the frequency of pedestrian-vehicle conflicts, the cut-off values for critical leads and critical lags need to be defined. For this purpose, the team conducted 10 VISSIM runs of the No Control (NC), Unassisted (UA) and Perfect Information (PI) scenarios and extracted all lead and lag data. The team then gradually increased the critical values for leads and lags in 0.5 seconds increments and observed how the percentage of risky decisions was affected (Table 2).

Table 2: Effect of Critical Lead/Lag Thresholds on % Risky Decisions

% Risky Leads (as a Function of Different Critical Lead Times for 3 Scenarios)

Critical Lag Time (sec.)	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
No Control (NC)	16.7%	21.1%	22.9%	27.0%	30.1%	34.1%	36.4%	39.0%
Unassisted Crossing (UA)	0.0%	0.0%	0.1%	2.1%	13.8%	26.6%	35.2%	37.4%
Perfect Information (PI)	0.0%	0.0%	0.0%	0.0%	0.4%	0.7%	1.5%	2.6%

% Risky Lags (as a Function of Different Critical Lag Times for 3 Scenarios)

Critical Lag Time (sec.)	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
No Control (NC)	11.4%	15.4%	19.3%	23.7%	27.9%	31.1%	33.9%	36.8%
Unassisted Crossing (UA)	0.5%	0.5%	0.5%	1.2%	11.2%	16.5%	22.0%	26.8%
Perfect Information (PI)	0.0%	0.0%	0.0%	1.2%	36.6%	47.8%	52.0%	54.9%

As expected, the percentage of risky decisions (leads and lags) steadily increases in the NC case as the cut-off values increase. As discussed earlier, these ‘conflicts’ in the NC case are merely a function of random pedestrian and vehicle arrival volume at the conflict point.

By definition, there shouldn’t be any conflicts in the PI case, because all vehicles were specified to yield to pedestrians and no pedestrians were assigned ‘risky’ behavior. The critical values will therefore be defined as the largest value that does not result in any conflicts in the PI case. The resulting critical values for lead and lag are by definition 3.0 seconds and 2.5 seconds, respectively.

Results

The experimental set-up of the six treatment scenarios conceptually corresponds to a vertical line in Figure 2, implemented at a volume of 300 vehicles per hour. The resulting delay and risk measures of effectiveness from 10 simulation replications per scenario are shown in Table 3.

Table 3: Measures of Effectiveness from VISSIM

Treatment Functionality (assume 100% Yield Detection)		Measures of Effectiveness (average of 10 VISSIM runs)							
		Actual Driver Yield - % Yield		% Conflicts		Pedestrian Delay (seconds)		Vehicle Delay (seconds)	
		Averages	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
NC	No Control	0.0%	0.00%	23.2%	2.60%	0.0	0.00	2.4	-
UA	Unassisted Crossing	3.8%	0.99%	1.3%	0.80%	4.4	0.28	3.1	0.32
YS	Yield Sign for Drivers	9.3%	1.16%	0.6%	0.60%	4.1	0.20	4.2	0.29
VD	Vehicle Detect for Pedestrians	3.7%	0.84%	1.4%	0.80%	4.3	0.37	3.1	0.27
YSVD	Yield Sign and Vehicle Detect	9.0%	1.33%	0.6%	0.70%	3.9	0.27	4.2	0.31
PI	Perfect Information, Everybody Yields	15.0%	2.00%	0.0%	0.00%	3.5	0.30	5.4	0.41

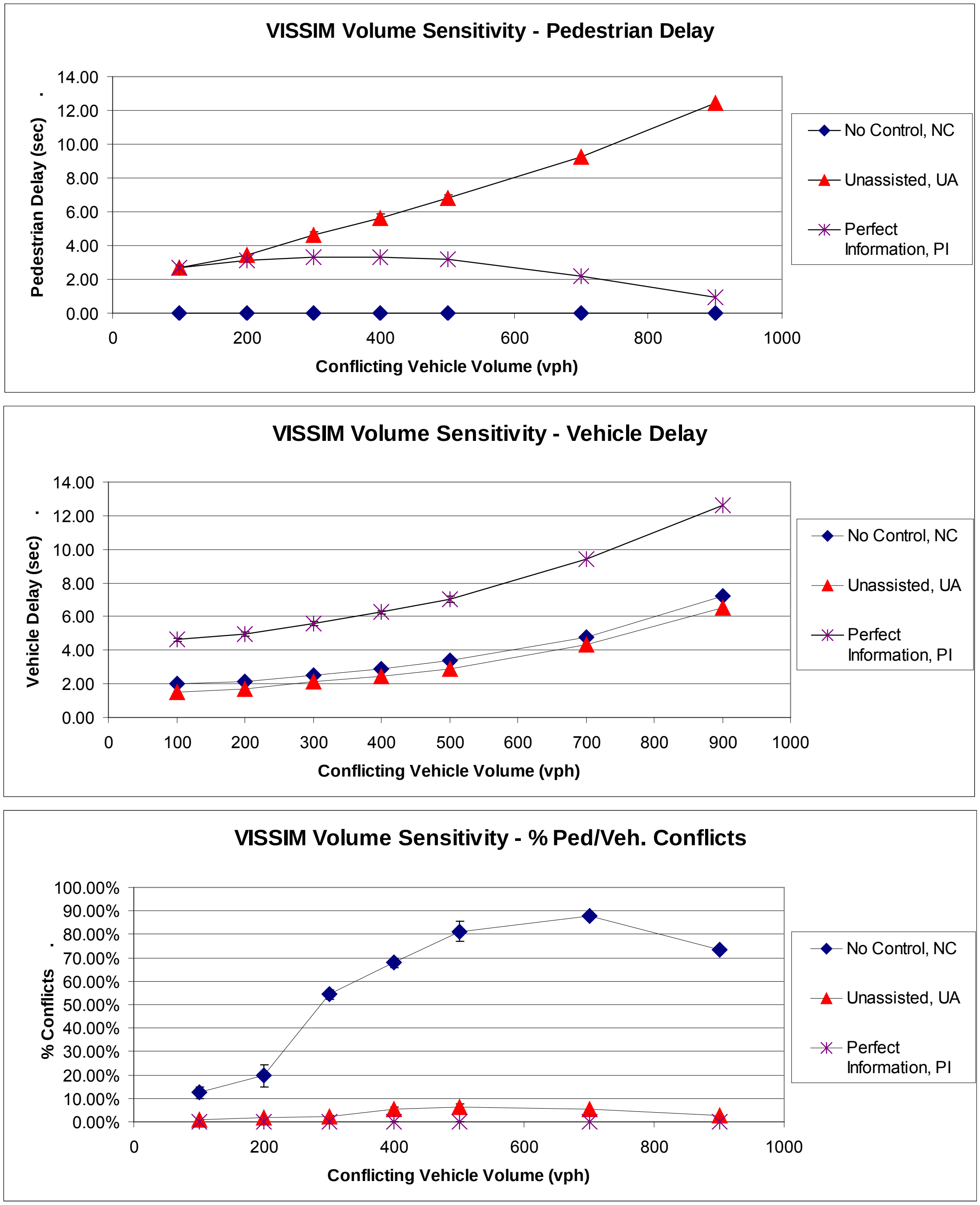
The numbers suggest that an increased likelihood of drivers yielding (case YS) decreases the percentage of conflicts. Improving vehicle detection (VD) for pedestrians appears to slightly increase observed conflicts compared to the unassisted case. Looking at the large standard deviations of the risk estimates, it can not be stated if this is a real effect at the given sample size. This suggests the need for large sample sizes in the model trials to show significant effects when evaluating actual treatments.

In comparison, the delay MOEs suggest that as drivers yield more, delay for pedestrians decreases while driver delay increases. The table also indicates that the percent of actual driver yields is considerably less than the specified percent theoretical yielders. This finding is expected at low pedestrian volumes, as the majority of drivers do not encounter a pedestrian waiting at the crosswalk. This observation suggests challenges to estimating the required model input of ‘potential yielders’ (P[Y]) from field observations of ‘actual yielders’.

Volume Sensitivity

In an attempt to replicate the effect of traffic volumes suggested in Figure 2, vehicle inputs were tested over a range from 100 to 900 vehicles per hour. Figure 3 shows the results for the three performance measures in the NC, UA, and PI cases.

Figure 3: VISSIM Volume Sensitivity for Conflicts and Delay Performance Measures



The graphs in Figure 3 show the anticipated and previously hypothesized effects. As vehicle volumes increase, pedestrian delay stays at zero in the NO CONTROL case, while the percentage of conflicts increases. Vehicle delay also increases, not because of the interaction with pedestrians, but as a function of increasing congestion (car-following algorithm). The percentage of conflicts increases drastically as volumes increase, because pedestrians become more likely to encounter a vehicle in the crosswalk. Interestingly, there appears to be a maximum limit for conflicts in this case, presumably as a function of dropping vehicle speeds with congestion.

In the unassisted case, pedestrian delay increases with increasing traffic in the turn lane. The percentage of conflicts also increases, but at a much slower rate than the pedestrian delay. The curve for vehicle delay also increases and is slightly higher than in the NO CONTROL case. This difference can be interpreted as the added vehicle delay due to interaction with pedestrians (pedestrian-induced vehicle delay).

In the perfect information case, conflict stays zero throughout the range of volumes as a result of the safe pedestrian and vehicle parameters. Vehicle delay is highest in this case, because all drivers are coded to yield to pedestrians. Interestingly, pedestrian delay peaks at around 300-400 conflicting vehicles per hour and then decreases as vehicle flows increase further. This can be explained, because at slower congested travel speeds, vehicles are more likely to exhibit yielding behavior, which in turn creates more crossing opportunities for pedestrians.

CONCLUSION

The analysis presented in this document showed that it is possible to use microsimulation models to extract conflict and delay data for pedestrian-vehicle interaction as a function of run-specific attributes of the two groups. The approach describes the interaction of the two modes in terms of four probability parameters; the likelihood of crossable gap occurrence P[G], the likelihood of gap detection P[GD], the likelihood of driver yielding, P[Y] and the likelihood of yield detection, P[YD]. From a preliminary analysis, it appears that the delay and conflicts estimates produced by the model in fact follow expectations. There is some concern that the results presented here are a function of the built-in algorithms in the selected simulation program. Additional research, model calibration, and expansion to other simulation models are needed to strengthen the framework proposed in this paper.

The advantage of the proposed framework is that the measures of effectiveness used to define performance and access at pedestrian crossing facilities can be readily measured in the field, or predicted for future designs using simulation models. As long as treatment effects can be defined in terms of improved driver yielding, and improved pedestrian yield detection or gap detection, the procedure should be able to predict their effect on traffic performance for all users.

For future analysis, the run-specific attributes of pedestrians and vehicles need to be calibrated from field data. To predict the impact of pedestrian crossing treatments on the four parameters, early engineering assumptions will eventually have to be confirmed through field observations and can be adjusted as necessary during model calibration. Early trial runs have shown large sample variances, so that it is expected that the modeling of future treatments will require a large number of simulation runs, depending on the effect-size of interest.

Future research may also include a more detailed assessment of a decay function for critical gap times as a function of waiting time or the number of rejected gaps. Finally, a long-term goal of continued data collection and model calibration may be the development of deterministic equations and attribute tables that can be used independent of simulation models.

REFERENCES

Ashmead, Daniel H., David Guth, Robert S. Wall, Richard G. Long, and Paul E. Ponchilla. Street Crossing by Sighted and Blind Pedestrians at a Modern Roundabout. In *ASCE Journal of Transportation Engineering*. Volume 131, Issue 11, ASCE, November 2005, pp. 812-821.

Bennet, S., A. Felton, and R. Akcelic. Pedestrian Movement Characteristics at Signalized Intersections, 23rd Conference of Australian Institutes of Transport Research (CAITR 2001), Melbourne, Australia, 2001.

Blue, V.J. and J.L. Adler. Cellular Automata Model of Emergent Collective Bi-Directional Pedestrian Dynamics. In *Artificial Life,* VII Bedau, M.A., McCaskill, J.S. Packard, N.H. and Rasmussen, S. MIT Press, 2000. Available at http://www.ulster.net/~vjblue/research.htm. Last visited October 31, 2005.

Cambridge Systematics. NGSIM Task E.1-1: Core Algorithm Assessment. Prepared for Federal Highway Administration. Oakland, California. February 2004.

Dunn, R., and R. Petty. Mid-Block Pedestrian Crossings – An Examination of Delay. 12th Annual Australian Road Research Board Conference Proceedings, Hobart, Tasmania, Australia. August 1984.

FHWA. Surrogate Safety Measures From Traffic Simulation Models, Publication No: FHWA-RD-03-050. Turner-Fairbank Highway Research Center, Federal Highway Administration, McLean, VA, 2003.

Geruschat, Duane R. and Shirin E. Hassan, Driver Behavior in Yielding to Sighted and Blind Pedestrians at Roundabouts. In *Journal of Visual Impairment and Blindness*. Volume 99, Number 5, May 2005.

Guth et al. Blind and Sighted Pedestrians' Judgment of Gaps in Traffic at Roundabouts. In *Human Factors*, Vol. 47, No. 2, Summer 2005. pp. 314-331.

Harrel, W.A.. The Impact of Pedestrian Visibility and Assertiveness on Motorist Yielding; In *Journal of Social Psychology*, Vol. 133(3), 2001, pp. 353-360.

NGSIM web page. Federal Highway Administration. http://ngsim.fhwa.dot.gov/. Accessed July 26, 2006.

NCHRP 3-78 project web page. National Cooperate Highway Research Program. Transportation Research Board, Washington, D.C. http://www4.trb.org/trb/crp.nsf/All+Projects/NCHRP+3-78. Accessed July 26, 2006

PTV VISSIM 4.10 User Manual. PTV. Karlsruhe, Germany. March 2005.

Rouphail, Nagui, Ron Hughes and Kosok Chae. Exploratory Simulation of Pedestrian Crossings at Roundabouts. In *ASCE Journal of Transportation Engineering*. March 2005. pp. 211-218

Sun et Al. Modeling of Motorist-Pedestrian Interaction at Uncontrolled Mid-Block Crosswalks. Presented at 82nd Annual Meeting of the Transportation Research Record. Washington, DC., 2003

HCM 2000. *Highway Capacity Manual*. Transportation Research Board, Washington, DC., 2000

Troutbeck, Rod J. and Werner Brilon. Chapter 8: Unsignalized Intersection Theory, Revised Monograph on Traffic Flow Theory. Turner-Fairbank Highway Research Center. http://www.tfhrc.gov/its/tft/tft.htm., 2002. Accessed July 26, 2006.

APPENDIX J: Details on Accessibility Measures

This Appendix was previously published as conference proceedings at the 88th Annual Meeting of the Transportation Research Board, January 13-17, 2009. The citation for this work is:

Schroeder, Bastian J., Nagui M. Rouphail and Ron Hughes. *A Working Concept of Accessibility - Performance Measures for the Usability of Crosswalks for Pedestrians with Vision Impairments.* 88th Annual Meeting of the TRB, 2009.

A Working Concept of Accessibility – Performance Measures for the Usability of Crosswalks for Pedestrians with Vision Impairments

By

Bastian J. Schroeder, PhD*
Research Associate
Institute of Transportation Research and Education (ITRE)
North Carolina State University
Centennial Campus, Box 8601
Raleigh, NC 27695-8601
Tel.: (919) 515-8565
Fax: (919) 515-8898
Email: Bastian_Schroeder@ncsu.edu

Nagui M. Rouphail, Ph.D.
Director, Institute for Transportation Research and Education (ITRE)
Professor of Civil Engineering
North Carolina State University
Centennial Campus, Box 8601
Raleigh, NC 27695-8601
Tel.: (919) 515-1154
Fax: (919) 515-8898
Email: rouphail@eos.ncsu.edu

Ronald G. Hughes, Ph.D.
Director, Visual Analytics, Modeling and Simulation (VAMS) Group
Institute for Transportation Research and Education (ITRE)
North Carolina State University
Centennial Campus, Box 8601
Raleigh, NC 27695-8601
Tel.: (919) 515-8523
Fax: (919) 515-8898
Email: rghughes@ncsu.edu

February 2009

Submitted for consideration for publication and presentation at the 88th Annual Meeting of the Transportation Research Board, January 13-17, 2008

Word Count: 5,920 text words plus 1,500 for figures/tables (6*250) = 7,420 total

* Corresponding Author

--- This paper has been revised from its original submission ---

Abstract

This research presents an analysis framework and associated performance measures for quantifying the accessibility of pedestrian crossings at modern roundabouts for pedestrians who are blind. The measures, developed under two ongoing national research projects, NCHRP 3-78a and NIH/NEI BRP R01 EY12894-03, attempt to isolate the components of the crossing task for a blind pedestrian into computable and replicable quantities that allow the comparison of accessibility across individuals or sites. The framework differentiates between crossing opportunities in the form of yields and crossable gaps and the utilization of these opportunities by the pedestrian. It further accounts for the amount of delay and risk involved in the crossing. The analysis framework and measures are demonstrated for two single-lane roundabouts in North Carolina, evaluated under aforementioned research projects. The application shows that the accessibility of a pedestrian crossing to a blind pedestrian is characterized by a combination of the different measures, and further depends on crossing geometry, traffic volume, driver behavior and the travel skills and risk-taking behavior of the individual. With successful demonstration at roundabout crosswalks, it is hypothesized that the analysis framework has broader application to unsignalized pedestrian crossings, including mid-block locations.

Introduction

In recent years, extensive research has been conducted on the accessibility of roundabouts and other complex intersections to pedestrians who are blind. Among those, two multi-year research projects, NCHRP 3-78a (TRB, 2008) and NIH/NEI Bioengineering Research Grant R01 EY12894-03, have carried out numerous studies evaluating the crossing performance of blind travelers at roundabouts and intersections with channelized right turn lanes. While roundabouts in the US are still not as common as they are in other countries, over 1,400 are known to be in operation at the time of this research (Kittelson Associates, 2008). With national research documenting their proven safety and operational benefits for vehicular traffic (FHWA, 2000; TRB, 2007) it is expected that many more will be built in the near future.

One of the primary challenges in conducting research on the accessibility of roundabout pedestrian crossings (and similarly for the evaluation of pedestrian facilities in general), is assessing the crossing performance in quantifiable and reproducible terms. This paper presents a framework of performance measures that can be used to describe the crossing performance of (blind) pedestrians and presents supporting data from two single-lane roundabouts evaluated under aforementioned projects to illustrate the concepts.

Background

Recent research on the crossing performance of people who are blind at complex intersections demonstrated that there are unique challenges for this population (Ashmead et al., 2005; Guth et al., 2005). In particular, the crossing task can be categorized into four distinct components:

1. Locating the Crosswalk
2. Aligning to Cross
3. Deciding when it is safe to cross
4. Maintaining Alignment during crossing

A pedestrian traveling along a sidewalk needs to identify the location of the crosswalk, which can be facilitated by the use of audible pedestrian signals (Harkey et al., 2007) or other wayfinding aids such as landscaping. Once at the crosswalk, the traveler needs to align to the crossing in a way that the crossing path is aimed at the far-end of the crosswalk. Alignment treatments such as detectable warning surfaces or sloped curb-cuts can help with this task (Barlow et al., 2005).

The focus of this research is on measures describing the third component, the task of identifying crossing opportunities in a conflicting traffic stream. At unsignalized crossings, these crossing opportunities generally take the form of crossable gaps in moving traffic or of drivers yielding to pedestrians at or near the crosswalk. At signalized crossings, the pedestrian WALK phase presents a planned crossing opportunity that is a function of signal phasing. Finally, the pedestrian still needs to maintain alignment during the crossing, which is greatly facilitated by straight crosswalk geometry and may be supplemented by other treatments such as a far-side locator beacon.

Complex intersections, including roundabouts, present some unique challenges for pedestrians with vision impairments. The traffic control strategy at a roundabout entry leg is typically a yield sign, and many drivers are able to enter the circle without the requirement to come to a full stop. Similarly, traffic exiting the roundabout is free-flowing, resulting in largely uninterrupted traffic flow at the exit portion of the crosswalk. Roundabout crosswalks are typically not signalized (FHWA, 2000) and the task of identifying crossing opportunities is thus unassisted. Depending on the geometric design of the roundabout and the location of the crosswalk, vehicle speeds may be relatively high and the auditory interpretation is complicated because vehicles are moving on a circular path (Ashmead et al., 2005). At signalized intersections, the two traffic streams typically move perpendicular to each other, making it easier for somebody who is blind to interpret directional traffic movements. Finally, the continuous flow of traffic circulating the roundabout can create a difficult auditory environment and the listening task is complicated by elevated levels of ambient noise.

What makes a site accessible?

The question of accessibility is as complex as the crossing task described above. A variety of factors contribute to the ability of a blind pedestrian to safely cross at a particular facility. The Unites States Access Board is tasked with developing standards by which the accessibility that is required by law and implementing regulations governing new construction can be measured. It recently published The Draft Public Rights of Way Accessibility Guidelines (PROWAG, US Access Board, 2006), outlining geometric requirements for making a site compliant with the 1990 American with Disabilities Act (ADA). The document is fundamentally based on Title II of the ADA legislation, which specifies that a new public facility shall be “readily accessible to and usable by individuals with disabilities” (US DOJ, 1990), including those with vision loss, mobility impairments or other disabilities.

While there is as of yet no accessibility standard for roundabouts, the document outlines geometric features that if adopted make a site compliant with ADA. Specifically, the provision of a pedestrian signal with Accessible Pedestrian Signal (APS) technology provides a 'safe harbor' for multilane roundabout approaches, making the site usable by pedestrians who are blind.
The language in the PROWAG document has been relaxed in relation to single-lane roundabouts, but it remains unclear how different roundabout geometries compare in terms of crosswalk usability and accessibility.

Even after the geometric components of crosswalk usability are accounted for, the crossing task for a blind traveler at an unsignalized roundabout crossing is impacted significantly by the level of conflicting traffic volume, driver behavior, background noise, and ultimately by his or her personal travel skills and risk-taking behavior.

Given the multitude of factors contributing to the usability question, it is important to propose metrics that can be used to compare the crossing ability across sites, before and after a crossing treatment is installed, or even from one pedestrian to another.

A framework for evaluating unsignalized pedestrian crossings

In an initial effort to quantify pedestrian crossing performance, Schroeder and Rouphail (2007) suggested that pedestrian-vehicle interaction at unsignalized crosswalks can be conceptualized as the function of four probability parameters:

P(G) - the likelihood of a crossable gap in the traffic stream to allow for a safe crossing
P(GD) - the likelihood that the crossable gap is detected by the pedestrian
P(Y) - the likelihood of a driver yielding, and
P(YD) - the likelihood that the yield is detected by the pedestrian

In the above probability parameters, a gap is defined as the time between two successive vehicle arrivals at the crosswalk and is measured in seconds. A yield is defined as a voluntary deceleration by an approaching driver with the intent to give way to the pedestrian.

The authors developed this analysis framework with the intent of representing pedestrian-vehicle interaction in a microsimulation environment. The authors argued that different pedestrian populations and the impact of crossing treatments could be represented through changes in one or more of these probabilities. Using hypothesized distributions of above probabilities, it was demonstrated that a simulation model could be made responsive to changes in parameters resulting in increased or decreased vehicle and/or pedestrian delay and conflicts.

In ongoing research on the accessibility of complex intersection to people who are blind (TRB, 2008) it has since become evident that the terminology of yield and gap *detection* is misleading, because pedestrians may well be able to identify a yielding vehicle, but may still choose not to seize the opportunity because they are uncomfortable crossing in front of a stopped car. Consequently, the following discussion will generally refer to yield and gap *utilization*, because it directly describes observed crossing behavior. No further interpretation is given about the rationale for utilizing a crossing opportunity. This facet of this research is described elsewhere (Schroeder, 2008).

In this paper, the authors expand on these concepts by customizing the measures to the particular situation of blind travelers to include additional measures to quantify pedestrian delay and risk. The measures are then applied to field data collected at two single-lane roundabouts in North Carolina.

Accessibility Criteria

The crossing task at an unsignalized pedestrian crosswalk is assessed in terms of four accessibility criteria:

I. Crossing Opportunity Criterion
  - Are there *sufficient* crossing opportunities in the form of **yields** or ***crossable*** gaps?

II. Opportunity Utilization Criterion
  - Are the crossing opportunities ***utilized*** by the pedestrian?

III. Delay Criterion
  - Is a crossing opportunity taken within a ***reasonable time***?

IV. Safety Criterion
  - Does the crossing interaction occur without a ***significant degree of risk?***

At a pedestrian signal, the first criterion would be equivalent to the relative frequency of the WALK indication. At an unsignalized crossing, it describes whether the traffic characteristics and driver behavior result in crossing opportunities. At lower conflicting flows, pedestrians will encounter gaps that are long-enough for a safe crossing. Conceptually, the decision of whether or not a gap is crossable is a function of the crossing width, pedestrian walking speed and a safety buffer upon completion of the crossing. In Schroeder et al. (2006) the *minimum time for a safe crossing* was defined as 75% of the average crossing time, reasoning that pedestrians are safe even before completing the entire crossing. This notion is consistent with software interpretations of pedestrian crosswalks, where the *effective crosswalk* width is less than the actual distance between curbs (SIDRA Solutions, 2008). Alternatively, different approaches to describing pedestrian gap acceptance accounted for an additional safety buffer to distinguish crossable from too-short gaps. In particular, Yang et al. (2006) and Rouphail et al. (2005) calculated the crossable gap by dividing the crossing distance by an assumed walking speed and adding a 1-2 second safety buffer.

Crossing opportunities may also take the form of yields. While legislation in most US states requires drivers to yield to pedestrians already in the crosswalk, the law is oftentimes ambiguous about the requirement to yield to a pedestrian waiting at the curb. Consequently, a wide range of driver yielding rates has been observed at unsignalized pedestrian mid-block crossing in the US (Fitzpatrick et al., 2006). Yielding behavior at roundabouts has been studied by Geruschat and Hassan (2005), who found an increased likelihood of yielding at the roundabout entry lane and that yielding is sensitive to vehicle speed, pedestrian behavior, and in some cases the presence of a long cane.

The second criterion quantifies the level of pedestrian utilization of the available crossing opportunities. The utilization of crossable gaps is a function of the gap acceptance characteristics of the pedestrian. It may further be influenced by background noise at the site. At a roundabout in particular, the noise from circulating traffic may mask the auditory information at the crosswalk impacting the ability of a blind pedestrian to identify a crossable gap or yield (Guth et al., 2005). Previous research has shown that pedestrians with vision impairments oftentimes do not cross in front of yielding vehicles, because they either cannot hear the car or they are not confident that the crossing is safe despite the yield condition (Ashmead et al., 2005; Davis and Inman, 2007). Multiple threat situations (FHWA, 2004) at multilane approaches, where a vehicle in the near-lane visually and/or auditorily masks the events in the far lane, further complicate yield utilization.

Based on the first two criteria, most pedestrians will eventually utilize a crossing opportunity, raising the question of what amount of delay is acceptable before this happens. The Highway Capacity Manual, HCM (TRB, 2000) uses delay to define levels of service for pedestrian crossings. From an engineering perspective, it is thus intuitive that an inordinate amount of delay would make a crossing inaccessible. In the HCM, a (sighted) pedestrian delay over 45 seconds at an unsignalized intersection corresponds to level of service (LOS) F, which is the worst category on an A through F scale. The chapter further emphasizes that the likelihood of risk-taking behavior (by sighted pedestrians) is *very high* at this level of delay.

Finally, the fourth criterion attempts to quantify the safety of a crosswalk. Even if pedestrians utilize crossing opportunities within an acceptable amount of time, it can be argued that the site remains inaccessible if these crossings occur in dangerous situations. Schroeder et al. (2006) found that blind pedestrians make significantly more risky decisions than sighted pedestrians at unsignalized crosswalks at channelized right-turn lanes. In a study of blind pedestrians crossing at a two-lane roundabout, Ashmead et al (2005) found that the experimenter sometimes had to physically restrain the study participant from crossing to avoid a potential collision. The overall observed *intervention rate* of 6% was a clear indication of the risky nature of the studied two-lane roundabout crossing.

Performance Measures

The accessibility criteria stated above create a framework for evaluating crossing performance at pedestrian crossings. The following section defines performance measures in line with these criteria that can be measured from field observations. The following performance measures are defined from the time the pedestrian arrives at the crosswalk until he or she initiates crossing:

- <u>P(Yield) = Probability of Yielding</u>
  defined as the ratio of the number of conflicting vehicles that have yielded, to all vehicles encountered during the observation period while a pedestrian is waiting to cross. In some cases it may be necessary to exclude vehicles that were unable to come to a stop, because they were too close to the crosswalk at the time the pedestrian arrived (Schroeder, 2008).

- <u>P(GO|Yield) = Probability of GO Given Yield</u>
  defined as the ratio of yields that resulted in a pedestrian crossing, or GO decision to all yields encountered during the observation period. Conceptually, this measure represents the rate of *yield utilization*.

- <u>P(Gap>Min) = Probability of a Crossable Gaps</u>
  defined as the ratio of the number of time-based vehicle gaps that exceeded the crossable gap time, to all gaps encountered during the trials. The crossable gap size is calculated by dividing the crossing distance by an assumed crossing speed of 3.5 ft/sec and adding a 2 second safety buffer. This definition of crossable gap is conservative and can be further calibrated.

- <u>P(GO|Gap>Crossable Gap) = Probability of GO Given Crossable Gap</u>
  defined as the ratio of crossable gaps that resulted in a GO decision to all crossable gaps encountered during the observation period. This measure represents the rate of crossable *gap utilization*.

- <u>Observed Delay (sec.)</u>
  defined as the time elapsed from the pedestrian arrival at the crosswalk until the crossing is initiated, in seconds

- <u>Delay>Min = Delay Beyond First Opportunity</u>
  defined as the difference between the observed delay and the delay assuming the pedestrian had crossed at the first crossing opportunity (i.e. the first encountered yield or first crossable gap after arrival).

- <u>P(Risky Crossings)</u>
  defined as the proportion of actual crossings that are considered *risky*. A risky situation

> may be defined in terms of pedestrian-vehicle conflicts, where a collision may have occurred barring a pedestrian or driver intervention. In field observations, a conflict may be evident by a forced yield (rapid driver deceleration), a pedestrian running across the road, or the pedestrian pulling back from an initiated crossing. In controlled field research with pedestrians who are blind, the rate of experimenter interventions is correlated to the relative safety of the crossing decision.

A tale of two roundabouts

To illustrate the implementation of the analysis framework, the performance measures were calculated for two single-lane roundabouts studied under the NCHRP 3-78a (TRB 2008) and NIH (2000) research projects.

The first single-lane roundabout at the intersection of 9th Street and Davidson Avenue in Charlotte, NC (Site DAV-CLT) was studied as part of NCHRP 3-78a. The second single-lane roundabout at the intersection of Pullen Rd. and Stinson Dr. in Raleigh, NC (Site PS-RAL) was evaluated during the NIH project to test the feasibility of a system that automatically detects and reports the presence of yielding vehicles at the crosswalk. In this study, only the crossing data when the yield detection system at the PS-RAL site was deactivated were used.

Data at both roundabouts were gathered by the same observers and by applying an identical data collection protocol. In both cases, blind study participants were asked to cross the road independently while accompanied by an Orientation and Mobility (O&M) specialist. Participants would cross the road when they felt comfortable that it was safe. The O&M specialist would *intervene* if necessary to avoid potential collisions. Trials in both projects were videotaped and were reviewed and extracted by the same analysts.

Site Comparison

The DAV-CLT roundabout has an inscribed diameter of approximately 140’ (42.7m) and approach speed limits of 25mph (40km/h). It is located in a mostly residential neighborhood just north-east of uptown Charlotte, NC. The crossing distance for each lane is 16’ (4.9m), corresponding to a crossing time of 4.6 seconds at a walking speed of 3.5 ft/sec (1.1 m/s).

The PS-RAL site has a smaller inscribed diameter of 88’ (26.8m) and similar approach speed limits of 25mph (40km/h). The roundabout is located in close proximity to the main campus of North Carolina State University and thus experiences frequent pedestrian activity from students walking to and from class. The crossing distance is 13’ (4.0m) indicating a theoretical crossing time of 3.7 seconds.

Figure 1 shows aerial views of both sites. The tested crosswalks are highlighted. The major approaches at the two roundabouts are north-south arterial streets with a mix of commuter and local traffic. Both roundabouts further have university or city bus stops in close proximity and thus exhibit at least some heavy vehicle activity. While both roundabouts have sidewalks and marked pedestrian crossings, it needs to be recognized that the proximity of PS-RAL to a major university likely raises driver expectation of ongoing pedestrian activity.

In terms of traffic volumes, the major approaches to the roundabouts, namely Davidson Ave. and Pullen Rd., have an approximate Average Annual Daily Traffic (AADT) of 9,900 and 15,000 vehicles per day, respectively. Both sites have much lower volumes on the side streets. Table 1 shows the peak hour entering volumes for both sites.

The peak hour volumes suggest that the AM and PM peak hours at the PS-RAL have about 50% and 90% more traffic than the DAV-CLT site, respectively. More importantly, the lunch peak hour at PS-RAL has 240% more traffic, mostly as a result of the generally low daytime volumes at the DAV-CLT site. A similar trend was observed during the experimental trials. While the DAV-CLT showed medium traffic volumes in the AM and PM peak hours, traffic during the actual experimental trials was relatively low.

The research team also took sample speed observations at both sites. The approach speeds on the entry approach lanes to the north and south crosswalk at the DAV-CLT site were 27.6 and 26.0 mph (44.4 and 41.8 km/h), respectively. Upon entry, the average vehicle speed drops to approximately 17.6 mph (28.3 km/h) due to the roundabout geometry. The average approach speed at the southern crosswalk of the PS-RAL roundabout is lower than at DAV-CLT, at 22.8mph (36.7 km/h). The average entering speed to the PS-RAL roundabout is 15.6 mph (25.1 km/h). The average exiting speeds at DAV-CLT and PS-RAL are approximately 17.3 and 15.3 mph (27.8 and 24.6 km/h), respectively. The lower speeds at PS-RAL are likely attributable to the smaller inscribed diameter and associated lower design speed of the roundabout.

The data analysis at DAV-CLT included a total of 10 blind study participants. The data set for PS-RAL resulted in usable data from 12 blind participants. At both sites, a *trial* consisted of four *lane* crossings (for example entry-exit-exit-entry) with the starting order of lanes randomized for each subject. At DAV-CLT each subject completed 3 trials at the northern and 3 trials at the southern crosswalk, resulting in a total of 12 entry and 12 exit lane crossings. At the PS-RAL site each subject completed 8 full trials at one crosswalk, resulting in 16 entry and 16 exit lane crossings.

Analysis

From an assessment of vehicle operations, PS-RAL can be described as the smaller-diameter, higher-volume and lower-speed site, relative to DAV-CLT. The smaller inscribed diameter and correspondingly lower speeds at the PS-RAL might suggest that the site is more accessible. Lower speeds have been linked to higher yielding rates (Geruschat and Hassan, 2005) and lower injury rates in the event of a collision (Leaf and Preusser, 1999; FHWA, 2004). On the other hand, the much lower traffic volumes at DAV-CLT suggest more frequent gap crossing opportunities and a reduced likelihood to encounter a vehicle when crossing. Ultimately, it is difficult to rate the accessibility of either site, without investigating the behavioral components of pedestrians and drivers. The proposed usability measures allow for this type of assessment.

Table 2-a compares the yield probabilities for the two sites. It shows generally higher yielding rates at the PS-RAL roundabout, which may be related to the proximity to a major college campus. The PS-RAL site further suggests lower yielding at the roundabout exit leg, which is not evident at DAV-CLT. Both sites further exhibit a range of yielding percentages. For participants

at PS-RAL the yielding rate varied from 9.4% to 70% (mean 37.2%) with a smaller range evident at DAV-CLT (0% to 33.3%, mean 11.3%).

Table 2-b shows the yield utilization rates at the two sites. A lower yield utilization rate is evident at DAV-CLT (67.4%) than at PS-RAL (85.4%). Both sites suggest a slightly higher yield utilization rate at the exit leg. By combining yielding and yield utilization rates, it can be stated that the PS-RAL site exhibits a higher likelihood of crossing in a yield than DAV-CLT. The range of observed yield utilization points to difference in crossing abilities among participants, with some utilizing 100% of yields, while others don't utilize any.

The observed yield probabilities and yield utilization rates can be multiplied to obtain the probability that a pedestrian crosses in a yield. For DAV-CLT this average likelihood of a yield crossing is 7.6% of all observed events. For PS-RAL the corresponding probability is 31.8%, indicating that a crossing in a yield is significantly more likely at this site.

Table 3-a shows the availability of crossable gaps at the two sites. Following the definition above, the minimum crossable gaps for DAV-CLT and PS-RAL are approximately 7.0 and 6.0 seconds, respectively. To allow for a direct comparison across sites, the results for PS-RAL are shown for minimum gap thresholds of 6.0, as well as, 7.0 seconds. The table shows that DAV-CLT (61.5%) has a slightly higher rate of gaps greater than the crossable gap than PS_RAL (51.8% for 6-second gap). The difference in gap availability is of course greater if the threshold for "crossable" is increased to 7.0 seconds at PS-RAL. For both sites, the gap occurrence is comparable for entry and exit legs.

Table 3-b shows gap utilization rates for DAV-CLT of approximately 60%. At the PS-RAL the gap utilization rate is higher for the exit leg than the entry leg with 63.6% and 52% utilization, respectively. When increasing the crossable gap definition to 7.0 seconds, the utilization rate expectedly increases. Overall, the gap utilization rates across the two sites are comparable. Combining gap occurrence and utilization, there is a somewhat higher likelihood of crossing in a gap at DAV-CLT. The range of gap utilization again varies between 0% and 100% emphasizing the need for a sufficient sample size given the variability of crossing behavior. In this context it is also important to point out that no utilized gaps below the defined crossable gap threshold were observed at either site. However, for some sighted pedestrians that were included in the PS-RAL research (not shown), gap utilization of shorter gaps was common.

Consistent with the discussion above, the probability of a crossable gap occurring and gap utilization can be multiplied to obtain the overall likelihood of crossing in a gap. For the DAV-CLT roundabout this likelihood of a gap crossing is 38.9%. For PS-RAL, the corresponding probability is 29.9% or 27.2%, depending on whether a crossable gap is defined to 6 or 7 seconds. The difference between the two sites in the probability of a gap crossing is thus less than for yield crossings.

Table 4-a compares the observed delay experienced by the blind pedestrians at both sites and suggests significantly lower delays at PS-RAL. Interpreting this difference in light of the results in tables 2 through 5, the lower delay is likely attributable to greater P(Yield) and greater P(GO|Yield) at this site. The delay at DAV-CLT correspondingly is higher because pedestrians

wait for crossable gaps in the absence of yields. The delay is comparable for the entry and exit leg at both sites. The average total delay to get across both entry and exit lanes represents the sum of the two estimates.

Table 4-b shows the delay beyond the first crossing opportunity for both sites. The findings are similar to those in table 4-a with pedestrians at PS-RAL experiencing less "unnecessary delay" compared to DAV-CLT. Again, the reason for the differences is likely related to P(Yield) and P(GO|Yield). When raising the crossable gap threshold at PS-RAL to 7.0 seconds, the delay over minimum reduces slightly, because some pedestrians encountered a crossable gap earlier. The difference in delay suggests that a crossing opportunity is utilized more quickly at PS-RAL. If these sites were analyzed using LOS definitions in the HCM, the average delay times at PS-RAL and DAV-CLT (approximately 11 and 25 seconds) would correspond to LOS scores C and D, respectively. To recall, the HCM defines levels of service on a scale from A (best) to F (worst) in terms of average daily per person.

It needs to again be emphasized that the delay estimates varied greatly among subjects as indicated by the ranges shown in table 4. Also, the values in table 4 represent the range of average delay per subject, with even greater variability in individual crossings per subject. For example, the highest observed delays observed for one lane crossing at PS-RAL and DAV-CLT were 127 and 180 seconds, respectively. Also, all delay figures are reported per lane crossed, because participants paused on the splitter island at the roundabout crossings. Consequently, the average total delay per crossing for PS-RAL and DAV-CLT was 22 and 50 seconds, resulting in HCM LOS equivalents D and F, respectively.

Table 5 shows the rate of experimenter interventions. The intervention rates at PS-RAL are clearly higher than DAV-CLT, and especially the exit lane crossing is risky at an intervention rate of 5.8%. However, with repeated crossings even the 1.0% intervention rate at DAV-CLT could result in a high likelihood of a risky decision over time. Ashmead et al. (2006) discussed that the probability of a dangerous crossing decision is given by $1-(1-p_{\text{per crossing}})^n$, where $p_{per\ crossing}$ is the observed intervention rate and n the number of crossing attempts. Consequently, for a pedestrian who crosses this roundabout twice a day, the probability of a dangerous decision after one month (10 crossings per week over 4 weeks) is 33.1%. At the 3.9% intervention rate for PS-RAL this likelihood increases to 79.6%.

From a safety perspective, these figures suggest that the PS-RAL is riskier to cross and thus less accessible from that perspective.

Discussion

It was hypothesized that both site geometry and conflicting traffic volumes contribute to the accessibility of a site, but that ultimately, driver and pedestrian behavior may play the most crucial role in rendering a site accessible to and usable by pedestrians who are blind. With more frequent occurrence of yields and similar crossable gap frequency, the PS-RAL site appears to be more accessible than DAV-CLT. Especially in light of similar yield and gap utilization statistics, it appears as if a crossing is more likely at PS-RAL. In fact, the delay measures suggest that travelers at PS-RAL find a crossing opportunity more quickly. The site is thus more usable from a delay perspective, although the delay times are still high using thresholds in the Highway Capacity Manual for unsignalized crossings.

But the question of usability is not only a function of delay, as the relative risk of the crossing needs to be considered. The rate of experimenter interventions was higher at PS-RAL indicating lower usability from a safety perspective. It is unclear what factors contribute to the higher rate of interventions, but it is likely a combination of background noise, auditory confusion, travel skills and ultimately higher traffic volumes. Clearly, more research is necessary to isolate any of these effects.

The analysis demonstrated that the usability framework and associated performance measures are transferable across sites. More importantly, the framework enables the analyst to distinguish between different performance measures and thus isolate the specific effects that contribute to the usability of a crosswalk for pedestrians who are blind.

In light of these findings, it becomes evident that the question of roundabout accessibility is complex and cannot be reduced to a simple relationship to traffic volumes. While a low-volume site may have the appearance of being usable, a higher-volume site may result in lower delay if combined with a greater rate of yielding. The greater usability from a delay perspective of the PS-RAL site is attributable to higher P(Yield) and P(GO|Yield) probabilities. These two factors seemed to have a significant overall impact on reduced pedestrian delay, despite the fact that the site had higher volumes and consequently a lower availability of crossable gap, P(Gap>Min). Given a high propensity to yield, the greater volumes at PS-RAL thus result in more frequent crossing opportunities per unit of time. However, higher volumes also lead to more noise and an increased likelihood of a vehicle approaching as the pedestrian steps into the crosswalk. This may explain the higher rate of interventions at the site. It also raises the question of what the intervention rate at DAV-CLT would have been at higher traffic volumes.

Conclusion

This research presented a framework for quantifying the usability of crosswalks at modern roundabouts for pedestrians who are blind. While the tasks of locating the crosswalk, wayfinding and crossing alignment also contribute to the overall usability of a crosswalk, the ability to make the decision to cross remains the vital task. It was argued that the crossing task at an unsignalized roundabout crosswalk can be described by four components: the availability of crossing opportunities, the utilization of these opportunities, the delay until an opportunity is utilized and the overall risk involved in the task.

The discussion further identified several simple performance measures that are associated with these usability components. The approach implementation was illustrated at two single-lane roundabouts. The two sites differed in geometric configuration and traffic volume levels, and correspondingly performed very differently. While the higher-volume site may have seemed less usable at first glance, it became evident that the frequent utilization of yield crossing opportunities actually resulted in a low average delay to the blind study participants. However, the site also exhibited significant amount of risky decisions, thereby reducing the overall usability. While seemingly safer, a lower-volume site actually resulted in significant delay to the participants related to a low yielding rate and utilization of crossing opportunities. At P(Yield) in the range of 10-12% there appears to be much room for improvement and it can be hypothesized that the accessibility of the site could be increased by increasing the likelihood of drivers yielding. It can also be hypothesized that an increase in traffic volumes likely would have decreased the overall usability, because of (1) fewer gap crossing opportunities, (2) higher background noise, and (3) a potentially increased likelihood of risky decisions. An interesting follow-on study would assess the crossing ability of the same study participant across different sites, which is planned as part of NCHRP 3-78a in the comparison of a single-lane and a multilane roundabout.

The analysis showed that one site is more usable from a delay perspective, while the other is more usable because of safety. It can be argued that personal safety outweighs delay, especially if actual crossing are infrequent. At the same time, there is some limit to how much delay is acceptable even if a crossing is attempted only rarely. At some risk and delay thresholds, it is likely that a traveler will avoid using a site altogether, at which point it must be considered unusable and thus in violation of the ADA legislation.

Based on these limited findings, a crisp definition of accessibility for single-lane roundabouts remains elusive, and more data at varying geometries and volume levels are needed before final conclusions can be drawn. Nevertheless, the analysis showed that it is possible to quantify and contrast operational differences of various sites using the proposed framework and measures. In future research, it will thus be beneficial to apply these measures at additional sites and fill in the blanks on the question of roundabout accessibility and the effectiveness of crossing treatments. It is hypothesized that with this successful demonstration at two roundabout sites, the analysis framework has broader application to unsignalized pedestrian crossings, including those at mid-block locations.

While the analysis framework represents a tool to quantify crossing performance, it is recognized here that it will not be usable directly by the US Access Board or engineering agencies, since it does not tie crosswalk usability to specific geometric configurations or traffic conditions. In other words, crosswalk usability is not defined in terms of metrics that are available to agencies faced with making decisions about roundabout construction or about pedestrian treatments to be installed at roundabouts. In future research, it is necessary to link crossing performance of blind travelers to actual roundabout geometries and physical treatments that can be installed by agencies to make a site more usable by this group of pedestrians. The authors see their contribution as developing a set of performance measures that can be used to quantify the effect of geometric differences and pedestrians treatments beyond anecdotal evidence. Using the developed analysis framework along with expert judgment about thresholds for the different measures, future research will be able to quantify the net effect of a treatment on crosswalk usability.

Acknowledgment

The authors would like to acknowledge the National Institutes of Health and the National Academies for their financial support and the members of the project teams, who have provided continuous feedback to the research efforts. The authors would further like to acknowledge staff at Western Michigan University and Accessible Design for the Blind, who were instrumental in running the studies. The authors would also like to thank the Cities of Charlotte and Raleigh, NC for facilitating the data collection efforts.

The project described was supported by Grant Number R01EY12894 from the National Eye Institute. This content is solely the responsibility of the authors and does not necessarily represent the official views of the National Eye Institute or the National Institutes of Health.

References

Ashmead, Dan, David Guth, Robert Wall, Richard Long, & Paul Ponchillia (2005). Street crossing by sighted and blind pedestrians at a modern roundabout. *ASCE Journal of Transportation Engineering,* Vol. 131, No. 11., November 1, 2005, 812-821

Barlow, Janet, Billie Louise Bentzen, and Tamara Bond. (2005) Blind pedestrians and the changing technology and geometry of signalized intersections: Safety, orientation and independence. *Journal of Visual Impairment and Blindness.* Vol. 99, (10),587-598.

Davis, Gregory and Vaughn Inman (2007), *Pedestrian Access to Roundabouts: Closed Course Test of Yielding Vehicle Detection System.* http://www.accessmanagement.gov/AM2004/AM0411p_Roundabouts.pdf. Last Accessed February 8, 2007.

FHWA (2000), *Roundabouts: An Informational Guide*. Federal Highway Administration. Turner Fairbank Highway Research Center. FHWA-RD-00-067. McLean, VA. 2000

FHWA (2004), *Pedestrian Safety Guide and Countermeasure Selection System (PEDSAFE).* Improved Right-Turn Slip-Lane Design. Report No. FHWA-SA-04-003, http://www.walkinginfo.org/pedsafe

Geruschat, Duane and Shirin Hassan (2005), *Driver Behavior in Yielding to Sighted and Blind Pedestrians at Roundabouts.* Journal of Visual Impairment and Blindness. Volume 99, Number 5, May 2005.

Guth, David, Dan Ashmead, Richard Long, Robert Wall, & Paul Ponchillia, (2005). Blind and sighted pedestrians' judgments of gaps in traffic at roundabouts. *Human Factors, 47*, 314-331.

Harkey, David., Daniel Carter, Janet Barlow, Billie Louise Bentzen, Linda Myers, and Alan Scott (2007) *Guidelines for Accessible Pedestrian Signals, Final Report.* Contractor's Final Report for NCHRP Project 3-62, NCHRP Web-Only Document 117B

Kittelson and Associates, Roundabout / Traffic Circle Inventory Database. http://roundabouts.kittelson.com/InvMain.asp. Accessed November 04, 2008.

Leaf, William and David Preusser (1999) *Literature Review on Vehicle Travel Speeds and Pedestrian Injuries* (DOT HS 809 021). National Highway Traffic Safety Administration, US Department of Transportation. Washington, DC. October 1999.

NIH/NEI Bioengineering Research Partnership Grant R01 EY12894-03

Rouphail, Nagui, Ron Hughes and Kosok Chae (2005), *Exploratory Simulation of Pedestrian Crossings at Roundabouts.* ASCE Journal of Transportation Engineering. March 2005. pp. 211-218

Schroeder, Bastian and Nagui Rouphail (2007). *A Framework for Evaluating Pedestrian-Vehicle Interactions at Unsignalized Crossing Facilities in a Microscopic Modeling Environment*. Presented at the 86th Annual Meeting of the Transportation Research Board, Washington, DC. 2007

Schroeder, Bastian, Nagui Rouphail and Robert Wall Emerson (2006), *Exploratory Analysis of Crossing Difficulties for Blind and Sighed Pedestrians at Channelized Turn Lanes*. Journal of the Transportation Research Board, No. 1956. October 2006

Schroeder, Bastian (2008), *A Behavior-Based Methodology for Evaluating Pedestrian-Vehicle Interaction at Crosswalk*. Doctoral Dissertation in Civil Engineering, North Carolina State University. May 2008

SIDRA SOLUTIONS (2008) SIDRA Intersection User Guide

TRB (2000), *Highway Capacity Manual (HCM),* Transportation Research Board (TRB), Washington, DC 2000.

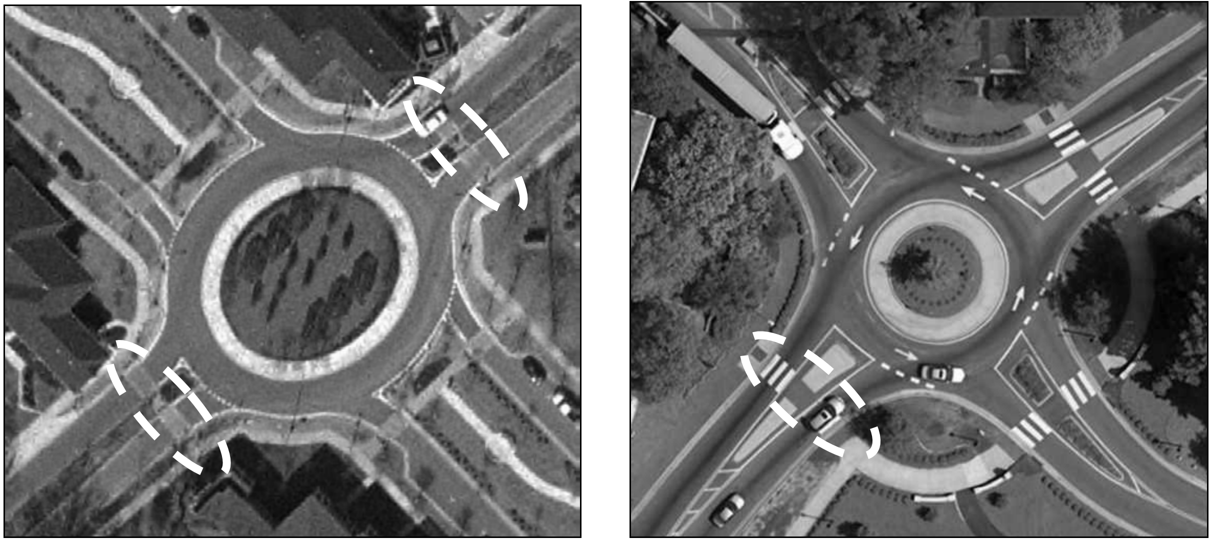
TRB (2007), *Roundabouts in the Unites States*. NCHRP Report 572. National Cooperative Highway Research Program. Transportation Research Board. Washington, DC.

TRB (2008), National Cooperative Highway Research Program (NCHRP) Project 3-78 (ongoing). Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities. Institute of Transportation Research and Education. Raleigh, North Carolina

US Access Board (2006), *Revised Draft Guidelines for Accessible Public Rights-of-Way*. http://www.access-board.gov/prowac/draft.htm. Accessed July 8, 2008

Yang, Jianguo, Wen Deng, Jinmei Wang, Quingfeng Li, Zhaoan Wang. “Modeling Pedestrians’ Road Crossing Behavior in Traffic System Micro-Simulation in China.” Transportation Research Part A 40, 2006, pp. 280-290.

Figure 1: Aerial views of Comparison roundabouts (Source: www.google.com)



a) DAV-CLT

b) PS-RAL

Table 1: Peak Hour Entering Volumes for Study Sites

a) DAV-CLT

PS-RAL	Peak Hour Volumes Total Entering Volumes, Sep-2007				
	North	East	South	West	TOTAL
AM Peak (7:30-8:30AM)	779	3	461	36	1279
Lunch Peak (12:15-1:15PM)	583	38	560	113	1294
PM Peak (5:00-6:00PM)	454	20	887	123	1484

b) PS-RAL

DAV-CLT	Peak Hour Volumes Total Entering Volumes, Nov-2007				
	North	East	South	West	TOTAL
AM Peak (7:30-8:30AM)	157	79	506	92	834
Lunch Peak (1:00-2:00PM)	198	26	272	39	535
PM Peak (5:00-6:00PM)	364	70	277	76	787

Table 2: Yield Availability and Utilization Comparison

a) P(Yield)

DAV-CLT	Avg.	Min.	Max.	Std.Dev.
Entry	10.8%	0.0%	21.3%	8.9%
Exit	11.8%	0.0%	33.3%	7.9%
Overall	11.3%	0.0%	33.3%	8.3%
PS-RAL				
Entry	41.5%	13.9%	66.7%	18.2%
Exit	32.8%	9.4%	70.0%	17.9%
Overall	37.2%	9.4%	70.0%	18.2%

b) P(GO|Yield)

DAV-CLT	Avg.	Min.	Max.	Std.Dev.
Entry	64.1%	0.0%	100.0%	41.2%
Exit	70.4%	0.0%	100.0%	44.1%
Overall	67.4%	0.0%	100.0%	42.3%
PS-RAL				
Entry	83.0%	50.0%	100.0%	20.4%
Exit	87.8%	60.0%	100.0%	14.1%
Overall	85.4%	50.0%	100.0%	17.3%

Table 3: Gap Availability and Utilization Comparison

a) P(Gap>Min)

DAV-CLT	Avg.	Min.	Max.	Std.Dev.
Entry	62.1%	38.5%	85.7%	14.2%
Exit	60.9%	28.6%	83.3%	12.9%
Overall	61.5%	28.6%	85.7%	13.4%
PS-RAL (Min=6sec.)				
Entry	53.5%	16.7%	100.0%	28.1%
Exit	50.2%	17.0%	100.0%	23.5%
Overall	51.8%	16.7%	100.0%	25.4%
PS-RAL (Min=7sec.)				
Entry	40.9%	0.0%	100.0%	29.0%
Exit	40.8%	0.0%	100.0%	26.5%
Overall	40.8%	0.0%	100.0%	27.2%

b) P(GO|Gap>Min)

DAV-CLT	Avg.	Min.	Max.	Std.Dev.
Entry	66.3%	25.0%	100.0%	20.6%
Exit	60.3%	33.3%	100.0%	17.9%
Overall	63.3%	25.0%	100.0%	19.3%
PS-RAL (Min=6sec.)				
Entry	52.0%	0.0%	100.0%	41.3%
Exit	63.6%	18.8%	100.0%	26.6%
Overall	57.8%	0.0%	100.0%	34.4%
PS-RAL (Min=7sec.)				
Entry	60.3%	0.0%	100.0%	37.6%
Exit	72.4%	25.0%	100.0%	28.5%
Overall	66.6%	0.0%	100.0%	26.1%

Table 4: Observed Delay Comparison

a) Observed Delay per Leg (sec.)

DAV-CLT	Avg.	Min.	Max.	Std.Dev.
Entry	26.6	11.2	74.0	17.0
Exit	24.0	11.4	41.8	9.7
Overall	25.3	11.2	74.0	13.8
PS-RAL				
Entry	10.5	4.1	34.2	8.9
Exit	11.6	5.2	26.7	6.8
Overall	11.1	4.1	34.2	7.8

b) Delay>Min (sec.)

DAV-CLT	Avg.	Min.	Max.	Std.Dev.
Entry	18.8	4.8	59.4	15.5
Exit	17.2	5.2	35.1	9.6
Overall	18.0	4.8	59.4	12.8
PS-RAL (Min=6sec.)				
Entry	5.6	0.8	24.7	7.2
Exit	6.1	0.8	19.4	5.8
Overall	5.8	0.8	24.7	6.4
PS-RAL (Min=7sec.)				
Entry	5.2	0.8	23.0	6.7
Exit	5.7	0.8	19.1	5.7
Overall	5.5	0.8	23.0	6.1

Table 5: Experimenter Interventions

P(Risky Crossing)

DAV-CLT	**Avg.**
Entry	1.0%
Exit	1.0%
Overall	1.0%
PS-RAL	
Entry	2.1%
Exit	5.8%
Overall	3.9%

APPENDIX K: Details on Pedestrian Delay Models

This Appendix was previously published as conference proceedings at the 89th Annual Meeting of the Transportation Research Board, January 10-14, 2010. The citation for this work is:

Schroeder, Bastian J., and Nagui M. Rouphail. *Mixed-Priority Pedestrian Delay Models at Single-Lane Roundabouts.* 89th Annual Meeting of the TRB, 2010.

Mixed-Priority Pedestrian Delay Models at Single-Lane Roundabouts

By

Bastian J. Schroeder, Ph.D*
Research Associate
Institute of Transportation Research and Education (ITRE)
North Carolina State University
Centennial Campus, Box 8601
Raleigh, NC 27695-8601
Tel.: (919) 515-8565
Fax: (919) 515-8898
Email: Bastian_Schroeder@ncsu.edu

Nagui M. Rouphail, Ph.D.
Director, Institute for Transportation Research and Education (ITRE)
Professor of Civil Engineering
North Carolina State University
Centennial Campus, Box 8601
Raleigh, NC 27695-8601
Tel.: (919) 515-1154
Fax: (919) 515-8898
Email: rouphail@eos.ncsu.edu

November 2009

Submitted for consideration for publication and presentation at the 89th Annual Meeting of the Transportation Research Board, January 10-14, 2010

Word Count: 5,316 text words plus 2,000 for figures/tables (8*250) = 7,316 total

* Corresponding Author

--- This paper has been revised from its original submission ---

ABSTRACT

This paper presents an approach for developing mixed-priority pedestrian delay models at single-lane roundabouts using behavioral crossing data. Mixed-priority refers to crosswalk operations where drivers sometimes yield to create crossing opportunities, but where pedestrians sometimes have to rely on their judgment of gaps in traffic to cross the street. The models use probabilistic behavioral parameters measured in controlled pedestrian crossings by blind pedestrians as part of NCHRP project 3-78a. While blind pedestrians clearly represent a special population of pedestrians, the developed delay model is structured to be applicable to other pedestrian populations. Delay is predicted as a function of the probability of encountering a crossing opportunity in the form of a yield or crossable gap, and the probability of utilizing that opportunity, which are aggregated to an overall probability of crossing. The paper presents the theoretical approach to estimating the probability parameters and uses a multi-linear log-transformed regression approach to predict the average pedestrian delay. The final delay model explains 64% of the variability in the observed data and therefore represents a reasonable model for predicting pedestrian delay at single-lane roundabouts. The paper concludes with a discussion of how agencies can estimate the underlying probability parameters for existing or proposed roundabouts using empirical and theoretical approaches, and how pedestrian crossing treatments can be used in the context of the model to reduce average pedestrian delay. The research is important in light of the ongoing debate of the accessibility of modern roundabouts to pedestrians who are blind. However, the results have further application to the general evaluation of pedestrian facilities at roundabouts, an application where existing Highway Capacity Manual methods are limited. The probabilistic approach to predicting pedestrian delay is universal and can be applied other pedestrian populations with the right probability parameters. Calibration to other crossing geometries is feasible with future data collection.

INTRODUCTION

Modern roundabouts are a popular new form of intersection control in the US with over 1,500 existing and many more proposed (*1*). In contrast to older traffic circles, modern roundabouts are compact, unsignalized, have low design speeds, and use a yield prioritization at the entering approach with circulating traffic having the right-of-way. The strongest selling points for modern roundabouts are a significant reduction in collisions compared to signalized intersections (*2*), aesthetic appeal, and the ability to process varying traffic patterns without the need to adjust signal parameters.

Many modern roundabouts are constructed in areas with pedestrian activity, including downtown areas or suburban residential areas. Roundabout crosswalks are typically marked with a zebra pattern or another form of marking (*3*) and feature a two-stage crossing with a splitter island between entry and exit legs for pedestrian refuge. State motor vehicle codes commonly give pedestrians the right of way within the crosswalk (*4*). This suggests that roundabouts should be accessible to pedestrians. But yielding laws can be misinterpreted and the actual yielding behavior varies over a range of observed values at different sites and geometries (*2*). Consequently, pedestrians are expected to experience some delay when attempting to cross at these locations.

The 2000 US Highway Capacity Manual (HCM) (*5*), the guide book for traffic operational analysis methodologies for the US and many other countries, currently offers no delay methodology for a mixed-priority crossing situation, where drivers sometimes yield to create crossing opportunities, but where pedestrians sometimes have to rely on their judgment of gaps in traffic to cross the street. The HCM gap acceptance-based methods are limited to cases where pedestrians have full priority (100% of traffic yields) or where drivers have priority (no yields) and pedestrians are limited to crossings in gaps only. An updated pedestrian delay model that allows for a reduction of pedestrian delay due to drivers that yield is currently being considered for the 2010 release of the HCM. However, the proposed theoretical model is not calibrated from field data and does not distinguish between different sub-populations of pedestrians.

In the context of building modern roundabouts, much national attention has been given to pedestrians who are blind. Without the ability to see, blind travelers have to rely on auditory cues to identify crossing opportunities. Research has shown that roundabouts can cause significant challenges to this group of travelers, evident by long delays, missed crossing opportunities, and risky situations (*6, 7, 8*). In the absence of a signal equipped with an accessible pedestrian signal (APS), a pedestrian who is blind has a difficult time discerning between exiting and circulating traffic and interpreting curved vehicle trajectories causing a confusing auditory environment.

This paper presents an approach for estimating pedestrian delay at single-lane roundabouts on the basis of observable behavioral parameters by pedestrians and drivers. The analysis uses field-observed probabilities of yielding, gap occurrence, and the rate of utilization of yield and gaps to develop statistical pedestrian delay models. The models are developed from observations of blind pedestrian crossings at three single-lane roundabouts, but can be expanded to other pedestrian populations and roundabout geometries from literature findings and traffic flow theory concepts. The underlying performance assessment framework for (blind) pedestrian crossings at roundabouts was previously published by the authors in (*10*) and (*11*).

BACKGROUND

The question of pedestrian delay at modern roundabouts, and more specifically the accessibility of modern roundabouts to pedestrians who are blind is being investigated in two ongoing research projects: National Cooperative Highway Research Program (NCHRP) Project 3-78a (*12*) and a National Eye Institute Bioengineering Research Partnership investigating *Blind Pedestrian Access to Complex Intersections* (*13*). The data used in this paper were collected for those two projects.

Research on pedestrian behavior is typically of an observational nature, as researchers observe and quantify behavior by pedestrians and drivers. This approach has been adopted in a NCHRP-funded national survey of pedestrian crossing treatments (*2*) and research on the operational performance of modern roundabouts (*14*). The latter project observed a total of 769 pedestrian crossing events at seven different roundabouts, but the dataset was deemed insufficient to develop pedestrian delay models for roundabouts and no special pedestrian populations were included in the study.

Other countries have developed methodologies for estimating the impact of pedestrians on vehicular traffic, assuming pedestrian priority (*15*). Those approaches are conceptually similar to the US HCM methods mentioned above (*5*), that quantify pedestrian delay at a vehicle-priority crossing or driver delay at pedestrian-priority crosswalk. A mixed-priority pedestrian delay model will enable engineers to make predictions about the current or future operational performance of a roundabout for this non-motorized mode. It further aids in comparing pedestrian performance of a roundabout to a signalized intersection alternative. Finally, without the ability to predict crossing performance for blind travelers, engineers cannot adequately address requirements for the accessibility of modern roundabouts to pedestrians who are blind.

The American with Disabilities Act (ADA) of 1990 mandates equal access to public facilities to all users of that facility, including those with mobility or vision impairments (*16*). The US Access Board is tasked with interpreting the ADA legislation and issuing guidance to engineers and planners to assure that the public right of way is *accessible to and usable by* pedestrians with disabilities. The US Access Board has recognized the crossing challenges at roundabouts and has proposed language that supports the installation of APS-equipped pedestrian signals at multi-lane roundabouts (*17*).

Through the aforementioned blind pedestrian research projects (*12, 13*), crossing behavior was studied through controlled experiments. In the studies, pedestrians would cross repeatedly at the same crosswalk under supervision of an orientation and mobility (O&M) specialist, resulting in extensive pedestrian-specific behavioral data sets than cannot be obtained from uncontrolled observational studies.

In prior work, the authors have developed a framework for describing the accessibility of modern roundabouts for blind pedestrians (*11, 18*). The accessibility framework is intended to provide measures to quantify the crossing performance at these locations. In particular, the crosswalk usability measures quantify the *availability* of crossing opportunities in the form of yields and crossable gaps, the *rate of utilization* of those opportunities, and the *delay* and *risk* experienced by pedestrians during the crossing. This paper expands on that prior work and relates the performance outcome, delay, to the observed behavioral probability parameters.

METHODOLOGY

The data used for the delay model development were collected in controlled crossing experiments with blind volunteers as part of two ongoing research projects (*12, 13*) investigating the accessibility concerns of modern roundabouts to pedestrians with vision impairments. While blind pedestrians represent a special pedestrian population, the approach allows the analyst to distinguish between driver and traffic behavior and pedestrian characteristics. It can thus be hypothesized what the delay would have been in a different behavioral context. For example sighted pedestrians would have a higher rate of yield utilization (presumably 100%). However, the blind pedestrian data set had the advantage that the full range of crossing performance was observed (e.g. yield utilization ranging from 0% to 100%). The distribution of explanatory variables across a range of values is a critical prerequisite for model development as discussed below.

In the experiments, a total of 40 blind participants crossed independently at three different roundabouts, with each site having a sample of 10-18 pedestrians. The pedestrians were always accompanied by an O&M specialist and were familiarized with the roundabout and the study design before crossing. Each pedestrian crossed the roundabout multiple times, where each trial consisted of four lane crossings (for example entry-exit-exit-entry). Depending on the site, each pedestrian completed four to six trials at the roundabout, resulting in 16 to 24 lane crossings with half of the crossings at the entry and exit leg, respectively. The dataset used for model development uses the average crossing performance for a single pedestrian at a given leg (entry or exit), resulting in a total of 80 data points. Using the average of all trials for a participant results in a more robust dataset. It assures a sufficient representation of accepted and rejected opportunities for each pedestrian needed to calculated opportunity usability statistics. Overall, a total of approximately 800 observations were used to generate the 80 data points.

Observational Variables

The following intermediate variables are calculated for each of the 80 data points.

- **P(Yield):** The probability of a vehicle yielding to the pedestrian, defined as the number of yields divided by the number of yields plus the number of non-yielding vehicles that cross the plane of the crosswalk while a pedestrian is waiting to cross. This parameter describes driver behavior and does not include gap events.
- **P(Y_ENC):** The probability of encountering a yield event, defined as the number of yields divided by the total number of events encountered by the pedestrian until he/she completes the crossing. An event is defined as the interaction of a pedestrian with a single vehicle. This measure is used to develop the pedestrian delay models.

- **P(GO|Yield):** The probability of yield utilization, defined by the number of crossings in a yield divided by total number of yields encountered by the pedestrian.
- **P(CG):** The probability of a gap being crossable, defined as the number of crossable gaps (CGs) divided by the number of all crossable plus non-crossable gaps. This parameter describes gap occurrence and does not include any yields events. In this study, the CG was calculated from the time required to cross at a walking speed of 3.5 ft/s (1.07) plus 2 seconds to account for start-up and clearance time. This is consistent with the pedestrian critical gap definition in the HCM, given below in equation 3.
- **P(CG_ENC):** The probability of encountering a CG event, defined as the number of crossable gaps divided by the total of all events (vehicles) encountered by the pedestrian. **P(GO|CG):** The probability of crossable gap utilization, defined by the number of crossings in a CG divided by total number of CGs encountered by the pedestrian.
- **Observed Delay per Leg (sec.):** The average pedestrian delay in seconds, defined as the time difference between when the trial started and when the pedestrian initiated the crossing at the leg. Note that a full crossing at the roundabout includes two legs and this delay is given per leg!
- **Minimum Delay (sec.):** The minimum delay or waiting time until the first opportunity, defined as the time difference between start of the trial and the first yield or crossable gap encountered by the pedestrian. Presumably, this delay corresponds to the experience of a sighted pedestrian who utilizes all yields and all crossable gaps (at the defined CG time).

The above variables are largely identical to measures used to define pedestrian accessibility that were presented in (*11*). That paper used P(Yield), P(GO|Yield), P(CG), P(GO|CG), but stopped short of relating those to pedestrian delay in a predictive model. For the purpose of developing predictive delay models, it was necessary to define two additional variables that describe the probability of encountering a yield and crossable gap. The measures P(Y_ENC) and P(CG_ENC) use the same denominator: The total number of pedestrian-vehicle interaction events, where one event is always defined as the interaction of one vehicle and one pedestrian. With the same denominator, the two terms become additive and their sum by definition is limited by 1.0. Figure 1 illustrates the definition of observational variables using a hypothetical example of a pedestrian encountering 10 different vehicles (10 events).

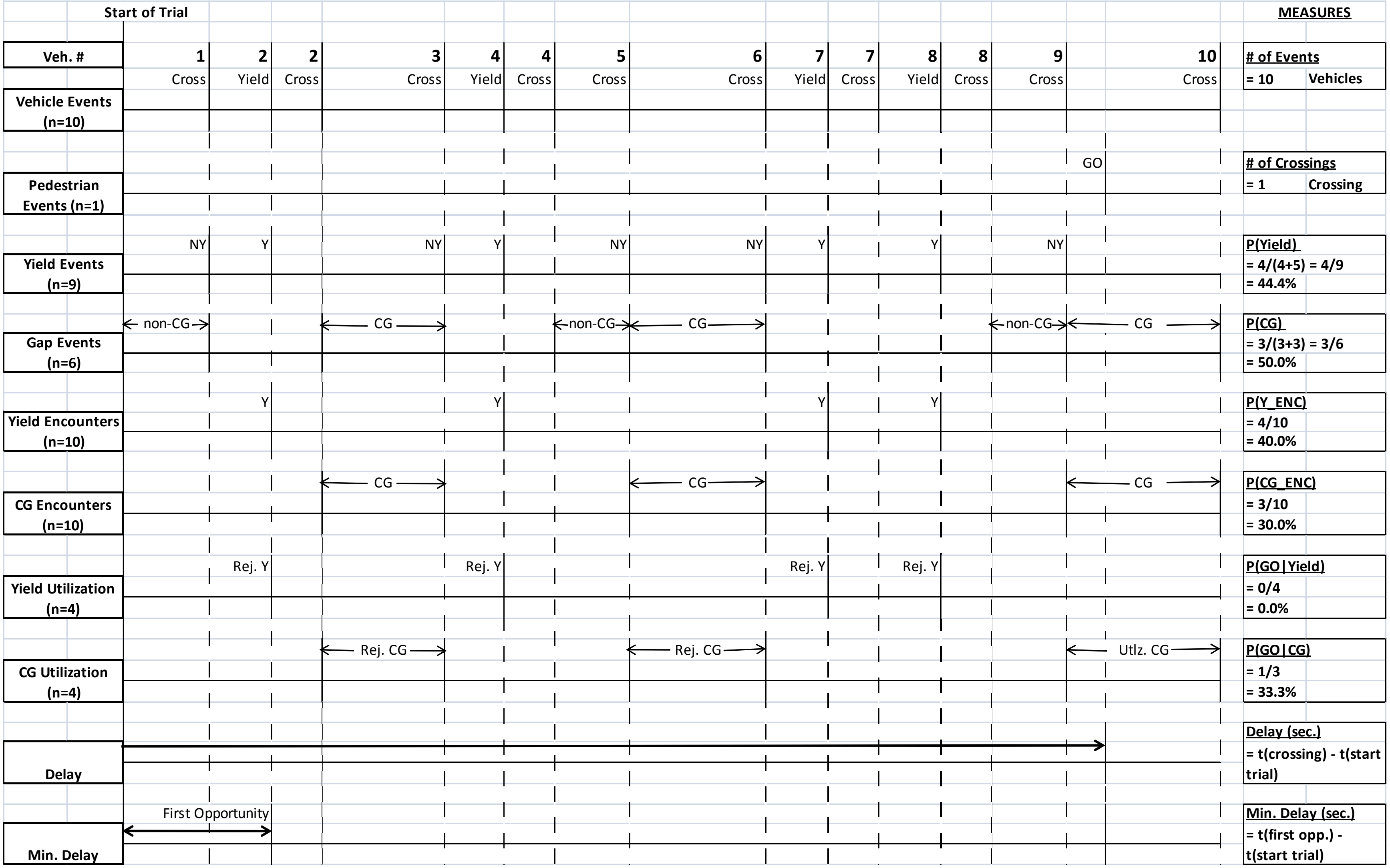


Figure 1: Graphical Illustration of Variable Definitions

Figure 1 shows a timeline of a pedestrian encountering 10 hypothetical vehicle events. The timeline proceeds from left to right, from the start of the experimental trial until the last vehicle that interacts with the pedestrians crossed the plane of the crosswalk. Of the ten vehicles, vehicles 2, 4, 7, and 8 yielded to the pedestrian, but none of these yields were utilized. Vehicles 1, 3, 5, 6, 8, and 9 didn't yield even though a pedestrian was waiting at the crosswalk. No yield information is available for vehicle 10, since the pedestrian had already crossed by the time it crossed the plane of the crosswalk. Consequently, the variable P(Yield) is calculated from four yields divided by a total of nine drivers that could have yielded and equals 44.4%. In contrary, the variable P(Y_ENC)=40% is calculated by diving four yields by a total of 10 vehicles encountered in the trial.

The temporal separation between vehicles 2-3, 5-6, and 9-10 constituted three crossable gaps, the last of which was utilized by the pedestrians. The gap from the start of the trial to vehicle 1, and the gaps between vehicles 4-5 and 8-9 were below the crossable gap threshold. The measure P(CG)=50.0% is calculated by dividing three crossable gaps by six total gaps encountered. P(CG_ENC)=30.0% is calculated by dividing three crossable gaps by a total of ten events.

The rates of yield and crossable gap utilization are calculated at P(GO|Yield)=0.0% and P(GO|CG)=33.3%, respectively. The reasons for not utilizing one of these crossing opportunities may include uncertainty about driver intent or high levels of ambient noise. Delay is defined as the temporal duration from the time the trial starts until the pedestrian initiates the crossing. The Minimum Delay is less, calculated as the time spent waiting until the first crossing opportunity, which in this case is the yield by vehicle 2.

Site Description

All three studied roundabouts have one circulating lane and single-lane entries and exits. The major approaches at the roundabouts are arterial streets with a mix of commuter and local traffic. All three roundabouts have university or city bus stops in close proximity and thus exhibit at least some heavy vehicle activity. Site DAV-CLT is located at the intersection of 9th Street and Davidson Street in Charlotte, NC in a downtown residential area and has an inscribed diameter of 100-120 feet (30.5-36.6m). The major approach at DAV-CLT has an approximate Average Annual Daily Traffic (AADT) of 9,900 vehicles. Site PS-RAL is located at the intersection of

Pullen Road (AADT 15,000) and Stinson Drive in Raleigh, NC near a major university with an inscribed diameter of 88 feet (26.8m). Site ULY-GOL is located at the intersection of Golden Road (AADT 15,000) and Ulysses Drive in Golden, CO in a suburban business district and has an inscribed diameter of 100 feet (30.5m). Figure 2 shows aerial views of all three sites. The studied crosswalks are highlighted.

a) DAV-CLT

b) PS-RAL

c) ULY-GOL

Figure 2: Aerial views of Comparison roundabouts (Source: www.bing.com)

Descriptive Statistics

Table 1 shows a summary of the comparison of the three roundabouts for the described measures. The three studied single-lane roundabouts exhibit considerable differences in the performance assessment. Site ULY-GOL shows higher P(Yield) rates than the remaining two sites, with DAV-CLT having the lowest yielding rates. The likelihood of encountering a yield, P(Y_ENC), follows a similar trend. The rates of yield utilization are comparable for PS-RAL and ULY-GOL, with a slightly lower rate observed for DAV-CLT.

Table 1: Summary Comparison of Three Single-Lane Roundabouts

	Site ID					
	DAV-CLT		**PS-RAL**		**ULY-GOL**	
	ENTRY	EXIT	ENTRY	EXIT	ENTRY	EXIT
P(Yield)						
Mean	10.8%	11.8%	41.5%	18.2%	65.6%	20.2%
Std.Dev	8.9%	7.9%	32.8%	17.9%	36.1%	17.2%
P(Y_ENC)						
Mean	5.8%	6.7%	37.9%	28.1%	51.1%	29.6%
Std.Dev	4.8%	5.0%	17.8%	14.4%	18.4%	13.7%
P(GO|Yield)						
Mean	64.1%	70.4%	83.0%	87.8%	82.8%	76.0%
Std.Dev	41.2%	44.1%	20.4%	14.1%	20.1%	26.1%
P(CG)						
Mean	62.1%	60.9%	53.5%	50.2%	53.7%	29.8%
Std.Dev	14.2%	12.9%	28.1%	23.5%	21.6%	12.2%
P(CG_ENC)						
Mean	29.8%	27.8%	17.7%	20.5%	26.3%	20.6%
Std.Dev	6.9%	6.7%	8.9%	9.7%	12.4%	8.4%
P(GO|CG)						
Mean	66.3%	60.3%	52.0%	63.6%	83.2%	86.8%
Std.Dev	20.6%	17.9%	41.3%	26.6%	23.7%	23.4%
Delay (sec.)						
Mean	26.6	24.0	10.5	11.6	10.9	13.0
Std.Dev	17.0	9.7	8.9	6.8	7.3	7.9
Delay >Min (sec.)						
Mean	18.8	17.2	5.6	6.1	2.8	2.7
Std.Dev	15.5	9.6	7.2	5.8	2.1	2.3

The rates of gap availability show the reverse trend from the yielding data with DAV-CLT showing the highest availability of crossable gaps, followed by PS-RAL and ULY-GOL. The rate of gap utilization is highest at ULY-GOL, followed by DAV-CLT and PS-RAL.

The overall delay is comparable for PS-RAL and ULY-GOL, but highest at DAV-CLT, a trend mirrored by the Delay>Min statistics. Interestingly, the highest delay is evident at the site with the lowest availability of yields and a lower rate of yield utilization. At similar crossable gap and gap utilization rate across the three sites, this may suggest that the lack of yielding at the site contributes to delay difference. This point is explored further on the delay model development for individual participants.

The results in Table 1 point to a high level of inter-subject variability as evident in high observed standard deviations. With high standard deviations, the interpretation of the accessibility of a single site is challenging. But for the purpose of model development, the observed variability is considered an asset. For example, if no variability in yielding was observed, it would be impossible to use that variable to predict pedestrian delay. The critical point in this context is that the observed variability (in yielding) is correlated with pedestrian delay. Consequently, if the model development process shows that an increasing likelihood of yielding results in reduced pedestrian delay, the yield probability becomes an important explanatory variable in the delay prediction model.

MODEL DEVELOPMENT

For the purpose of model development, some additional performance measures are defined in this section that are used as independent variables in model development, in addition to the ones already defined above. The dependent variables are the two delay variables as defined previously. The following three variables are obtained by summation and multiplication of the intermediate behavioral probability parameters.

- **P(Yield_and_GO):** The probability of crossing in a yield, defined as the probability of utilizing a yield multiplied by the probability of encountering a yield:

  P(Y_and_GO) = P(Y_ENC)*P(GO|Y).
- **P(CG_and_GO):** The probability of crossing in a crossable gap, defined as the probability of utilizing a CG multiplied by the probability of encountering a CG:

  P(CG_and_GO) = P(CG_ENC)*P(GO|CG).
- **P(Crossing):** The probability of crossing, defined as the sum of the probabilities of crossing in a yield and crossing in a crossable gap.

  P(Crossing): = P(Y_and_GO) + P(CG_and_GO)

Additional independent variables used in the analysis are:

- **Site_Gol:** Dummy variable that identifies the site as GOL-PRE if Site_Gol=1.
- **Site_RAL:** Dummy variable that identifies the site as PS-RAL if Site_RAL=1. By definition, if Site_Gol=Site_Ral=0 then the data refers to an observation at DAV-CLT.
- **ENTRY**: Dummy variable denoting that the observation represents the average of events at the roundabout entry if ENTRY=1.

A total of 40 subjects were included in the analysis from three different sites. Each observation represents the average of four or more lane crossings at a particular site. With the distinction of entry versus exit crossings, the dataset contains 80 observations. However, four observations had to be excluded because these subjects had one or more zero observations. This can occur because they either didn't encounter any crossable gaps or because no drivers yielded for them. As a result, the final data set contained 76 observations. Descriptive statistics for the data set in Table 2 suggest that a range of values was observed for most probability terms, suggesting a good basis for model development.

Table 2: Descriptive Statistics for Delay Model Data Set

Variable	Site	N	Mean	Std Dev	Min	Max
P(Y_ENC)	All	76	27.7%	18.8%	1.7%	66.7%
P(GO|Yield)	All	76	61.4%	37.0%	0.0%	100.0%
P(CG_ENC)	All	76	24.7%	8.3%	4.8%	44.4%
P(GO|CG)	All	76	71.5%	28.0%	0.0%	133.3%*
p(yield_and_go)	All	76	21.7%	18.5%	0.0%	58.3%
p(CG_and_go)	All	76	17.5%	8.6%	0.0%	44.4%
p(Crossing)	All	76	39.2%	21.1%	12.1%	88.9%
Entry	All	76	48.7%	50.3%	0.0%	100.0%
Delay	All	76	15.5	10.6	3.5	58.3
Delay_overMin	All	76	7.8	9.1	0.1	46.0

* A value of P(GO|CG)>1.0 can occur when a pedestrian utilizes a "non-crossable" gap that is below the selected CG threshold.

The model development uses a multi-linear regression approach to predict the dependent variable, delay, as a function of various independent variables. All variables are given on a per leg basis at the roundabout and as a result the total delay at the crossing is the sum of predicted entry and exit delays. A histogram of the distribution of the delay variable showed significant skew to the left, suggesting a log-normal distribution. Consequently, all predictive probability variables were transformed by applying the natural logarithm of the variable. All regression is performed in SAS statistical analysis software using PROC GLM, a procedure to perform multi-linear regression.

RESULTS

The analysis includes a range of models to explain the dependent variable as a function of the behavioral probability terms. Table 3 shows seven models for the Delay dependent variable.

Table 3: Regression Results for Dependent Variable Delay

	Model A	**Model B**	**Model C**	**Model D**	**Model E**	**Model F**	**Model G+**
	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate
Intercept	-15.40 ***	0.90	-11.21 **	9.31 **	-4.45 *	-1.54	-0.78
ln_y_enc	-4.65 ***	-2.35 *					
ln_GO_given_y	-5.78 ***	-3.54 ***					
ln_cg_enc	-3.48 **	-2.62					
ln_GO_given_CG	-9.32 ***	-8.66 ***					
ln_yield_and_go			-6.11 ***		-3.33 ***		
ln_gap_and_go				-9.20 ***	-6.03 ***		
ln_cross						-15.75 ***	-14.99 ***
Entry	1.29						
site_gol	13.21 ***		14.97 ***	-12.43 ***		1.97	
site_ral	8.30 **		13.71 ***	-17.34 ***		-3.29	
Pr > F	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
DF	7	4	3	3	2	3	1
R-Square*	0.779	0.679	0.634	0.460	0.640	0.683	0.641
Adj. R-Square*	0.755	0..659	0.619	0.436	0.630	0.670	0.636

\+ Represents Suggested Model
* Significant at $p < 0.1$
** Significant at $p < 0.05$
*** Significant at $p < 0.01$

The delay models in Table 3 suggest a good overall fit, with most variables having a significant explanatory effect on the response. The variable ENTRY is not significant in any model, including others that are not shown. This is explained, because differences in behavior at entry and exit leg are already captured in the probability terms. Model A and several other models suggests a significant effect of the site dummy variables with variables SITE_RAL and SITE_GOL shifting the overall delay curve upward relative to site DAV_CLT. This finding is significant, because the descriptive statistics in Table 1 suggested that this site had the highest overall delay. The model results suggest that the high observed delays at DAV_CLT are explained by the relative lack of crossing opportunities and that the delays at PS_RAL and ULY_GOL would have been much higher with more traffic (fewer crossable gaps) and less courteous driver behavior (fewer yields).

The goal of this analysis is the development of a universal pedestrian delay model for single-lane roundabouts. Therefore, additional models were tested without the site effects. The guiding principles for the final model were significant parameter estimates, a high adjusted R-Square value, and a relatively simple model form. When removing the site variables from Model A, the four probability terms in Model B lose statistical validity. Consequently, the remaining models use the pooled probability terms. Model E and G both represent viable alternatives, predicting delay as a function of P(Yield_and_Go) and P(CG_and_GO) and the overall probability P(Cross), respectively. Both models have comparable adjusted R-Square values and significant parameter estimate. Ultimately, model G was selected, because it provides a better fit with the data at low probability values. In turn Model E was overly optimistic at low probabilities. Both models converge in the higher probability ranges (See Figure 3).

The recommended model G predicts pedestrian delay as a function of P(Cross), which is calculated from the four individual probability parameters. The overall model and the P(Cross) parameter are significant p<0.0001. The adjusted R-Square value suggests that 63.6% of the variability in the data is explained by the model, which is very high given that inter-subject variability of crossing performance was very high. Equation 1 shows the suggested pedestrian delay model.

Equation 1: Suggested Pedestrian Delay Model (Model G)

$$d_p = -0.78 - 14.99 * LN(P_{CROSS})$$

where,

d_p = average pedestrian delay (s)

P_{CROSS} = Probability of Crossing

= P(Y_ENC)*P(GO|Yield)+P(CG_ENC)*P(GO|CG)

Figure 3 plots the predicted pedestrian delay as a function of P(Cross), which is the sum of the $P_{Y\&GO}$ and $P_{CG\&GO}$ model parameters. The different data points were obtained by strategically varying P(Y_ENC) and P(CG_ENC) for a fixed utilization of P(GO|YIELD)=P(GO|CG)=0.5. The figure shows that the general trends of the model delay curves fall within the cloud of observed data (blue crosses). The figures shows that in a comparison of Models E (green triangle) and G (blue squares) with field-observed delays, the latter fits the data better in the lower P(Y_ENC) and P(CG_ENC) region.

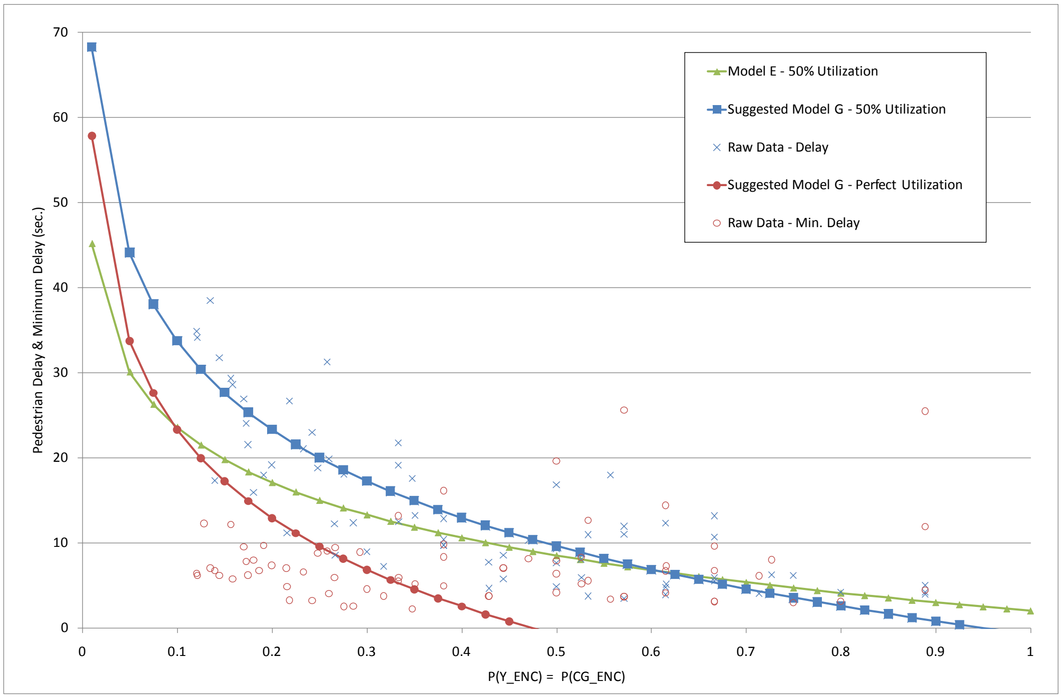


Figure 3: Graphical Comparison of Model 5 against Field Data

Figure 3 further plots the curve for suggested model G corresponding to perfect opportunity utilization of P(GO|YIELD)=P(GO|CG)=1.0 (red filled circles). This curve may approximate the behavior of a sighted pedestrian, assuming that this group of pedestrians has identical thresholds for crossable gaps. Given that the definition used for crossable gap is consistent with the HCM, the resulting delay should be an appropriate, albeit conservative estimate. The perfect utilization curve generally fits well with the observed minimum delay times (red hollow circles), which were calculated by subtracting the Delay_OverMin from the observed delay for each subject.

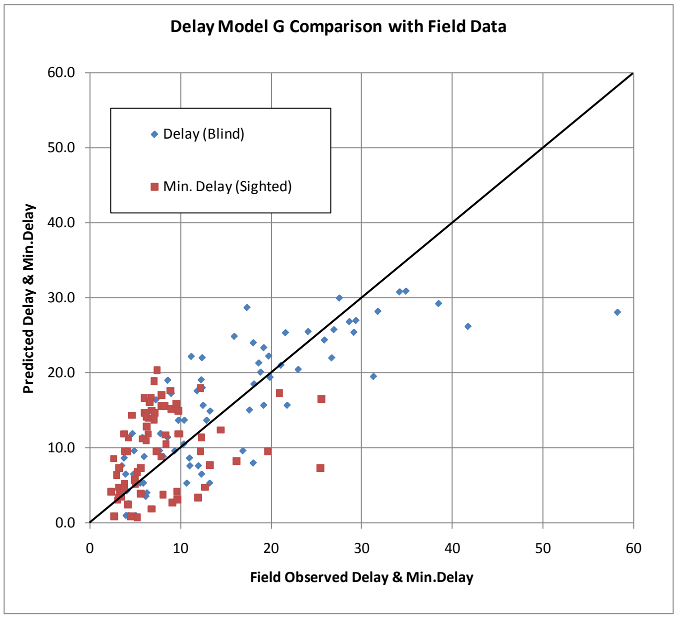


Figure 4: Field Observed versus Predicted Delay and Min. Delay

Figure 4 plots the field-observed and predicted delay and minimum delay for all 76 data points. The delay corresponds to the actual crossing experience of the blind study participants. The minimum delay approximates the corresponding crossing experience of sighted pedestrians encountering the same number of yields and crossable gaps, but having perfect opportunity utilization.

Figure 5 shows a sensitivity analysis of the four base probability parameters (P(Y_ENC), P(GO|Yield), P(CG_ENC), and P(GO|CG) against the field-observed range of those data. In each of the sub-figures, one of the probability parameters was varied from 0.0 to 1.0 (shown on the x-axis), while keeping the other three fixed at two varying levels. The first level uses the field average for that parameter for all subjects as shown in Table 2. The second level again assumes perfect utilization, approximating the delay for a sighted pedestrian.

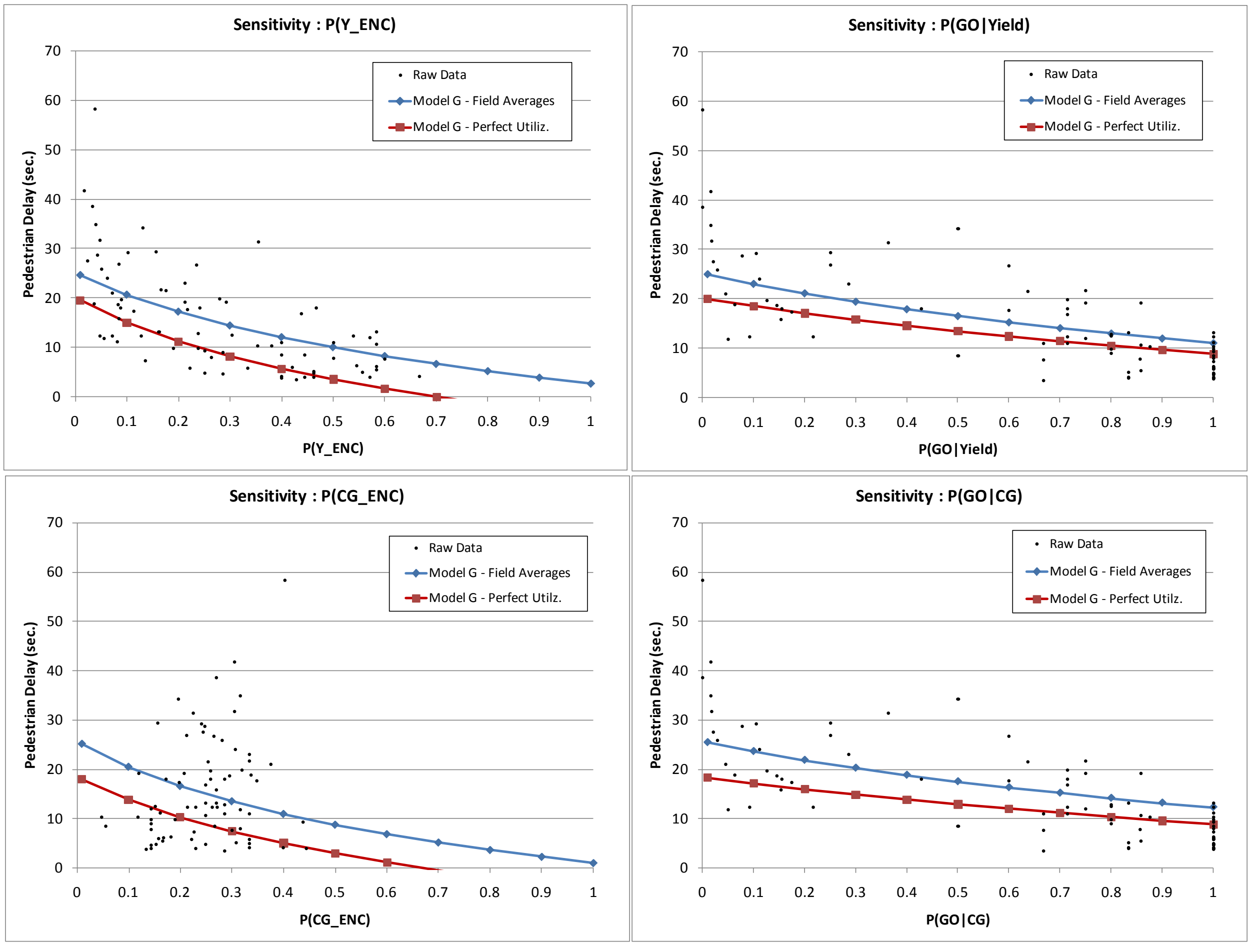


Figure 5: Model 5 Sensitivity versus Field Data

The plots in figure 5 show how the delay model responds to changes in one of the four probability terms. The greatest sensitivity is evident for rates of yield and gap encounter, P(Y_ENC) and P(CG_ENC), suggesting that changes in these parameters have the biggest impact on the predicted delay. The sensitivity curves for the utilization curves are flatter, suggesting that improvements to the ability (or willingness) of pedestrians to utilize crossing opportunities has less of an effect than changing the overall occurrence of these opportunities. All plots generally show a good fit with observed field data. The worst fit is evident for the P(CG_ENC) plot, where the majority of field observations are clustered towards a low gap occurrence rate. With increasing probability levels, the predicted pedestrian delay decreases. The delay estimate for perfect utilization is expectedly below the field averages.

DISCUSSION

The delay model presented in equation 1 above can be used to predict the delay at single-lane roundabouts by estimating the four probability parameters P(Y_ENC), P(GO|YIELD), P(CG_ENC), and P(GO|CG) that ultimately feed into the model parameters. In order to apply the model to predict delay at single-lane roundabouts, theses parameters therefore need to be field-measured or derived from literature, previous studies, and traffic theory.

The rate of driver yielding and the availability of crossable gaps can easily be measured in the field using manual tally and stop watch methods described in the ITE Manual of Transportation Studies (*19*) or other sources. In the absence of field data, a recent NCHRP Report (*14*) has collected data on driver yielding behavior at US roundabouts that can be used for guidance. The availability of crossable gaps can be estimated using traffic flow theory concepts based on traffic volume and an assumed headway distribution. Using a negative exponential distribution, the probability of observing a headway greater than t_c seconds is given by (*20*):

Equation 2: Estimating P(CG_ENC) from Traffic Flow Theory (*20*)

$$P(headway \geq t_c) = e^{-\frac{t_c}{t_{avg.}}}$$

where,
t_c = critical headway for crossable gap (sec.)
t_{avg} = average headway, defined as t_{avg}=(3,600sec/hour) / (V vehicles/hour)

In the absence of pedestrian platoons, the critical gap for pedestrians can be calculated by equation 3 following the HCM (*5*) methodology:

Equation 3: Pedestrian Critical Gap after HCM2000 Equation 18-17 (*5*)

$$t_c = \frac{L}{S_p} + t_s$$

where,
L = crosswalk length (ft)
S_p = average pedestrian walking speed (ft/s), and
t_s = pedestrian start-up and clearance time (s)

Using the above relationship, the probability of observing a crossable gap in a stream of 400 vehicles per hour at a 14 foot-lane at a roundabout and a corresponding critical headway of t_c=14/3.5+2=6 seconds is:

$$P(headway \geq 6\,\text{sec.}) = e^{-\frac{t_c}{t_{avg.}}} = e^{-\frac{6}{9}} = 51.3\%$$

The estimation of yield and gap utilization rates is more difficult for blind pedestrians, since it requires controlled field experiments. In the absence of field data, the results from the three roundabouts used in this analysis that were presented in Table 1 can be used as a starting point. For sighted pedestrians utilization rates of or near 1.0 can be assumed. For other special pedestrian populations, including children and the elderly analyst judgment will be required. A basic sensitivity analysis can assure that a range of values are considered.

The sensitivity of the model to the different probability parameters that was presented in Figure 5 can inform the debate on how to reduce pedestrian delay through the use of pedestrian crossing treatments. An extensive national survey of different pedestrian crossing treatments and their impact on driver yielding behavior is found in NCHRP Report 562 (*14*). For example, a treatment that enhances driver yielding from 10% to 30% while keeping the availability of crossable gaps fixed at 20% would presumably decrease the pedestrian delay for sighted pedestrians (perfect utilization) from 13.0 to 4.6 seconds, and the delay for a blind pedestrian (assumed 50% utilization) from 23.3 to 15.0 seconds.

Pedestrian crossing treatments tested in (*14*) included some with red signal indication, some with yellow flashing beacons, and other static signs that are all intended to increase driver yielding. The results suggested a large variability of the effectiveness of different treatments depending on site-specific parameters. In other research (*7*) driver yielding behavior was found to increase with decreasing vehicle speeds. Consequently, low roundabout design speeds and traffic calming treatments may be the most effective treatment to assure pedestrian accessibility. This hypothesis is supported by the model response to increases in P(Y_ENC) shown in Figure 5.

The forthcoming report of NCHRP Project NCHRP 3-78 (*12*) will include field-observed data on the effect of special blind pedestrian treatments in enhancing both the availability and utilization of crossing opportunities. Following the delay framework, any treatment that improves one or more of the underlying probability parameters will reduce overall pedestrian delay.

CONCLUSION

This paper demonstrated the application of a framework based on pedestrian and driver behavioral parameters to develop a mixed-priority delay models for pedestrian crossings at single-lane roundabouts. Mixed-priority refers to crosswalk operations where drivers sometimes yield to create crossing opportunities, but where pedestrians sometimes have to rely on their judgment of gaps in traffic to cross the street. The underlying data set was obtained from controlled experiments including 40 blind pedestrians at three different single-lane roundabouts. It can however be readily adopted to sighted pedestrians or other special populations by varying the appropriate probability parameters. The use of data from blind pedestrians proved to be extremely valuable, since it allowed the distinction between available crossing opportunities and the actual utilization of these opportunities. A dataset containing only sighted pedestrians expectedly would not have captured the utilization effect, since sighted pedestrians would likely utilize the first opportunity that is presented to them. The delay to sighted pedestrians can be predicted with the developed model by assuming perfect utilization. However, the model further allows the analyst to consider pedestrian populations with less-than perfect rates of opportunity utilization. In addition to fully blind participants, the approach is therefore adoptable to people with low vision or children, who have been shown to have difficulty judging the speed and distance of oncoming traffic (9).

The resulting mixed-priority delay model is statistically significant and produces good estimates of pedestrian delay that match observed field data. It is applicable to situation where pedestrian delay is governed by a mix of pedestrian gap acceptance and driver yielding behavior. The underlying probability terms can be estimated from field observations for other sites, or can be estimated from literature or traffic flow theory concepts. In future research, the authors hope to expand the data collection and analysis to other unsignalized crossing locations, including multi-lane roundabouts, which pose more severe crossing difficulties for both blind and sighted pedestrians.

The authors recognize that the material presented here has potential implications for the ongoing national debate in the US on the accessibility of modern roundabouts to pedestrians who are blind. The focus of this paper is not to make policy statements, but rather to contribute to that debate. The question of roundabout treatments and signalization are much discussed in the roundabout engineering and accessibility communities and go far beyond the scope of this paper.

The authors hope that the developed delay models can assist with that discussion by offering readers a methodology for quantifying and predicting (blind) pedestrian delay at roundabouts. However, it is emphasized that the approach presented here disregards the implications on pedestrian safety, which is at least equally important to delay. The readers are encouraged to consult the final report for NCHRP project 3-78a (*11*) for a more complete discussion of these accessibility issues.

ACKNOWLEDGMENTS

The authors would like to thank the National Institutes of Health and the National Academies of Science for their financial support and the members of the project teams, who have provided continuous feedback to the research efforts. The authors would further like to acknowledge staff at Western Michigan University and Accessible Design for the Blind, who were instrumental in running the studies. The authors would also like to thank the Cities of Charlotte, NC, Raleigh, NC, and Golden, CO for facilitating the data collection efforts.

The NIH project described was supported by Grant Number R01EY12894 from the National Eye Institute. This content is solely the responsibility of the authors and does not necessarily represent the official views of the National Eye Institute or the National Institutes of Health.

REFERENCES

1) Kittelson and Associates, Roundabout / Traffic Circle Inventory Database. http://roundabouts.kittelson.com/InvMain.asp. Accessed July 24, 2009.

2) Rodegerts, Lee, et al. (2007), *Roundabouts in the Unites States*. NCHRP Report 572. National Cooperative Highway Research Program. Transportation Research Board. Washington, DC. 2007

3) FHWA (2000), *Roundabouts: An Informational Guide*. Federal Highway Administration. Turner Fairbank Highway Research Center. FHWA-RD-00-067. McLean, VA. 2000

4) Michigan Legislature (1949), *Michigan Vehicle Code - Section 257.612 (ii).* http://www.legislature.mi.gov. Accessed, July 27, 2009. Detroit, MI, 1949.

5) *Highway Capacity Manual (HCM),* Transportation Research Board (TRB), Washington, DC 2000.

6) Ashmead, Dan, David Guth, Robert Wall, Richard Long, & Paul Ponchillia (2005). Street crossing by sighted and blind pedestrians at a modern roundabout. *ASCE Journal of Transportation Engineering,* Vol. 131, No. 11., November 1, 2005, 812-821

7) Geruschat, Duane and Shirin Hassan (2005), *Driver Behavior in Yielding to Sighted and Blind Pedestrians at Roundabouts*. Journal of Visual Impairment and Blindness. Volume 99, Number 5, May 2005.

8) Guth, David, Dan Ashmead, Richard Long, Robert Wall, & Paul Ponchillia, (2005). Blind and sighted pedestrians' judgments of gaps in traffic at roundabouts. *Human Factors, 47*, 314-331.

9) Connelly, M,. Isler, R.. & Parsonson. B. (1996), Child pedestrians' judgments of safe crossing gaps at three different vehicle approach speeds: A preliminary study. *Education and Treatment of Children, t9.* 19-29.1996

10) Schroeder, Bastian and Nagui Rouphail (2007). *A Framework for Evaluating Pedestrian-Vehicle Interactions at Unsignalized Crossing Facilities in a Microscopic Modeling Environment*. Presented at the 86th Annual Meeting of the Transportation Research Board, Washington, DC. 2007

11) Schroeder, Bastian, Nagui Rouphail, and Ronald Hughes, (in press). *A Working Concept of Accessibility - Performance Measures for the Usability of Crosswalks for Pedestrians with Vision Impairments*. Transportation Research Record: Journal of the Transportation Research Board. Washington, D.C. in press

12) TRB (2008), National Cooperative Highway Research Program (NCHRP) Project 3-78 (ongoing). Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities. Institute of Transportation Research and Education. Raleigh, North Carolina

13) NIH/NEI Bioengineering Research Partnership Grant R01 EY12894-03

14) Fitzpatrick, Kay, et al. (2006), *Improving Pedestrian Safety at Unsignalized Intersections*. TCRP Report 112/NCHRP Report 562. Transportation Research Board. http://onlinepubs.trb.org Accessed February 2009. Washington, D.C. 2006.

15) Brilon, W., B. Stuwe, and O. Drews. Sicherheit und Leistungsfähigkeit von Kreisverkehrsplätzen (Safety and Capacity of Roundabouts). Research Report. Ruhr-University Bochum, 1993.

16) Department of Justice, DOJ (1990), *The Americans with Disabilities Act of 1990*. Title 42, Chapter 125 of the United States Code. The United States Access Board. http://www.ada.gov. Accessed February 2009. Washington, D.C. 1990.

17) US Access Board (2006), *Revised Draft Guidelines for Accessible Public Rights-of-Way*. http://www.access-board.gov/prowac/draft.htm. Accessed July 8, 2008

18) Schroeder, Bastian (2008), *A Behavior-Based Methodology for Evaluating Pedestrian-Vehicle Interaction at Crosswalk*. Doctoral Dissertation in Civil Engineering, North Carolina State University. May 2008

19) Robertson, Douglas, Joseph Hummer, and Donna Nelson (1994), *Manual of Transportation Engineering Studies*. Institute for Transportation Engineers (ITE). Washington, D.C. 1994

20) May, Dolf (1990), *Traffic Flow Theory Fundamental*. Prentice Hall, Inc., Upper Saddle River, NJ. 1990

APPENDIX L: Details on Roundabout Signalization Modeling

This Appendix was previously published as conference proceedings at the 86th Annual Meeting of the Transportation Research Board, January 21-25, 2007. The citation for this work is:

Schroeder, Bastian J., Nagui M. Rouphail and Ron Hughes. *Exploratory Analysis of Pedestrian Signalization Treatments at One- and Two-Lane Roundabouts Using VISSIM Microsimulation*. 86th Annual Meeting of the TRB, 2007.

Exploratory Analysis of Pedestrian Signalization Treatments at One- and Two-Lane Roundabouts Using VISSIM Microsimulation

By

Bastian Jonathan Schroeder, E.I.*
Graduate Research Assistant
Institute of Transportation Research and Education (ITRE)
North Carolina State University
Centennial Campus, Box 8601
Raleigh, NC 27695-8601
Tel.: (919) 515-8565
Fax: (919) 515-8898
Email: Bastian_Schroeder@ncsu.edu

Nagui M. Rouphail, Ph.D.
Director, Institute for Transportation Research and Education (ITRE)
Professor of Civil Engineering
North Carolina State University
Centennial Campus, Box 8601
Raleigh, NC 27695-8601
Tel.: (919) 515-1154
Fax: (919) 515-8898
Email: rouphail@eos.ncsu.edu

Ron Hughes, Ph.D.
Director, Visual Analytics, Modeling and Simulation (VAMS) Group
Institute for Transportation Research and Education (ITRE)
North Carolina State University
Centennial Campus, Box 8601
Raleigh, NC 27695-8601
Tel.: (919) 515-8523
Fax: (919) 515-8898
Email: rghughes@ncsu.edu

November 2006

Submitted for publication and presentation at the 86th Annual Meeting of the Transportation Research Board, January 21-25, 2007

Word Count: 5,551 text words plus 2,000 for figures/tables (8*250) = 7,551 total

* Corresponding Author

ABSTRACT

This paper explores the use of signalized pedestrian crossing treatments at one- and two-lane roundabout facilities. Motivated through increasing debate on the safety of roundabouts for pedestrians, this paper assesses the potential for signalization as a means for regulating the interaction of vehicles and pedestrians at these facilities. The use of pedestrian signals at roundabouts is controversial because of the potential for queue spillback into the circulating lane. This paper aims to quantify the effects of different signalization treatments through microsimulation.

The paper uses the microscopic modeling tool VISSIM to estimate impacts on pedestrian and vehicle delay for different crossing geometries and signalization schemes. The range of alternate crossing geometries includes ‘proximal’, ‘zig-zag’, and ‘distal’ crossings with varying offset distances of entry and/or exit crosswalk from the circulating lane. The modeled signalization options include one-stage and two-stage pedestrian-actuated control, as well as, the use of HAWK signals. The vehicle models for one- and two-lane roundabouts have been calibrated and will be used to conduct sensitivity analyses for a range of pedestrian and vehicle demands for the different scenarios.

The results suggest that the impact of a pedestrian signal at roundabouts is greatest as vehicle volumes approach capacity, but that vehicle delay and queuing can be minimized through innovative signal configurations. The findings are important in light of recent discourse concerning the accessibility of roundabouts to pedestrians with vision impairments that may ultimately move towards a requirement for signalization for certain facility types.

INTRODUCTION

The installation of pedestrian crossing signals at roundabout facilities is a controversial topic in the traffic engineering community. While some US cities have experimented with their use and while their application is more common in Europe and Australia, a common contention is that any form of signalization disrupts the flow of traffic in a roundabout.

The attractiveness of a well-designed roundabout is the ability of vehicles to navigate this unsignalized intersection form in a safe and efficient manner. But as more roundabouts are being designed in pedestrian-intensive urban areas, there is a need to evaluate their accessibility for the pedestrian mode. In fact, many downtown revitalization and gateway projects that include roundabouts also focus on a significant pedestrian element.

While signals are not the only imaginable treatment to facilitate pedestrian access to modern roundabouts, they are a certain contender in areas of heavy vehicular traffic and at multi-lane facilities. This paper uses a microsimulation approach to assess and compare different alternative signalization treatments at a one-lane and a two-lane roundabout. The analysis includes an evaluation of modified crosswalk geometries and signalization schemes under a range of pedestrian and vehicular volumes. The goal of this effort is to explore these alternatives and provide traffic engineers with a quantitative basis for the discussion of roundabout signalization.

BACKGROUND

The accessibility of modern roundabouts for pedestrians with vision impairments has received a lot of attention in recent years. At unsignalized facilities, blind pedestrians have to rely on auditory cues when making a crossing decision – a task that is complicated through the ambient noise and uninterrupted flow at roundabouts. Ashmead et al (2002) found that these facilities indeed pose serious difficulties for blind pedestrians. More specifically, researchers have found that crossing becomes increasingly difficult as the conflicting vehicle volume increases and that multi-lane facilities are more challenging than single-lanes (Wall et al. 2005). Guth at al (2005) further showed that crossings at roundabout exit legs are more difficult than at entry legs.

The objective of the NCHRP 3-78 research effort is to identify treatments that hold potential for improving access of blind pedestrians to modern roundabouts and channelized right-turn lanes, while maintaining acceptable vehicle levels of service. The research is working to develop a toolbox of treatments to reduce pedestrian risk and delay. The final list of treatments will cover a range of low to high-cost alternatives, distinguish retrofit treatments and guidance for new site construction, and discuss treatments for varying levels of geometry. The authors have submitted a discussion of an evaluation framework of unsignalized facilities in a separate paper for consideration for publication and presentation at the 86th Annual Meeting of the Transportation Research Board.

In the mix of treatments, signalized alternatives are attractive in terms of providing accessibility, but fall on the high-cost end of the spectrum. If outfitted with audible pedestrian signals (APS), signals presumably assure equal access to pedestrians with vision impairments. In fact, the ‘Revised Draft Guidelines for Accessible Public Rights-of-Way’ (US Access Board, 2005) call for the provisions of "pedestrian activated signals … for each segment of each crosswalk, including the splitter island" at multi-lane facilities. The perceived trade-off of this accessibility from a traffic engineering perspective is an interruption of the intended unsignalized operations of the roundabout. Of concern is especially the increased likelihood of queue spillback into the circulating lane from the exit leg crossing.

While any signalization treatment is intuitively associated with some added delay to vehicular traffic, it is unclear as to how much impact a pedestrian signal would actually have on roundabout operations. The abilities of modern microsimulation software offer the unique opportunity to modeling such treatments in a laboratory setting and evaluating the impact of signals prior to implementation.

APPROACH

The objective of this paper is to evaluate the *pedestrian-induced* impacts of roundabout signalization on vehicular performance. Using calibrated models of a one-lane and a two-lane roundabout, the authors simulated varying signalization options at one approach to the roundabout and compared performance measures to the no-pedestrian base case.

Microsimulation offers a method for unobtrusive evaluation of a range of treatments, implemented at a range of volumes, while minimizing data collection cost. The team used the VISSIM simulation model, because its link-connector structure offers great flexibility in modeling unique roundabout and crosswalk geometries. VISSIM is further able to model user-defined 'priority rules' by vehicle or pedestrian class (PTV, 2005) and includes flexible signal control logic to model unconventional signalization schemes. The evaluation of other simulation packages such as CORSIM, Paramics or AIMSUN was beyond the scope of this effort.

This paper assesses signalization alternatives at roundabouts in three dimensions: crossing geometry, signal phasing schemes, and traffic/pedestrian intensity.

Crossing Geometry

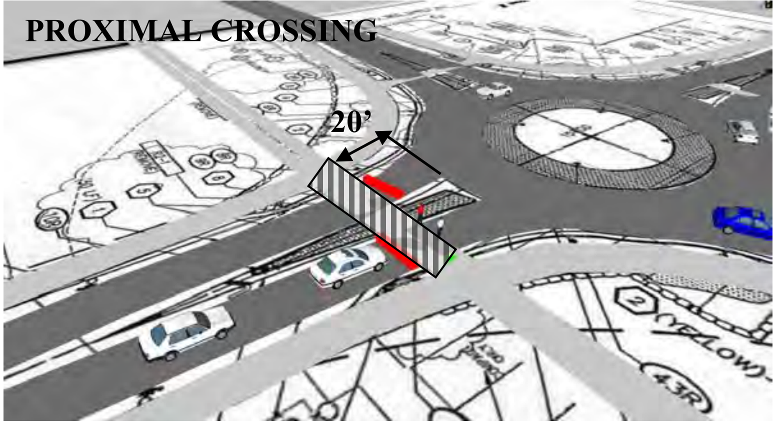
The analysis included three alternative crosswalk configurations for roundabouts. The default crossing configuration at most roundabouts in the US is to place the pedestrian crossing at the splitter island. In the following, this will be referred to as the *proximal* crossing location.

Under the premise that the biggest concern for roundabout signalization from a traffic operations perspective is the potential for queue spillback into the circulating lane, the team experimented with two alternate crosswalk configurations that move all or part of the crossing further away from the circle. In the *zig-zag* crossing configuration, the exit leg component of the pedestrian crossing is 'off-set' by a predefined distance to allow for additional queue storage on the exit leg. Assuming that the default proximal crossing location is at a distance of 20 feet (6.1 meters or approximately one car length) from the circulating lane, the zig-zag configuration moves the exit portion of the crosswalk to a distance of 60 feet (18.3 meters) from the circle. Theoretically, this allows for two additional vehicles per lane to be stored before encroaching on circulating traffic.

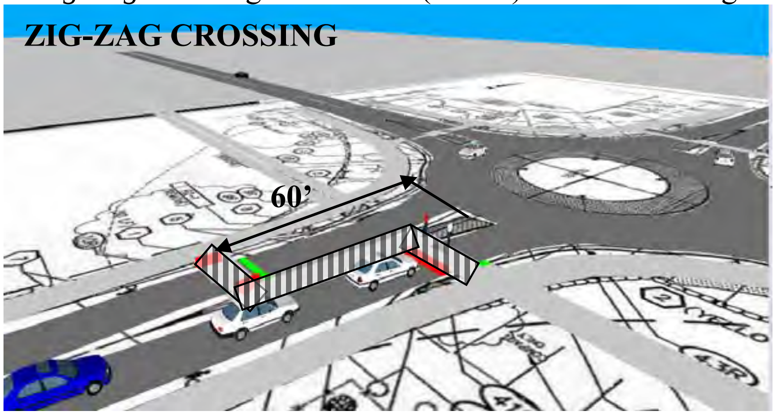
Following the same reasoning, the *distal* crossing configuration moves the entire crosswalk to a distance of 100 feet (30.5 meters) from the circulating lane. In this set-up, both entry and exit leg portions will be moved, to prevent pedestrians from having to travel too far in a longitudinally extended splitter island. The distal crossing theoretically allows for queue storage of 5 vehicles per lane at the exit leg. Figure 1 shows VISSIM screenshots of the proximal, zig-zag and distal crossing configurations for the one-lane roundabout.

Figure 1: Roundabout Crosswalk Configurations

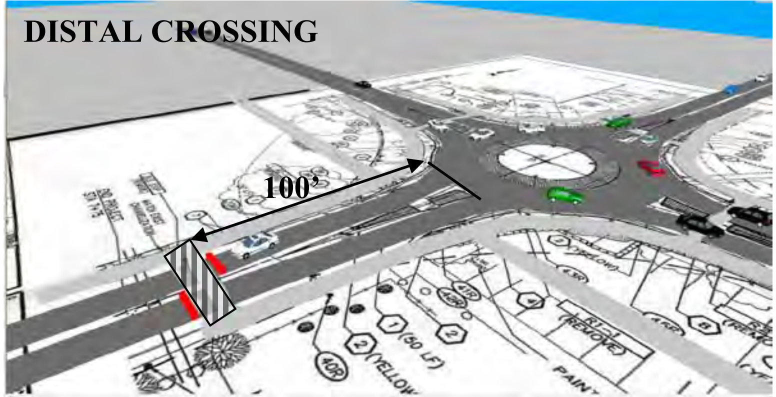
1-a: *Proximal* Crossing located 20’ (6.1m) from circulating lane



1-b: *Zig-Zag* Crossing located 60’ (18.3m) from circulating lane



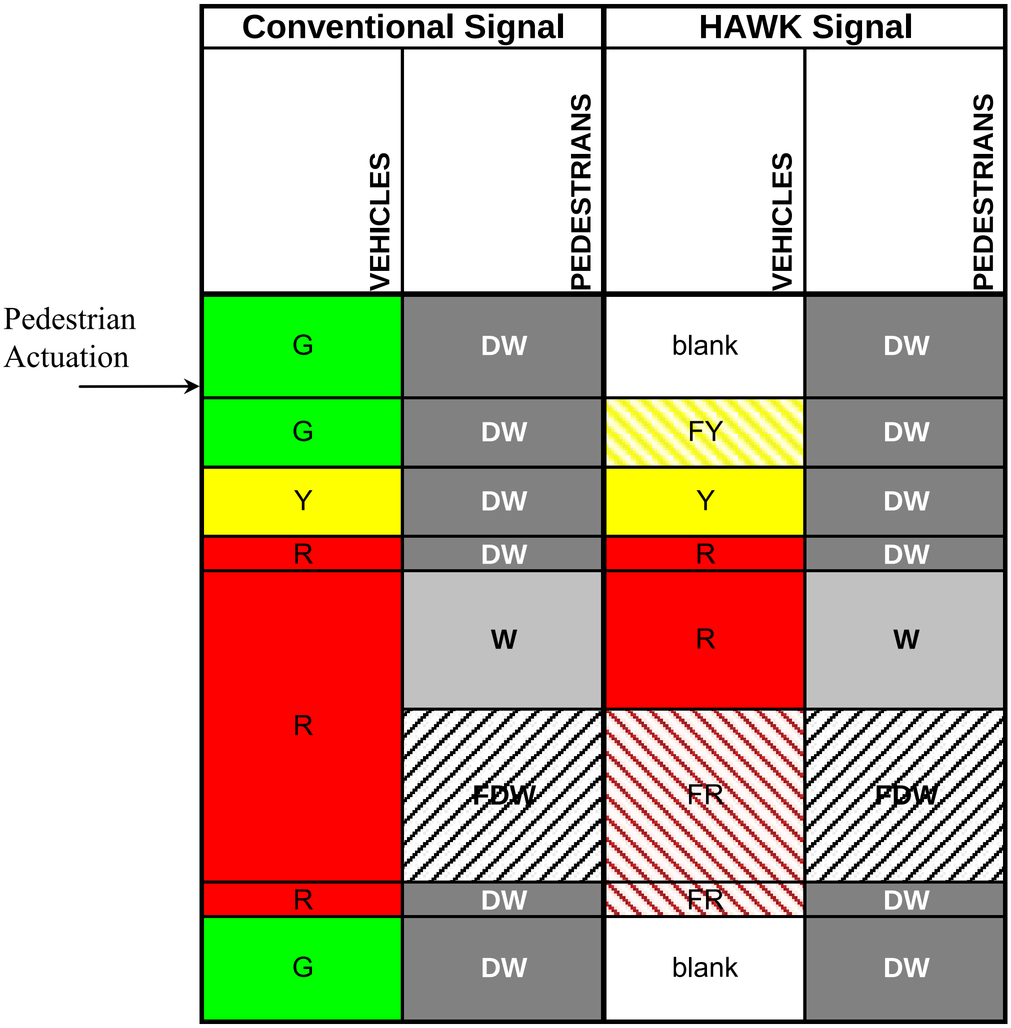
1-c: *Distal* Crossing located 100’ (30.5m) from circulating lane



Signal Phasing Schemes

The analysis compares two different signalization schemes: a conventional pedestrian-actuated (PA) signal, and a pedestrian-actuated '*High-Intensity Activated crossWalk' (HAWK*) signal. The main characteristic of a HAWK signal that distinguishes it from a PA is that vehicles are allowed to 'proceed with caution' during the pedestrian *Flashing Don't Walk* (FDW) phase.
This is achieved by including a *Flashing Red (FR)* phase for vehicles in the phasing sequence. Figure 2 illustrates this concept in a side-by-side comparison with a conventional PA signal.

Figure 2: Comparing Phasing Sequences of 'Conventional PA' and 'HAWK' signals



Pedestrian Actuation

Conventional Signal		HAWK Signal	
VEHICLES	PEDESTRIANS	VEHICLES	PEDESTRIANS
G	DW	blank	DW
G	DW	FY	DW
Y	DW	Y	DW
R	DW	R	DW
R	W	R	W
	FDW	FR	FDW
R	DW	FR	DW
G	DW	blank	DW

In the absence of a pedestrian actuation, the HAWK signal indication for vehicles is *blank*, meaning that the signal heads are not illuminated. Once a pedestrian places a call to the signal, the HAWK signal switches to a flashing *yellow* (FY) indication to alert the driver that a pedestrian is waiting to cross. The HAWK signal then goes through a sequence of *yellow* (Y), *red* (R), and *pedestrian walk* (W) phases, just as a conventional signal would. However, once the pedestrian signal indication switches to *flashing don't walk* (FDW) the vehicle indication becomes a *flashing red* (FR). Similar to the flashing red indication at a signalized intersection in 'nighttime flashing mode', driver need to stop and give the right-of-way to the conflicting stream, in this case the crossing pedestrians. After the pedestrian has left the crosswalk, vehicles can proceed with caution and do not have to wait for the entire FDW clearance interval to elapse as they would at a conventional signal. It is important to note, that from a pedestrian perspective, the sequences of a conventional PA and a HAWK signal are identical.

HAWK signals are currently used in Tucson, AZ (Tucson DOT, 2006) at signalized pedestrian mid-block crossings and may be used in other municipalities in the US. Their proposed benefit from a vehicle operations perspective is a shorter delay to drivers. Especially at multi-lane facilities, the required clearance time for the pedestrian FDW indication can be very long – a function of pedestrian walking speed and the crossing distance. By allowing drivers to proceed with caution as soon as the pedestrian has left the conflict area, the average waiting time for vehicles can presumably be reduced significantly, without sacrificing pedestrian safety or delay.

Just as at midblock crossing, pedestrian signals at roundabouts operate independently of any minor street (at a fully signalized intersection with pedestrian phases a HAWK scheme wouldn't be applicable). It is reasoned that a HAWK signal could provide significant improvements to vehicle delay when compared to a conventional pedestrian-actuated signal; especially at long two-lane roundabout crossings.

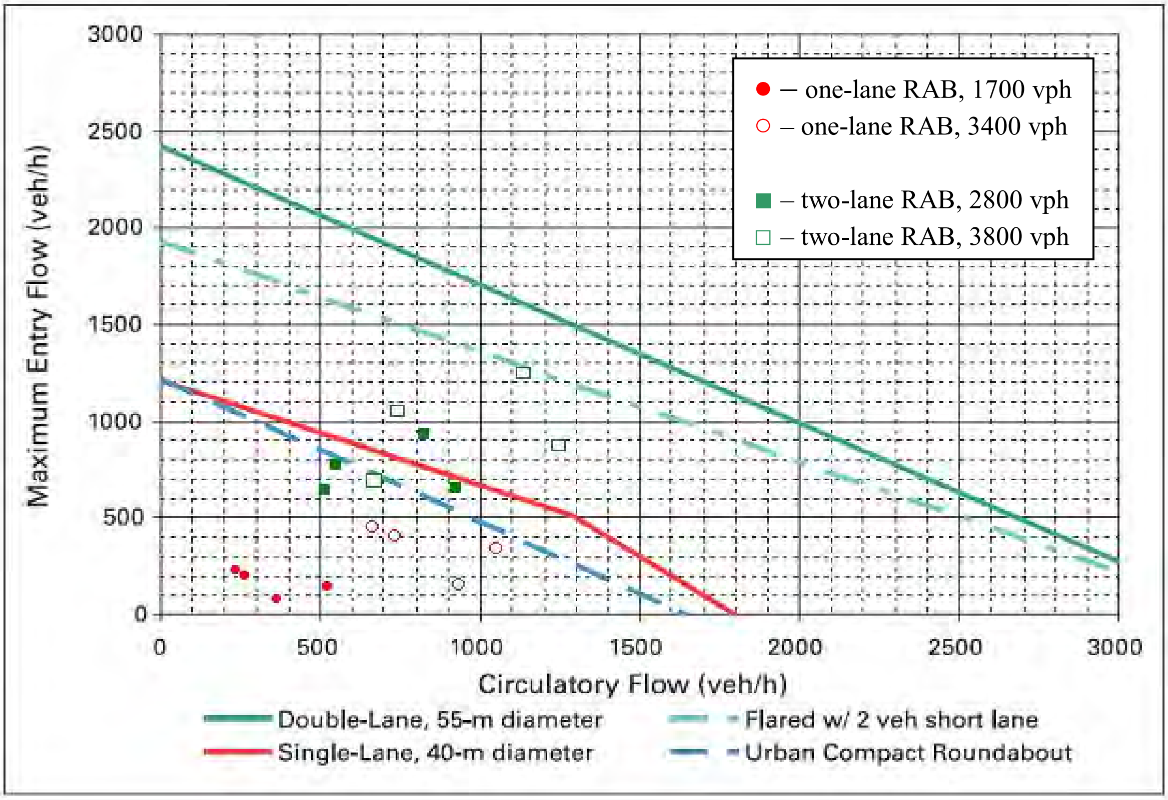
Population Parameters and Intensities

In addition to varying crosswalk geometry and signalization schemes, the analysis included a range of pedestrian and vehicle volumes. Each modeling scenario was analyzed at volumes of zero, 10 and 50 pedestrians per hour. To assess the variability of the pedestrian effect as a function of the frequency of actuations per hour, selected scenarios were tested at an even greater range of pedestrian volumes.

All performance measures of interest, including vehicular delay and queuing were analyzed as *pedestrian-induced* impacts, defined as the difference between a measure at some pedestrian volume compared to the zero-pedestrian case. This form of comparison is possible in a microsimulation environment, if the same random number seeds are used in the two scenarios. With the same random seed, the model will generate the exact same distribution of vehicles, thereby isolating the pedestrian effect.

The analysis further evaluated all scenarios at three different vehicle intensities. In the base volume case, the team used actual traffic volumes collected at a one-lane and a two-lane roundabout site during the NCHRP 3-65 research effort (see 'Model Implementation' section below). In both cases, the observed volumes were below the theoretical capacity for the respective roundabout size as described in the literature (FHWA, 2000). In order to assess signalization impacts at more congested vehicle operations, the traffic intensities were increased at fixed percentages to get them closer to capacity. Figure 3 shows the approximate volume levels of the one-lane and two-lane roundabout test sites superimposed on the roundabout capacity figure in the FHWA guide.

Figure 3: Roundabout Entry Volumes Relative to FHWA Theoretical Capacity



SOURCE: FHWA (2000), Roundabouts: An Informational Guide

In Figure 3, the filled circles indicate the volumes for the four approaches at the one-lane roundabout and the filled rectangles correspond to the two-lane roundabout volumes. These volumes correspond to approximately 1700 vehicles per hour (vph) and 2800 vph, respectively. To investigate signalization impacts at higher volumes, growth rates were applied to each case. The one-lane roundabout volumes were increased by 50% and 100% to get volume scenarios of about 2500 vph and 3400 vph, respectively. For the two-lane roundabout, growth rates of 25% and 35% were used, resulting in 3500 vph and 3800vph. Figure 3 also shows the highest volume cases for the one-lane and two-lane site as hollow circles and rectangles, respectively.

Conceptually, the three vehicle volume levels can be described as ‘existing/below capacity’, ‘approaching capacity’ and ‘oversaturated condition’. When modeling the pedestrian signal, it was generally assumed that the crossing at the approach with the highest vehicle volumes would be signalized.

TREATMENT MATRIX

In developing the treatment test matrix, all three crosswalk configurations were tested in combination with both signalization schemes. In implementing the pedestrian signals, the authors made some assumptions as to whether a particular signal would be more likely to be configured as a one-stage or a two-stage crossing. At a one-stage crossing, the same pedestrian indication is valid for the entire crossing distance and covers both entry and exit lane. Any pedestrian is able to cross the entire roundabout approach and the W and FDW phases are timed accordingly. At a two-stage crossing, it is assumed that the entry and exit lane crossing at a roundabout are timed independently and that it could therefore occur that a pedestrian has to wait on the splitter island.

A two-stage crossing generally results in shorter pedestrian phases and therefore less vehicular delay. While this is a reasonable goal from a traffic engineering perspective, its application is only reasonable where the crossing provides adequate and safe pedestrian storage on the splitter island. At a two-stage crossing, a pedestrian is expected to adhere to the signal indication and wait on the splitter island if so directed. The team assumed that this two-stage implementation is only feasible at the zig-zag crossing configuration and at the proximal crossing at of a two-lane roundabout, because it is reasonable to assume a larger splitter island in those cases. All other crossing configurations are coded as one-stage crossings for reasons of safety and for fear of pedestrian non-compliance.

In the resulting test matrix, the one-lane roundabout was tested with one-stage proximal and distal, and two-stage zig-zag crossings. The two-lane roundabout was tested with one- and two-stage proximal, two-stage zig-zag, and one-stage distal crossings.

For the one-lane roundabout, the team evaluated the 3 crossing configurations and tested each using a conventional pedestrian-actuated (PA) signal and HAWK phasing. Each of the resulting 6 treatment scenarios was modeled for 3 vehicle volume levels and 3 pedestrian intensities, for a total of 54 combinations. The four two-lane roundabout implementations were evaluated accordingly for a total of 72 combinations. Each of the resulting 126 models was replicated 10 times with 10 different random number seeds.

MODEL IMPLEMENTATION

The team coded two roundabout models, a one-lane and a two-lane, and validated the vehicle operations with data obtained from the NCHRP 3-65 research effort. The two models were coded with observed traffic volumes, turning movements, and lane distributions (for two-lane roundabouts) and with geometric design speeds following the FHWA 'Roundabout Informational Guide'. The yielding behavior was coded following the 'priority rule' concept in VISSIM and was applied consistent with guidance in the software manual. The operational performance of the models was validated by comparing model output travel times and approach queuing to field observations. It was assumed that the pedestrian signal is placed at the busiest approach.

Performance Measures

The objective of the analysis was to determine the impact of pedestrians crossing at a signalized approach to the roundabout. In order to distinguish this pedestrian effect from the existing vehicle delay, the team evaluated the roundabout in terms of *pedestrian-induced* impacts as discussed above.

For ease of discussion, the team aggregated the delay outputs to the intersection level by defining a data collection *node* around the entire roundabout. This allowed estimation of average pedestrian delay, and average pedestrian-induced vehicle delay for the roundabout system. Results are reported as the mean values and standard errors from 10 replications.

The team further extracted data on pedestrian-induced vehicle queues; measured just upstream from the entry and exit crosswalks using the default queue definition in VISSIM. The software provides the average (50th percentile) and the maximum queue observed during the analysis period of one hour. A more in-depth queue analysis including 85th percentile queues and a measure of spillback potential was beyond the scope of this effort.

Signalization

When coding the varying signalization schemes, the team used an assumed vehicle minimum green time of 45 seconds, measured from the beginning of vehicular green. A pedestrian call at the signal will only be served after this minimum green time has elapsed and in the absence of such call, the signal will default to vehicle green. The team acknowledges that this phasing implementation is possibly overly simplistic, but was used here for ease of discussion and to allow for a clean comparison between alternative treatments. A more detailed analysis of a traffic detection-based signal implementation including minimum green, maximum green and gap extension parameters is left for future research.

The team assumed an ‘amber’ phase of 3.0 seconds and an ‘all-red’ clearance time of 1.0 second for vehicles. Pedestrian ‘walk’ phases were assumed at 4.0 seconds for two-stage single-lane crossings and at 7.0 seconds for all others. Pedestrian ‘flashing don’t walk phases’ were timed as a function of the crossing distance and an assumed pedestrian walking speed of 3.5 feet per second. The resulting FDW times were 5.0 seconds for single-lane two-stage crossings, 10.0 seconds for single-lane one-stage crossing, 9.0 seconds for two-lane two-stage crossings, and 19.0 seconds for two-lane one-stage crossings. It was assumed that pedestrians will initiate crossing during the walk phase and the first 1.0 seconds of the FDW interval.

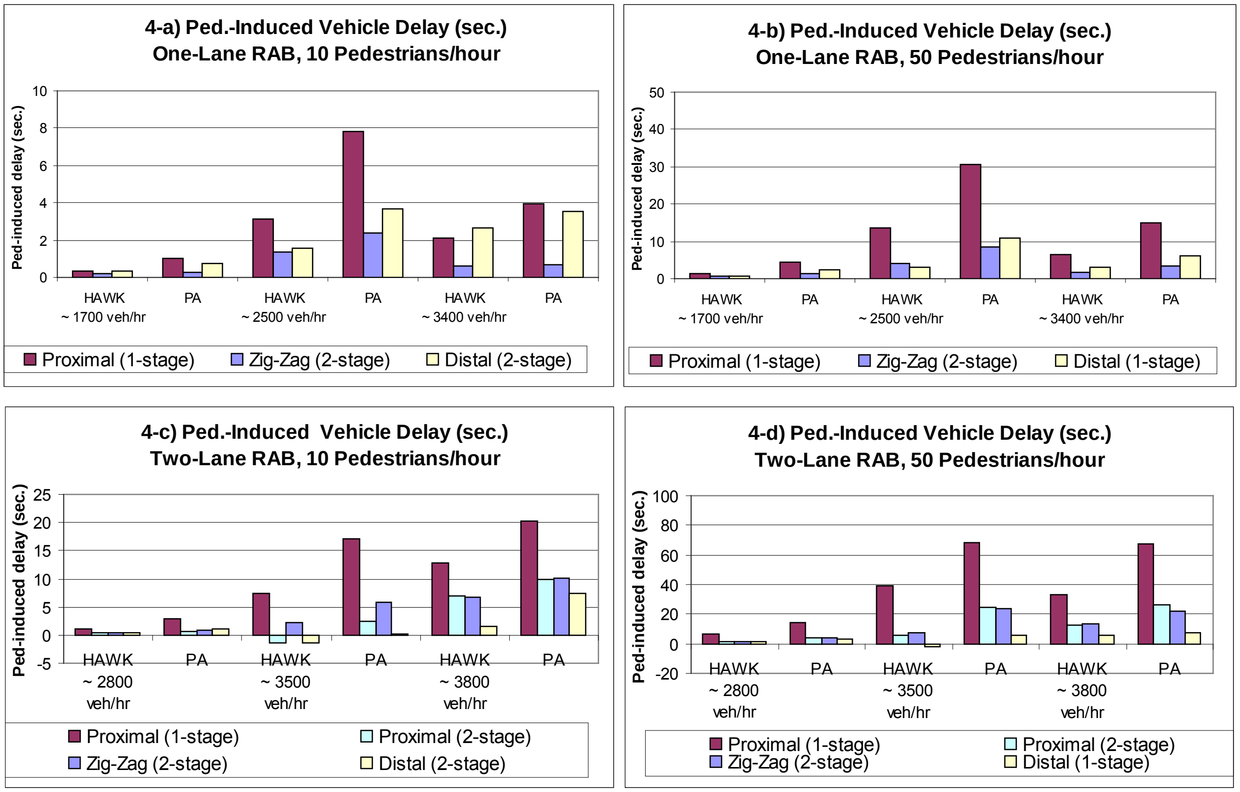
In the implementation of the HAWK signal, the flashing red phase for vehicles typically begins after 1.0 seconds of FDW and it is assumed that all vehicles in fact yield to pedestrians in the crosswalk. In the case of a one-stage crossing at a two-lane roundabout, the FR phase is delayed by 10.0 seconds into the FDW phase to assure that any pedestrian who started to cross at the end of W has at least made it past the splitter island. The authors made this assumption, because of a fear of non-compliance of drivers at the far end of the crossing in a real implementation (not yielding to a pedestrian who has yet to reach the splitter island).

RESULTS

Pedestrian-Induced Vehicle Delay

Pedestrian-induced delay is defined as the difference in roundabout system delay at pedestrian volume x, minus the same measure in the zero-pedestrian case. Figures 4a and 4b show the results for the 3 one-lane roundabout scenarios at 10 and 50 pedestrians, respectively. Accordingly, figures 4c and 4d show the four two-lane roundabout scenarios at both signalization schemes and both pedestrian volume levels. The figures further show varying vehicle intensities of 1700, 2500, and 3400 vehicles per hour for the one-lane site and 2800, 3500, and 3800 vph for the two-lane roundabout. Note that each sub-figure is presented at a different scale.

Figure 4: Pedestrian-Induced Vehicle Delay


4-a) Ped.-Induced Vehicle Delay (sec.) One-Lane RAB, 10 Pedestrians/hour

4-b) Ped.-Induced Vehicle Delay (sec.) One-Lane RAB, 50 Pedestrians/hour

4-c) Ped.-Induced Vehicle Delay (sec.) Two-Lane RAB, 10 Pedestrians/hour

4-d) Ped.-Induced Vehicle Delay (sec.) Two-Lane RAB, 50 Pedestrians/hour

The one-lane roundabout results suggest that the delay impact of a pedestrian signal on vehicle performance is highest at the 2500 veh/hr scenarios. At lower and higher traffic volumes, the impact is less, due to slow traffic and because of already high vehicle delays at the high-volume case. This suggested *non-linear* relationship between pedestrian signalization and vehicle volumes is an interesting finding that will be explored more in the future.

The proximal crossing location clearly results in the highest vehicle delays across all scenarios. This is explained, because the proximity to the circulating lane results in high queue spillback potential. Also across all pedestrian and vehicle volume levels, the HAWK signal consistently ranks better than the PA signal. Again, the benefits are most predominant at the middle vehicle volume level, but are evident in all cases.

When comparing crossing geometry, the zig-zag crossing shows a lot of potential for application at one-lane roundabouts. The combined effects of added queue storage and two-stage phasing resulting in up to 70% delay savings over the proximal alternative. The additional queue storage for the distal crossing does results in some delay savings over the proximal crossing, but does not beat the shorter two-stage phasing in the zig-zag crossing. This suggests that while additional queue storage is important, the impact of shorter vehicle red times is more significant. Both, two-stage crossings and HAWK signalization have that effect.

The observed trends at the two-lane roundabout are very similar to the one-lane site, with the difference that the distal crossing seems to outperform the zig-zag alternative. Other findings are consistent: two-stage phasing, HAWK implementation and offset exit-leg crosswalk all significantly improve vehicle operations over the one-stage proximal pedestrian-actuated signal.

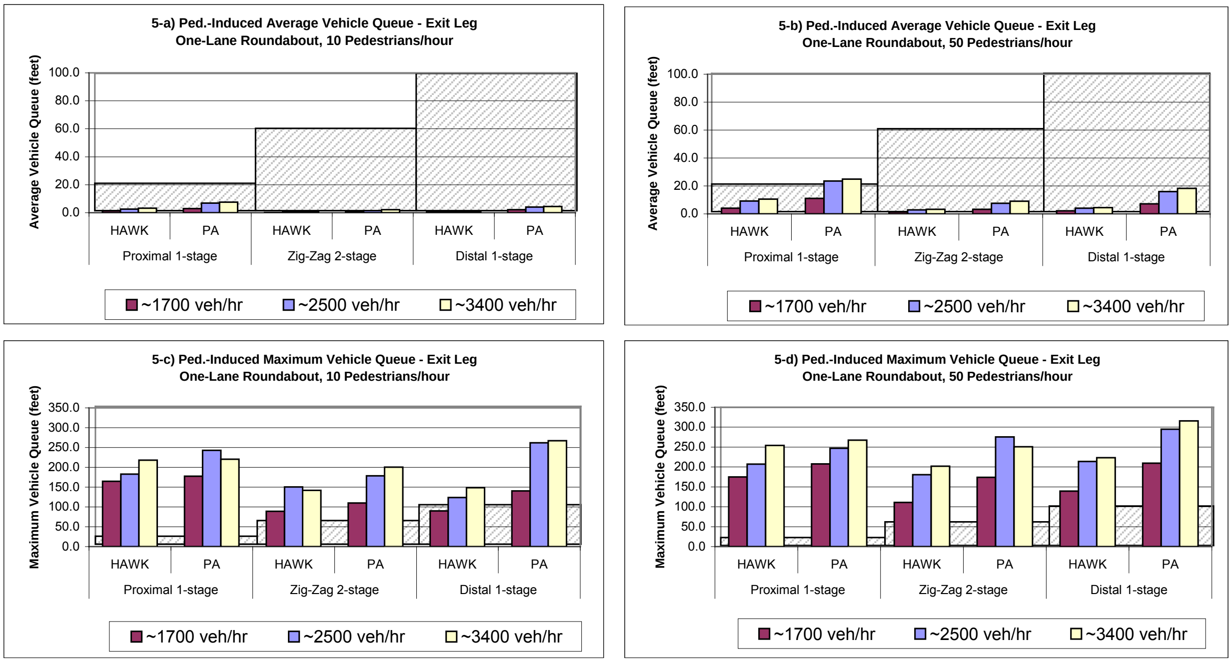
As an interesting caveat, some of the treatment scenarios result in negative pedestrian-induced vehicle delay estimates. In other words, the occurrence of pedestrian actuations actually improves the overall performance of the roundabout. This is explained, because the pedestrian signal acts as a metering signal on the busiest approach and thus facilitates vehicle entry at other (downstream) legs of the roundabout.

Vehicle Exit Queues

Following the same reporting pattern as for vehicle delay, Figures 5 and 6 show the results for the pedestrian-induced vehicle exit queues for all scenarios. In each case, figures a) and b) show average (50%) queues for 10 and pedestrians, and figures c) and d) show maximum queues for both pedestrian intensities. Each measure represents an average of 10 simulation replications and all values are given in feet (1 foot = 0.305 meter).

The authors further attempted to directly compare the observed queues with the available exit lane storage capacity. To recall, the proximal, zig-zag, and distal crossing geometries allow for theoretical queue storage of 20, 60, and 100 feet per lane, respectively. For each figure, the shaded background reflects this capacity for each crossing type.

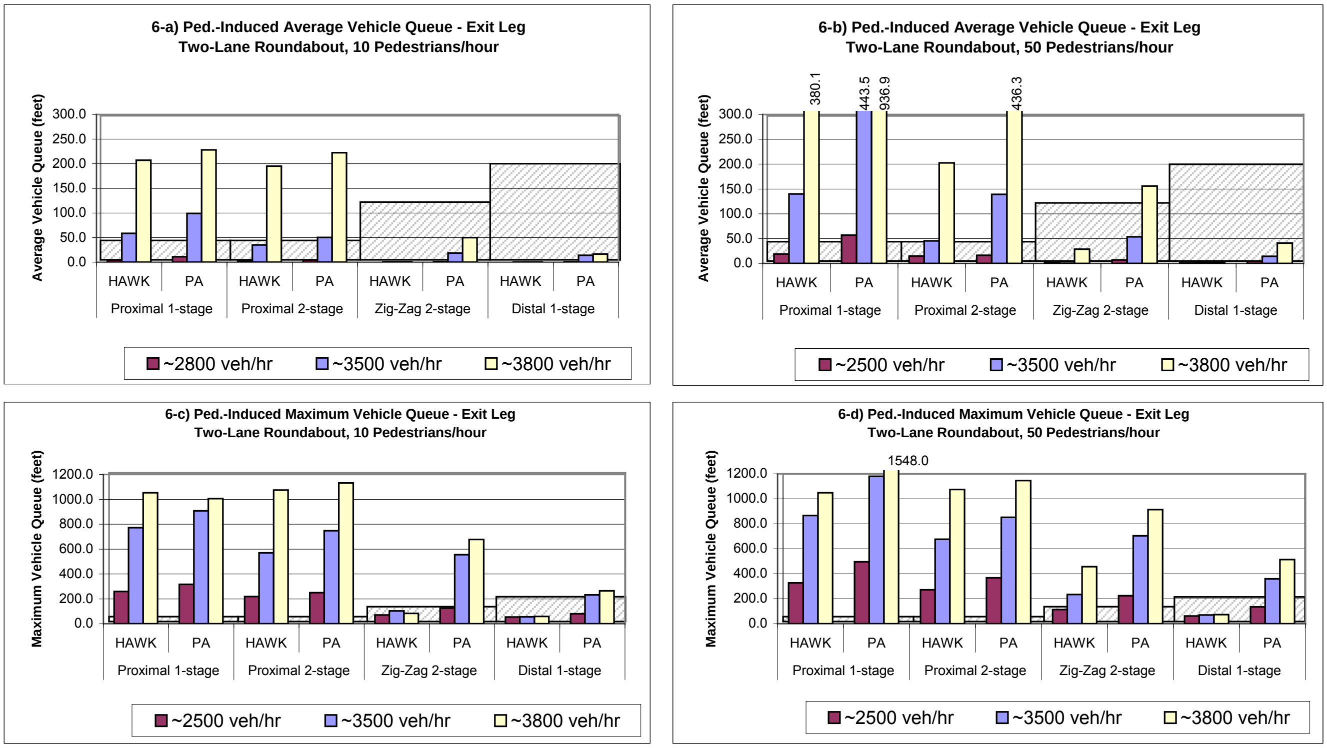
Figure 5: Pedestrian-Induced Exit Queues - One-Lane Roundabout



Results in Figure 5 suggest that the average queues at the one-lane roundabout were mostly well-inside the available queue storage for all scenarios. At 50 pedestrians per hour, the average queue at the proximal PA scenario consistently spills over the available storage at higher vehicle demands. Both the zig-zag and distal crossing provide ample storage for the average queue.

Looking at the maximum queues, it becomes evident that all scenarios will experience queue spillback into the circulating lane at least once during a one-hour analysis period. The mean maximum queue from 10 replications even extends beyond the 100-foot storage of the distal crossing as pedestrian and vehicle volumes increase. Nonetheless, the short two-stage phasing of the zig-zag crossing consistently results in the lowest queues and it is further evident that the creation of additional vehicle storage at the exit leg is a valuable approach. The HAWK signal queue is less than the PA queue in all cases.

Figure 6: Pedestrian-Induced Exit Queues - Two-Lane Roundabout



The results for the two-lane roundabout in Figure 6 generally show much higher pedestrian-induced queues compared to the one-lane site analysis. Judging from the average queue lengths, the benefits of an offset exit crosswalk (zig-zag or distal) are immense. Furthermore, the benefits of the HAWK signal are even more significant than in the one-lane case. At a pedestrian intensity of 50 peds/hour, the average queues at higher vehicle volumes approach 1000’ in the proximal one-stage PA scenario, and are around 400’ for several other proximal scenarios. With added queue storage, the average queues can generally be contained to the exit lane. It is important to point out that the theoretical queue storage is shown for both lanes combined and is thus double to that shown at the one-lane roundabout.

The maximum queues paint a similar picture. Roundabout exit queues at the signal can be reduced drastically by creating additional queue storage, by implementing a two-stage crossing and by using the HAWK signalization scheme.

Pedestrian Delay

The pedestrian delay measure is defined as the difference between actual travel time and theoretical travel time (at a randomly distributed walking speed around a mean of 3.5 ft/sec.) through the roundabout node. Given that the signal timing was implemented without vehicle green extension parameters (gap time and max. green) it is expected that this delay is constant for all three volume levels. Similarly, pedestrian delay is the same for the conventional pedestrian-actuated signal and the HAWK scheme.

At the one-lane roundabout, the resulting pedestrian delay numbers for the proximal, zig-zag, and distal crossing were 12.3, 21.7, and 11.8 seconds per pedestrians for the 10 peds/hour intensity level and 19.5, 35.2, and 19.5 seconds for the 50 peds/hour level. For the two-lane roundabout, the delay for the proximal 1-stage and 2-stage crossings came out to be 11.2 and 18.2 seconds for 10 peds/hour; and 20.7 and 31.7 seconds for 50 peds/hour. The two-lane roundabout zig-zag and distal crossing pedestrian delay numbers were 17.3 and 18.7 seconds for 10 peds/hour and 30.8 and 31.3 seconds for 50 peds/hour.

The one-lane roundabout numbers indicate that the delay at the zig-zag crossing is higher than for the other two, because some pedestrians will likely have to wait at both signals of the two-stage crossing. A comparison of one-stage and two-stage crossings at the two-lane roundabout shows the same results. Furthermore, the delay for 50 peds/hour is consistently higher than for 10 peds/hour, because pedestrians are more likely to arrive during the minimum green constraint. It is expected that this trend will level of as the number of pedestrians increases further (see volume sensitivity section). By coordinating the two phases of a two-stage crossing, it may be possible to partially overcome the apparent disadvantage of the configuration compared to a single-stage crossing.

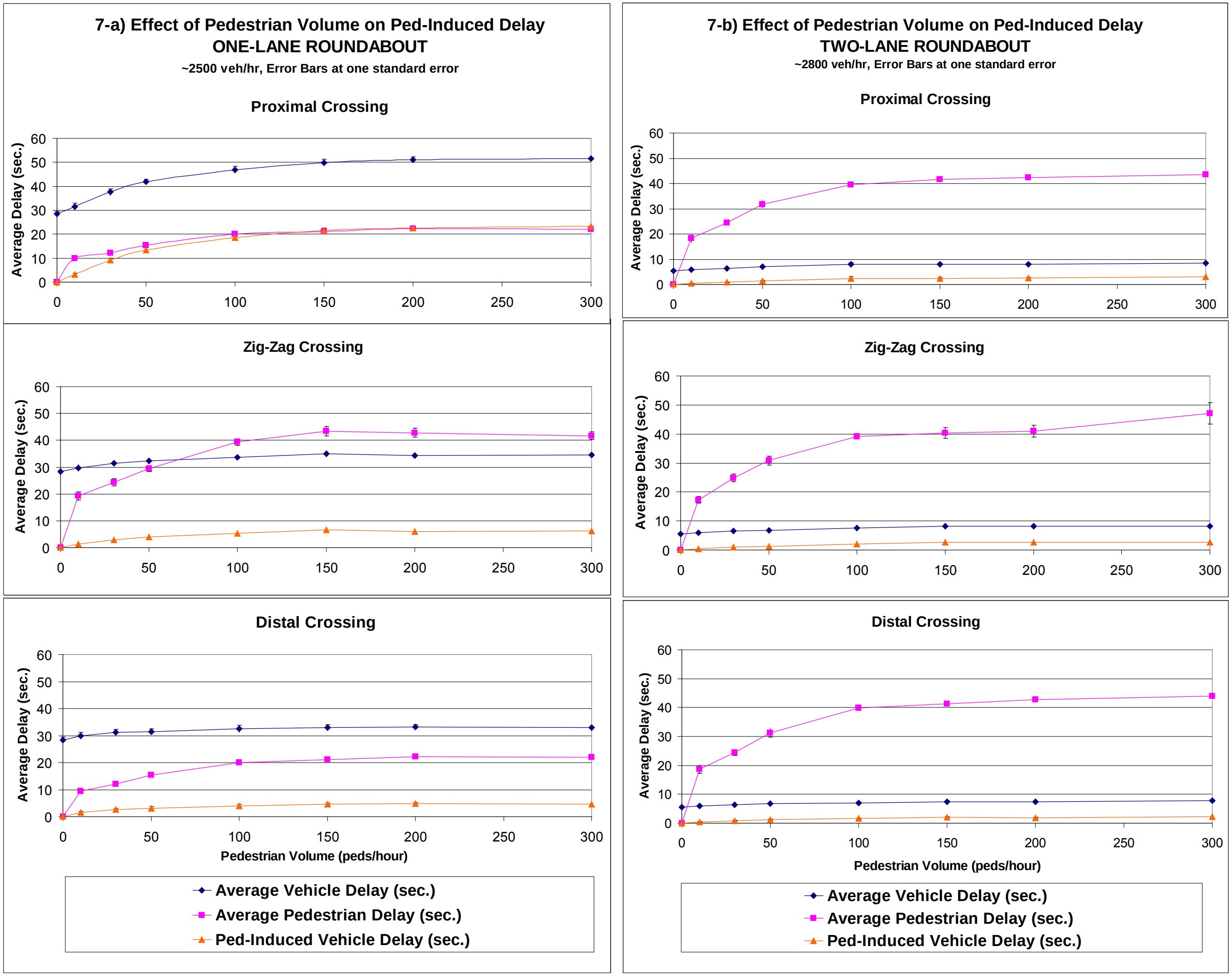
It is important to keep in mind that the different crossing geometries are expected to vary in pedestrian travel time through the crossing due to varying path deflections. These pedestrian travel time numbers are a function of the origin-destination characteristics at a particular site. In that sense, a zig-zag or distal crossing may or may not result in higher travel times depending on the particular pedestrian route.

Pedestrian Volume Sensitivity

In the final analysis step, the range of pedestrian intensities was varied between zero and 300 pedestrians per hour to perform a sensitivity analysis on the pedestrian-induced effects. It can be reasoned that delay as a function of pedestrian intensity will eventually flatten as the intensity approaches the maximum number of actuations per hour. In a fixed-cycle signal system, the maximum number of pedestrian actuations is given by 3600 seconds divided by the particular cycle length.

Figures 7 a) and b) show curves of pedestrian delay, vehicle delay and pedestrian-induced vehicle delay as a function of traffic volume for the one-lane and two-lane roundabout sites. Each figure shows the corresponding curves for the proximal, zig-zag, and distal crossing configuration. The graphs are shown for vehicle volume levels of 2500 and 2800 vehicles per hour for the one-lane and two-lane site, respectively. All numbers shown are for the HAWK signalization scheme, but similar trends are expected for a conventional pedestrian-actuated signal, as well as, for other vehicle volumes. Each data point is the average of 10 simulation replications.

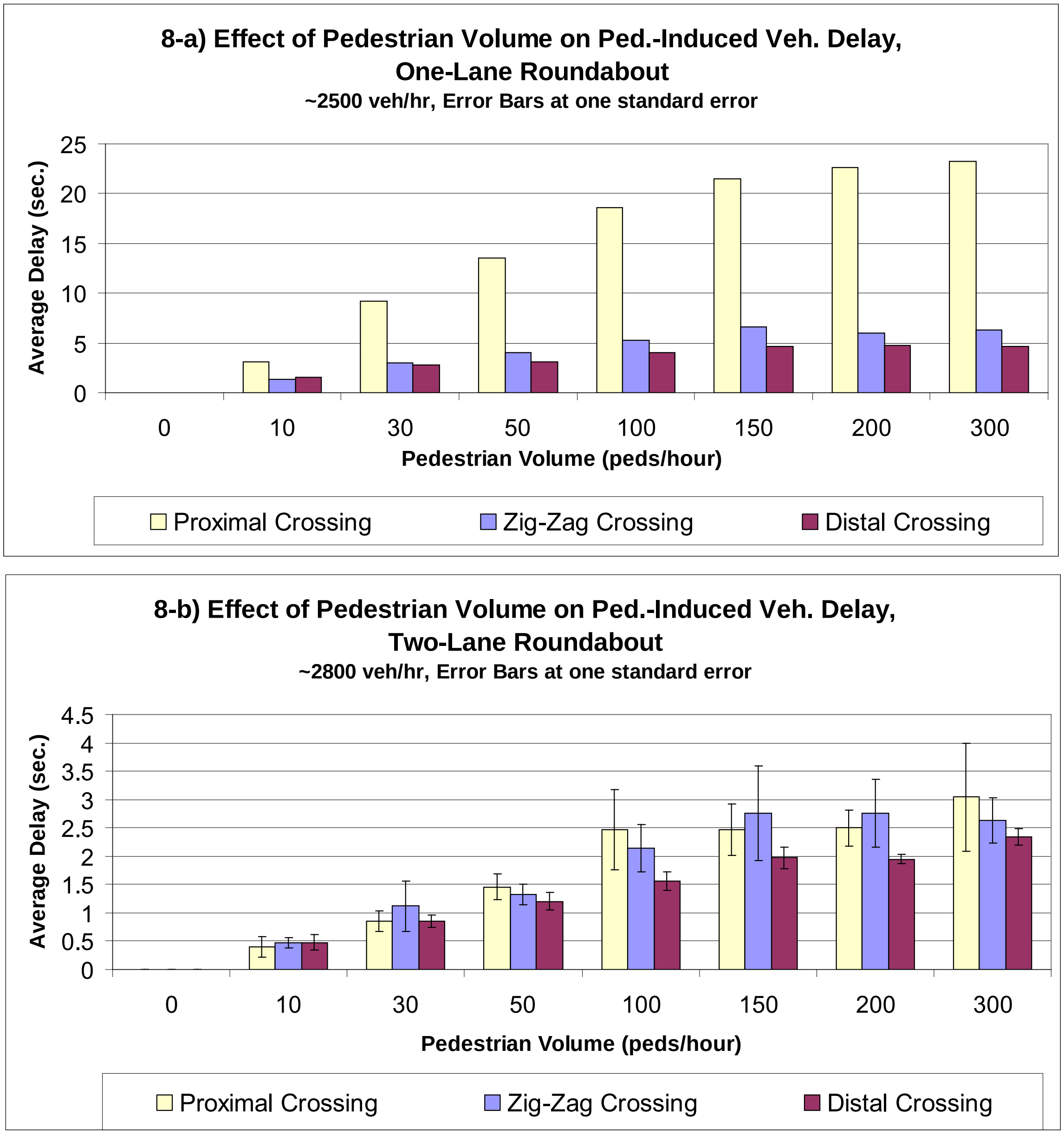
Figure 7: Pedestrian Volume Sensitivity Analysis



The figure shows that as the pedestrian intensity increases, any additional pedestrians will arrive during an existing call for green and won't further impact vehicle operations. Assuming compliance, a pedestrian signal therefore places a limit on pedestrian-induced vehicle delay even at high volumes, whereas an unsignalized crossing would result in uncontrolled and presumably dangerous situations.

To allow for a comparison between crossing geometries, Figures 8 a) and b) aggregate the results for pedestrian-induced vehicle delay for the proximal, zig-zag and distal crossing for the one-lane and two-lane roundabout.

Figure 8: Pedestrian-Induced Vehicle Delay as a Function of Pedestrian Intensity



It is evident from Figure 8-a), that zig-zag and distal crossing configurations provide a clear benefit over the proximal location at the one-lane roundabout. For the two-lane roundabout, the distal crossing again appears to outweigh the zig-zag configurations, although large standard errors of the estimate require additional simulation replications to make this claim statistically significant.

CONCLUSION

The analysis presented in this paper has provided a quantitative comparison between different options for signalized pedestrian crossings at one-lane and two-lane roundabouts. The results indicate that innovative signalization treatments, including HAWK signals and two-stage crossings can significantly decrease vehicle delay. Modified crossing geometries such as a zig-zag or distal crosswalk, can further reduce spillback potential into the circulating lane due to added vehicle storage at the roundabout exit lane.

The analysis further suggested a non-linear relationship between the treatments and the levels of vehicle volumes as pedestrian-induced vehicle delays appeared to be greatest as traffic volumes approach roundabout capacity, but not as conditions became oversaturated. The need for innovation in pedestrian signal application is therefore less pronounced at low or very high traffic volumes, but should be a key consideration at busy roundabout junctions.

An sensitivity analysis of increasing pedestrian volumes supported the hypothesis that an increase in pedestrian intensities eventually doesn't add any further delay, as the signal operations approach the limit of 'maximum number of actuations per hour'. Pedestrian and vehicular delays generally appear to plateau in excess of 200 pedestrians per hour. This suggests an application for signalization as a means of controlling 'pedestrian interference' to vehicular operations – an interesting twist to the existing pedestrian signal warrant that evaluates only the available crossing opportunities for pedestrians within a given time interval.

LIMITATIONS

Due to the nature of existing microsimulation software, some additional consideration ought to be given to the results. For example, the high vehicle volume scenarios are likely underestimating capacity, because they assume unchanged driver gap acceptance behavior compared to the calibrated base case. In reality, it is expected that drivers waiting to enter the roundabout will lower their critical gap and follow-up times as traffic gets heavier, thereby increasing capacity. The current use of 'priority rules' in VISSIM does not allow for a decaying critical gap function as a function of waiting time.

Also, as discussed above, the queue definitions of maximum and average queues are not as interesting from a traffic engineering perspective as an 85th queue or a measure of 'percent spillback' would be. In the current configuration of VISSIM, it is possible to extract queue data for shorter time intervals and thus perform a 'queue study' for one-minute intervals, but this analysis was beyond the scope of the effort presented here. For a reference on this alternate approach, please refer to Rouphail et al. (2005).

The lane distribution at the entry lane of the two-lane roundabout was obtained from NCHRP 3-65 data and is valid for the base case. The data showed a significant skew towards the right approach lane, suggesting underutilization of the left lane that is probably evident at most two-lane roundabouts in the US. However, as volumes get closer to capacity it is expected that a more even lane distribution is obtained as drivers tend to shift to the lane with the shorter queue. The resulting entry capacity in the simulation models therefore is likely to be somewhat low.

Finally, it is debatable whether the measure of 'pedestrian delay' is indeed the most appropriate. Assuming that all pedestrian origins and destinations (O/D) are at the roundabout, the additional travel times for zig-zag and distal locations are significant. This assumption clearly is not valid, because pedestrian travel paths clearly are dependent on O/D patterns outside the roundabout influence area.

Nonetheless, there is always the potential of additional travel time and the related concern of pedestrian compliance to the suggested geometries and signalization schemes. The authors believe that through the use of landscaping features (trees, bushes, walls, fences) and through proper design of pedestrian paths – paths that lead to the crosswalk, not to the intersection – compliance can be maximized.

FUTURE RESEARCH

For future research, it would be highly interesting to compare the results of pedestrian signalization to capacity reductions from unsignalized pedestrian crossings. This would require a more detailed analysis of pedestrian gap acceptance and driver yielding behavior, as is discussed in a second paper the authors submitted to TRB. In some circumstances, signalization may actually slightly reduce overall vehicle delay and contribute to pedestrian safety.

Also, it would be interesting to compare the results for signalized and unsignalized pedestrian crossings obtained in microsimulation to estimates obtained from deterministic equations in the HCM2000 or roundabout analysis software such as aaSIDRA or KREISEL. It would be in the general interest of the traffic engineering community to generalize the results obtained here and to develop improved equations describing pedestrian-vehicle interaction that can be applied independent of microsimulation.

ACKNOWLEDGMENTS

The research leading up to this document was supported by the NCHRP 3-78 project, ‘Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Visual Disabilities’. The authors would like to thank the National Academies for the opportunity to be involved in the project and for permission to share these results with the Transportation Research Board Community. The authors would also like to thank the members of the project panel, who have provided continuous feedback to the research efforts. Finally, the authors would like to thank the other members of the project team, who have been invaluable in discussing the application of microsimulation models to the project.

REFERENCES

Ashmead, D., Guth, D., Wall, R., Long, R., & Ponchillia, P. Street crossing by Sighted and blind pedestrians at a modern roundabout. In *ASCE Journal of Transportation Engineering,* Vol. 131, No. 11, November 1, 2005, 812-821

Rouphail, N., Hughes, R., & Chae, K., *Exploratory Simulation of Pedestrian Crossings at Roundabouts*. In ASCE Journal of Transportation Engineering. Vol. 131, No. 3, March 2005

FHWA, *Roundabouts: An Informational Guide*. Federal Highway Administration. Turner Fairbank Highway Research Center. FHWA-RD-00-067. McLean, VA. 2000

Guth, D., Ashmead, D., Long, R., Wall, R., & Ponchillia, P. Blind and sighted pedestrians' judgments of gaps in traffic at roundabouts. In *Human Factors, 47*, 314-331.

National Cooperative Highway Research Program (NCHRP) Project 3-78. Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities. Institute of Transportation Research and Education. Raleigh, North Carolina. http://www4.nationalacademies.org Last visited July 26, 2006

PTV (2005), VISSIM 4.10 User Manual. Karlsruhe, Germany. March 2005.

Tucson DOT, *Pedestrian Traffic Signal Operations*. City of Tucson Department of Transportation, http://dot.ci.tucson.az.us/traffic/tspedestrian.cfm. Accessed July 31, 2006

US Access Board, Revised Draft Guidelines for Accessible Public Rights-of-Way. http://www.access-board.gov/prowac/draft.htm. Accessed July 29, 2006

Wall, R., Long, R., Guth, D., Ashmead, D., & Ponchillia, P. Roundabouts: Problems of and strategies for access. International Congress Series 1282, In *Proceedings of Vision 2005*, April 2005, London

APPENDIX M: Use of Visualization in NCHRP 3-78a

This Appendix was previously published as conference proceedings International Symposium of 3D/4D Visualization in Transportation in Denver, CO in 2006. The citation for this work is:

Hughes, Ronald G., Bastian J. Schroeder and Thomas Fischer, *3D Visualization and Microsimulation Applied to the Identification and Evaluation of Geometric Solutions for Improving Visually Impaired Pedestrian Access to Roundabouts and Channelized Turn Lanes*. International Symposium on 3D/4D Visualization in Transportation Denver, CO, 2006

3D Visualization and Micro-Simulation Applied to the Identification and Evaluation of Geometric and Operational 'Solutions' for Improving Visually Impaired Pedestrian Access to Roundabouts and Channelized Turn Lanes

Ronald G. Hughes, Ph.D. and Bastian Schroeder
Institute for Transportation Research and Education
North Carolina State University

Thomas Fischer
Design Visualization Section
New York State Department of Transportation

The Institute for Transportation Research and Education (ITRE) at North Carolina State University is responsible for an NCHRP funded effort to identify and evaluate roundabout and channelized turn lane treatments intended to improve facility access for visually impaired pedestrians. As part of this effort, ITRE is utilizing VISSIM micro-simulation/modeling capabilities to investigate the (estimated) effectiveness of proposed treatments in advance of their full scale field evaluation. While VISSIM provides effective animation capabilities for use by engineers for preliminary design, its primary focus is on the representation of traffic operations. While the program has a very useful AVI graphic output, it does not have the capability to generate the type of photo-realistic 3D models shown to be useful in public involvement settings. ITRE, working in conjunction with the NY State DOT has generated additional 3D visual environments showing the range of treatments and treatment combinations currently proposed. The principle audience for this work were the NCHRP "panel' members whose responsibility it was to provide the go-ahead to the Phase II treatment implementation and evaluation phase. The paper provides an overview of how 3D visual simulation and micro-simulation/modeling were used in an integrated fashion to address geometric design and operational facility performance issues. The work is responsive to research needs identified by the TRB Visualization Technical Committee that call for more effective techniques for integrating real time and non real time simulation methods and for increased recognition of modeling requirements underlying the visual simulation of transportation system 'operations.' The methodology being employed in NCHRP 3-78 is an outgrowth of the use of VISSIM by an NIH funded bioengineering research partnership effort that was headed by Western Michigan University and supported by NC State University, Vanderbilt University, Johns-Hopkins, and Accessible Design for the Blind. This is the first time, to our knowledge that photo-realistic visualization methods and computer simulation/modeling have been applied to this problem area.

BACKROUND

While modern roundabouts have, in general, been shown to result in fewer serious vehicle crashes compared to comparable signalized intersections (1,2), pedestrian acceptance based upon their real and/or perceived safety and accessibility remains equivocal. The accessibility of roundabouts and other 'complex intersections' (e.g, channelized turn lanes) for visually impaired pedestrians has been questioned by the US Access Board (3,4,5). Accessibility for visually impaired pedestrians is confirmed by the results of a number of studies (6,7,8,9) that have been funded, in large part, by the Eye Institute of the National Institutes of Health.

These studies have focused on the performance of both blind and sighted pedestrians at (mostly single lane) roundabouts in the US. At least in one instance, performance at a multi-lane facility was the focus (6). In general, these studies indicate that:

- Visually impaired pedestrians experience more delay at roundabouts than sighted pedestrians (especially at exit lanes) in large part due to the difficulty they experience in detecting crossable gaps.
- Visually impaired pedestrians are more likely than sighted pedestrians to take 'risky' gaps (i.e., gaps that are too short to cross before an approaching vehicle reaches the crosswalk).
- Despite laws to the contrary, motorists do not reliably yield to pedestrians.
- Even when motorists yield, visually impaired pedestrians are often unable to detect the presence of a vehicle that is yielding (a problem likely to increase with the gradual introduction of 'quiet' vehicles).

While recognizing the safety benefit of roundabouts to motorized traffic, the US Access Board has pointed out to the traffic engineering community that roundabouts, to the extent that they are government funded facilities in the 'public right of way,' need to be accessible to 'all' pedestrians,' sighted or not; and that unless other alternatives can be identified, signalization may be required, at least at multi-lane roundabouts.

The accessibility issue applies not only to visually impaired pedestrians' ability to utilize roundabouts, but also to their ability to utilize channelized turn lanes (7). The accessibility issue has prompted a research study funded by the National Cooperative Highway Research Program (NCHRP), an applied, contract research program that develops near-term, practical solutions to problems facing transportation agencies. This particular study, referred to as NCHRP 3-78A, "Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities, "is charged with the identification and evaluation of possible 'solutions'/'treatments.'

Effective solutions in this case are identified functionally in terms of the extent to which the treatment satisfies one or more of the following criteria:

- The availability of crossable gaps in traffic
- The pedestrian's ability to reliably detect crossable gaps when present
- The pedestrian's ability to reject 'risky' gaps
- The likelihood of drivers yielding to pedestrian in the crosswalk
- The ability of blind pedestrians to detect the presence of drivers who yield
- Treatments that reduce or minimize delay to both the pedestrian and to motorized traffic

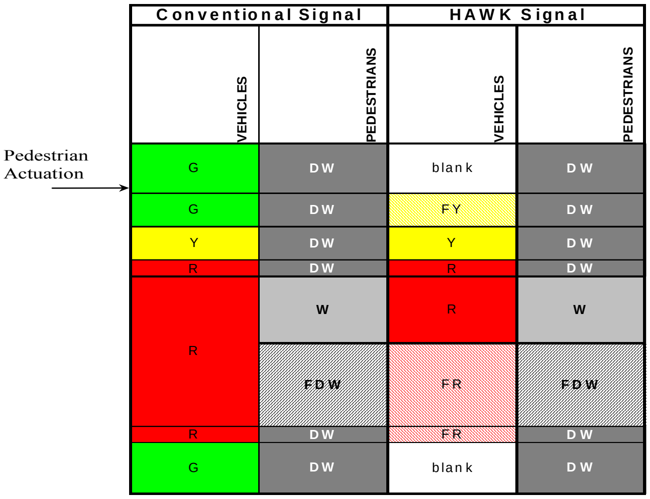
The present paper describes the integrated use of modeling and visual simulation in efforts to provide preliminary estimates of treatment effectiveness. To our knowledge, this is one of the only instances where a micro-simulation traffic model, in this case VISSIM (8), has been adapted to study pedestrian-vehicle interactions at roundabouts and where photo-realistic 3D simulation has been used in support of design efforts intended to improve access for visually impaired pedestrians at complex intersections. The VISSIM work represents a logical extension of the NIH/NEI research mentioned above inasmuch as pedestrian gap acceptance data collected in the field on visually impaired as well as sighted pedestrians has been used in a micro-simulation context to characterize differences in pedestrian crossing attributes under different treatment conditions. Moreover, it is the first time, to our knowledge, that VISSIM has been adapted for use where both pedestrian gap acceptance attributes and driver likelihood of yielding have been jointly modeled to address the issue of pedestrian 'risk.'

METHODOLOGY

General Approach

The selection of VISSIM (11) for the purpose of modeling pedestrian-vehicle interactions at roundabouts has been described by Rouphail, Hughes, and Chae (12) and by Chae in an unpublished doctoral dissertation (13). The Rouphail, et. al. work describes how pedestrian gap acceptance attributes were collected under operational conditions as a basis for simulating pedestrian crossing performance in the micro-simulation (modeling) environment. Data are presented that characterize differences in crossing performance for blind and sighted pedestrians under typical, single-lane roundabout conditions where both pedestrian and vehicle volumes have been systematically varied. NCHRP 3-78 (14) is applying this same methodology to representative single and multi-lane roundabouts whose operational characteristics have been identified in the NCHRP 3-65 inventory of roundabouts in the US (2). Existing data from NCHRP 3-65 are being used to calibrate the model(s). The VISSIM models are presently being used to investigate the pedestrian, vehicle, and system-level delay effects associated with alternative signalization strategies identified by researchers in the NCHRP 3-78 work; in particular, the (estimated) operational effects associated with proximal versus distal crosswalk locations, the application of a staggered/off-set crossing application in conjunction with the use of pedestrian-activated signals, both traditional and HAWK.

The proposed use of a HAWK signal in this context is new. The relationship between a pedestrian activated HAWK signal a conventional pedestrian activated RGY signal is shown in Figure 1, along with the correlation between signal phases as seen by the driver and the phases of the pedestrian Walk/Don't Walk display as seen by the pedestrian. Current evidence for the effectiveness of the HAWK signal comes mostly from its application at mid-block locations (TCRP/NCHRP Project D-08/3-71, "Improving Pedestrian Safety at Unsignalized Crossings" (15) and from work done in Tucson, Arizona. Its unique phasing has been shown to be associated with reduced vehicle delay.



Conventional Signal		HAWK Signal	
VEHICLES	PEDESTRIANS	VEHICLES	PEDESTRIANS
G	DW	blank	DW
G	DW	FY	DW
Y	DW	Y	DW
R	DW	R	DW
R	W	R	W
	FDW	FR	FDW
R	DW	FR	DW
G	DW	blank	DW

Figure 1. Comparison Between Vehicle and Pedestrian Phases and Observed Displays for Conventional and HAWK Signal

The terms 'distal' and 'proximal' have been introduced by the NCHRP 3-78 project to refer to the location of the crosswalk relative to the circulatory lane of the roundabout; i.e., whether it is located 'proximal' to (in close proximity to) the circulatory lane – as is the typical placement- or 'distal' (at some distance from) to the circulatory lane. In Figure 2, the proximal location of the pedestrian crosswalk (top view) is shown at approximately 20 feet (nominal 2-car lengths) from the circulatory lane; a staggered design (middle view) where location of the entry lane crosswalk is identical to that of the proximal design and where the exit lane crosswalk is located 60 feet (nominal 3 car lengths) from the circulatory lane; and distal (bottom view) where both entry and exit lane crosswalks are located 100 feet from the circulatory lane.

Figure 2a. Proximal Condition

Figure 2b. Staggered or Off-Set Condition

Figure 2c. Distal Condition

Figure 2. Proximal, Off-Set, and Distal Crosswalk Placements

Figure 3. Example of Off-Set or Staggered Crosswalk Condition

The NCHRP 3-78 application of the staggered treatment reverses the customary direction of the offset such that the entry lane crosswalk remains at the conventional or proximal location and the exit lane crosswalk is located down-stream of the circulatory lane by a distance dictated by the extent of the desired vehicle storage between the circulatory lane and the exit lane crosswalk. The potential value of the design is that vehicle queues that form either when drivers voluntarily yield to pedestrians or when drivers are required to stop by the presence of a signal can be stored outside the circulatory lane thereby reducing the likelihood of spillback that could negatively impact the operation of the roundabout. In addition to facilitating a two stage pedestrian crossing, it has the benefit of providing additional pedestrian storage capacity.

VISSIM was used to model each of these crosswalk placement alternatives under a range of likely pedestrian volumes and a range of likely vehicle volumes (16). The framework for evaluation of pedestrian-vehicle interactions at unsignalized crossing facilities in a microscopic modeling environment has been described elsewhere (17). The simulations were run where (a) the signalization was a pedestrian-actuated HAWK signal, and (b) a pedestrian-actuated 'conventional' signal. Simulations were run for single lane and multi-lane roundabout conditions under two level of pedestrian volume (10 ped/hr and 50 ped/hr) and three levels of vehicle volume (1700 veh/hr, 2500 veh/hr and 3400 veh/hr). The results are shown in Figure 4 in terms of pedestrian-induced system (vehicle) delay. Pedestrian-induced system delay is defined as the difference in roundabout system delay at pedestrian volume x, minus the same measure in the zero-pedestrian case.

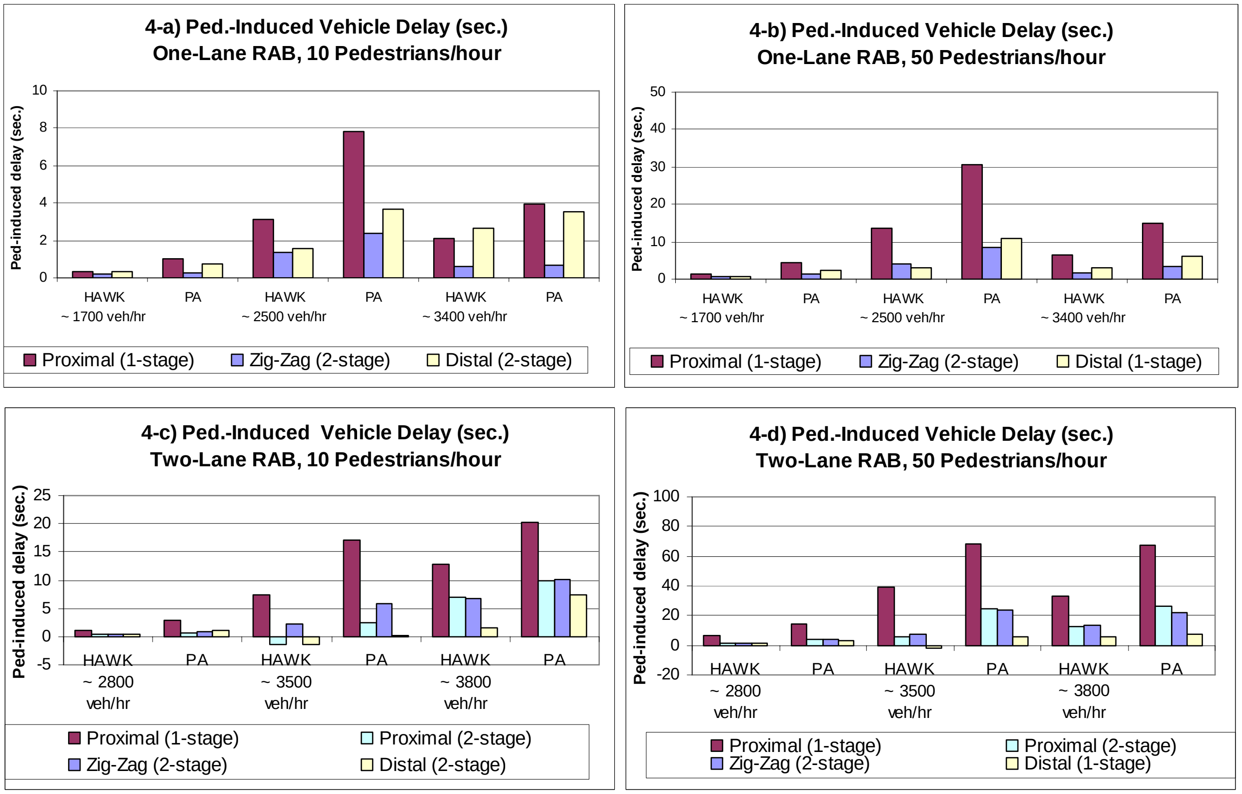


Figure 4. Pedestrian-Induced System (Vehicle) Delay as a Function of Type of Signalization, Pedestrian Level, and Vehicle Level

The one-lane roundabout results suggest that the delay impact of a pedestrian signal on vehicle performance is highest at the 2500 veh/hr scenarios. At lower and higher traffic volumes, the impact is less, due to slow traffic and because of already high vehicle delays at the high-volume case. This suggested non-linear relationship between pedestrian signalization and vehicle volumes is an interesting finding that will be explored more in the future.

The proximal crossing location clearly results in the highest vehicle delays across all scenarios. This is explained, because the proximity to the circulating lane results in high queue spillback potential. Also across all pedestrian and vehicle volume levels, the HAWK signal consistently ranks better than the pedestrian actuated signal with conventional display. Again, the benefits are most predominant at the intermediate vehicle volume level, but are evident in all cases.

The results for a two-lane roundabout are shown in the Figure 5 in terms of average and maximum exit lane queues predicted for a two lane roundabout. The results for the two-lane roundabout generally show much higher pedestrian-induced queues compared to the one-lane site analysis. Judging from the average queue lengths, the benefits of an offset exit crosswalk are significant, and deserve additional design attention.

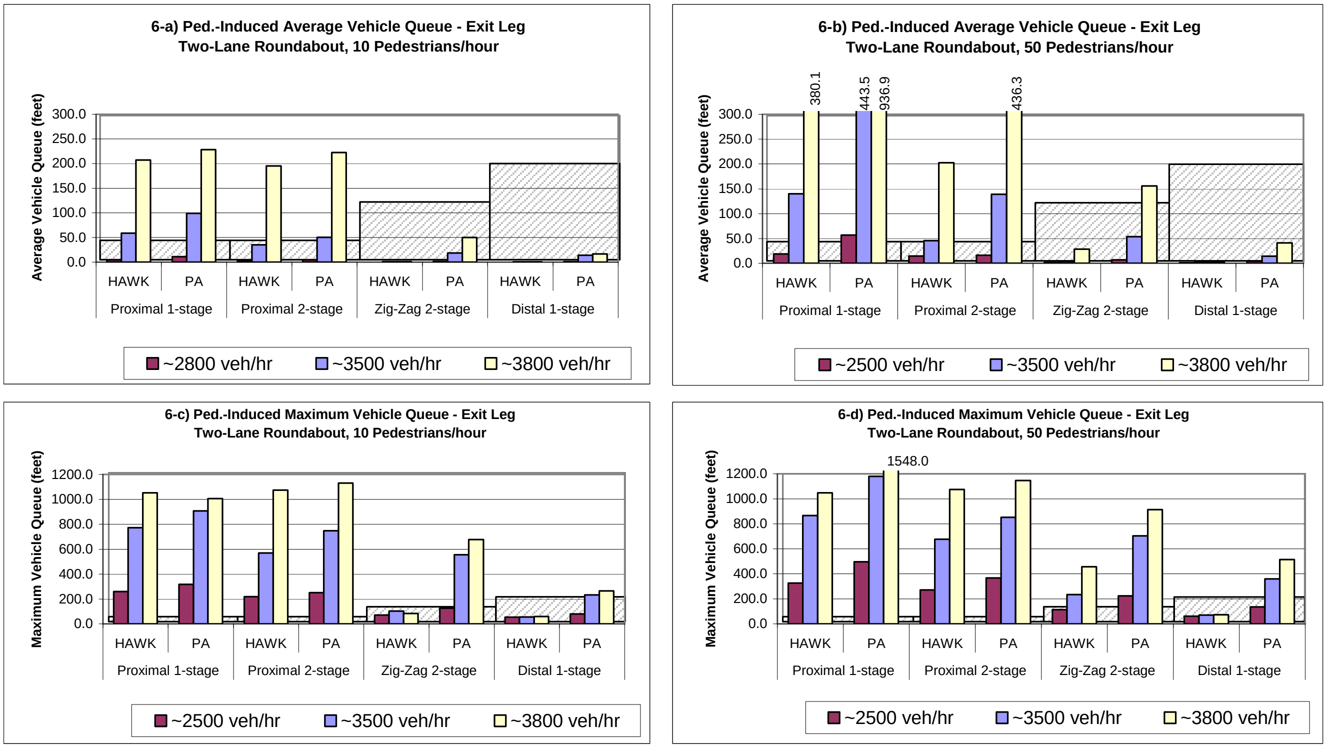


Figure 5. Pedestrian-Induced Vehicle Queue at the Exit Leg of a Two Lane Roundabout as a Function of Type of Signal, Vehicle Level, and Pedestrian Level

Furthermore, the benefits of the HAWK signal in the two-lane application are even more significant than in the one-lane case. At a pedestrian intensity of 50 peds/hour, the average queues at higher vehicle volumes approach 1000' in the proximal one-stage PA scenario, and are around 400' for several other proximal scenarios. With added queue storage, the average queues can generally be contained to the exit lane. It is important to point out that the theoretical queue storage is shown for both lanes combined and is thus double to that shown at the one-lane roundabout.

The maximum queues paint a similar picture. Roundabout exit queues at the signal can be reduced drastically by creating additional queue storage, by implementing a two-stage crossing and by using the HAWK signalization scheme. The notion of designing for adequate vehicle storage clearly apparent even to the non-traffic engineer in both the application of VISSIM and from the 3D photo-realistic visualization (see Figure 6). The model simply provides the analytical and quantitative support for the extent of the benefit.

Simulating Un-Signalized Treatment Alternatives

Confidence in 'simulating' the predicted effectiveness of alternative signalized treatments is based in large part on the assumption of a high level of control for drivers in a signalized situation, recognizing that perfect control will never be achieved. For un-signalized treatments to be evaluated in NCHRP 3-78, the less predictable behavior of pedestrians, as well as motorists (in terms of yielding), dictates that VISSIM estimates of effectiveness must be validated by actual field data before the model(s) can be calibrated and used to extend the range of potential treatment effectiveness (i.e., to pedestrian and vehicle volumes outside the range of the original data collection and/or to different levels of pedestrian (gap acceptance) and driver (yielding) attributes. In the initial absence of such validation data, modeling is best used to explore the 'sensitivity' of key variables across a range of possible conditions.

On the Integrated Use of Photo-Realistic 3D Visualization

Because of the somewhat 'unconventional', in some cases 'counter-intuitive,' treatments introduced as part of NCHRP 3-78, a decision was made to make limited use of photo-realistic 3D visualizations of the proposed treatments' in particular, those involving some form of signalization. By 'limited,' we mean using selected, static perspective views from the 3D model versus an animated, or 4D, 'drive through' presentation. For visualization of the operational aspects of the alternative treatments, the project relied upon the less realistic, but 'operationally correct,' output of VISSIM. Graphic output (AVI) files from VISSIM were used to clarify the method/process by which pedestrian/vehicle conflicts were modeled and not for direct visual inference of pedestrian behavior over time. Assistance in the development of the photo-realistic 3D visuals was provided by the visualization section of the NY State Department of Transportation. NYSDOT has been a charter member of the TRB Visualization in Transportation Task Force since its inception, is active in roundabout design, and has championed the use of visualization as part of Context Sensitive Solutions (18).

Figure 6. Oblique View of Queue Storage at Unsignalized Staggered/Off-Set Crosswalk

The 3D visuals utilized an existing NYSDOT design for an existing single lane roundabout. Certain aspects of the design (e.g., reduced deflection at the exit lane) may be unique to NYSDOT. To the basic roundabout design were added the treatments being considered by the NCHRP 3-78 research team. The 3D visuals provided views of both signalized and un-signalized treatments. Un-signalized treatments included the use of a raised pedestrian crosswalk, sound strips similar in concept and placement to those described by FHWA researchers (19), as well as a pedestrian activated (flashing) beacon. Where signalization was modeled, the visuals show implementation of a HAWK signal. The HAWK was shown being used in conjunction with pedestrian WALK/DON'T WALK signals. Both were shown as pole mounted on either side of the travel lane. The pedestrian activated beacon was described (not shown here) as being associated with a voice annunciated message saying, to the effect, "beacon is flashing." Also 'described' but not actually shown or demonstrated was the use of Accessible Pedestrian Signals (APS) in conjunction with HAWK signal phasing and to annunciate the on/off status of the pedestrian actuated beacon. Visible in the 3D models were the use of tactile warnings, as well as signing indicating a pedestrian crossing. The design of the staggered crosswalk showed the presence of a 'cut through'

Figure 7. Oblique View of Proximal Crosswalk Location

Figure 8. Driver View Approaching Exit Lane With HAWK Signal

(street level) pedestrian pathway through the median. Curb cuts and tactile warnings were shown at points where the pedestrian entered the entry and/or exit lane crosswalks. Selected examples of 3D visualizations are shown in Figures 6-10. The images show representative views from oblique, driver, and pedestrian viewpoints of different crosswalk locations and configurations, some signalized and others not.

Figure 9. Oblique View of Unsignalized Distal Crosswalk Location Showing Storage of Vehicle Queue Formed When Vehicles Yield to Pedestrians

Figure 10. Pedestrian View at Entry Lane of Off-Set Crosswalk Using HAWK Signal and Pedestrian WALK/DON'T WALK Signals

The (Perceived) Value of the Visualization Methods Used

While no attempt was made to formally quantify the 'value' of the present visualization efforts, we believe that the following represents the consensus of the 3-78 research team as well the NCHRP panel charged with providing project oversight to this work. Remember, that both the NCHRP panel as well as the research team were 'diverse' in their makeup, representing roadway design practitioners, traffic engineers, representatives of professional organizations such as AASHTO and ITE, the US Access Board, FHWA, as well as blind travelers and representatives of prominent blindness organizations. We believe the following accurately represents the consensus of those present at the panel meeting convened to reach consensus on the treatments and to move forward to their evaluation in Phase II.

- The analysis of proposed signalization alternatives provided through the use of VISSIM was effective in aiding a diverse group of 'stakeholders' and researchers to more effectively understand the 'estimated' operational effectiveness of the different signalization treatments.

- The spatial realism of the photo-realistic 3D visuals, along with VISSIM AVI and screen capture outputs, permitted those present to more clearly understand the rationale for alternative crosswalk placements (i.e., proximal, staggered, and distal) . . . enabling them to observe more directly resulting differences in vehicle storage capacity associated with each of the treatments (i.e., to provide a more intuitive reference or context for the quantitative results generated by the model.

- The views generated in the 3D photo simulations of the driver's perspective upon entering either the entry or exit lane of the roundabout provided important insights into the potential problem of visual 'clutter' created by the multiple, pole-mounted signs, signals, etc.

- Clearly, neither VISSIM nor the photo realistic visual simulation alone was sufficient to infer the potential value of a raised crosswalk in terms of its desired effect on vehicle speeds and/or the likelihood of drivers yielding. Visualization cannot be used to represent events or conditions for which there are inadequate underlying data.

- It was also clear that regardless of the 'realism' of the photo simulations one could not anticipate the extent to which motorists would accelerate upon exiting and how such a tendency to accelerate might decrease their likelihood yielding to pedestrians in exit lane crosswalks 'distal' to the circulatory lane. Field data are clearly essential to understanding this effect of the distal designs.

- The photo realistic images prompted questions regarding the conspicuity of the sound strips placed in advance of the crosswalk. Their high contrast appearance in the visualizations prompted concerns that if their presence were visually detected by motorists it might prompt motorists to confuse their function with a yield line causing them to yield well in advance of the crosswalk, a problem which would increase the difficulty experienced by blind pedestrians in detecting, on a more purely auditory basis, the presence of a yielding vehicle.

- Neither results from VISSIM trials nor the photo-realistic visualizations could convey the subtleties of the auditory attributes of the crossing task for the blind pedestrian or the extent to which auditory aids (e.g., the surface mounted strips) might serve to improve their ability to detect drivers who were yielding.

- Typical 'confusions' that occurred in trying to communicate geometric and operational attributes of treatments to the NYSDOT visualization support team included the use of WALK/DON'T WALK signals in conjunction with treatments that provided no signal and thereby no signal phasing to be correlated with a WALK/DON'T WALK pedestrian display. Wherever there is a significant departure from customary practice additional care must be taken in communicating 'specifics' to the person responsible for the visualization. What may be obvious to the traffic engineer is not necessarily obvious to the individual creating the visualization.

- Other design issues immediately prompted by the 3D visualizations included the manner in which one would transition between a typical six inch curb and a raised crosswalk and how a cut-through design used in the median area might transition to/from a raised crosswalk. Needless to say, the raised crosswalk prompted design questions regarding adequate drainage.

- While the photo realistic visual simulations used for presentation to the 3-78 Panel did not attempt to explicitly show all treatment 'combinations,' their combined presentation was effective in prompting a useful discussing of what might constitute the most effect treatment combinations for field test and evaluation.

GENERAL OBSERVATIONS

The present joint use of micro-simulation methods and realistic 3D visual simulations suggest that each form of modeling and simulation has an important role to play; micro-simulation in understanding how a facility or specific treatment will 'work' from an operational perspective; photo realistic 3D visualization from the standpoint of enabling those involved (both engineering and non-engineering) to arrive more quickly at a common understanding of the more 'physical' elements of a proposed design (e.g., geometric design elements, spatial location, likely visual appearance from the standpoint of different users, signing, surface markings, etc.). The absence of photo realistic detail in the VISSIM graphic (AVI) outputs served to help those viewing these simulations to focus on the more important operational effects of alternative treatments while the static, highly realistic photo simulations provided no capability for correctly inferring operational effects. One can only predict that as time goes on and computational and graphic capabilities improve there will be a merger of analytic (modeling) and visual simulation methods such that micro-simulations like VISSIM will possess highly realistic, real time, graphic output capabilities.

An important element of the blind pedestrian's performance not captured or addressed by these visual and operational simulations is the roll of traffic generated 'sounds' and their effect upon the auditory discrimination process used by blind pedestrians to judge crossable gaps. An important representation (not visual in nature, but auditory) would be the realistic and accurate representation of traffic sounds as they might be perceived by a blind pedestrian under each of the alternative crosswalk placement alternatives. If our 'analysis' of that environment were to show no measurable basis for differentiation by humans it would question, for example, the extent to which the Orientation and Mobility (O&M) community could expect 'training' to be a significant factor. NCHRP 3-78 as well as research being conducted on a parallel effort by the National Institute of Health will address whether crosswalk placement (especially those that are 'distal' to the circulatory lane) can, even without the additional of signalization, improve the blind pedestrian's ability to correctly identify crossable gaps. Similarly, the blind pedestrian's ability to correctly 'locate' the crosswalk is not a 'visual' problem, but rather a tactile and in some cases (e.g, with the use of locator tones) an auditory task. As a group, we need to devise effective methods for representing (through analytic modeling efforts and other means) the other-than-visual' elements of a design, especially for those where 'access' is critically dependent on such elements.

SUMMARY

Clearly, those responsible for developing new facility designs must focus on both the physical and the operational attributes of a design. Computational, often call 'constructive,' approaches to modeling and simulation, provide an excellent means of *estimating* the effectiveness of those designs. Until recently, such methods were best suited to applications involving motorized traffic, having little or no capability to realistically represent non-motorized (pedestrian) traffic or the interactions between the two. The present example serves to demonstrate how the essential elements of pedestrian crossing behavior can be modeled using operational field data and how this can be used to characterize the decision making performance of different classes of pedestrians (in this case, those with normal vision and those who have pronounced visual impairments). This particular design problem underscores the need to better understand driver attributes that govern yielding to pedestrians, given that pedestrians (often blind pedestrians) will accept 'risky gaps' that place them in the path of approach vehicles. The present illustration of visualization serves to point out the type of detailed understanding of driver-pedestrian interactions required to effectively model the potential effectiveness of treatments lying outside the realm of normal routine practice; and, that often, the decision to proceed with the experimental evaluation of treatment designs considered to be somewhat 'unorthodox' can be aided by visualization methods that are highly realistic (in a visual sense) but less realistic in an operational sense. Until computational and computer image generation capabilities allow for integration of both within the same application, the integration will remain the responsibility of the project engineer.

ACKNOWLEDGMENTS

This work was sponsored by the American Association of State Highway and Transportation Officials (AASHTO), in cooperation with the Federal Highway Administration (F"HWA), and was conducted in the National Cooperative Highway Research Program, which is administered by the Transportation Research Board of the National Research Council.

The opinions and conclusions expressed or implied in this report are those of the research agency and not necessarily those of the Transportation Research Board, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, or the individual states participating in the National Cooperative Highway Research Program.

REFERENCES

(1) Federal Highway Administration (2000). Roundabouts: An Information Guide (FHWA-RD-00-067). Turner-Fairbank Highway Research Center, McLean, VA.

(2) Retting, R.A., Persaud, B.N., Gardner, P.E., and Lord, D. (2001). Crash and Injury Reduction Following Installation of Roundabouts in the United States. American Journal of Public Health, 91(4), 628-631.

(3) US Access Board (2001a). Pedestrian Access to Modern Roundabouts: Design and Operational Issues for Pedestrians Who are Blind. Washington, D.C.: Author

(4) US Access Board (2001b). Building a True Community: Final Report, Public Rights-of-Way Access Advisory Committee. Washington, D.C.: Author.

(5) US Access Board (2005). Board places right-of-way guidelines in docket. Access Currents, 11(6),3.

(6) Guth, D.R., Long, R.G., Ashmead, D.,Wall, R., and Ponchilla, P. (2003) Crossing Streets With and Without Vision at an Urban Double Lane Roundabout. Paper presented at The Urban Streets Symposium, Los Angeles, CA.

(7) Guth, D.R., Long, R.G., Wall, R., and Ponchilla, P. (2005) Blind and Sighted Pedestrians' Judgments of Gaps in Traffic at Roundabouts. Human Factors, 47, 314-331.

(8) Ashmead, D.A., Guth, D.A., Long, R.G., Wall, R., and Ponchilla, P (2005). Street Crossing by Sighted and Blind Pedestrians at a Modern Roundabout. Journal of Transportation Engineering, 1321, Washington, D.C, 812-831,

(9) Gershat, D.R. and Hassan, S.E. Yielding Behavior of Drivers to Sighted and Blind Pedestrians at Roundabouts (2005) Journal of Visual Impairment and Blindness, 99, 2896-302.

(10) Schroeder, B., Rouphail, N. and Wall-Emerson, R. (in press) Exploratory Analysis of Crossing Difficulties for Blind and Sighted Pedestrians at Channelized Turn Lanes. Transportation Research Board Bulletin.

(11) VISSIM User Manual (2004). Planung Transport Verkehr AG (PTV).

(12) Rouphail, N., Hughes, and Chae, K. (2005) Exploratory Simulation of Pedestrian Crossings at Roundabouts. ASCE Journal of Transportation Engineering, 131, 211-218.

(13) Chae, K. (2005). Simulation of Pedestrian Vehicle Interactions at Roundabouts. Unpublished doctoral dissertation. North Carolina State University, Raleigh, NC

(14) Hughes, R. Improving Access to Roundabouts and Channelized Turn Lanes for the Visually Impaired: An Update on NCHRP Project 3-78 (2006) . In Proceedings of 2006 Annual Meeting of the Institute of Transportation Engineers, Milwaukee.

(15) Improving Pedestrian Safety at Unsignalized Crossings (2006). TCRP/NCHRP Project D-08/3-71. Transportation Research Board. National Research Council, Washington, DC.

(16) Schroeder. B., Rouphail, N., and Hughes, R. Exploratory Analysis of Pedestrian Signalization Treatments at One- and Two-Lane Roundabouts Using VISSIM Microsimulation. Submitted for publication and presentation at the 86th Annual Meeting of the Transportation Research Board, January 2007.

(17) Schroeder, B. and Rouphail, N. A Framework for Evaluating Pedestrian-Vehicle Interactions at Unsignalized Crossing Facilities in a Microscopic Modeling Environment. Submitted for publication and presentation at the 86th Annual Meeting of the Transportation Research Board, January 2007.

(18) NYSDOT Context Sensitive Solutions Website at: http://www.dot.state.ny.us/design/css/css.html (last accessed on August 17, 2006).

(19) Inman, V., Davis, G., and Sauerburger, D. (2005). Roundabout Access for Visually Impaired Pedestrians: Evaluation of a Yielding Vehicle Alerting System for Double Land Roundabouts. Proceedings of the TRB National Roundabout Conference. Transportation Research Board, Washington, DC.

APPENDIX N: Approved IRB

This Appendix contains the signed and approved Institutional Review Board (IRB) document granting permission with human subjects in this research.

WESTERN MICHIGAN UNIVERSITY
Human Subjects Institutional Review Board

Date: November 3, 2008

To: Richard Long, Principal Investigator

From: Amy Naugle, Ph.D., Chair Amy Naugle

Re: HSIRB Project Number: 08-10-29

This letter will serve as confirmation that your research project entitled "Testing Interventions to Improve Street Crossing Performance of Individuals who are Blind at a Channelized Turn Lane" has been **approved** under the **expedited** category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may **only** conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: November 3, 2009

Walwood Hall, Kalamazoo, MI 49008-5456
PHONE: (269) 387-8293 FAX: (269) 387-8276

WESTERN MICHIGAN UNIVERSITY
H. S. I. R. B.
Approved for use for one year from this date:
NOV 0 3 2008
HSIRB Chair

1903

WESTERN MICHIGAN UNIVERSITY

October, 2008

AIDS FOR IMPROVING STREET CROSSINGS AT CHANNELIZED TURN LANES

Principal Investigator: Richard G. Long

We are inviting you to participate in a research study. This study is similar to the study you participated in last spring. The purpose of this study is to evaluate two ways to make street crossings easier and safer at channelized turn lanes. If you choose to participate, we will provide transportation to a channelized turn lane in Charlotte. We you arrive at the site, we will explain how traffic moves at this location. After you are familiar with the turn lane, I will invite you to cross the street about 36 times. Each time, we will be standing near the street and at the crosswalk. I will give you a signal to begin, and after you hear the signal you may begin to cross when you think it is an appropriate time. I am a certified Orientation and Mobility specialist and I will be next to you each time you begin crossing. I am here to monitor your crossings and inform you if you cross at a risky time. If you cross at a risky time, I will ask you to stop and I may reach out and prevent you from stepping in front of a moving vehicle. After all the crossings are completed, I'll ask you some questions about how you felt about crossing the street here. I ask that you wear this wireless microphone so that we can record what you say about each of your crossings.

We have installed two features here that may affect your ability to cross the street. One feature is a flashing beacon with an audible message, which can be activated by pushing a button. When it is on, approaching drivers will see flashing lights at the crosswalk. The other feature is a strip of plastic that is put on the road near the crosswalk. It makes noise when a car rolls over it. This aid may be helpful in hearing when cars are approaching the crosswalk.

Your participation will take about two hours. Your participation in this research study is voluntary. You are free to stop participating in this study at any time. Stopping will not penalize or prejudice you in any way. In the event new information becomes available that may affect the risks or benefits associated with this research study or your willingness to participate in it, you will be notified so that you can make an informed decision whether or not to continue your participation in this study.

This study carries a risk of a pedestrian-vehicle accident, since you would be crossing a public street used by drivers who are unaware of the research project. To minimize the risk, a certified Orientation & Mobility specialist will accompany you at all times. If the Orientation & Mobility specialist believes a crossing is unsafe, he or she will prevent you from starting to cross, by verbally telling you to stop or restraining you if necessary. Aside from the accident risk, the study could be uncomfortable because of outside weather conditions. As in all research, there may be unforeseen risks to the participant. If an accidental injury occurs, appropriate emergency measures will be taken including calling 911 and requesting ambulance transportation and rendering whatever aid the research team can provide. However, no compensation or additional treatment will be made available to you except as otherwise stated in this consent form.

WESTERN MICHIGAN UNIVERSITY
H. S. I. R. B.
Approved for use for one year from this date:

NOV 03 2008

x Amy Naugle
HSIRB Chair

The potential benefits to blind people that may result from this study are an increased understanding of the safety of continuous turn lanes for pedestrians, including those with visual impairments. There probably are no specific benefits to you as an individual from this study.

You will be paid $40 for participating. You will be paid this amount when you arrive at the research site, and the payment is yours to keep whether you complete all of the street crossings or only part of them.

The videotape and the data from this study will be kept confidential by the experimenters, and you will not be identified by name in any written or verbal presentation of the results of this study. Paper and video records pertaining to this project will be stored in a locked file cabinet in for five years at the NC State University Institute for Transportation Research and Education in Raleigh NC, or in Room 4460 of the College of Health and Human Services Building at Western Michigan University. Data stored on computer files that pertain to this project will also be kept secured in one of these two locations. No computer records will be identified by your name. Only numbers will be used as identifiers on computer and paper records, and the names associated with the codes will be kept on secured and separate from the data records. Data will only be accessible by members of the North Carolina State University and Western Michigan University research teams.

If you have questions about this study, you can contact Dr. Richard Long at (269) 387-3451 at (269) 387-3446. The participant may also contact the Chairperson of the Western Michigan University Human Subjects Institutional Review Board at (269) 387-8293 or the Vice-President for Research at (269) 387-8298 if questions or problems arise during the study. You may also contact Dr. Ronald Hughes, NCSU/ITRE Principal Investigator for the study at 919-515-8523.

This consent document has been approved for use for one year by the Human Subjects Institutional review Board (HSIRB) as indicated by the stamped date and signature of the board chair in the upper right hand corners of both pages. Participants should not sign this document if the corners of each of the two pages do not show a stamped date and signature.

My signature below indicates my willingness to participate in this study:

____________________	____________________
Signature of participant	Signature of investigator
____________________	____________________
Printed name	Date
____________________	
Date	

WESTERN MICHIGAN UNIVERSITY
Human Subjects Institutional Review Board

September 18, 2008

Dr. Ronald Taylor
National Academies
Committee to Review Studies on Human Subjects
500 Fifth Street, NW
NAS 123
Washington, DC 20001

Ref: WMU HSIRB Protocol 08-05-25 "Testing Interventions to Improve Street Crossing Performance in Individuals Who are Blind at a Multilane Roundabout and a Single Lane Roundabout", Richard G. Long and David Guth, Principal Investigators

Dear Dr. Taylor,

Based on information provided by the research team conducting Project NCHRP project 3-78, I confirm that pilot testing of consent and procedures has taken place, that the research team views the consent process to be adequate, and that physical safety guidelines as documented in the institutional review board protocol approved at Western Michigan University on June 16, 2008 are being followed.

Sincerely,

Amy Naugle

Amy Naugle, Ph.D., HSIRB Chair

cc: Dr. Richard G. Long, Associate Dean, College of Health and Human Services, WMU
Dr. Ronald Hughes, Institute for Transportation Research and Education, North Carolina State University, Campus Box 8601, Raleigh, North Carolina 27695-8601
Mr. Stephan Parker, Senior Program Officer, CRP, Transportation Research Board, Keck 446, 500 Fifth Street, NW, NAS 213, Washington, DC 20001

Walwood Hall, Kalamazoo, MI 49008-5456
PHONE: (269) 387-8293 FAX: (269) 387-8276

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Committee to Review Studies on Human Subjects

500 Fifth Street, NW, NAS 213
Washington, DC 20001
Phone: 202 334 1659
Fax: 202 334 2493
E-mail: rtaylor@nas.edu

July 22, 2008

TRANSPORTATION
RESEARCH BOARD
JUL 28 2008
COOPERATIVE
RESEARCH PROGRAMS

Dr. Stephan A. Parker
Senior Program Officer, CRP
Transportation Research Board
Keck 446

Re: Crossing Treatments at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities (NCHRP Project, 3-78A)

Dear Stephan:

On June 17, 2008, the Committee to Review Human Subjects, acting as the National Academy of Sciences' Institutional Review Board, met to consider the progress and status of the referenced on-going project.

I am pleased to inform you that the Committee has approved the continuation of this project consistent with 45 CFR 46 and its Federal-Wide Assurance, FWA 00003198.

Please inform the Principal Investigator at the Institute for Transportation Research and Education, at North Carolina State University, Dr. Ronald G. Hughes, and ask him to inform the chair of the IRB at the University of this action. I would appreciate being informed about any actions that IRB takes regarding this project in the future.

If the research is not completed by June 2009, the project shall be reviewed again at the Committee's annual meeting to be scheduled in early summer next year. Otherwise, please notify me when the research has been completed or if there are any changes in the approved protocols.

Sincerely,

Ronald D. Taylor, Chair

NATIONAL ACADEMY OF SCIENCES • NATIONAL ACADEMY OF ENGINEERING • INSTITUTE OF MEDICINE • NATIONAL RESEARCH COUNCIL

WESTERN MICHIGAN UNIVERSITY
Human Subjects Institutional Review Board

Date: June 16, 2008

To: Richard Long, Principal Investigator
David Guth, Co-Principal Investigator

From: Amy Naugle, Ph.D., Chair Amy Naugle

Re: HSIRB Project Number: 08-05-25

This letter will serve as confirmation that the changes to your research project "Testing Interventions to Improve Street Crossing Performance in Individuals Who are Blind at a Multilane Roundabout and a Single Lane Roundabout" requested in your memo dated June 13, 2008 (addition of a single lane roundabout as a data collection site; extend participation time to 2.5 hours; change title as reflected above; changes to consent document to reflect these changes) have been approved by the Human Subjects Institutional Review Board.

The conditions and the duration of this approval are specified in the Policies of Western Michigan University.

Please note that you may **only** conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: June 2, 2009

Walwood Hall, Kalamazoo, MI 49008-5456
PHONE: (269) 387-8293 FAX: (269) 387-8276

1903

WESTERN MICHIGAN UNIVERSITY

WESTERN MICHIGAN UNIVERSITY
H. S. I. R. B.
Approved for use for one year from this date:
JUN 02 2008
x Amy Naugle
HSIRB Chair

May, 2008

AIDS FOR IMPROVING STREET CROSSINGS AT ROUNDABOUTS

Principal Investigator: Richard G. Long

We are inviting you to participate in a research study. The purpose of this study is to evaluate two ways to improve the ability of people who are blind to cross streets at roundabout intersections. If you choose to participate, I will ask you a few questions about your mobility and your vision loss. Then, if you want to continue participating, I will explain how traffic moves at a roundabout and I will show you around this roundabout . After you are familiar with the roundabout I will ask you to cross the street several times at two crosswalks. Each time, we will be standing near the street and at the crosswalk. I will give you a signal to begin, and after you hear the signal you may begin to cross when you think it is appropriate. I am a certified Orientation and Mobility specialist and I will be next to you each time you cross. I am here to monitor your crossings and inform you if you cross at a risky time. If you cross at a risky time, I will ask you to stop and I also may physically stop you from stepping in front of a moving vehicle. If you can't cross after listening to traffic for several minutes, we'll move on to the next location and begin again. After all the crossings are completed, I'll ask you some questions about how you felt about crossing the street here. We will be videotaping the traffic and all your crossings, and I will wear a microphone so that we can record what you say about each of your crossings.

Our research team invites you to participate today and again about three months from now. The second time you come to participate, a team member will read to you this consent form again and invite you to participate. If you accept the invitation, you will again be asked to cross the street, but there will be new features installed at the crossings that may help you cross. We will describe these features to you when you come again to participate. Your participation today and your participation about three months from now will each require about two hours of your time.

Your participation in this research study is voluntary. You are free to stop participating in this study at any time, including the time between today and when we ask you to come back for the second time. Stopping will not penalize you in any way. In the event new information becomes available that may affect the risks or benefits associated with this research study or your willingness to participate in it, you will be notified so that you can make an informed decision whether or not to continue your participation in this study.

This study carries a risk of a pedestrian-vehicle accident, since you will be crossing a public street used by drivers who are unaware of the research project. To minimize the risk, a certified Orientation & Mobility specialist will accompany you at all times. If the Orientation & Mobility specialist believes a crossing is unsafe, he or she will prevent you from starting to cross, by verbally telling you to stop or restraining you if necessary. Aside from the accident risk, the study could be uncomfortable because of outside weather conditions. As in all

WESTERN MICHIGAN UNIVERSITY
H. S. I. R. B.
Approved for use for one year from this date:
JUN 02 2008
x Amy Naugle
HSIRB Chair

research, there may be unforeseen risks to the participant. If an accidental injury occurs, appropriate emergency measures will be taken including calling 911 and requesting ambulance transportation and rendering whatever aid the research team can provide. However, no compensation or additional treatment will be made available to you except as otherwise stated in this consent form.

The potential benefits to persons who are blind that may result from this study are an increased understanding of the safety of traffic roundabouts for pedestrians, including those with visual impairments. There probably are no specific benefits to you as an individual from this study.

You will be paid $50 for each of the two sessions you participate in – the one today and the one about three months from now. You will be paid this amount when you arrive at the research site, and the payment is yours to keep whether you complete all of the street crossings on a particular day or only part of them.

The videotape and the data from this study will be kept confidential by the experimenters, and you will not be identified by name in any written or verbal presentation of the results of this study. Paper and video records pertaining to this project will be stored in a locked file cabinet for five years at the NC State University Institute for Transportation Research and Education in Raleigh NC, or in Room 4460 of the College of Health and Human Services Building at Western Michigan University. Data stored on computer files that pertain to this project will also be kept secured in one of these two locations. No computer records will be identified by your name. Only numbers will be used as identifiers on computer and paper records, and the names associated with the codes will be kept on secured and separate from the data records. Data will only be accessible by members of the North Carolina State University and Western Michigan University research teams.

If you have questions about this study, you can contact Dr. Richard Long at (269) 387-2540 or Dr. David Guth at (269) 387-3446. You may also contact the Chairperson of the Western Michigan University Human Subjects Institutional Review Board at (269) 387-8293 or the Vice-President for Research at (269) 387-8298 if questions or problems arise during the study. You may also contact Dr. Ronald Hughes, NCSU/ITRE Principal Investigator for the study at 919-515-8523.

This consent document has been approved for use for one year by the Human Subjects Institutional review Board (HSIRB) as indicated by the stamped date and signature of the board chair in the upper right hand corners of both pages. Participants should not sign this document if the corners of each of the two pages do not show a stamped date and signature.

My signature below indicates my willingness to participate in this study:

______________________	______________________
Signature of participant	Signature of investigator
______________________	______________________
Printed name	Date

WESTERN MICHIGAN UNIVERSITY

Human Subjects Institutional Review Board

Date: August 14, 2007

To: Richard Long, Principal Investigator

From: Amy Naugle, Ph.D., Chair Amy Naugle

Re: HSIRB Project Number: 07-07-22

This letter will serve as confirmation that your research project entitled "Interventions to Improve Street Crossing Performance of Individuals Who are Blind at a Single Land Roundabout and a Channelized Right Right Turn Lane" has been **approved** under the **expedited** category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may **only** conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: August 14, 2008

Walwood Hall, Kalamazoo, MI 49008-5456
PHONE: (269) 387-8293 FAX: (269) 387-8276

WESTERN MICHIGAN UNIVERSITY

1903

Human Subjects Institutional Review Board

Date: February 4, 2008

To: Richard Long, Principal Investigator

From: Amy Naugle, Ph.D., Chair Amy Naugle

Re: HSIRB Project Number: 07-07-22

This letter will serve as confirmation that the changes to your research project "Interventions to Improve Street Crossing Performance of Individuals Who are Blind at a Single Land Roundabout and a Channelized Right Right Turn Lane" requested in your memo January 31, 2008 (Minor changes to consent forms for clarification) have been approved by the Human Subjects Institutional Review Board.

The conditions and the duration of this approval are specified in the Policies of Western Michigan University.

Please note that you may **only** conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: August 14, 2008

Walwood Hall, Kalamazoo, MI 49008-5456
PHONE: (269) 387-8293 FAX: (269) 387-8276

WESTERN MICHIGAN UNIVERSITY
H. S. I. R. B.
Approved for use for one year from this date:
AUG 14 2007
x
HSIRB Chair

1903

January, 2008

WESTERN MICHIGAN UNIVERSITY

AIDS FOR IMPROVING STREET CROSSINGS AT ROUNDABOUTS

Principal Investigator: Richard G. Long

We are inviting you to participate in a research study. The purpose of this study is to evaluate two ways to improve the ability of people who are blind to cross streets at roundabout intersections. If you choose to participate, I will ask you a few questions about your mobility and your vision loss. Then, if you want to continue participating, I will explain how traffic moves at a roundabout and I will show you around this roundabout . After you are familiar with the roundabout I will ask you to cross the street several times at two crosswalks. Each time, we will be standing near the street and at the crosswalk. I will give you a signal to begin, and after you hear the signal you may begin to cross when you think it is appropriate. I am a certified Orientation and Mobility specialist and I will be next to you each time you cross. I am here to monitor your crossings and inform you if you cross at a risky time. If you cross at a risky time, I will ask you to stop and I also may physically stop you from stepping in front of a moving vehicle. If you can't cross after listening to traffic for several minutes, we'll move on to the next location and begin again. After all the crossings are completed, I'll ask you some questions about how you felt about crossing the street here. I ask that you wear a microphone so that we can record what you say about each of your crossings.

Our research team invites you to participate today and again about 4 to 6 weeks from today. The second time you come to participate, about four to six weeks from now, a team member will read to you this consent form again and invite you to participate. If you accept the invitation, you will again be asked to cross the street, but there will be aids installed at the crossings that may help you cross. One aid is a flashing beacon with an audible message, which you can activate by pushing a button. We will demonstrate this aid for you when you come again to participate. When it is on, approaching drivers will see flashing lights at the crosswalk. The other aid is strips of plastic that are put on the road near the crosswalk which will make noise when cars roll over them. This may be helpful in determining when cars are approaching the crosswalk. Your participation today and your participation 4 to 6 weeks from now will each require about two hours of your time.

Your participation in this research study is voluntary. You are free to stop participating in this study at any time, including the time between today and when we ask you to come back for the second time. Stopping will not penalize you in any way. In the event new information becomes available that may affect the risks or benefits associated with this research study or your willingness to participate in it, you will be notified so that you can make an informed decision whether or not to continue your participation in this study.

This study carries a risk of a pedestrian-vehicle accident, since you will be crossing a public street used by drivers who are unaware of the research project. To minimize the risk, a certified Orientation & Mobility specialist will accompany you at all times. If the Orientation & Mobility specialist believes a crossing is unsafe, he or she will prevent you from starting to cross, by verbally telling you to stop or restraining you if necessary. Aside from the accident risk, the

WESTERN MICHIGAN UNIVERSITY
H. S. I. R. B.
Approved for use for one year from this date:
AUG 14 2007
x Amy Naugle
HSIRB Chair

study could be uncomfortable because of outside weather conditions. As in all research, there may be unforeseen risks to the participant. If an accidental injury occurs, appropriate emergency measures will be taken including calling 911 and requesting ambulance transportation and rendering whatever aid the research team can provide. However, no compensation or additional treatment will be made available to you except as otherwise stated in this consent form.

The potential benefits to persons who are blind that may result from this study are an increased understanding of the safety of traffic roundabouts for pedestrians, including those with visual impairments. There probably are no specific benefits to you as an individual from this study.

You will be paid $40 for each of the two sessions you participate in – the one today and the one 4 to 6 weeks from now. You will be paid this amount when you arrive at the research site, and the payment is yours to keep whether you complete all of the street crossings on a particular day or only part of them.

The videotape and the data from this study will be kept confidential by the experimenters, and you will not be identified by name in any written or verbal presentation of the results of this study. Paper and video records pertaining to this project will be stored in a locked file cabinet for five years at the NC State University Institute for Transportation Research and Education in Raleigh NC, or in Room 4460 of the College of Health and Human Services Building at Western Michigan University. Data stored on computer files that pertain to this project will also be kept secured in one of these two locations. No computer records will be identified by your name. Only numbers will be used as identifiers on computer and paper records, and the names associated with the codes will be kept on secured and separate from the data records. Data will only be accessible by members of the North Carolina State University and Western Michigan University research teams.

If you have questions about this study, you can contact Dr. Richard Long at (269) 387-3451 or Dr. David Guth at (269) 387-3446. You may also contact the Chairperson of the Western Michigan University Human Subjects Institutional Review Board at (269) 387-8293 or the Vice-President for Research at (269) 387-8298 if questions or problems arise during the study. You may also contact Dr. Ronald Hughes, NCSU/ITRE Principal Investigator for the study at 919-515-8523.

This consent document has been approved for use for one year by the Human Subjects Institutional review Board (HSIRB) as indicated by the stamped date and signature of the board chair in the upper right hand corners of both pages. Participants should not sign this document if the corners of each of the two pages do not show a stamped date and signature.

My signature below indicates my willingness to participate in this study:

___________________________ ______________________
Signature of participant Signature of investigator

___________________________ ______________________
Printed name Date

WESTERN MICHIGAN UNIVERSITY
H. S. I. R. B.
Approved for use for one year from this date:
AUG 14 2007
x
HSIRB Chair

1903

WESTERN MICHIGAN UNIVERSITY

January, 2008

AIDS FOR IMPROVING STREET CROSSINGS AT CHANNELIZED TURN LANES

Principal Investigator: Richard G. Long

We are inviting you to participate in a research study. The purpose of this study is to evaluate two ways to improve the ability of people who are blind to cross streets at channelized turn lanes. If you choose to participate, I will ask you a few questions about your mobility and your vision loss. Then, if you want to continue participating, I will explain how traffic moves at a channelized turn lane and I will show you the turn lanes at this intersection that we'll be using in this research. After you are familiar with the turn lanes, I will invite you to cross the turn lanes here several times. Each time, we will be standing near the street and at the crosswalk. I will give you a signal to begin, and after you hear the signal you may begin to cross when you think it is an appropriate time. I am a certified Orientation and Mobility specialist and I will be next to you each time you begin crossing. I am here to monitor your crossings and inform you if you cross at a risky time. If you cross at a risky time, I will ask you to stop and also I may physically stop you from stepping in front of a moving vehicle. If you can't cross after listening to traffic for several minutes, we will move to another location and begin again. After all the crossings are completed, I'll ask you some questions about how you felt about crossing the s crossing. I ask that you wear a wireless microphone so that we can record what you say about the crossings.

We invite you to participate today and again about 4 to 6 weeks from today. The second time you come to participate, about four to six weeks from now, we will read to you this consent form again and invite you to participate. If you accept our invitation, you will again be asked to cross the street, but there will be aids installed at the crossings that may help you cross. One aid is a flashing beacon with an audible message, which you can activate by pushing a button. We will demonstrate this aid for you when you come again to participate. When it is on, approaching drivers will see flashing lights at the crosswalk. The other aid is strips of plastic that are put on the road near the crosswalk which will make noise when cars roll over them. This may be helpful in determining when cars are approaching the crosswalk. Your participation today and your participation 4 to 6 weeks from now will each require about two hours of your time.

Your participation in this research study is voluntary. You are free to stop participating in this study at any time, including the time between today and when we ask you to come back for the second time. Stopping will not penalize you in any way. In the event new information becomes available that may affect the risks or benefits associated with this research study or your willingness to participate in it, you will be notified so that you can make an informed decision whether or not to continue your participation in this study.

This study carries a risk of a pedestrian-vehicle accident, since you will be crossing a public street used by drivers who are unaware of the research project. To minimize the risk, a certified Orientation & Mobility specialist will accompany you at all times. If the Orientation & Mobility specialist believes a crossing is unsafe, he or she will prevent you from starting to cross, by

WESTERN MICHIGAN UNIVERSITY
H. S. I. R. B.
Approved for use for one year from this date:
AUG 1 4 2007
x Amy Naugle
HSIRB Chair

verbally telling you to stop or restraining you if necessary. Aside from the accident risk, the study could be uncomfortable because of outside weather conditions. As in all research, there may be unforeseen risks to the participant. If an accidental injury occurs, appropriate emergency measures will be taken including calling 911 and requesting ambulance transportation and rendering whatever aid the research team can provide. However, no compensation or additional treatment will be made available to you except as otherwise stated in this consent form.

The potential benefits to persons who are blind that may result from this study are an increased understanding of the safety of continuous turn lanes for pedestrians, including those with visual impairments. There probably are no specific benefits to you as an individual from this study.

You will be paid $40 for each of the two sessions you participate in – the one today and the one 4 to 6 weeks from now. You will be paid this amount when you arrive at the research site, and the payment is yours to keep whether you complete all of the street crossings on a particular day or only part of them...

The videotape and the data from this study will be kept confidential by the experimenters, and you will not be identified by name in any written or verbal presentation of the results of this study. Paper and video records pertaining to this project will be stored in a locked file cabinet in for five years at the NC State University Institute for Transportation Research and Education in Raleigh NC, or in Room 4460 of the College of Health and Human Services Building at Western Michigan University. Data stored on computer files that pertain to this project will also be kept secured in one of these two locations. No computer records will be identified by your name. Only numbers will be used as identifiers on computer and paper records, and the names associated with the codes will be kept on secured and separate from the data records. Data will only be accessible by members of the North Carolina State University and Western Michigan University research teams.

If you have questions about this study, you can contact Dr. Richard Long at (269) 387-3451 or Dr. David Guth at (269) 387-3446. You may also contact the Chairperson of the Western Michigan University Human Subjects Institutional Review Board at (269) 387-8293 or the Vice-President for Research at (269) 387-8298 if questions or problems arise during the study. You may also contact Dr. Ronald Hughes, NCSU/ITRE Principal Investigator for the study at 919-515-8523.

This consent document has been approved for use for one year by the Human Subjects Institutional review Board (HSIRB) as indicated by the stamped date and signature of the board chair in the upper right hand corners of both pages. Participants should not sign this document if the corners of each of the two pages do not show a stamped date and signature.
My signature below indicates my willingness to participate in this study:

Signature of participant	Signature of investigator
Printed name	Date