Exploring Pedestrian Scramble Options in a Single-Lane Roundabout: Experimental Delay Analysis

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ABSTRACT

Single-lane roundabouts are modeled with installation of pedestrian scramble crossings to allow heavy volumes of pedestrians to walk across the legs and through the center. VISSIM microsimulation considers experimental origin-destination (O-D) balanced flow scenarios (total traffic flow into and out of every roundabout approach is the same) with three pedestrian volumes (100, 500, and 1000 per hour) and with different scramble scenarios (none, two, four, and with signals). Simulated right-turning traffic volumes for a roundabout approach range from 50 to 500 vehicles per hour. Experiment results indicate that average vehicle delay of a roundabout is sensitive to changing pedestrian volumes and scramble behavior, before oversaturation occurs. As expected, results indicate scramble affects the rate of pedestrian-vehicle conflicts and roundabout average delays. This study evaluates impacts of incorporating pedestrian scramble crosswalks on pedestrian and vehicle delays within a roundabout. Roundabout vehicle delays are significantly increased with increased pedestrian scramble volume, except where a signaled pedestrian scramble is used; with a signal, delay remains constant. Finally, with utilization of two scrambles, at high pedestrian volume (1000 per hour) total average pedestrian delay decreased by 13%. With utilization of four scrambles pedestrian delay decreased by 41%. With use of signaled scrambles, pedestrian delay decreased by 82%.

Key words: Roundabout, pedestrians, average delay, VISSIM, pedestrian crossing scramble.

INTRODUCTION

In signalized intersections with high pedestrian traffic, a "Pedestrian Scramble" crossing stops all vehicular traffic to allow pedestrians to cross in every direction, including diagonally, at the same time. A pedestrian crossing phase pattern (two-way or scramble) may be allocated in an exclusive pedestrian phase (scramble) or allowed to move during a vehicular phase (two-way crossing).

Several states in the U.S. have implemented pedestrian scramble at city intersections. In IL, for instance, downtown Chicago's State and Jackson intersection averages about 41,600 pedestrians and 20,500 vehicles on a typical weekday, according to the City of Chicago-Transportation Department (*1*). Washington, DC and San Antonio, TX also utilize pedestrian scramble at a number of intersections. Internationally, Japan utilizes pedestrian scramble in Tokyo, at a crossing outside Shibuya Station in Hachiko Square that is used by more than a million people every day; Canada utilizes a pedestrian scramble in Vancouver at the intersection of No.1 Road and Moncton Street (*2*).

According to study reports (*3*) by New York's Metropolitan Transportation Authority (MTA), pedestrian volumes are highest in the Wall Street part of Lower Manhattan, in some cases; A.M. and P.M. peak pedestrian volumes were verified as exceeding 300-350 persons per 15 minutes (over 1,200 per hour) on a particular midblock sidewalk. Closer to the borough's municipal center, near Chambers Street and Broadway, midblock pedestrian volumes between 1,000 and 1,500 per hour have been recorded, indicative of acceptable levels of service. Just north of Canal Street along the Bowery, hourly pedestrian volumes are within the 700-900 range. Near East Midtown's northern boundary at 60th Street, hourly pedestrian volumes along Third Avenue range from 4,000 to 6,000 persons per hour. Pedestrian volumes along 42nd Street peak as high as 5,000-6,000 per hour.

In Oakland, California, Bechtel et. al. (*4*) evaluated a pedestrian scramble signal at the intersection of 8th Street and Webster Street, finding that the scramble has reduced pedestrian-vehicle conflicts at the intersection.

Using an automated video detection application, Ismail (*5*) and Saunier (*6*) analyzed conflict between pedestrians and vehicles, and they developed an evaluation of the safety benefit of the pedestrian scramble phase that protected pedestrian safety at intersections.

As modern roundabouts gain popularity in the U.S., according to NCHRP Reports 572 (*7*) and 672 (*8*), no studies are yet found for pedestrian scramble as a crossing option within roundabouts. Several studies, however, have evaluated roundabout operational performance, using VISSIM (*9*) to change and analyze geometric and behavior features including pedestrians. For example, Schroeder et. al. (*10*) used VISSIM to conduct a sensitivity analysis for pedestrian impacts and to evaluate the "pedestrian-induced" impacts of roundabout signalization on vehicular performance. They estimated the impacts on pedestrian and vehicle delay for different crossing geometries and signalization schemes for a one-lane and a two-lane roundabout. They tested several ranges of alternate crossing geometries—including 'proximal,' 'zig-zag,' and 'distal' crossings—with varying offset distances of entry and/or exit crosswalk from the circulating lane. To complete their analysis, they considered a range of pedestrian intensities between 1 and 50 pedestrians per hour.

Al-Ghandour et al. (*11*) experimentally studied roundabout performance with and without a slip lane, by simulating both balanced (total traffic flow into and out of each roundabout approach is the same) and more realistic unbalanced flow scenarios (traffic flow into and out of different roundabout approaches is different) for a range of volume levels, likewise using a microscopic simulation package (VISSIM). They considered four pedestrian volume levels, ranging from 0 to 100 pedestrians per hour. Results from VISSIM modeling at the higher traffic volume confirm that a roundabout with a free-flow slip lane type experiences the highest increase in delay: for instance, a free-flow slip lane with pedestrian traffic at 100 pedestrians per hour can increase roundabout delay from 6.6 to 34.7 sec/vehicle.

Pedestrian scramble crossing at signal intersections, widely used throughout the world and reintroduced in Canada and the United States, prioritizes pedestrian movement by stopping all vehicular traffic movement and allowing pedestrians to cross in every direction at the same time. Because no research was found evaluating pedestrian scramble in roundabout performance, there is a need to determine its value in roundabouts and to quantify its contribution to overall pedestrian safety and roundabout operational performance. To that end, this paper has two specific objectives:

1. To explore an experimental procedure that considers some pedestrian crossing patterns with scramble, using VISSIM simulation.
2. To quantify average delay for pedestrians and roundabout vehicle traffic from utilization of a scramble option.

APPROACH

Al-Ghandour (*12*, *13*) studied both experimental balanced (total traffic flow into and out of each roundabout approach is the same) and more realistic unbalanced flow scenarios (traffic flow into and out of different roundabout approaches is different) for a range of volume levels. In this study, single-lane roundabout-based experimental simulation was used to determine average delay of roundabout and pedestrian traffic with different pedestrian scrambling crossings. Four balanced experimental traffic percentage turning volume distributions (scenarios) were studied under the assumption that total traffic flow into and out of each roundabout approach is the same. The scenarios (S1 to S4) were initialized, analyzed, and then controlled through several iterations (Figure 1).

The base scenario (S1) is a single-lane roundabout, with four legs and a typical inscribed circle diameter of 100 ft., with a standard pedestrian crossing at each approach and no scrambling crossing (Figure 1, S1). Pedestrians are meant to cross only at the designated crosswalks and never to the central island. At the crosswalks, pedestrians have the right-of-way; they cross one lane at a time, using the splitter island as refuge from vehicle traffic before crossing the next lane.

To the roundabout format of S1, Scenario S2 added two perpendicular scrambling crosswalks, placed at the northbound-southbound and eastbound-westbound entrances (Figure 1, S2); to S2, Scenario S3 added two more scrambling crosswalks, diagonal to the legs, for a total of four (Figure 1, S3); finally, S4 added signals with fixed cycle timing (90 seconds) for each of the scrambling crosswalks including the roundabout approaches (Figure 1, S4). Signals turned red for vehicles (red for 20 seconds, green for 65 seconds, amber for 5 seconds), and green for pedestrians (green 70 seconds, and red for 20 seconds).

The scenarios S1 to S4 were initialized, analyzed, and then controlled through several iterations. Several variables were tested across the traffic percentage distribution scenarios: 1) right-turning traffic volume as the dominant turn (from 50 vehicles per hour to 500 vehicles per hour, in increments of 50 representing low, moderate, and high volumes); 2) traffic percentage distribution flow patterns (75%); and 3) three different pedestrian volumes per hour (low: 100, moderate: 500, and high: 1000).

These four traffic volume distribution scenarios were coded into VISSIM to evaluate the performance of the roundabout. For each simulation scenario, 20 VISSIM runs, of one hour each, were executed using different random number seeds, for a total of 800 simulations. In total, 40 scenarios were modeled: 1 traffic O-D (75%) x 10 traffic volumes (50 to 500 vehicles per hour) x 4 scenarios (S1-S4).

All default values from VISSIM were retained: vehicle types (cars and trucks), desired speed, acceleration and deceleration, priority rules minimum gap time (2.5 seconds), pedestrian speed (4 ft. /sec), and driving behavior parameters.

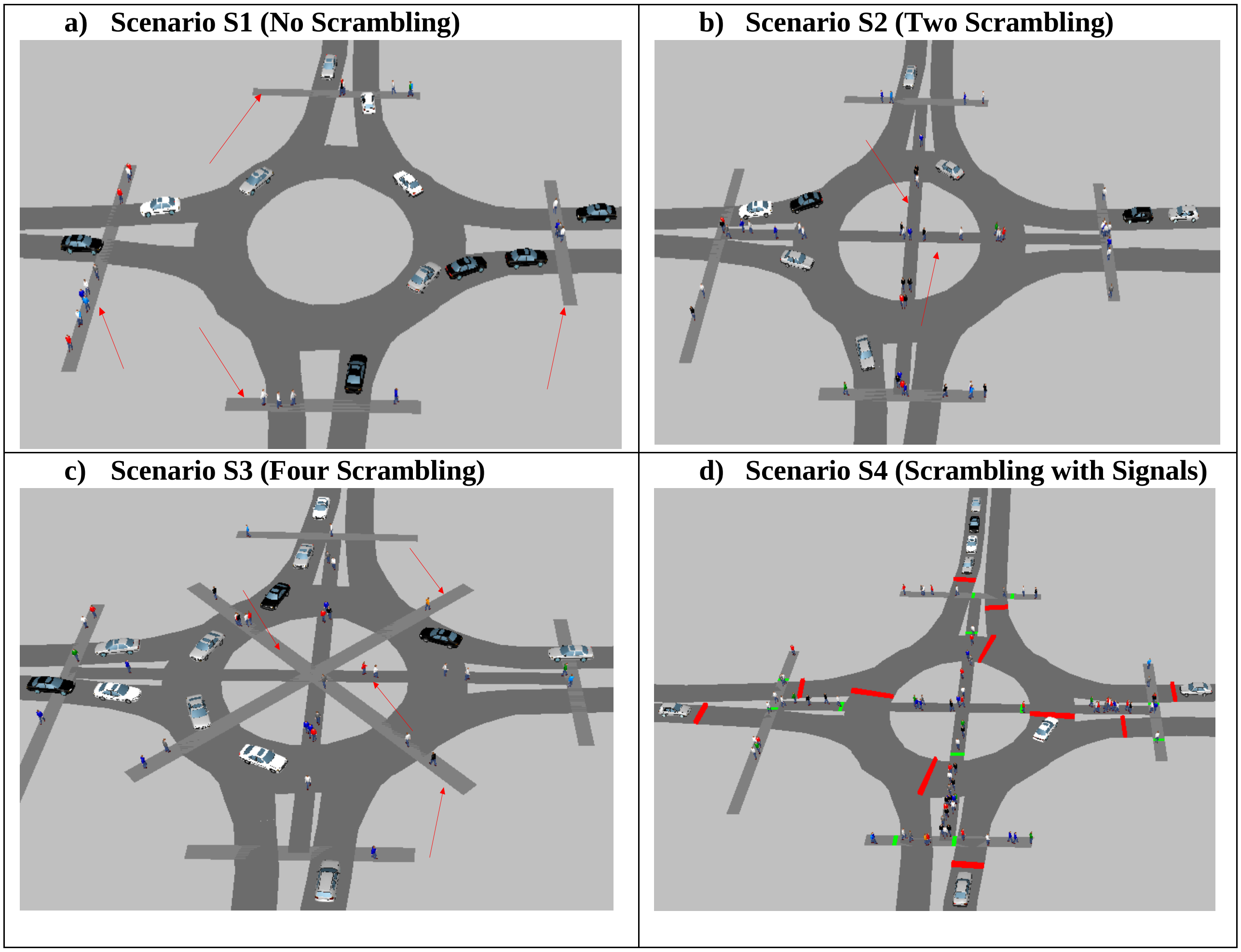


FIGURE 1 VISSIM Snapshots with Pedestrian Scrambling Crosswalk Scenarios (S1-S4).

Pedestrian traffic was modeled as VISSIM allows for pedestrians; vehicle type and vehicle model were both selected as pedestrian. The scrambling crosswalk geometry was constructed using links modeled as footpath (one lane in each direction was created for the crosswalks, each six feet). A fixed pre-timed signal cycle length of 90 seconds was considered for all the scrambling crosswalks in the experiment. The priority rule was that drivers must yield the right-of-way to pedestrians crossing. Average roundabout delay (in seconds) for all vehicles entering the roundabout and average delay per pedestrian (in seconds) was used as the Measure of Effectiveness (MOE) of the roundabout.

ANALYSIS AND RESULTS

A sample of total approach (V_a) volume flows for scenarios S1-S4 is summarized in Table 1. At high traffic volumes (V_{rt} = 500 vehicles per hour), northbound approach volume (V_a) is 677 vehicles per hour. Scenario (S1), which has no scrambling crosswalk, sustains more vehicles circulating than the other scenarios S2, S3, and S4.

TABLE 1 Sample of Total Approach Volumes, Vehicles per Hour

V_{rt}: Right-Turn Volume at Northbound (NB) Approach (Vehicle/hour)	$V_{(a)}$: Volumes (Vehicle/hour)	S1-S4 (75%)
V_{rt} = 50 (Low)	V_a	166
V_{rt} = 250 (Moderate)	V_a	333
V_{rt} = 500 (High)	V_a	677

V_a : Approach volumes. V_{rt}: A dominant right turn volumes, vehicles per hour.

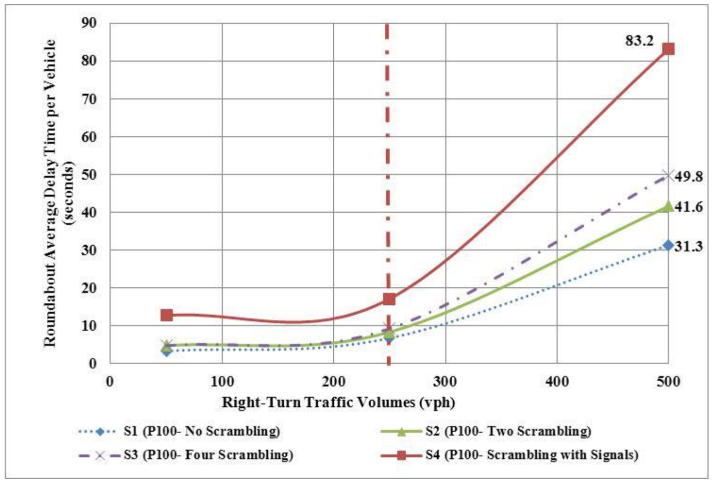
Average Roundabout Delay with Pedestrian Scramble

VISSIM results with pedestrian volumes for balanced scenarios were analyzed. With the assumption that pedestrians have the right-of-way at the crosswalks, results show average vehicle delay in seconds for all vehicles in the roundabout for three pedestrian volume levels (100 to 1000 pedestrians per hour). Figures 2a to 2c show the roundabout average delay time per vehicle, with pedestrians. For example, for low pedestrian volume P100 (100 per hour), delay increases from 31.3 seconds per vehicle (S1: no scramble crossings) to 41.6 seconds per vehicle (S2: two scramble crossings) at right-turn volumes V_{rt}= 500 vehicles per hour; this is a 32.9% change (Figure 2a). At moderate pedestrian volume P500 (500 per hour), S3 (four scramble crossings) shows the highest delay for the roundabout with pedestrians (104.7 seconds per vehicle), compared to no scramble crossings (90.1 seconds per vehicle) (Figure 2b).

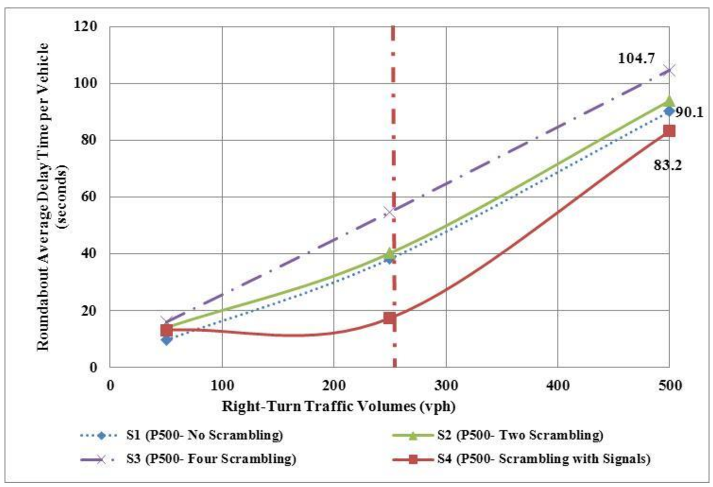
Impacts on average delay (seconds per vehicle) of varied high pedestrian volumes, for all scenarios (S1-S4) are illustrated in Figure 2c. The curves show analytical sensitivity and the effect of pedestrian traffic on average delay in the single-lane roundabout with scramble, for four volumes of pedestrian traffic (100, 500, and 1000 per hour). Therefore, for non-signaled scramble crossings, roundabout vehicle delays are significantly increased with increased scrambled pedestrian volume and with the presence of more scrambled pedestrian crosswalks; where pedestrian scramble with a signal is used, delay remains constant at 83.2 seconds.

Figure 3 shows values of induced delay, defined as the difference between roundabout average delay with a specific scrambling type and no scrambling, at specific pedestrian traffic volumes. Induced delay is more significant when a roundabout includes pedestrian scramble with signals (S4: 1.4 sec), compared to four non-signaled pedestrian scramble crossings, at any pedestrian volumes. When roundabout traffic becomes oversaturated, theoretical capacity threshold values (limits) for right-turning volumes (V_{rt}) are estimated to be within a range of 150 to 350 vehicles per hour for various balanced traffic distribution volumes (vertical dashed line in Figure 2).

a) Low Pedestrian Traffic (P100) 100 per hour



b) Moderate Pedestrian Traffic (P500) 500 per hour



c) High Pedestrian Traffic (P1000) 1000 per hour

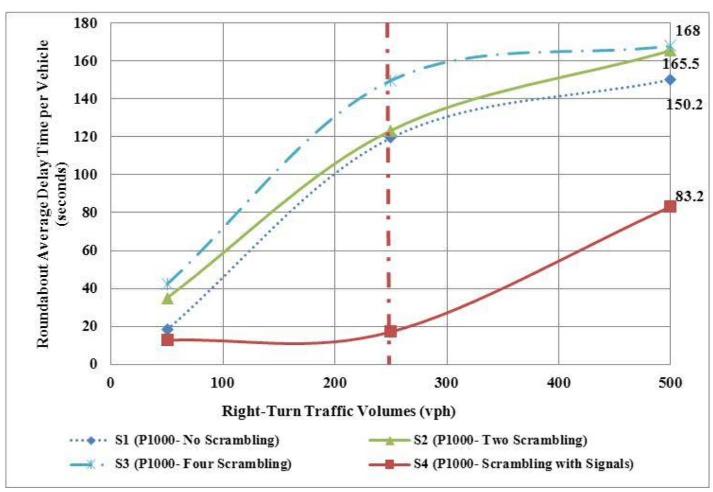


FIGURE 2 Sample of Outputs from VISSIM: Comparison of Roundabout Average Delay, Scenarios S1-S4.

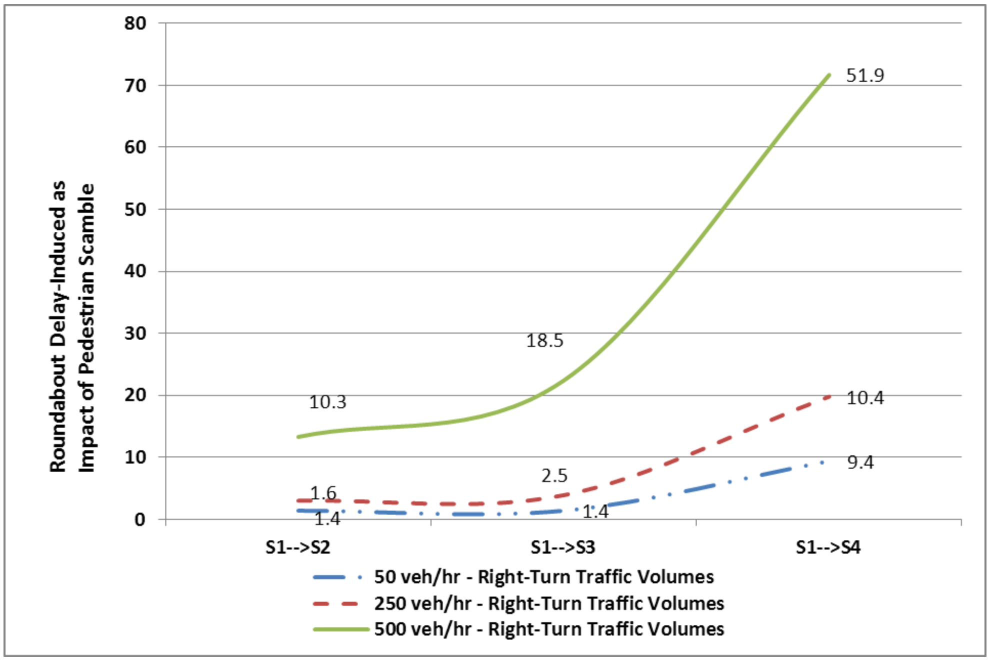


FIGURE 3 Sample VISSIM: Roundabout Delay Induced as Impact of Pedestrian Scramble Traffic in Scenarios S1-S4

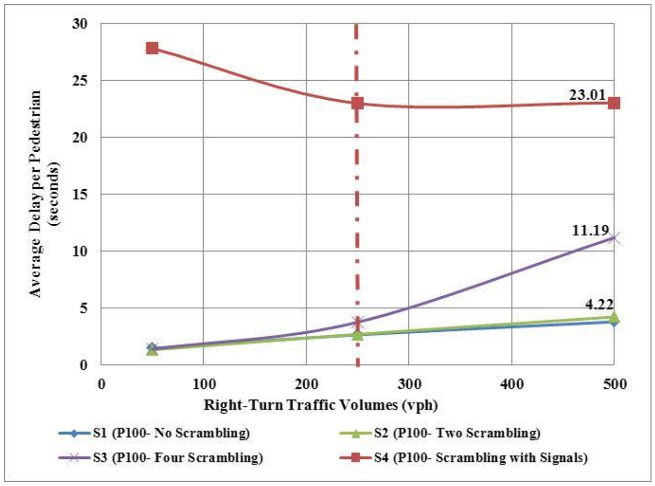
Average Pedestrian Delay with Pedestrian Scramble

Average delay (in seconds) per pedestrian for balanced scenarios was analyzed for three pedestrian volumes from 100 to 1000 per hour (Figures 4a to 4c). VISSIM results show that for low pedestrian volume P100 (100 per hour), pedestrian average delay increases from 4.22 seconds (Scenario S1 - no scramble) to 11.19 seconds (S3 – four scrambles) at right-turn volumes V_{rt}= 500 vehicles per hour (Figure 4a). Scenario S4 (scramble with signals) shows the highest delay (worst performance) for the low and moderate pedestrian volumes (Figures 4a and 4b).

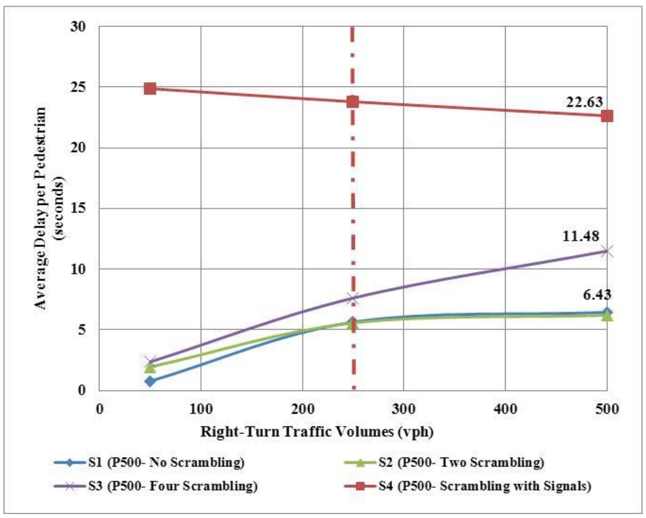
S4 shows that scramble with fixed timing signals creates the highest increase of pedestrian delay, comparing four scrambles: from 1.39 to 27.29 seconds per pedestrian (at 100 per hour), from 3.7 to 22.96 seconds per pedestrian (at 500 per hour), and from 11.19 to 23.01 seconds per pedestrian (at 1000 per hour).

It is interesting and reasonable that in this instance the scramble with signals shows more pedestrian delay than non-signal scrambles: scrambling with signals type by design is not intended to stop traffic per fixed timed signal cycle, compared to the other scrambling types, which are designed for vehicles to slow down or stop to allow pedestrians to cross (priority is for pedestrians). It is expected that pedestrian delay increases with increases in pedestrian and vehicle traffic volumes, and that pedestrian delay decreases with utilization of a scramble crossing. For example, at high pedestrian volume (1000 per hour), total average pedestrian delay with two scramble crossings decreased by 13%; with four scramble crossings, it decreased by 41%. S4 (Scrambles with signals) shows lowest delay (better performance) for high pedestrian volumes (Figure 4c), a change of (-82%).

a) Low Pedestrian Traffic (P100) 100 per hour



b) Moderate Pedestrian Traffic (P500) 500 per hour



c) High Pedestrian Traffic (P1000) 1000 per hour

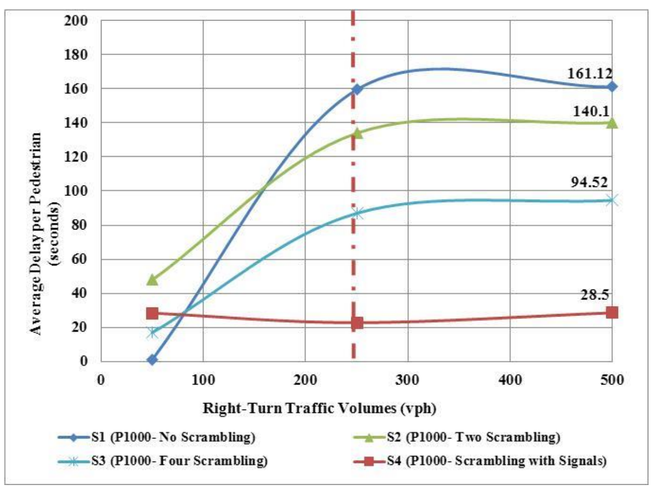


FIGURE 4 Sample of Outputs from VISSIM: Comparison of Pedestrian Average Delay, Scenarios S1-S4.

Validation

The base model of a single roundabout (S1) was validated by field data from the City of Carmel, Indiana (*14*). For approximately ten single-lane roundabouts, these data provided an analysis of traffic turning movement delays. The data were coded and simulated in VISSIM for validation. The same experiment was evaluated for four scenarios (S1-S4), using SIDRA macroscopic traffic analysis software (*15*). At medium-to-high traffic, there was no significant difference in the delays predicted by VISSIM simulation and SIDRA.

Finally, a statistical validation also was tested from VISSIM results for the four experiments, based on the standard error for the percentage change of pedestrian average delay, using a two-scramble pedestrian type 0.15 (Table 2). The 95% confidence interval is ±1.96 standard error from the average delay percentage of reduction. Therefore, with high pedestrian volume, the VISSIM 95% confidence interval for implementing a two-scramble pedestrian type is estimated between 5.89 and 6.49.

TABLE 2 Sample: Summary of VISSIM Pedestrian Average Delays in Balanced Scenarios (S1 and S2)

Pedestrian Scramble Scenarios	**V_{rt}: Right-Turn Volume at Northbound (NB) Approach (Vehicle/hour)**	**Average Pedestrian Delay in seconds (Standard Deviation(s) Errors for 20 Runs)**		
		Pedestrian Volumes (P100)	**Pedestrian Volumes (P500)**	**Pedestrian Volumes (P1000)**
S1 No Scrambling	50 (Low)	1.42 (0.03)	0.76 (0.08)	1.06 (0.23)
	250 (Med)	2.64 (0.11)	5.63 (0.68)	159.51 (10.35)
	500 (High)	3.79 (0.148)	6.43 (0.77)	161.13 (11.82)
S2 Two Scrambling	50 (Low)	1.33 (0.07)	1.94 (0.17)	47.83 (0.11)
	250 (Med)	2.69 (0.02)	5.56 (0.49)	133.99 (0.12)
	500 (High)	4.21 (0.14)	6.19 (0.68)	140.1 (0.09)

V_{rt}: A dominant right- turn volumes, vehicles per hour. S1: Scenario S1 (no scramble). S2: Scenario S2 (two scrambles). P100: Low pedestrian volume (100 ped/hr). P500: Moderate pedestrian volume (500 ped/hr). P1000: High pedestrian volume (1000 ped/hr).

CONCLUSIONS

By separating pedestrians and vehicles into separate phases, scrambles seek to eliminate conflicts between pedestrians and vehicles, reducing the number of pedestrian-vehicle conflicts, and scrambles afford short distances to travel, thereby increasing pedestrian safety.

Roundabout vehicle delays are significantly increased with increased pedestrian scramble volume, except where the pedestrian scramble with a signal is used, where delay remains constant at 83.2 seconds. At low pedestrian volumes, VISSIM simulation with two pedestrian scrambles confirms increase in total average roundabout delay of 24% with moderate pedestrian traffic, and 33% with high pedestrian traffic, before oversaturation.

Similarly, pedestrian delays are significantly increased with increased pedestrian volumes, except where the pedestrian scramble uses a signal. Finally, pedestrian delays are significantly decreased with implementation of multiple pedestrian scramble crossings and signal use. Results show that at high pedestrian volume (1000 per hour), total average pedestrian delay decreased by 13% with utilization of two pedestrian scrambles, decreased by 41% with utilization of four pedestrian scrambles, and decreased by 82% with utilization of scrambles with signals, perhaps the best choice for heavy pedestrian traffic.

RECOMMENDATION

Future research should include investigating the impact of implementing pedestrian scramble for the safety for pedestrians who are blind or have impaired vision. Additional analysis should be conducted for other variables such as roundabout geometry, slip lane types, and traffic flow, and more field data should be collected on pedestrian activity that affects roundabout operational performance. Finally, future analysis should consider more variations in percentages of trucks and actuated signals at pedestrian crossings, and a pedestrian hybrid beacon.

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