EVALUATION AND APPLICATION OF PEDESTRIAN MODELING CAPABILITIES USING COMPUTER SIMULATION

Final Report of Work
Performed Using Supplemental Funds
By

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For

Western Michigan University

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GENERAL INTRODUTION AND OVERVIEW

With supplemental funding from NIH/NEI, the Western Michigan University bio-engineering research partnership (BRP) has undertaken an evaluation of computer modeling and simulation capabilities that might be applied to the development and evaluation of alternative behavioral and engineering/design interventions aimed at improving the ability of blind pedestrians, and those with low vision, to successfully negotiate street crossings at complex intersections including roundabouts.

The UNC Highway Safety Research Center (HSRC) undertook this work, with technical assistance from the NC State University Institute for Transportation Research and Education (ITRE). Dr. Hughes and Mr. Harkey of HSRC provided supervision for the work; Dr. Nagui Rouphail, ITRE Director, was PI. Overall supervision was through Dr. Richard Long at Western Michigan.

The results of this initial capabilities evaluation are presented here in two sections. The first deals with a preliminary evaluation of concepts associated with modeling the interaction of vehicle and pedestrian traffic at an unsignalized crossing location. This portion of the effort was conducted in the context of the ARENA general-purpose simulation model, and confirmed the utility of a composite queuing model and associated measures of pedestrian delay and capacity as key measures of effectiveness. The results of the work with the ARENA model are described in Section I and provide the basis for the work reported in Section II. The work discussed in Section II deals with the evaluation of two commercially available models, VISSIM and Paramics, and their application to a specific roundabout design problem. For reasons detailed in the report, VISSIM was the model selected for more extensive review.

The VISSIM model was used to construct a simulation of the proposed Stinson-Pullen Park roundabout scheduled for construction on the NCSU campus during the last half of 2002. The proposed roundabout is to be a single lane urban design, and thus represents a reasonable starting point for an analysis of modeling and simulation capabilities applied to the problem being addressed by the NIH/NEI partnership.

VISSIM was used to model the gap selection characteristics of both blind and sighted pedestrians at the proposed Stinson-Pullen Park roundabout. The gap selection characteristics or 'attributes' of blind and sighted pedestrians were based on observational field data collected by the Western Michigan BRP at three roundabouts in the greater Baltimore metropolitan area.

The effects of traffic volumes (ranging from 60 percent to 140 percent of current base volumes at Pullen-Stinson) on measures of pedestrian and vehicle delay were evaluated for both blind and sighted pedestrians.

The results of these 'sensitivity' analyses indicated that the most problematic area for blind pedestrians and those with low vision is the 'exit' lane of the roundabout, where blind and low vision pedestrians were estimated to encounter delays (in waiting to cross) that were three times those of the sighted pedestrians modeled in the study. 'Conflicts' that might cause vehicle delays (e.g., those associated with a pedestrian intentionally or otherwise selecting an unsafe gap) were not modeled, and thus, measures of vehicle delay in the present study were not sensitive to the gap acceptance attributes of blind and sighted pedestrians. Such 'conflicts' and their effects are a real part of operational performance and should be addressed in future modeling efforts.

Several avenues of future research are indicated by these results. First, the threefold to fourfold difference between blind and sighted pedestrians in 'latency time' (i.e., the time between the beginning of an acceptable gap and the time the pedestrian actually begins to cross) suggests that the blind/low vision pedestrian experiences much greater difficulty in attempting to select a gap in the vicinity of the entry and exit lanes of a roundabout. This three to fourfold difference in latency, when combined with high traffic volumes and fewer crossable gaps, make the blind pedestrian's task of gap selection inordinately difficult . . . at least when performed at the traditional entry/exit lane crossing location.

These results suggest there might be value in considering alternate crossing locations; in particular, a pedestrian crosswalk (unsignalized or pedestrian-actuated) that is located 'downstream' from the exit lane (conversely, 'upstream' from the entry lane). Moving the crosswalk *away from* the area of the circulating traffic mitigates (if not eliminates) the difficult auditory discrimination problem associated with determining when vehicles in the circulating lane are about to exit. The auditory task for the blind pedestrian at the upstream/downstream location is more like that experienced at an ordinary unsignalized location.

It is proposed that VISSIM, or similar models of integrated vehicle/pedestrian behavior, be used to evaluate the operational effectiveness of such alternatives (insomuch as the upstream/downstream crossing location would, by definition, increase the overall distance that the individual would have to travel to reach his/or ultimate destination). However, the extent to which this increased travel time would be offset by a reduction in latency associated with ones crossing, has yet to be determined and needs to be researched.

The results also point to the potential utility of a pavement sensor/detector to be located in the area of the roadway between the exit lane and the downstream crossing location, the purpose of which would be to provide the blind pedestrian with a reliable cue as to the presence of an approaching vehicle and an associated 'unsafe' gap. From a user information standpoint, it is an interesting system design consideration as to whether the instrumentation should be used to alert the pedestrian as to the presence of an 'unsafe' gap or to the presence of a 'crossable' gap.

To the extent that vehicles tend to accelerate when leaving the exit lane of a roundabout, consideration is also being given to the application of traffic calming (speed control/reduction) measures beyond the exit lane; that is, in the area between the exit lane and the proposed downstream crossing. When considered together, the use of a downstream pedestrian crossing location and the use of traffic calming to maintain lower speeds in the area between the exit lane and the downstream crossing suggests that there is value from both a safety and operational perspective in 'enlarging' the operational area of influence/control of the roundabout.

The team has reviewed these results in detail and believes, as a team, that modeling and simulation need to be inherent parts of this work from this point on. As the research moves from problem definition to the development and evaluation of system concepts, modeling and simulation become increasingly important to 'focusing' the work toward effective outcomes.

The team has also given consideration to the application of modeling within a broader concept of modeling, simulation, and visualization (refer to unpublished manuscript by Hughes, Harlow, and Turner (2002) on the integrated application of these technologies within the context of a 'laboratory' for the study of system safety and operational performance issues of non-motorized traffic).

The 'team' is presently organizing a proposal for additional 'supplemental' funding aimed at project-specific applications of modeling and simulation. We would like for NIH/NEI to be aware of the broader context in which these technologies might be applied, but realize that efforts to this end are likely beyond the 'administrative' scope of 'supplemental' funding support.

EVALUATION AND APPLICATION OF PEDESTRIAN MODELING CAPABILITIES USING COMPUTER SIMULATION

Part I. Simulation of Pedestrian Crossing Process in Roundabout Area Using the Arena Simulation Package

Submitted to

Dr. Ronald G. Hughes and Mr. David Harkey, P.E.

HIGHWAY SAFETY RESEARCH CENTER (HSRC), UNC-CH
NATIONAL INSTITUTES OF HEALTH (NIH)

BY

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THE INSTITUTE FOR TRANSPORTATION RESEARCH AND EDUCATION (ITRE), NCSU

June 2002

I Executive Summary

This working paper documents the initial activities in the research project entitled "Evaluation and Application of Pedestrian Modeling Capabilities" sponsored by the Highway Safety Research Center (HSRC) and the National Institutes of Health (NIH). In this step we explore features of the pedestrian crossing process at roundabouts and use the Arena simulation model to simulate it. The research questions are: 1) can the pedestrian crossing process be modeled as entities flowing through a composite queuing system and 2) how to analyze pedestrian crossing capacity and delay using the Arena simulation model.

Pedestrian crossing at roundabout approaches where splitter islands exist can be divided into two stages. The first stage is the crossing from the near curb to the splitter island. For any pedestrian who wants to complete this stage, three conditions must be satisfied. Pedestrians have to be at the front of the crossing area; they must find a sufficient gap between approaching vehicles to cross the street safely; and their destination, the splitter island, must have room for them to enter.

The second stage is the crossing from the splitter island to the far curb. This stage is about the same as the first one in the sense that pedestrians also have to be at the front of the queue and pedestrians must wait for a gap larger than their critical gap. However, the holding capacity of the far curb is assumed to be infinite, so this stage does not have a holding capacity restriction.

The Arena simulation model is used to simulate this two-stage two-way pedestrian crossing at a hypothetical un-signalized roundabout. Each stage consists of multiple queues waiting for seizing necessary resources, (for example, waiting for holding spaces in the splitter island), or waiting for particular traffic conditions, (for example, waiting for a gap larger than the critical gap).

We model typical geometric properties, demand volumes and pedestrian behavioral attributes as control parameters, upon which we execute sensitivity tests and scenario analysis. The statistical output results from show that modeling the pedestrian crossing process, as a two-stage composite queuing process using the Arena simulation model is feasible to carry out pedestrian capacity and delay analysis.

II Introduction and Background

Background

Modern roundabouts are increasingly being used in the United States in light of their good capacity and safety performances compared to conventional signalized or un-signalized intersections. Many recent applications show that by enhancing priority control and speed enforcement, modern roundabouts can increase vehicle capacity as well as reduce accident rates.

Previous research on modern roundabouts was mainly concerned with vehicle performance. Since roundabouts in urban areas have the potential for servicing large volume of pedestrians, the evaluation of their overall performance should also include analysis of pedestrian crossing capacity, delay and safety issues.

At any crossing, a pedestrian signal is theoretically the safest control method since pedestrians have exclusive priority over other traffic during the "Walk" interval. However, since vehicles usually travel at low speeds in the roundabout area, un-signalized pedestrian crossings are more often used to increase vehicle capacity, decrease vehicle and pedestrian delay, and to avoid the potential of spillback of vehicle queues into the roundabout.

In this project we explore the pedestrian crossing street process under un-signalized control and use a simulation model to reproduce and analyze this process. Selected simulation outputs are used to analyze the effects of key control parameters on pedestrian crossing capacity and delay.

The simulation package used is Arena Simulation Model by Rockwell Software. It is a general-purpose simulation model that has been applied to the simulation of variety of systems including production processes, customer service systems, transportation systems, etc. Arena provides its users convenient flowchart modeling functions that users can pick to reproduce production or service processes logically, easily and quickly.

Besides its convenient model construction function, the Arena simulation model produces a host of statistical output and graphics of (a) multiple replications of terminating simulations, or (b) batch methods of steady-state simulation running. As a modern simulation package, it also incorporates powerful analyses tools including the Output Analyzer to execute advanced statistical analysis on the simulation results, the Process Analyzer to change control variables and gather results for different scenarios, and the Optimization Quest to optimize parameter sets according to specified conditions and scopes.

Modeling Concepts

Our model is an un-signalized pedestrian crossing at a hypothetical roundabout with typical geometry. After careful study of the pedestrian crossing process, we decompose it into two stages, where each stage is a composite queuing system composed of multiple waiting queues as depicted in Figure 1.

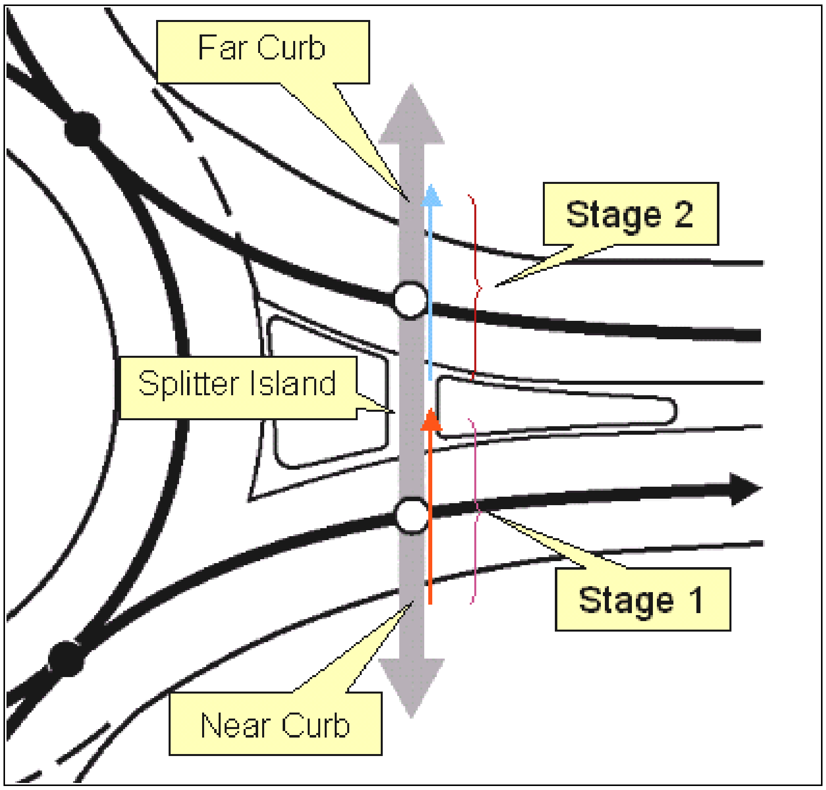


Figure 1 Two-stage pedestrian crossing model at a theoretical roundabout

We reproduce this two-stage pedestrian crossing process using the Arena simulation model. We use modules and blocks from Arena's Basic Process Panel, Advanced Process Panel and Advanced Transfer Panel to reproduce multiple waiting queues and organize them into a continuous process. These queues are formed either for necessary resources or for particular traffic conditions.

In the model we set typical attributes, such as the holding capacity of the splitter island, pedestrian demands, vehicle volumes, size of critical gaps, etc, as control parameters. We execute sensitivity tests for selected demand levels, geometric properties and pedestrian behavioral attributes and explore how these parameters affect pedestrian crossing street capacity and travel delay.

We first select one typical combination of simulation parameters as the base scenario. Using measurements of effectiveness to reflect capacities and levels of service for crossing pedestrians, we carry out replications for each scenario analysis, each having a different set of sensitive parameter values.

Objective and Scope

This research explores the feasibility of using a composite queuing system to reproduce the pedestrian crossing process at un-signalized crossing, and analyzes the pedestrian crossing process at roundabouts for typical demand volumes, geometric attributes and pedestrian behavior scenarios.

This is accomplished in the following steps:

1. Study the pedestrian street crossing process and find typical control parameters;
2. Use Arena to model street crossing process, combine waiting queues for different conditions for each stage;
3. Specify measures of effectiveness for the whole process and for each stage; add them to the Arena output report specification;
4. Record output measurements under typical set of parameters and verify them using other analysis tools such as HCM;
5. Carry out sensitivity tests for demand volumes, geometric properties, and pedestrian behavior attributes parameters;
6. Carry out multiple runs for scenarios that have different vehicle demand levels, and report the outputs;
7. Compare the outputs and determine the conclusions and recommendations.

The principal objectives are to find out:

1. If one can use a composite queuing system to reproduce pedestrian crossing street in roundabout areas;
2. How critical to pedestrian crossing capacity and delay are vehicle and pedestrian demand levels and key roundabout geometric properties.

III Methods and Analysis

Model Construction

The pedestrian crossing process is an arrive-queue-service-depart system that consists of multiple waiting queues for different resources or conditions. Thus, pedestrians 1) arrive at crossing, 2) wait for particular vehicle gaps so that waiting queues are formed, then 3) enter crossing and cross street once necessary conditions are all satisfied, finally 4) enter next stage or depart crossing system if they have arrived at their destinations.

Since the performance of the crossing process with un-signalized control highly depends on vehicle gap rejection and acceptance, we decompose the crossing process into two sub-models: vehicle arrival sub-model to deal with pedestrian gap acceptance behavior and pedestrian crossing sub-model to deal with pedestrian queuing and crossing behavior.

1. Vehicle Arrival Sub-Model

In the vehicle arrival sub-model vehicle arrival behavior at an observation point is reproduced. In this model this point is the pedestrian crossing. Obviously the number of vehicles arriving at this point during the simulation period should mirror the hourly vehicle demand. Therefore we assume that the inter-arrival times between vehicles follow a shifted negative exponential distribution whose mean value is equivalent to the reciprocal of the vehicle demand.

$$\begin{cases} i_1 \infty \lambda + \exp(\beta_1) & \text{for traffic leaving the roundabout} \\ i_2 \infty \lambda + \exp(\beta_2) & \text{for traffic entering the roundabout} \end{cases}$$

Where i_1, i_2 are inter-arrival times of vehicles; λ is minimum headway; β_1, β_2 are distribution parameters; and,

$$\begin{cases} V_1 = 3600/(\lambda + \beta_1) & \text{for traffic leaving the roundabout} \\ V_2 = 3600/(\lambda + \beta_2) & \text{for traffic leaving the roundabout} \end{cases}$$

Where V_1 and V_2 are vehicle demands for entering and leaving roundabouts respectively.

During each inter-arrival time, the time gap between vehicles is compared to the critical gap. In the model the critical gap is a parameter that is equivalent to the pedestrian crossing street time plus a safety factor. If a time gap is less than critical gap, a pedestrian will reject this gap and wait for the next available one.

Otherwise the difference between the time gap and the critical gap is considered as the pedestrian "green" period.

Before we can execute the above test, we need to convert inter-arrival times to vehicle gap times. To simplify the problem, we assume vehicles as particles. Therefore the comparison of time gap and critical gap can be performed using direct comparison of the inter-arrival time and the critical gap.

A binary variable to record the comparison results is defined as 1 when crossing is available and 0 otherwise. Summarizing the above procedure, we construct a flowchart shows as Figure 2:

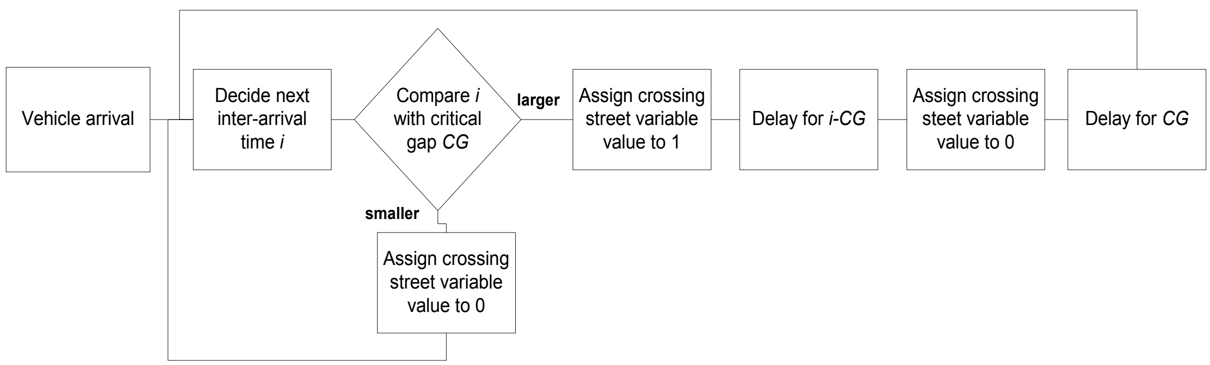


Figure 2 Flowchart of vehicle arrival sub-model

2. Pedestrian Crossing Sub-Model

In the pedestrian crossing sub-model, we generate multiple waiting queues of pedestrians and organize them. As we mentioned above, pedestrian crossing is a two-stage process that includes crossing from the near curb to the splitter island (stage 1) and crossing from the splitter island to the far curb (stage 2).

The pedestrian arrival process at the near curb in Figure 1 is modeled with inter-arrival times follow negative exponential distribution.

$$\begin{cases} i_3 \infty \exp(\beta_3) & \text{for direction opposed by exiting traffic} \\ i_4 \infty \exp(\beta_4) & \text{for direction opposed by entering traffic} \end{cases}$$

Where i_3, i_4 are inter-arrival times of vehicles; β_3, β_4 are distribution parameters; and,

$$\begin{cases} V_3 = 3600 / \beta_3 & \text{for direction opposed by exiting traffic} \\ V_4 = 3600 / \beta_4 & \text{for direction opposed by entering traffic} \end{cases}$$

Where V_3 and V_4 are pedestrian demands in pph (pedestrians per hour).

Modules and blocks used for this sub-model are shown in Figure 3:

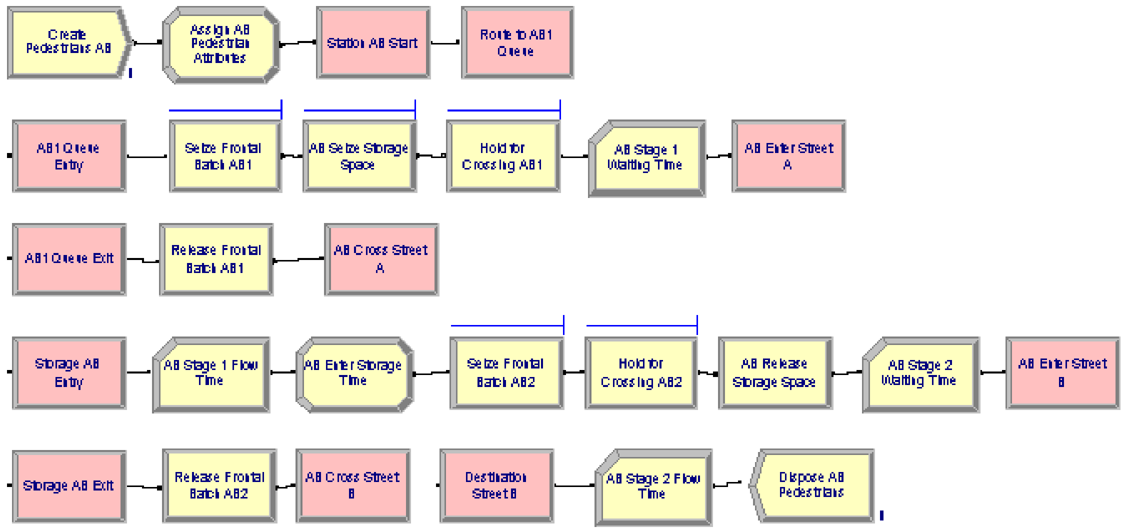


Figure 3 Modules and blocks of pedestrian crossing sub-model

To cross from the near curb to the splitter island, pedestrians need to have three conditions satisfied. The first condition is that pedestrians are queued and have access to the front of the crossing area. The number of frontal spaces depends on the width of the crosswalk. For example, a crossing that is wide enough for four pedestrians abreast two frontal spaces can be assumed to be available for each direction at any time. The number of frontal spaces also stands for number of channels in this queuing system.

The second condition is that the splitter island has available holding spaces for pedestrians to queue. The number of holding spaces depends on the geometric features of the splitter island.

The third condition is that pedestrians encounter sufficiently large vehicle gaps so that safe crossing is possible. This condition is dictated by the value of the binary variable indicating crossing availability.

The second stage, crossing from the splitter island to the far curb stage, is about the same as the first one in the sense that pedestrians also have to be at the front of the queue and pedestrians must wait for a gap larger than their critical gap. However, the holding capacity of the far curb is assumed to be infinite, so this stage does not have a holding capacity restriction.

3. Control Parameters

In the model key parameters are coded as control variables so that we can easily change them to test different scenarios. These parameters can be classified into: input demands, geometric properties and pedestrian behavior attributes.

- For input demands, λ, β_1, β_2, β_3 and β_4 are used to quantify vehicle and pedestrian demands.

- Geometric properties include the width of pedestrian crossing and the holding capacity of the splitter island. The width of pedestrian crossing determines the number of available frontal spaces at the crossing and consequently the number of queuing channels, ***m***. Since one pedestrian usually occupies a space ≈ 2.0 feet in width, we approximate the number of channels using the following equation:
$$m = \frac{\text{Crosswalk Width}}{2.0}$$
The holding capacity of Splitter Island, ***c***, controls the number of pedestrians that can occupy the space simultaneously.

- Regarding pedestrian behavior, the average pedestrian walking speed, ***s***, the crosswalk length, ***w***, and a safety factor, ***f***, together determine the size of the critical gap by the following equation:
$$CG = \frac{w}{s} + f$$
Where CG is the size of the critical gap.

Finally, the queue discharge headway parameter, ***h***, represents the minimum time between consecutive pedestrians crossing in a single channel assuming a continuous queue of pedestrian and an adequate gap size.

Queue discharge headway is commonly used to calculate crossing capacity under ideal conditions, using the following formula:
$$Capacity = \frac{3600}{h}$$
The HCM 2000 provides pedestrian service volumes for a 5.0 feet wide sidewalk, where level of service E corresponds to a 15-min pedestrian count of 1725. If we assume this to be a two-channel system, capacity for each channel is calculated as 3450 pedestrians per hour. Under this capacity the average queue discharge headway between pedestrians is slightly above 1 second.

Sensitivity Analysis

Input parameters for base scenario are summarized in Table 1:

Item	Unit	Value	Parameter	Value
Directional Vehicle Demand	vph	800	β_1, β_2	3.5
Two-Way Pedestrian Demand*	pph	400	β_3, β_4	18
Capacity of Splitter Island	peds	5	***c***	5
Width of Pedestrian Crossing	ft	8	***m***	2
Crosswalk Length	ft	18	***w***	18
Average Walking Speed	fps	4.5	***s***	4.5
Safety Factor	sec	2.5	***f***	2.5
Queue discharge Headway	sec	1.5	***h***	1.5

* 50/50 directional split

Table 1 Input and parameter values for base case study

In the following figures, the sensitivity of pedestrian waiting time (in seconds) for both stages combined is illustrated against several demand and geometric parameters.

In Figure 4, pedestrian delay increases sharply when two-way pedestrian demand exceeds 600 pedestrians per hour.

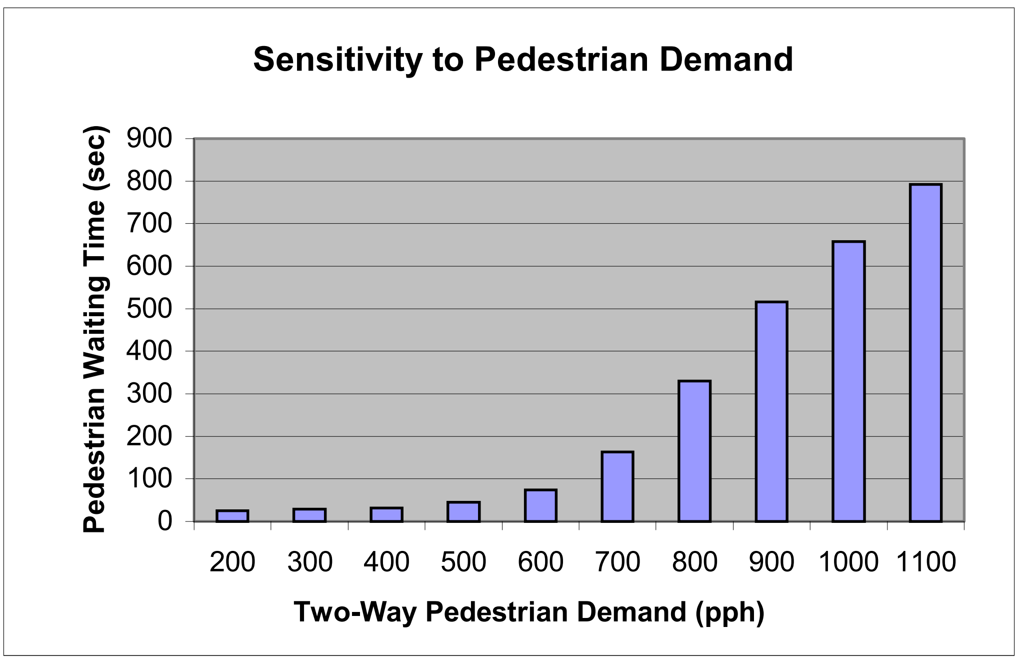
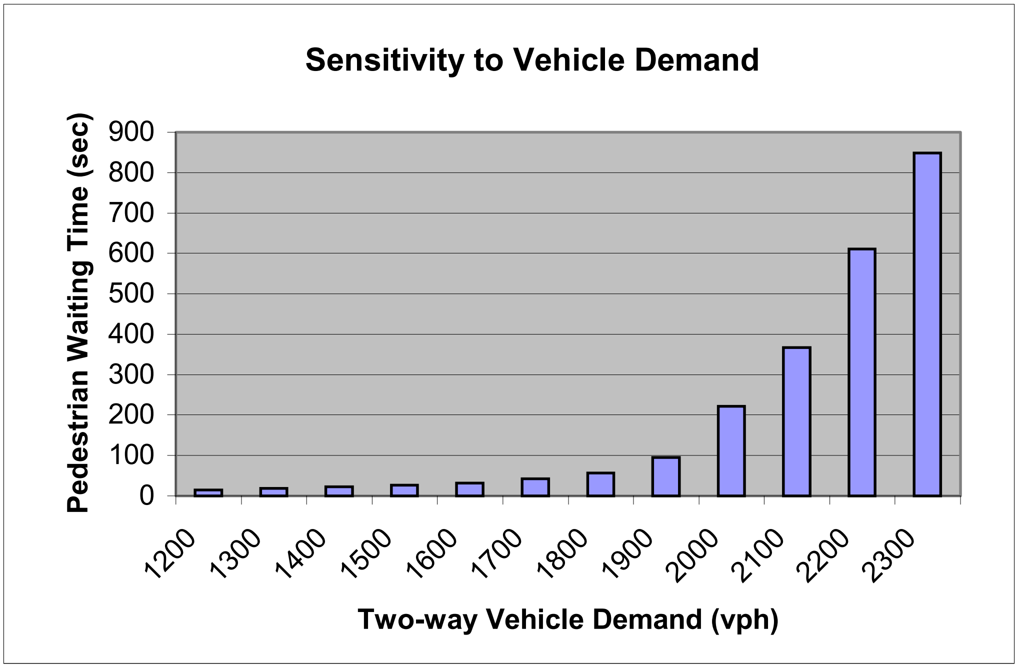


Figure 4 Sensitivity to Pedestrian Demand

In Figure 5, when directional vehicle demand approaches 1000 vehicles per hour, average pedestrian waiting time increases sharply.



* 50/50 directional split

Figure 5 Sensitivity to Vehicle Demand

The capacity of the splitter island affects pedestrian waiting time when the holding capacity is low. In Figure 6, notice that when holding capacity exceeds five, pedestrian waiting time remains stable when usage of holding spaces is far below capacity.

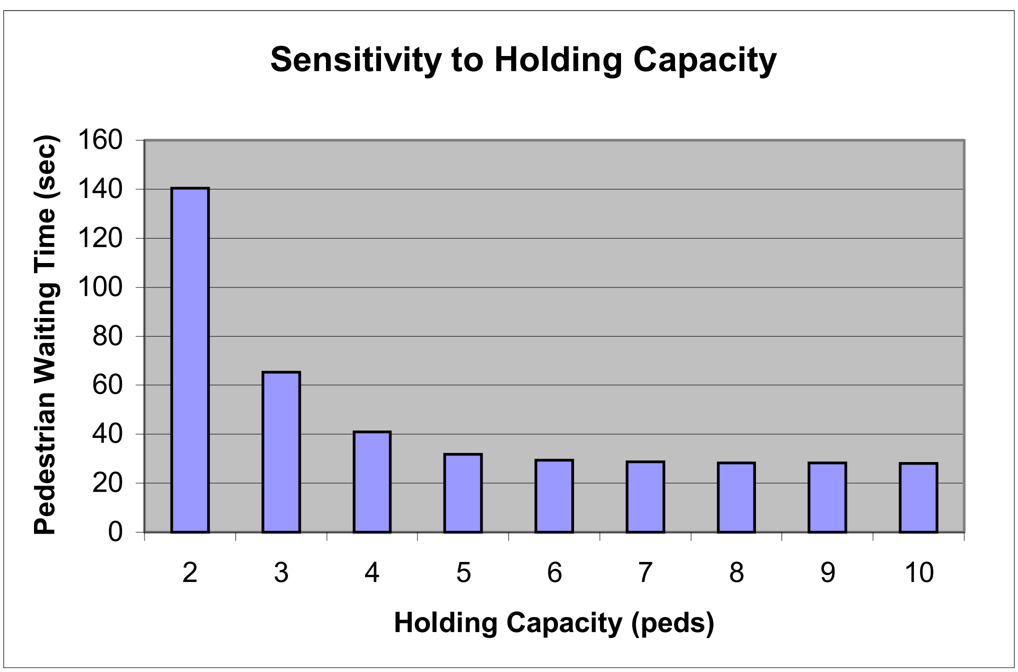


Figure 6 Sensitivity to Splitter Island Holding Capacity

The size of the critical gap is an indication of pedestrian behavior. The size of the critical gap depends on crosswalk length, pedestrian walking speed and a safety factor. Since the safety factor is a relatively stable value depending on pedestrian start-up lost time and end-clear time, sensitivity tests were performed on the crosswalk length and pedestrian walking speed. They are shown in Figure 7 and Figure 8.

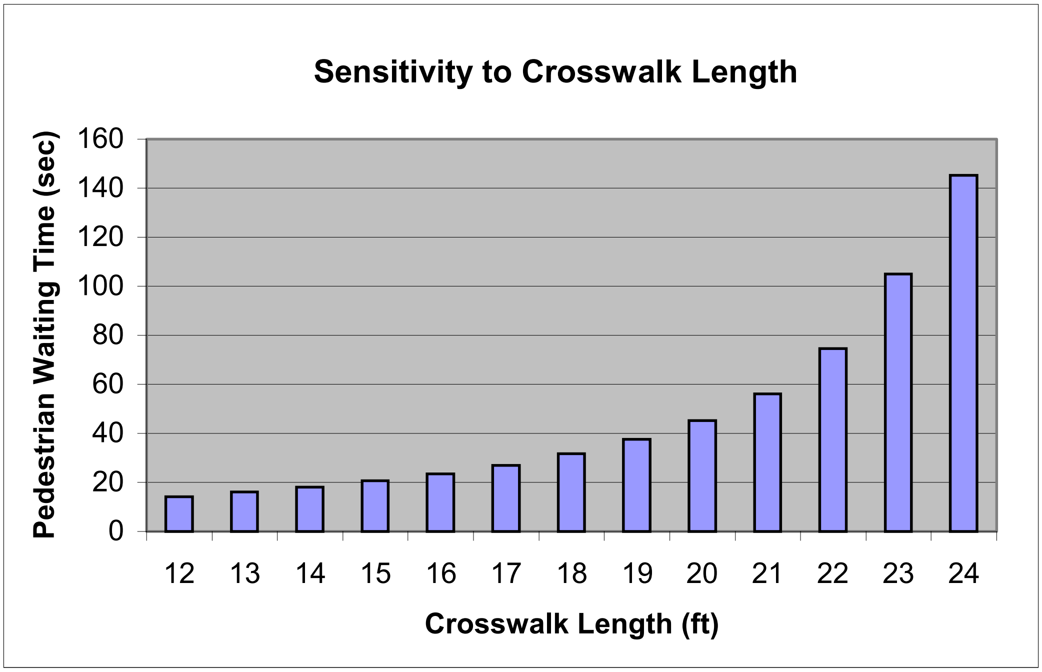


Figure 7 Sensitivity to Crosswalk Length

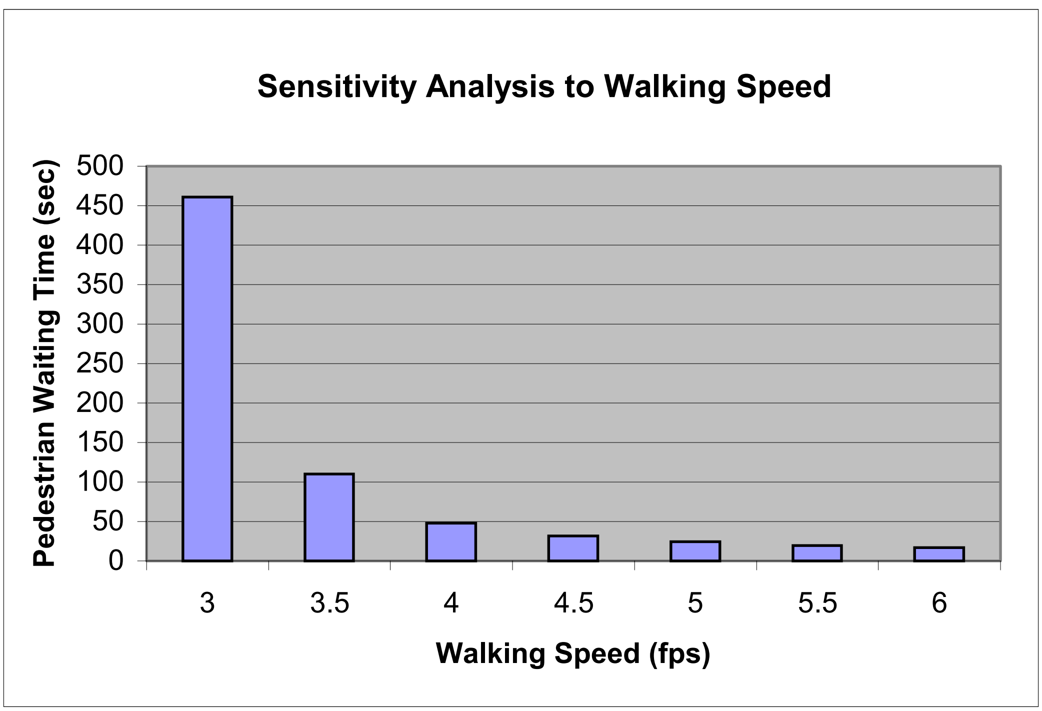


Figure 8 Sensitivity to Pedestrian Walking Speed

IV Results and Conclusions

Simulation Results

- **Delay Analysis**

Pedestrian overall travel time and overall delay time are used as major performance measurements of effectiveness. In all runs, one hour of simulation is performed, preceded by six minutes over which the system is initialized. This was done for 25 replications. Note that the average crossing time for each stage is on average 4 seconds.

Output measurements for the base scenario are summarized as following (see Figure 1):

Performance Measurements	Mean	Half Width of 95% CI
Direction Stage 1 Waiting Time	17.93	1.69
Direction Stage 2 Waiting Time	13.27	0.70
Two-Way Average Waiting Time	31.77	2.05
Two-Way Average Travel Time	39.84	2.05

Table 2 Output measurements for base case study

Interestingly, the half widths of 95 percent confidence intervals for all measurements are within ten percent of the mean values. That means that the number of replication is sufficient to generate statistics within good accuracy.

The outputs from the base scenario test show that the 95 percent confidence interval for the average pedestrian waiting time is (29.7, 33.8). Referring to the HCM 2000, it corresponds to level of service D or E. Considering the medium to high vehicle and pedestrian demand, we conclude that this result is reasonable.

Note that the wait time in stage 1 is about 4.5 seconds higher that in stage 2. That is due to the existence of the splitter island holding capacity restriction.

From output statistics, the average holding spaces used are 3.0 and capacity utilization ratio is about 60 percent on average. The utilization graph for holding capacity is shown in Figure 9.

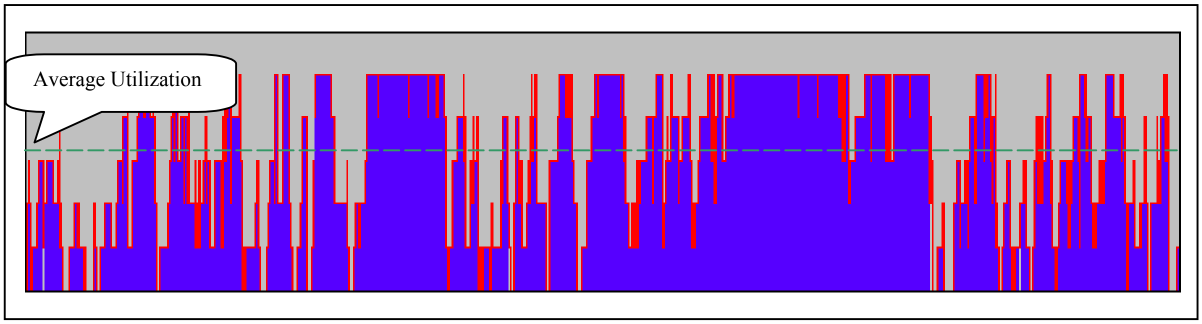


Figure 9 Plot of splitter island capacity utilization

- **Crossing Capacity**

One way to measure the crossing capacity in the simulation model is to increase the pedestrian demand and observe the number of pedestrians being served (Pedestrian Volume). Such graphs can be used to visually determine the pedestrian crossing capacity at different vehicle demand volumes.

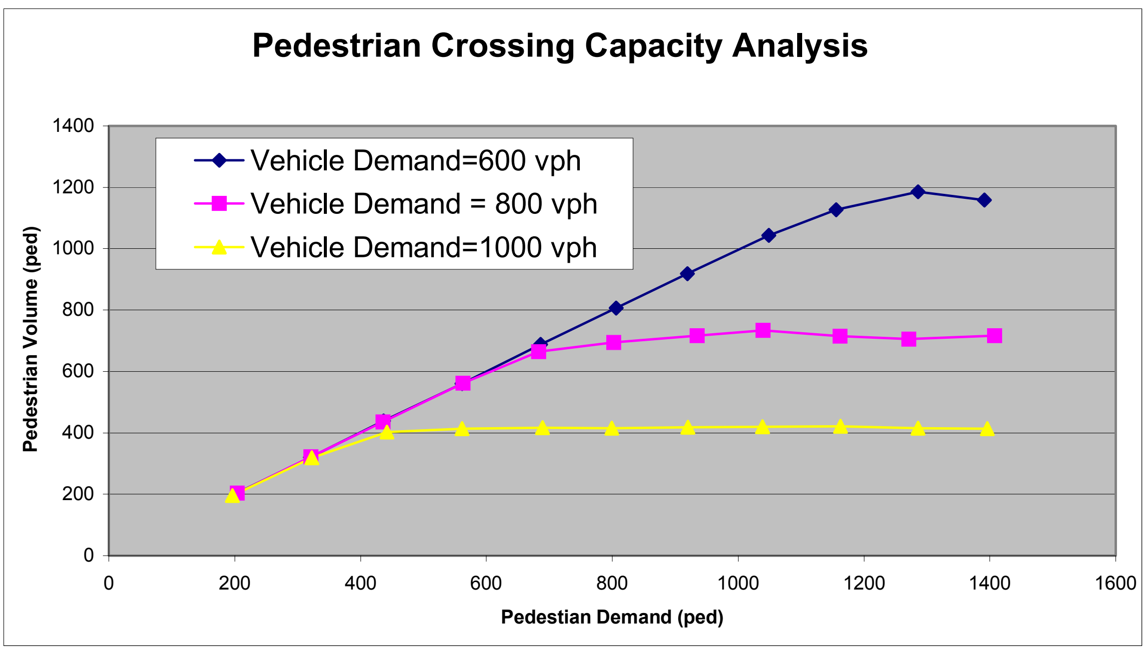
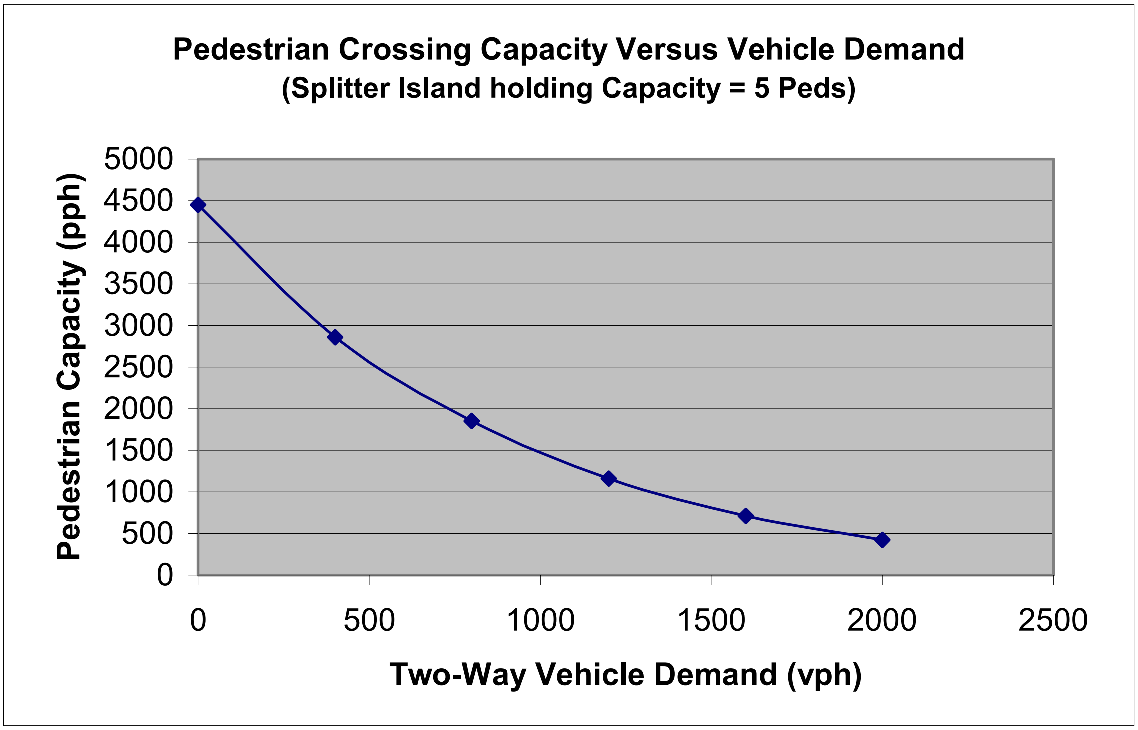


Figure 10 Plot of pedestrian crossing capacity analysis

Figure 10 shows that for vehicle demand of 1000 vehicles per hour, the maximum number of pedestrians being served is around 1150; for vehicle demand of 800 vehicles per hour, this number decreases to 700; for 1000 vehicles per hour, it drops further to around 400. This pattern clearly reflects capacity changes under different vehicle demand volumes.

Using the same method we carry out capacity analysis for vehicle demand levels of 400, 200, and 0 vehicles per hour. Combined with the results in Figure 10, a pedestrian capacity model is derived as in Figure 11.



* 50/50 direction split

Figure 11 Pedestrian crossing capacity at different vehicle demand

Note that in Figure 10 the pedestrian crossing capacity for 0 vehicle demand for this two-way four-channel system is only 4500 pph, far below the theoretical queue discharge capacity of 9600 (for 4 channels). That is because in our model, holding capacity plays an important role in case large pedestrian demand exists. Further experiments show that when we change the holding capacity to a very large number, the pedestrian crossing capacity is approaching 9600.

Conclusions

The results from the Arena model show that one can use a composite queuing system to reproduce the pedestrian crossing street process at roundabout area with un-signalized control. The modeling process is logical, simple and fast.

The Arena simulation model provides researchers with a powerful statistical test and convenient tools for scenario analysis that can be applied to delay analysis, capacity analysis and geometric design of pedestrian crossing.

A good understanding of pedestrian crossing street process helps users to reproduce it correctly and precisely. To improve strengths of the Arena simulation model, further research and data on pedestrian gap acceptance and queue discharge behavior are needed. For example,

1. Comparison with the theoretical probabilistic gap acceptance and queuing model is needed to verify the model;
2. The queue discharge headway distribution model should be improved. It will be sensitive to pedestrian locations in the waiting queue;
3. A probability approach should be employed to model variance in the pedestrian gap acceptance behavior;
4. Extensive field data are needed to calibrate and validate the model;
5. Pedestrian behavior and holding capacity constraint in the splitter island should be modeled.

V References

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EVALUATION AND APPLICATION OF PEDESTRIAN MODELING CAPABILITIES USING COMPUTER SIMULATION

Part II- Application of the VISSIM Model to Pedestrian and Vehicle Interaction at Roundabouts

Submitted to

HIGHWAY SAFETY RESEARCH CENTER (HSRC), UNC-CH
NATIONAL INSTITUTES OF HEALTH (NIH)

BY

THE INSTITUTE FOR TRANSPORTATION RESEARCH AND EDUCATION (ITRE), NCSU

Nagui M. Rouphail, Director, PI
Ko Sok Chae, Research Assistant

June 2002

Executive Summary

This final working paper documents the research project entitled "Evaluation and Application of Pedestrian Modeling Capabilities" sponsored by the Highway Safety Research Center (HSRC) and the National Institutes of Health (NIH). The work addresses the potential for using computer modeling tools to assess the ability of blind pedestrians and those with 'low vision' in the task of negotiating complex intersections. A feasibility study of computer models was conducted that could potentially be used to model pedestrian behavior in the context of present and proposed intersection treatment designs and their operation.

The principal focus of these initial evaluations was pedestrian behavior at roundabouts. An earlier working paper by Rouphail and Wan described the modeling of pedestrian vehicle interactions at roundabouts using a basic simulation tool, ARENA. That paper is appended to the end of this report. In this report two available models were evaluated, VISSIM (http://www.itc-world.com) and PARAMICS (http: //www.paramics-online.com/).

The VISSIM model was selected for more extensive evaluation, in part, on the basis of its capability to (a) generate high-fidelity 3D/4D visualizations of the model output and to (b) quantify the impedance of individual pedestrian movements to conflicting entering and exiting vehicles at a single lane roundabout.

The proposed Stinson-Pullen Park roundabout on the campus of NC State University (now under construction) was chosen as the principal context of the evaluation, given the availability of actual traffic counts from the NCDOT and plans to actually complete the facility in the Fall of 2002. The Stinson-Pullen Park roundabout is a single lane design.

Sensitivity analyses were carried out by varying (a) the gap acceptance 'attributes' for blind and sighted pedestrians and (b) conflicting vehicle traffic volumes. Observed differences in the gap acceptance behavior of blind and sighted pedestrians that were used in VISSIM are data derived from actual field observations collected by the Western Michigan University and Vanderbilt University researchers using blind and sighted pedestrians at three roundabouts in the Baltimore, Maryland metropolitan area (Towson, Annapolis, and UMBC).

The effects of pedestrian gap acceptance and traffic volume were analyzed in terms of their impact on pedestrian delay and vehicle delay. Simulated pedestrians in the model crossed at the splitter island (the conventional crossing point for pedestrians at roundabouts).

The initial results indicate that low vision/blind pedestrians will have more difficulty finding safe crossing opportunities under heavy conflicting, particularly on the exit side of a roundabout. The crossing performances of sighted pedestrians, according to the model, were not significantly affected by the range of vehicle volumes modeled in the study. However, the data suggest that low vision pedestrians cannot easily overcome these differences in traffic volume without some form of intervention. Several suggestions were put forth as means for providing either a more suitable vehicle gap distribution or for providing a more reliable cue that could be used for the discrimination of crossing gaps.

I Introduction and Background

Recent U.S. studies have shown that roundabouts enhance vehicle safety and capacity compared to other types of intersections. A comprehensive national study under the auspices of NCHRP project 3-65 is underway. It will provide further evidence of the relative safety of roundabouts compared to other intersection treatments. Pedestrian capacity and safety at roundabouts are not as well documented by research; however, the anecdotal evidence is promising. Pedestrian safety at roundabouts may improve as a result of the slower traffic speed and the division of the pedestrian crossing into two stages with the splitter island acting as a mid-point refuge. The splitter island allows pedestrians to focus on crossing one direction of the conflicting traffic stream at a time. The potential reduction in accidents is attributed to slower speeds and the reduced number of conflict points from 24 vehicle-to-pedestrian conflicts at a conventional intersection to 8 vehicle-to-pedestrian conflicts at a roundabout. Furthermore, and perhaps most importantly, the cause of most fatal or serious pedestrian accidents at intersections – the opposing left turn – is eliminated. Finally the lower the speed limit, the lower the expected risk and severity of pedestrian accidents.

Since modern roundabouts in urban areas have the potential for servicing large volumes of pedestrians, proper models should be developed to evaluate their overall performance including pedestrian crossing capacity, delay and safety features. Especially, this model should analyze the different characteristics among pedestrian behaviors and capabilities, and their impact on system performance.

In this research, we have explored the potential for using computer modeling tools to test the ability of sighted and blind or low vision pedestrians to negotiate roundabout crossings. We conducted a feasibility study of computer models that could potentially be used to model pedestrian behavior in the context of present and proposed intersection treatment designs and their operation.

The principal focus of these initial evaluations was pedestrian behavior at roundabouts. An earlier working paper by Rouphail and Wan (2002) described the modeling of pedestrian vehicle interactions at roundabouts using a basic simulation tool, ARENA. That paper is appended to the end of this report.

II. Model Selection and Evaluation

Appropriate microscopic traffic simulation models can be used to evaluate the performance of a roundabout. Among their advantages are the ability to represent platooned arrivals from upstream signals; queue spillback into the roundabouts from downstream signals or congested roundabouts; signalizing a roundabout crossing; relocating pedestrian crossing points; and/or comparing the relation between pedestrian and vehicle performance.

The principal focus of the presentl evaluations is pedestrian behavior at roundabouts. Two currently available microscopic simulation models were evaluated: the VISSIM Model by ITC in Germany (http://www.itc-world.com) and the Paramics Model by Quadstone in Scotland (http://www.paramics-online.com/)

VISSIM and Paramics are both stochastic, microscopic, computer simulation programs capable of modeling individual vehicle interactions on complex roadway networks. The following discussion gives a brief summary of the capabilities of VISSIM and Paramics models.

VISSIM

VISSIM is a microscopic stochastic simulation model that has the ability to evaluate vehicle, pedestrian, and transit operations on virtually any surface transportation facility. VISSIM was developed by PTV AG in Germany and is distributed in North America by Innovative Transportation Concepts. The model uses inputs such as lane assignments and geometries, intersection turning movement volumes, vehicle speeds, percentages of vehicles by type, and pre-timed and/or actuated signal timing. It is capable of producing output that contains measures of effectiveness such as total delay, stopped-time delay, stops, queue lengths, and fuel emissions for all default or user-input travel modes, including pedestrians and bicycles.

Paramics

Paramics was developed by Quadstone. It models roundabouts explicitly rather than by a set of one-way, stop-controlled links. The empirical method used by Paramics has been used in the United Kingdom and internationally for a wide range of simulation projects. Paramics has been favorably compared with its British counterpart ARCADY in evaluating roundabouts. One major limitation of Paramics is its inability to explicitly model pedestrians in a default mode without the need for an application programming interface, or API.

We conducted an evaluation of these models' capabilities and features with an emphasis on the ability to model the geometric characteristics and traffic and operational characteristics of modern roundabouts.

Table 1 provides a detailed comparison of the general capabilities of VISSIM and Paramics. Table 2 focuses on specific parameters of interest in this study.

Table 1. Comparison of Models' Capabilities and Features

Item	VISSIM	Paramics
Software Type	Microscopic traffic simulation models, represent individual vehicles, pedestrians, and bikes	
Country Developed	Germany	Scotland
Operating System	Windows	Unix/Exceed
Road Network components	Links, Connectors	Links, Nodes
Graphic Capabilities	2D/3D (HQ Visualization)	2D/3D
Roundabout Analysis	Yes	Yes
Ability to input O-D Data	Yes	Yes
Signal Operations	Yes (veh & ped)	Yes (veh & ped)
Routing Decisions	Path can be specified	Assignment
Dynamic Trip Assignment	Yes	Yes
Default modes of travel	Passenger Cars Trucks Bus Transit Rail Transit Pedestrian Bikes	Passenger Cars Trucks Bus Transit

Table 2. Parameters of Interest in the Study

Item	VISSIM	Paramics
- Diameter of central island	•	•
- Inscribed diameter	•	•
- Lane width	•	•
- Circulating roadway and characteristics of individual lanes (number, width, etc)	•	•
- Characteristics of entry/exit lanes (widths, radii, deflection angles, etc.)	•	•
- Splitter islands (only as holding space)	•	-
- O/D characteristics --- (turn movements)	•	•
- Speed reduction zones at entry/exit legs / in circle	•	-
- Variable Pedestrian crossing locations/traffic interruption effects	•	•
- Presence/absence of pedestrian 'refuge' Islands (other than splitter islands)	•	•
- Vehicle headway / gap distributions at selected points	•	•
- Signals upstream of roundabout	•	•
- Placement of 'sensors' (for volume, speed, & occupancy) at selected locations	•	•
- Simulation of occupancy (long loops) sensor	•	•
- Multiple Pedestrian Populations	•	•
- Animation (AVI file)	•	–

•; Requires API programming

On the basis of the stated comparisons in Table 1 and 2, we selected the VISSIM model for more extensive evaluation because of its capabilities to generate high fidelity 3D/4D visualizations of the model output, and its ability to directly generate the impedance of individual pedestrian's movement to conflicting entering and exiting vehicles at the roundabout.

III. Simulation Description

VISSIM

VISSIM is a microscopic, time-step behavior-based model. The theoretical construct for VISSIM was developed at Karlsruhe University, Germany in 1970 and commercial software appeared in 1993 by PTV AG. VISSIM consists of entities such as drivers, pedestrians, vehicles, and a road network. Model interactions among all users occur, and the network performance varies, depending on user behavior, system status, and time. VISSIM also tracks each individual vehicle type and driver including autos, trucks, buses, rail, pedestrians, and bicyclists.

VISSIM uses a psychophysical driver behavior car following model developed by Wiedemann. This car following model is processed for four states of driving: free driving, approaching, following, and braking. VISSIM has also a lane change model, which is run when it is desired to change lanes, if trailing or exiting. The model checks if lane changing improves the current situation, checks if it can be safely accomplished, and aborts it if it is deemed unsafe.

VISSIM consists of three major components –an input module, a simulator, and an output module. The input module is a Windows-based user interface. The simulator (processor) is used for generating and moving traffic, updating system status, and collecting statistics. The output module typically produces animation movie file and text output.

The Network Model in VISSIM typically consists of links and connectors, priority rules, and traffic routes. The links and connectors are used for flexible geometry and traffic modeling within intersections. The priority rules that can be used are:

two-way stop control, all way stop control, and roundabouts. VISSIM has three traffic routing methods: static routes, dynamic routes, and dynamic assignment. For a roundabout, routes are pre-specified from the approach through the circulating and the exiting legs for each movement.

VISSIM provides numerical and visual outputs. One of VISSIM's most powerful features is the ability to animate in 2D and 3D, a feature most microscopic simulation models do not offer. The ability to visually illustrate a traffic problem or impact can be very powerful when dealing with the public or with system stakeholders. Two formats exist for 2D or 3D animation. The first option is the animation format and the second option is the movie (avi) format. The first option can be useful when the modeler needs to review a result in the workspace. The movie file allows the user to share animation within or between agencies or the general public, without having the VISSIM Code installed on the computer. Common media software such as Windows Media Player or Real player are capable of using this movie format. Static images, such as buildings, parked cars, signals, traffic signs, trees, or other landscaping items can be inserted using the 3D module increase the visual realism of the animation.

The numerical output of VISSIM has the ability to gather user defined Measures of Effectiveness (MOEs) at user-specified locations, the ability to collect raw or aggregated data, as well as an integrated environmental model for emission statistics. Available outputs from the VISSIM model are stopped, control, or person delay, travel time, number of stops, queue lengths, emissions, and signal control statistics. Any model can deliver statistics on link travel times, delay, number of stops, but the ability to define which specific statistics to produce is the most versatile features of VISSIM. It requires that each data collection element be coded into the network.

VISSIM has been used on a number of applications such as:

- Corridor studies
- Freeway management design
- Light rail analyses
- Transit signal priority evaluation
- Transit center/bus mall design
- Railroad crossing analyses
- Toll plazas
- Public involvement
- Access management
- Signal timing optimization
- Signal control development and testing
- Neighborhood cut-through traffic
- Traffic calming
- Work zone traffic control plans
- Traffic impact studies
- Value Analysis studies

Modeling Vehicle-Pedestrian Interaction in VISSIM

For constructing a roundabout, the variety of input data required is shown in Tables 1 and 2. For animation and background, VISSIM requires a bitmap picture or CAD file of the site. For constructing the roundabout network, it requires detailed geometric data of the circle, all entry and exit approaches, the splitter island, and crosswalks. VISSIM does not consider the effect of road width; however the location and length of links are important. They affect the result directly. Also, VISSIM requires flow characteristic data such as vehicle or pedestrian origin and destination counts, composition, desired speed, entry headway distribution, follow-up, and critical gap size including latency and lag times.

To represent the interaction between sighted and blind/low vision pedestrian with vehicular traffic in the VISSIM model, *critical gap* is the most important parameter. Simply stated, a "modeled" pedestrian in VISSIM will cross, on average, when a gap occurs that is greater than his/her critical gap. Otherwise, he/she will wait until an acceptable gap occurs.

In arriving at a measure of 'critical gap,' two intervals (or gaps) must be measured. The first is referred to as *'latency;'* the second is referred to as *'lag.'* After the lead vehicle passes a pedestrian, the standing pedestrian at the front of crosswalk or on the splitter island must decide whether he/she can start crossing safely. When the pedestrian begins crossing, the difference between the time when the lead vehicle passes and the time when the pedestrian starts to cross is called the latency time. Latency depends upon assigned pedestrian attributes (e.g., processing time; uncertainty, risk tolerance, etc.), the specific roadway geometry, and the traffic conditions. In good weather, with favorable geometry and visibility, the latency may be close to zero seconds for sighted pedestrians. For the blind pedestrian or pedestrian with low vision, latency will, in some part, be associated with the pedestrian being able to determine (largely through aural cues) the presence of the next approaching vehicle . . . or its absence.

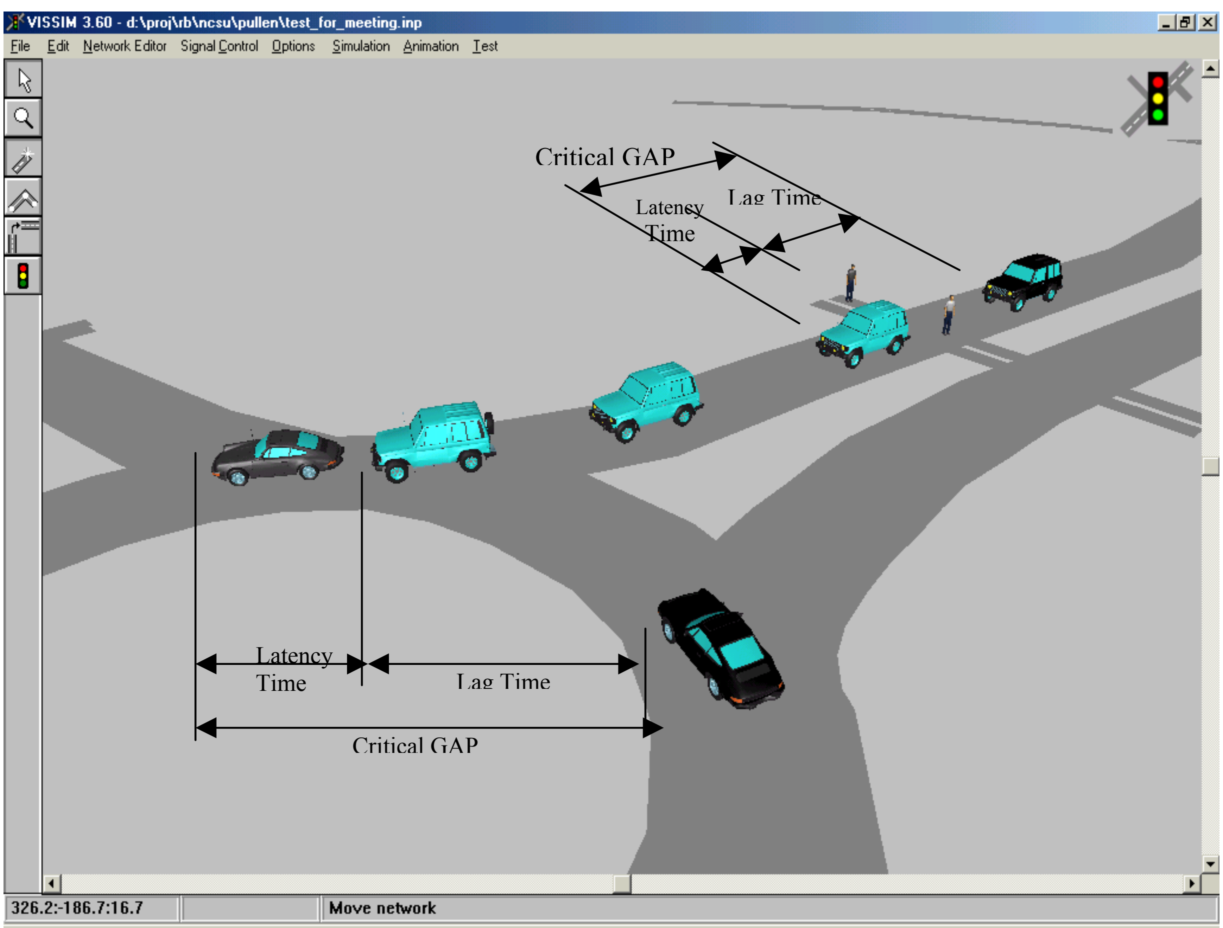
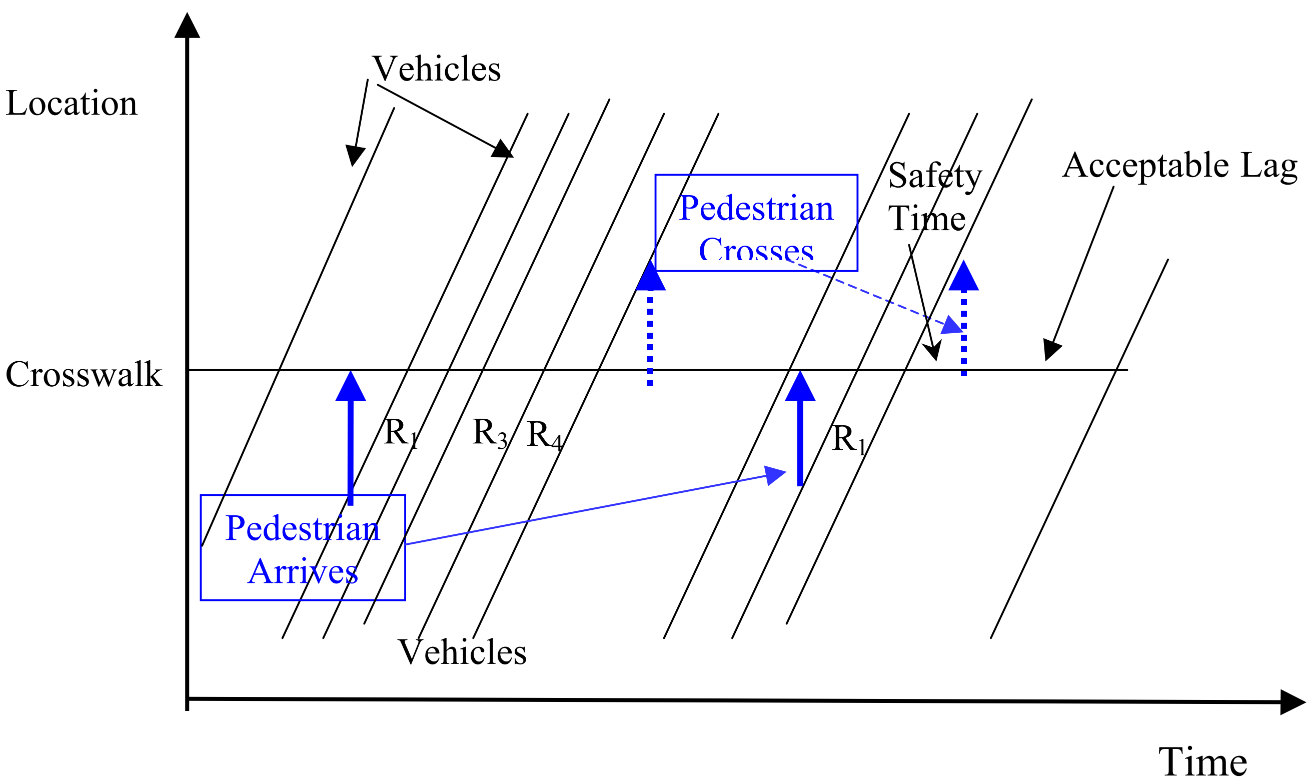


Figure 1. Critical Gap Concept

The *lag* time is the difference between the crossing start time and the arrival time of the following vehicle at the crossing point. Together, the sum of the latency and lag times is equal to the bumper-to-bumper time between successive vehicles. There will thus be gaps (temporal intervals) that are 'accepted' by the pedestrian and gaps that are 'rejected.' From these measures, it is possible to define 'critical gap.' Figure 1 shows, in concept, the notion of critical gap. Figure 2 shows, more from a computational standpoint, the notion of 'critical' gap as the 'relationship' between acceptable gaps and rejected gaps.



A_1, A_2 = Accepted gaps

R_1, R_2, $\cdots$ = Rejected gaps

l^i_1 = Latency time for accepted gap(i)

l^i_2 = Lag time for accepted gap(i)

Figure 2. Accepted and rejected gap definition at pedestrian crossings

The following describes the actual procedure for collecting critical gap information and how such data are used in the modeling process:

- Record pedestrian arrival and crossing times (continuously for more than one hour during peak and non-peak conditions)
- During that period, record all rejected gaps and the accepted gaps (i.e., not just the latency times for those occasions when the pedestrian actually crosses)
- For each pedestrian crossing, an estimation model will use the largest rejected gap and the accepted gap
- The maximum likelihood estimation technique will be used to derive the mean and standard deviation of the critical gap (assuming that the critical gap follows a Log-Normal distribution)

In VISSIM, the critical gap is used in the priority rule function. This priority rule is used to control the interaction between vehicles, and vehicles and pedestrians at merge areas and crosswalks, respectively. At the roundabout entrance, the circulating flow has priority over approaching flow; when a gap is larger than the critical gap, approaching vehicles can enter the circulatory road. To represent this priority, VISSIM uses a function of time and space. Usually, the space concept is reserved for congested situations. The function is also used to model pedestrian and vehicle interaction at crossing points.

Network Data

The proposed Stinson-Pullen roundabout on the campus of NC State University in Raleigh, NC (now under construction) was chosen as the principal context of the evaluation, given the availability of actual traffic counts from the NCDOT and plans to actually complete the facility in the Fall of 2002.

The current un-signalized Stinson-Pullen intersection is slated to be reconstructed as an urban compact roundabout. Currently Pullen Street consists of 2 – 10 ft lanes with on-street parking, and a speed limit of 25mph. Stinson Street also has two lanes. According to the improvement plan, the speed limit will decrease to 20 mph and there will be 1 - 12ft lane on each approach. The roundabout will have an 80ft inscribed diameter with splitter islands on all approach legs. Table 3 depicts the existing conditions and planned improvements. Figure 3 depicts the background of the study area and Figure 4 illustrates the basic network construction in VISSIM, including the links and connectors used in the case model, which are typical characteristics in a VISSIM network.

Table 3. Case Study Data

Parameter	Current	Proposed Roundabout
Approach speed Limit (mph)	25	20
Number of approach lanes	2	1
Number of circulating lanes	N/A	1
Lane widths (ft)	10	12
Circulatory roadway width (ft)	N/A	16
Inscribed diameter (ft)	N/A	80
Diameter of central island (ft)	N/A	48
Location of crosswalk from yield line (ft)	N/A	25
Speed limit at entry (mph)	N/A	15

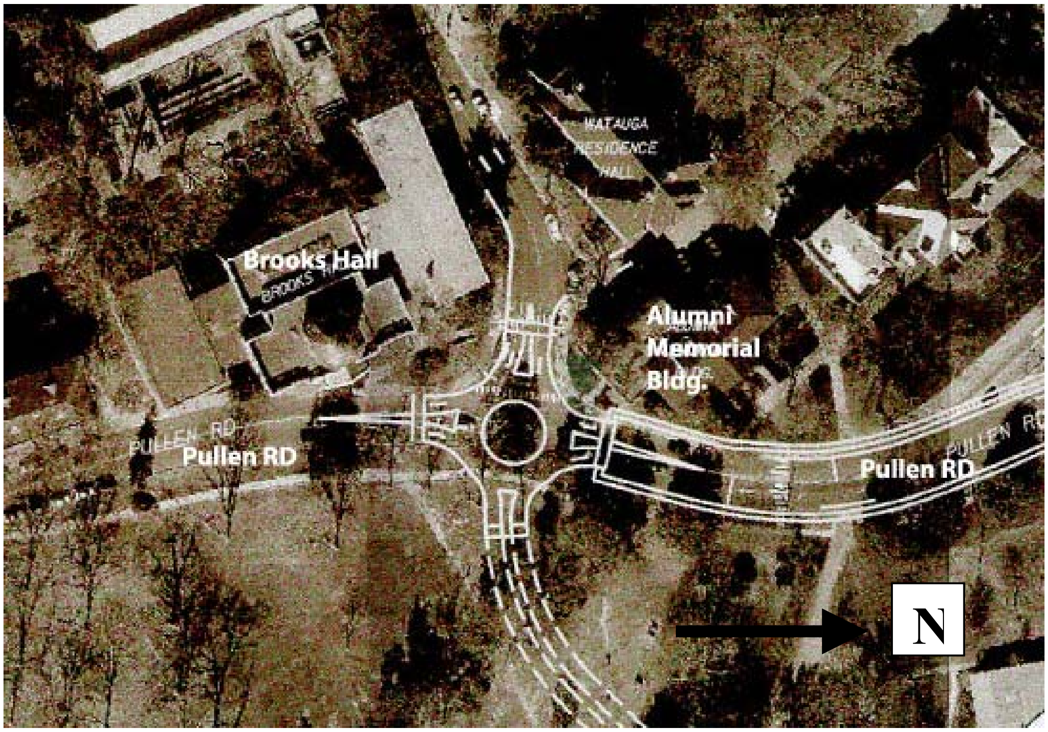


Figure 3. Case Study Area

Figure 4. Case Model Network (Links and Connectors)

Traffic Data

The present case study modeled uses the noon peak traffic volume, for which counts were conducted from 11:00 AM to 1:00 PM in November 2000. Traffic counts performed do not account for special events, but were conducted on typical days when the university was in session for the Fall semester. Passenger vehicles, trucks, transit buses (and their schedule) and pedestrians were counted. The original vehicle volume northbound on Pullen road was 668 vehicles per hour, while the southbound and eastbound volumes were 583, . . . 89 vehicles per hour respectively. The vehicle volume on the east leg at Stinson Drive was added to consider the improvement plan. Tables 4 and 5 show the origin and destination counts of vehicles and pedestrians used in the model.

Table 4. Base Vehicle O/D Counts at Pullen and Stinson

(Unit: Veh/hour)

O/D	To North	To South	To East	To West
From North on Pullen	0	535	5	48
From South on Pullen	567	0	4	101
From East on Stinson	5	4	0	1
From West on Stinson	45	44	1	0

Table 5. Base Pedestrian O/D Counts at Pullen and Stinson

(Unit: Ped both-way/hour)

O/D	North/South	West
At North crosswalk on Pullen	40	0
At South crosswalk on Pullen	40	0
At West crosswalk on Stinson	0	80

Observed differences in the gap acceptance behavior of blind/low vision and sighted pedestrians were derived from actual field data collected by the Western Michigan University and Vanderbilt University researchers using blind and sighted pedestrians at three roundabouts in the Baltimore, Maryland metropolitan area (Towson, Annapolis, and UMBC).

Towson and Annapolis roundabouts are of the urban double lane type and the UMBC roundabout is an urban single lane roundabout. The median latency time for pedestrians was taken from the Towson roundabout data, which also coincided with the values measured at UMBC. It is used to set up the multiple priority rules for constructing the different pedestrian behavior models (i.e., blind/low vision versus sighted). Table 6 shows the latency times at each roundabout.

Table 6. Observed Pedestrian Latency Time at three Roundabouts (Unit: sec)

	Towson				Annapolis				UMBC			
	Entry		Exit		Entry		Exit		Entry		Exit	
	Blind	Sighted	Blind	Sighted	Blind	Sighted	Blind	Sighted	Blind	Sighted	Blind	Sighted
Mean	3.40	1.37	4.56	1.97	4.99	1.36	4.43	1.96	3.37	1.58	5.44	2.03
STDEV	2.51	1.42	2.35	1.99	3.33	1.71	3.21	1.95	2.46	1.66	3.80	2.72
Median	3.00	1.00	4.00	1.00	4.00	1.00	4.00	1.00	3.00	1.00	4.00	1.00

* Shaded values are used in this analysis.

Using the latency times at Towson and UMBC, minimum crossing times for both sighted and low-vision pedestrians were calculated. Regarding pedestrian behavior, the average pedestrian walking speed 's,' the crosswalk length 'w,' and a latency time 'f,' together determine the minimum crossing time by the following equation:

$$CG = \frac{w}{s} + f$$

CG is the nominal size of the critical gap (i.e., the minimum time required for the pedestrian to cross between two successive vehicles.) The walking speed for both sighted and blind pedestrians was assumed to be 4ft/sec in this model.

Table 7 shows minimum crossing time, minimum-walking times, and distance at each crosswalk in Pullen and Stinson model.

Table 7. Minimum Crossing Times (per lane) and Acceptable Gaps (Unit: sec)

	Pullen North				Pullen South				Stinson			
	Entry		Exit		Entry		Exit		Entry		Exit	
	Blind	Sighted	Blind	Sighted	Blind	Sighted	Blind	Sighted	Blind	Sighted	Blind	Sighted
Distance	17.2 ft		15.9 ft		17.1 ft		16.7 ft		15.2 ft		15.6 ft	
Crossing Time	4.30sec		3.98sec		4.28sec		4.18sec		3.80sec		3.90sec	
Latency Time (Table 6)	3	1	4	1	3	1	4	1	3	1	4	1
Acceptable Gap	7.3	5.3	8.0	5.0	7.3	5.3	8.2	5.2	6.8	4.8	7.9	4.9

The above acceptable gap values are used to control the interaction between pedestrians and vehicles in the priority rule function in VISSIM. Priority rules consist of an interrupted section and interrupting section. In this model, an interrupted section is placed at a curb or on splitter island where pedestrians would typically wait when they can start crossing. An interrupting section is installed behind a crosswalk where vehicles would create a potential collision or conflict with pedestrians. If a pedestrian approaches an interrupted section, VISSIM checks to see if the defined minimum requirement for the pedestrian acceptable gap is met in front of the interrupting section. Otherwise the pedestrian will wait behind the interrupted section until that requirement is met. As mentioned in the previous section, the gap (time) and space is used in the priority rule function. To construct a more realistic model in VISSIM, it is necessary to obtain more detailed information for pedestrian behavior such as maximum rejected and accepted gap and latency times.

IV. Sensitivity Analysis and Results

Starting with the base model, a sensitivity analysis was conducted to investigate the relationship between the gap acceptance attributes for blind and sighted pedestrian and vehicle volume. These analyses were performed for a range of vehicle volumes from 60% to 140% of the base counts (100%), which were summarized in Table 4. As shown in Table 8, the number of NB through vehicles on Pullen road ranges from 340 vehicles per hour to 794 veh/h and the number of SB through vehicles on Pullen road ranges from 321 veh/h to 749 veh/h. The number of pedestrians is fixed at 160 pedestrians per hour on all crosswalks combined, in all scenarios.

Table 8. Input Vehicle Volume Scenarios

Volume Scenarios	NBT- Pullen	SBT- Pullen	NBL- Pullen	SBR- Pullen	EBR- Stinson	EBL- Stinson
60%	340	321	61	29	26	27
70%	397	375	71	34	31	32
80%	454	428	81	38	35	36
90%	510	482	91	43	40	41
100%	567	535	101	48	44	45
110%	624	589	111	53	48	50
120%	680	642	121	58	53	54
130%	737	696	131	62	57	59
140%	794	749	141	67	62	63

Pedestrian Delay Results

VISSIM provides several numerical measures of effectiveness (MOE) as outputs, as mentioned in the previous section. This analysis used the average delay of pedestrians and vehicles as the MOEs'. In VISSIM, delay is incurred whenever the speed of the vehicle or pedestrian is below the desired speed value. This includes stopped delay which is defined whenever the vehicle or pedestrian has a speed of 0 mph. To extract the delay values, VISSIM requires the coding of an entry measurement point and an exit measurement point. The delay measurement is accumulated between these two points. For collecting the pedestrian average delay, four entry areas and four exit areas were defined in VISSIM. Each area included half the crosswalk from the near curb to the splitter island and from the splitter island to the far curb.

In the previous section, it was shown that the minimum crossing time for blind pedestrians at the exit lane is greater than that at the entry lane. The VISSIM results for pedestrian delay in Table 9 indicate a consistency with the minimum crossing times in Table 7. The maximum delay (at 140% of base volume) is evaluated at 41 sec for blind pedestrians at the exit. Compared with the base value (17.3 sec), it increases by 237%. However, the largest percent increase (307.8%) occurs in the case of sighted pedestrians at the entry lane. Table 9 and Figure 5 show the pedestrian delays results, and Figure 6 shows the percent difference in pedestrian delays among the various scenarios. It is interesting to note that for sighted pedestrians, the delays are less than those experienced by blind/low vision pedestrians. More important, however, is that there appears to be no significant differences in pedestrian delay between the exit and entry legs for sighted pedestrians, but a very large difference for blind/low vision pedestrians

Table 9. Pedestrian Delay Sensitivity Analysis in VISSIM (sec/Ped)

Case (%) of Base Vol	Sighted Pedestrians Case		Blind Pedestrians Case	
	Exit	Entry	Exit	Entry
60	2	2.7	9.6	4.8
70	3.1	2.7	15.2	4.7
80	2.4	3.6	14.8	7.2
90	3.6	5.4	18.2	9.1
100	**4.6**	**5.1**	**17.3**	**12.3**
110	5.4	6.7	23.9	15.6
120	7.8	11.4	25.8	20.0
130	10.3	14.1	36.6	24.4
140	12.9	15.7	41.0	19.4

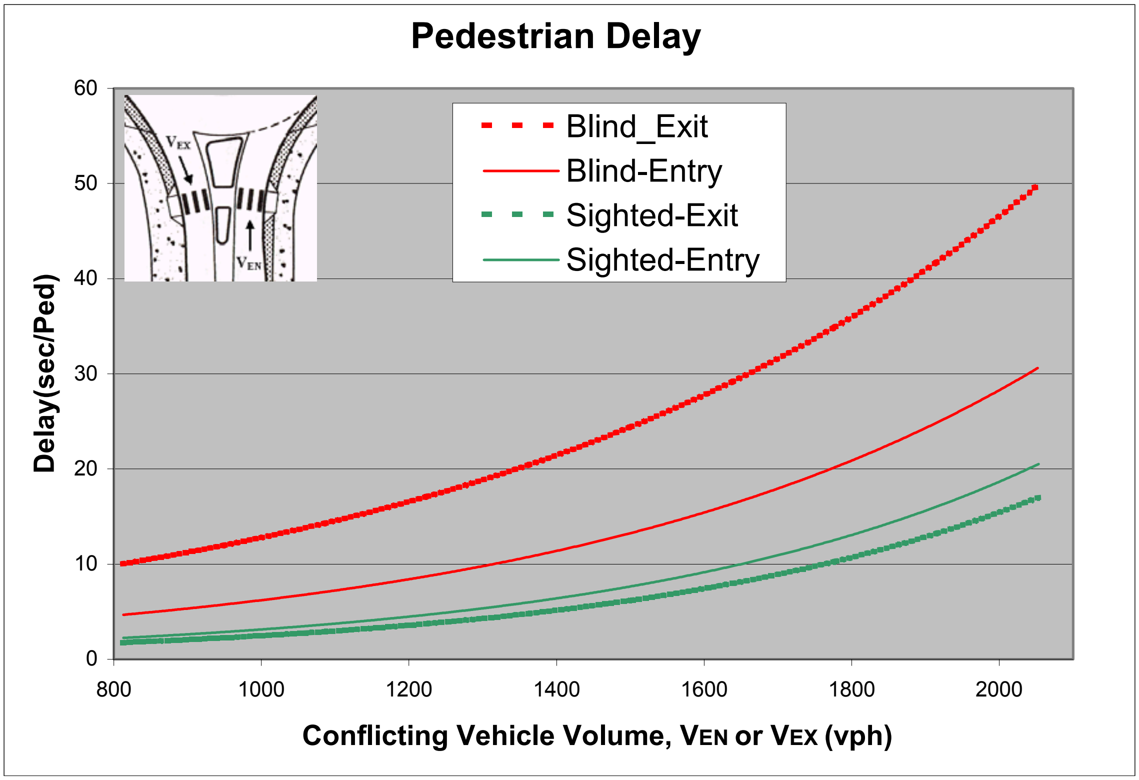


Figure 5. Pedestrian Delay Sensitivity Analysis Results

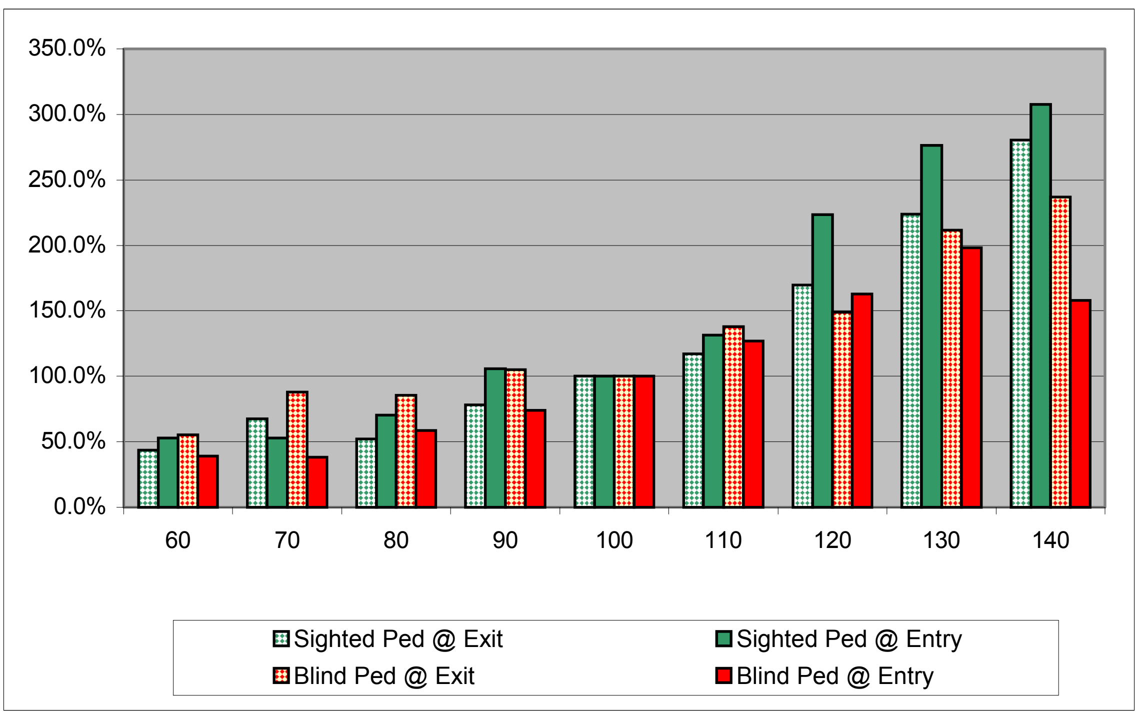


Figure 6. Percent Differences in Pedestrian Delays from Base Scenarios

Vehicle Delay Results

Like pedestrians, vehicle delay is measured between an entry measurement point and an exit measurement point. A specific section was coded to cover the crosswalk and the merge or diverge area at circulatory lane as depicted in the shaded area of Figure 7.

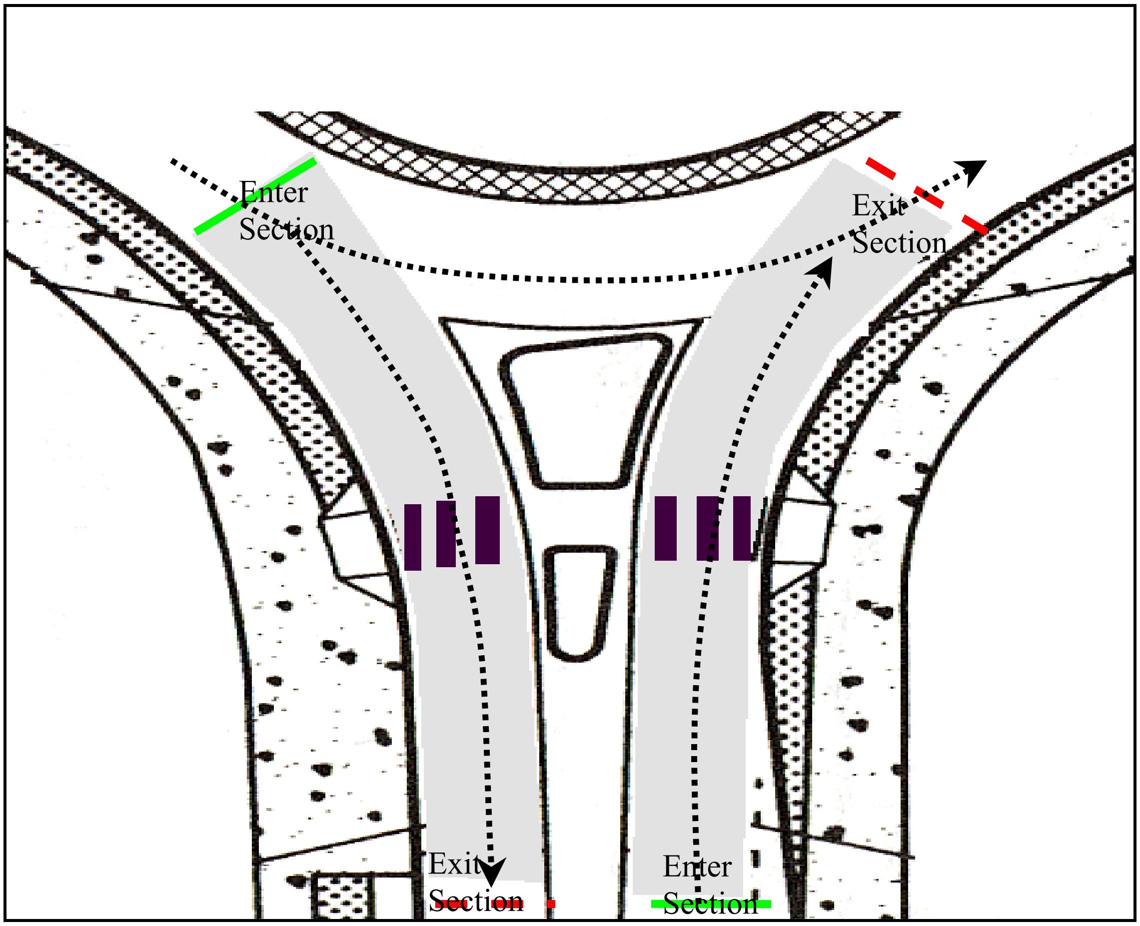


Figure 7. Vehicle Delay Section Definition

Vehicle delay is affected by factors that depend on the measurement location. At the exit side of the roundabout (Fig 7), only the presence of pedestrian effects vehicle delay. Figure 8 depicts the VISSIM results for blind and sighted pedestrians. That value is virtually independent of the pedestrian behavior at a negligible 0.2 sec per vehicle.

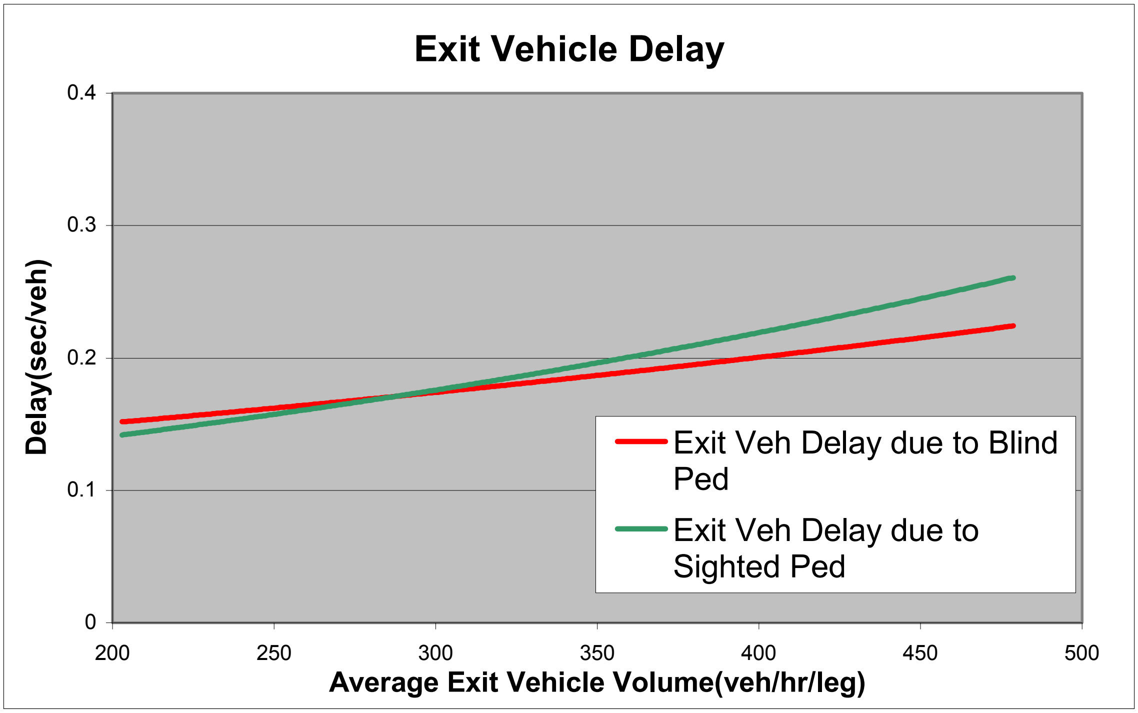


Figure 8. Average Vehicle Delay at a Roundabout Exit

At the roundabout entry, however, vehicle delay is incurred by circulating vehicle flow as well as by pedestrians. However, as shown in Figure 9, there appear to be no differences between the blind and sighted pedestrian cases. This result shows a range of vehicle delays from 0.2 sec/veh to 9 sec/veh at the entry. The entry vehicle delay depends predominately on the entry and circulating vehicle demands. The delay values in Figure 9 appear to be quite low, but are consistent with the modeled vehicle volume to capacity ratios that are all below 0.60.

The reader is reminded, however, that the scenarios analyzed here kept the pedestrian counts at their base levels depicted in Table 8. Had the pedestrian volumes been allowed to change, the results might well have been different. Besides, this case study is based only on latency time and walking speed, instead of the maximum rejected and accepted gaps (recall that the latter were not part of the original data collected at the operational sites).

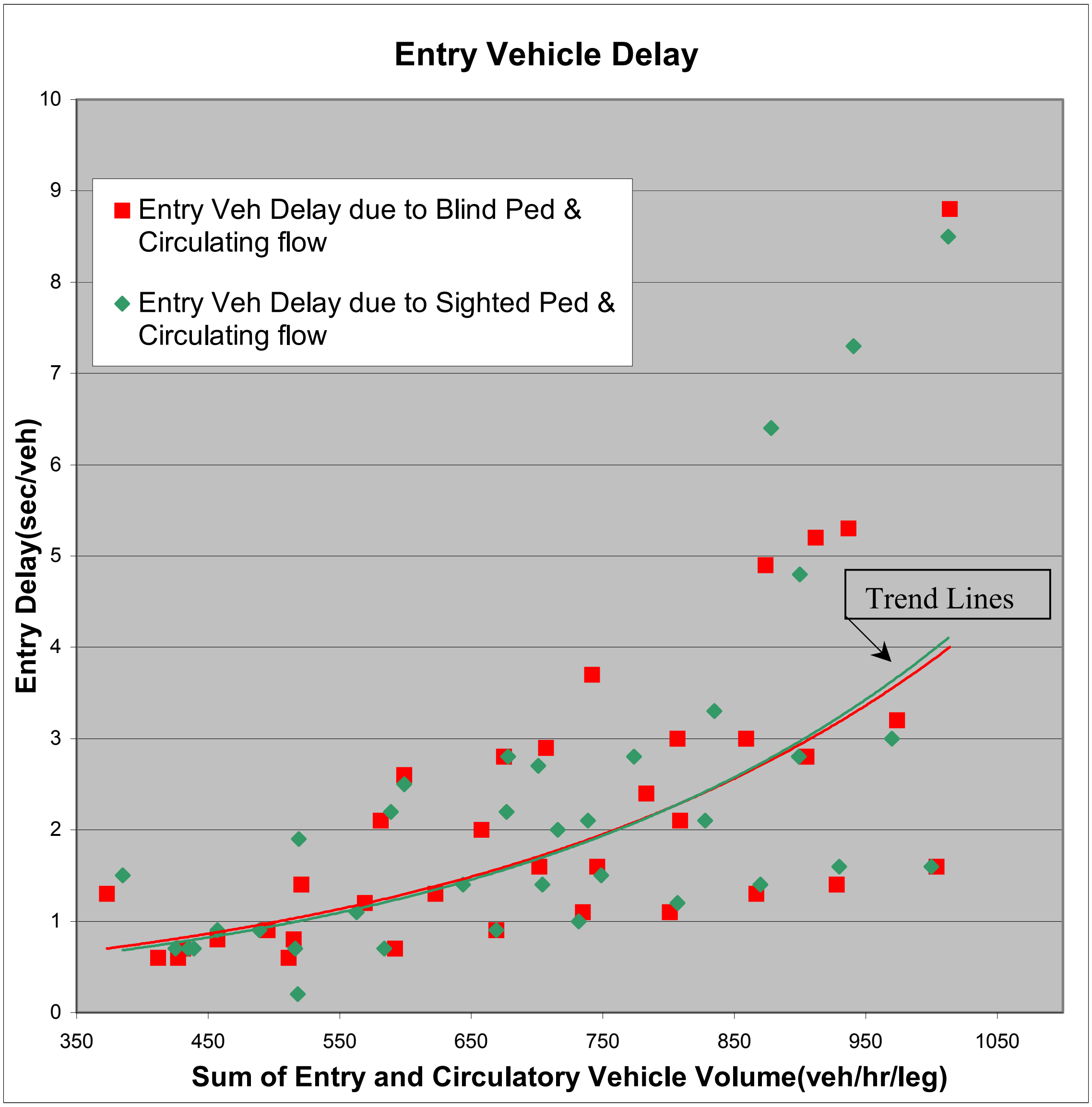


Figure 9. Average Vehicle Delay at Roundabout Entry

V. Conclusions and Recommendations

This work was conducted to explore the feasibility of modeling pedestrian behavior in the context of present and proposed intersection treatment designs and operations using available computer models.

The present research explored the functionality of two currently available computer models (VISSIM and Paramics). An operational roundabout scenario for low vision/blind and sighted pedestrian was constructed using measures of latency time obtained in a field setting. The effects of pedestrian gap acceptance and traffic volume were analyzed in terms of their impact on pedestrian delay and vehicle delay. These results showed that VISSIM could handle the interaction between vehicles and pedestrians or between vehicles, and could provide helpful information for any alternative intersection design or crossing arrangement under the associated traffic operation.

The analysis results indicate that while pedestrian delay can be expected to increase as a function of traffic volume (at both entry and exit lanes) for sighted as well as blind/low vision pedestrians, these differences in delay (i.e., time until an acceptable gap is obtained) are much more pronounced for blind/low vision pedestrians, with the worst case for the blind/low vision pedestrian being at the exit lane. Thus, not only is crossing time for the blind/low vision pedestrian greater (in large part due to differences in latencies between the two groups), but the delay encountered by the blind/low vision pedestrian in obtaining an acceptable gap is much longer than that of the sighted pedestrian, with this difference being accentuated when attempting to cross the exit lane of the roundabout.

The present data show that the blind/low vision pedestrian will experience significantly more difficulty than the sighted pedestrian when crossing the exit lane of a single lane roundabout having the range of traffic volumes modeled in the present study. And, recall that this increase in delay was observed in the present study under conditions where the volume to capacity ratio reached only .60 (i.e., 60 percent of capacity). From a pedestrian safety standpoint, the obvious concern would be for blind/low vision pedestrians' willingness to wait for 41 seconds in order to obtain an opportunity to cross the exit lane (compared to roughly 13 seconds for the sighted pedestrian). To the extent that impatience or impulsiveness could lead to the selection of an unsafe gap, the blind/low vision pedestrian is placed at risk. While some would argue that, at the slower speeds engendered by the circulatory path of the roundabout, the worst consequence associated with the selection of an unsafe gap would be that the motorist would have to yield to the pedestrian. This, of course, assumes (a) that the motorist 'sees' the pedestrian (presence of the white cane having been shown to be an unreliable cue to get motorists to yield), (b) that the motorist is willing to yield, and (c) that the motorist is willing to yield without fear of being rear-ended by the following vehicle . . . especially under high volume conditions.

While the data show that roundabouts may be negotiated without significant delay by sighted pedestrians, there is need to give more consideration to the conditions ensuring adequate crossing opportunities for blind/low vision pedestrians . . . especially at the exit lanes of roundabouts. Several possibilities have arisen as part of the project thus far.

The first has to with the provision of an alternative crosswalk location *downstream* from the exit lane of the roundabout. In principle, a downstream location might reduce the difficulty of the auditory discrimination task for the blind/low vision pedestrian in trying to discern the presence of an acceptable gap where vehicles are approaching along a circular path and where it may be difficult to discern from aural cues along which vehicles intend to exit in front of the pedestrian's path as opposed to continuing around the circle. Without having knowledge of the intended path of vehicles entering the roundabout or those already in the roundabout, it is not clear how the roundabout could be instrumented to provide a reliable and timely indication to the blind/low vision pedestrian as to the location a vehicle potentially exiting at his/her location.

Our thought is that such a downstream location might additionally be augmented with the placement of a 'sensor' in the roadway between the exit lane and the downstream crossing. The sensor would be sensitive to the presence of any vehicle in the area between the exit lane and the downstream crosswalk. That information could, in turn, be communicated (by auditory, tactile or other means) to the blind pedestrian waiting to cross. Spatial placement of the downstream crosswalk would be done in conjunction with the ability of the sensor to communicate the presence of an adequate (time) gap . . . defined as the (estimated) time for the vehicle to arrive at the crosswalk.

Since motorists also have a tendency to accelerate once exiting the roundabout, thought has also been given to the application of traffic calming (speed reduction) measures between the exit lane and the downstream crosswalk. It is our (currently untested) hypothesis that the use of the downstream crosswalk would have the effect of (a) mitigating the inherent latency differences between blind and sighted pedestrians, (b) reducing the difficulty of the auditory discrimination task upon which gap acceptance is dependent in large part for the blind pedestrian, and perhaps most important in (c) providing a reliable cue for the presence of a gap of duration sufficient to safely cross.

We feel VISSIM can be a valuable tool in evaluating this or similar hypotheses. We also feel that by linking a model such as VISSIM to a driving simulator it would be possible to evaluate typical motorists' response to these types of interventions . . from a driver's perspective. Changes, or additions/alternatives, to the conventional splitter island crossing location represent a somewhat different mindset of the 'area of influence' of the roundabout. Such notions suggest that the 'area of influence' (in particular, the influence over vehicle speeds) of the roundabout might more effectively extend beyond the area of the entry and exit lanes, and that an effective design for (all) pedestrians might be one that provided for multiple or alternative crossing locations. From an Intelligent Transportation System (ITS) perspective, the suggested use of some form of sensor to convey more reliable information about 'gaps' reflects the notion that facility operation can in many cases be improved through the provision of better system information to its users.

Lastly, from the standpoint of the NIH concept of the Bioengineering Research Partnership, the application of computer modeling to the problem of pedestrian behavior at complex intersections has emphasized the importance of simulation and modeling in providing a common ground for the analysis of complex, multi-disciplinary applied problems. Such models have not traditionally been the domain of the Orientation and Mobility (O&M) community, but have been, and continue to be, essential tools used by the traffic engineer. The use of VISSIM in the present case, has brought more focus, especially from a measurement standpoint to the multi-disciplinary analysis of 'critical' gaps and has been significant in establishing the measurement protocols for future collaborative research in this area.

Collectively, the members of the Western Michigan University partnership are presently involved in consideration of how VISSIM, as well as other 'models,' might be effectively utilized in the remaining period of the grant. Our thinking is that modeling and simulation represent essential components of the overall process leading from problem definition, to the specification of functional system requirements, to the development and evaluation of prototype concepts first in a 'laboratory' then in an operational setting. A plan for the systematic application of modeling and simulation to the problem of blind/low vision pedestrians at complex intersections is currently being developed by the team for NIH review.

VI References

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