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

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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
Pedestrian Actuation →	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.

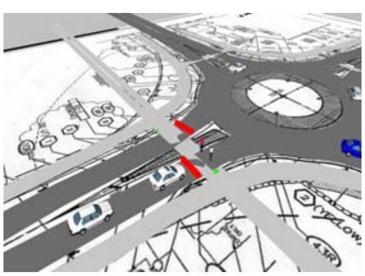

Figure 2a. Proximal Condition

Figure 2b. Staggered or Off-Set Condition

Figure 2c. Distal Condition

Figure 2. Proximal, Off-Set, and Distal Crosswalk Placements

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.

Figure 3. Example of Off-Set or Staggered Crosswalk Condition

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.

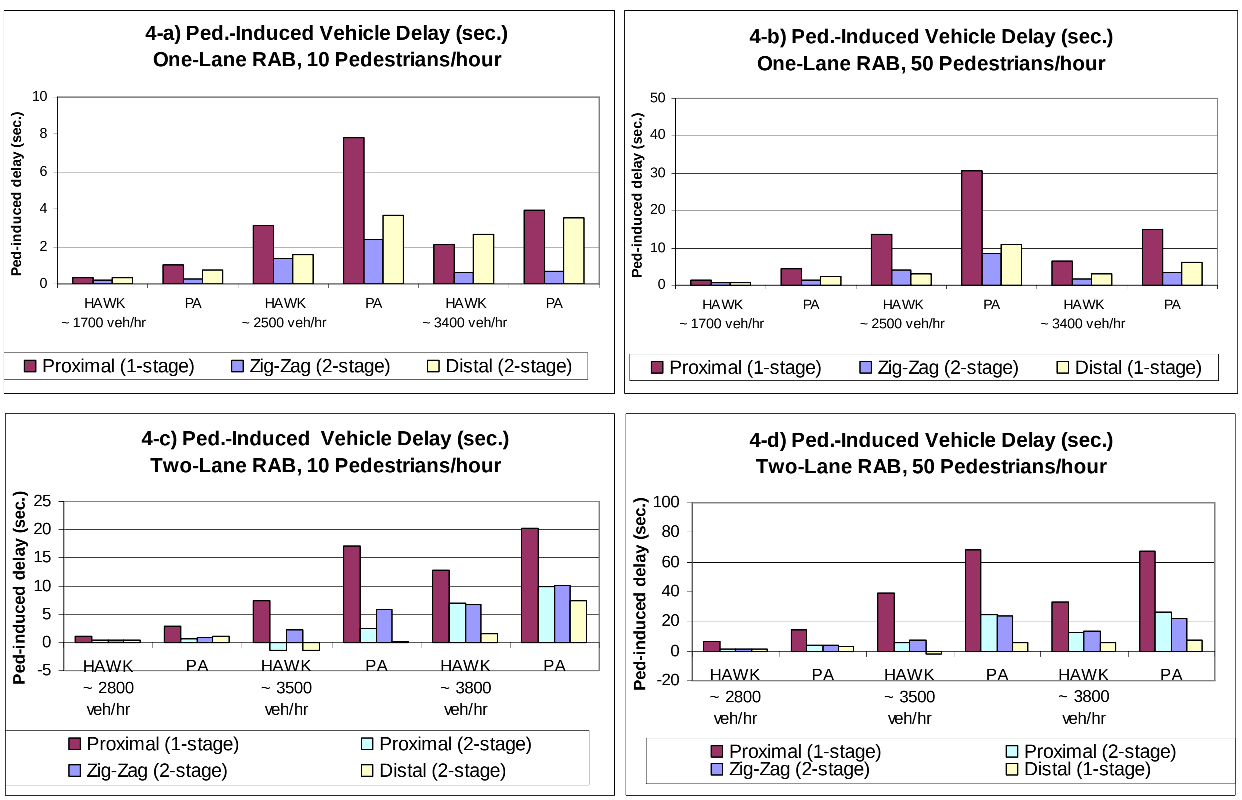

Figure 4. Pedestrian-Induced System (Vehicle) Delay as a Function of Type of Signalization, Pedestrian Level, and Vehicle Level

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.

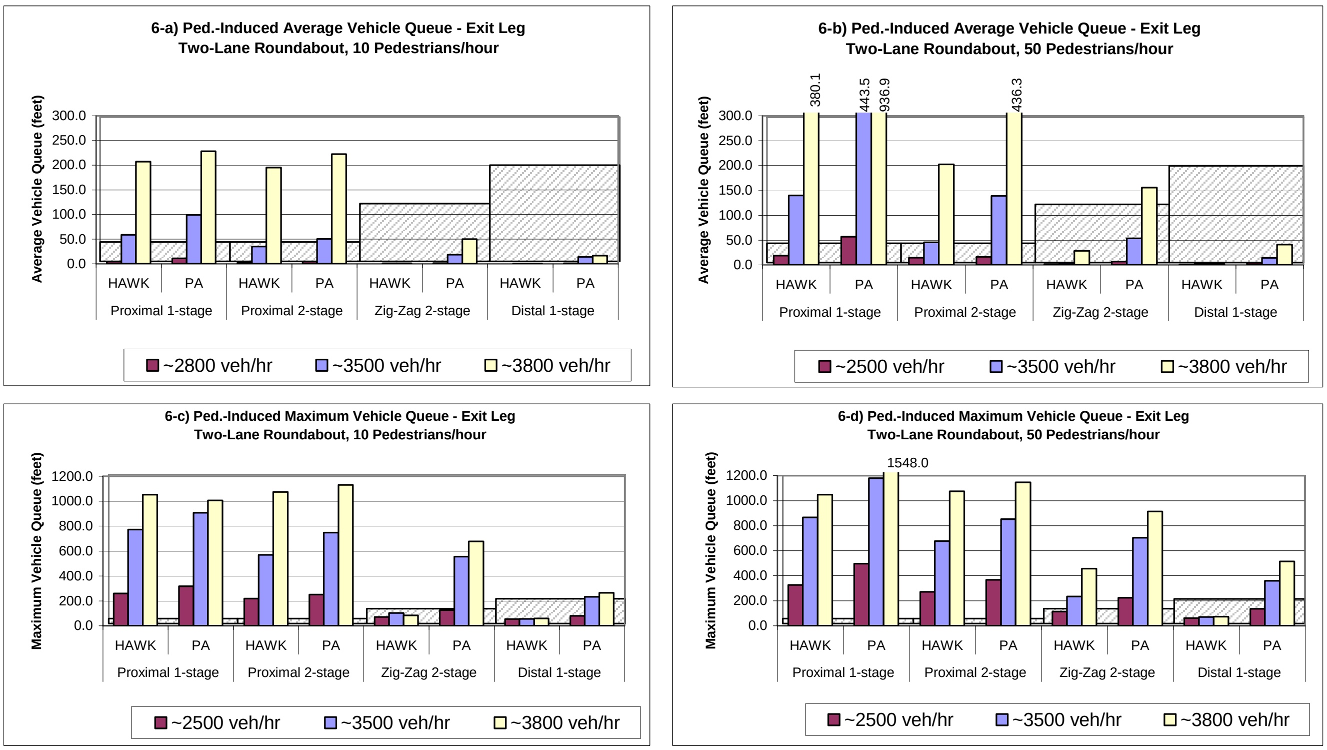

Figure 5. Pedestrian-Induced Vehicle Queue at the Exit Leg of a Two Lane Roundabout as a Function of Type of Signal, Vehicle Level, and Pedestrian Level

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.

ACKNOWLEDGEMENTS

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.

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