Pedestrian roundabout improvement strategy in subway stations

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Intersecting streams of pedestrians are frequently seen in subway stations. When two or more such streams encounter each other in the normal way, there is interference of progress and a reduction in speed. This research explores the impact of roundabout design on intersecting pedestrian streams by conducting a series of experiments on pedestrians in the field. First, the impact of roundabout size on different volumes of pedestrian traffic is examined; second, the effect of adding guiding signs is investigated; and third, a case where a greater number of streams intersect is studied. Results indicate that, although placing a roundabout at pedestrian intersections reduces the total space available and lengthens the average walking distance, the speed of pedestrian streams increases. The experiment reveals that the larger the radius of the roundabout, the more significant is the increase in speed and the smaller is the dispersion of acceleration. In addition, the role of the roundabout becomes more important as pedestrian traffic volume increases. Furthermore, the addition of guiding signs before the roundabout entrance is helpful in terms of regulating the direction of traffic and reducing possible conflict. Finally, the experiments reveal that inserting a roundabout also provides benefits in the case of three intersecting pedestrian streams.

1. Introduction

Because of the aggregation effect at transfer stations in subways, intersection of multiple pedestrian streams is commonly seen. These intersecting streams apparently cause pedestrian traffic conflicts and reduce travel speed, which is clearly undesirable when organising the transit of passengers through subways. However, they are practically unavoidable, even when the planning and design of pedestrian schemes has been reasonably well thought out, as it is unrealistic to expect to be able to use bridges or traffic lights for the purpose of separating these streams, unlike the case for intersecting vehicular traffic flow. In a recent survey carried out by the present research team, it was found that 43 out of the 46 stations investigated had two-stream pedestrian intersections. Also, of the 46 stations, 12 had three-stream intersections and five stations had intersections that involved more than three streams of pedestrians.

Ando *et al.* (1988) were forerunners in terms of investigating two crossing pedestrian streams in a subway station. They observed the macroscopic behaviour of pedestrians intersecting at an angle. However, the characteristics of intersecting streams have mostly been based on qualitative observations or simulation studies in the past (Helbing, 1996, 1998; Helbing and Molnar, 1998). A few researchers have pointed out that unstable roundabout traffic can be formed when streams bound in different directions intersect, which appears like a dummy roundabout set at the position of the pedestrian intersection (Duparcmeur *et al.*, 1995; Helbing, 1997; Molnar, 1996). The difference when

compared with actual roundabouts is that the direction of rotation of the circular pedestrian streams was alternating (Helbing *et al.*, 2001). Although traffic around roundabouts has to make a small detour, the frequency of necessary deceleration and stopping is found to decrease, thereby considerably reducing the potential for conflicts (Ando *et al.*, 1988; Helbing and Molnar, 1998). In addition, the style of the roundabout – for example, turbo roundabouts, flower roundabouts or target roundabouts – has been studied (Mauro, 2010; Tollazzi *et al.*, 2015a, 2015b). In order to stabilise roundabout traffic, Helbing *et al.* (2001) proposed that planting a column or a tree in the middle of a crossing could suppress the phases of ‘vertical’ or ‘horizontal’ motion in the area of the intersection. By conducting computerised simulations, the efficiency of transit speed of the pedestrian stream was demonstrated to be increased by up to 13%.

Self-organisation provides another focus for the study of pedestrians. The self-organisation phenomenon of a stripe formation in pedestrian intersecting streams has been extensively observed (Ando *et al.*, 1988; Dzubiella and Löwen, 2002; Hoogendoorn and Daamen, 2005; Hoogendoorn and Piet, 2003; Usher and Strawderman, 2008). Pedestrian stripes, like lanes on the highway, are a phenomenon of segregation. When pedestrian streams coming from two different directions intersect, pedestrians moving in the same direction become distributed in stripes (Dzubiella and Löwen, 2002). Within the same stripe, the pedestrians’ walking speed and travel direction are usually identical (Hoogendoorn and Piet, 2003). Indeed, the

stripe formation phenomenon is even more clearly observed when the intersecting angle is 90° (Hoogendoorn and Daamen, 2005). Based on the stripe formation phenomenon, providing a circular barrier at an intersection was assumed to form more marked and coherent stripes, and the circular barrier was found to perform better than a square barrier and no barrier in terms improvement of the efficiency of motion (Helbing *et al.*, 2005).

A review of the literature suggests that the insertion of roundabouts would benefit traffic at intersections and should therefore be encouraged. However, the existing studies on pedestrian roundabouts have mostly been based on theoretical research or computerised simulations, which can neither be validated nor reflect the characteristics of pedestrian behaviour in the real world. To obtain more quantitative characteristics of intersecting streams, experiments on pedestrians are an extensively used method (Guo *et al.*, 2010; Helbing *et al.*, 2005; Wong *et al.*, 2010; Xie *et al.*, 2013). In a study by Guo *et al.* (2010), speed and density were analysed for two intersecting streams. The passing time of two intersecting streams has been used to analyse the self-organisation effect (Helbing *et al.*, 2005).

In controlled experiments involving two pedestrian streams, macroscopic parameters such as speed, density and flow were extracted to calibrate the model of bidirectional pedestrian streams (Wong *et al.*, 2010; Xie *et al.*, 2013).

In the present research, the feasibility and effects of adding a roundabout for intersecting streams are explored using a series of experiments on pedestrians in the field. The methodology is given in the following section, and then the rest of the paper is organised into four sections. Section 3 investigates the impact of roundabout settings on the pedestrian stream. Section 4 evaluates the function of traffic guiding signs at roundabouts. The previous studies are then expanded to look at a three-stream intersection in Section 5. Finally, some conclusions and recommendations are provided.

2. Methodology

A series of pedestrian experiments was conducted in a courtyard of Beijing University of Technology (BJUT) on the afternoon of 17 April 2015. The experimental scenarios were established according to the scheme shown in Figure 1. To mimic the two intersecting streams, two entrances and exits

Figure 1. (a) Division into regions of the experimental scenario. (b) No-roundabout experimental scenario. (c) Experimental scenario with roundabout inserted

Table 1. Comparison of experiment and real environment

Comparison of scenario	Scenario setting		Significance of pedestrian characteristic factors		
	Volume	Number of pedestrians	Transit time	Speed	Acceleration
Scenario 1	1350	25	0.22	0.13	0.31
Scenario 2	2050	25	0.10	0.11	0.17
Scenario 3	4800	50	0.12	0.08	0.12

Figure 2. Experimental design of roundabout at two intersecting pedestrian streams

were designed. Considering the layout of the subway, 50 healthy undergraduate students from BJUT were recruited for the experiment. The number of participants was enough to develop several different experiments. Bearing in mind that any acquaintance among the students could lead to the production of biased experimental results, the participants were selected from different classes and departments. The ages of the participants ranged from 18 to 25 years old. Caps of different colours were used to distinguish the different streams. As can be seen in Figure 1(a), to obtain a normal flow without being affected by any starting delay, start lines positioned 1.5 m away from each entrance were drawn. To analyse the pedestrian behaviour in an automated way, a digital camera was placed at a height of 20 m above the experimental area. The digital camera had a resolution of 1920 × 1080 pixels and the capture rate was 30 frames/s, which is adequate to record pedestrian behaviour (Sun *et al.*, 2014). The field experiment scenes (screenshots from the experimental video) are shown in Figures 1(b) and 1(c).

As a data-processing tool, SIMI Motion (a software application that uses novel algorithms to process video footage) was used for motion capture in this study (Sun *et al.*, 2014). Pedestrians were labelled by using the SIMI Motion software. The position (*x*, *y*) of each pedestrian was then captured automatically by SIMI Motion every 0.2 s; the output also included speed, time, acceleration and so on.

Table 2. Experimental scenario settings of different roundabout designs

Scenario	Radius of roundabout: m	Volume of pedestrian traffic: (p/h)/m
Scenario 1a	—	4000
Scenario 1b	—	5000
Scenario 1c	—	6000
Scenario 2a	0.5	4000
Scenario 2b	0.5	5000
Scenario 2c	0.5	6000
Scenario 3a	1.0	4000
Scenario 3b	1.0	5000
Scenario 3c	1.0	6000
Scenario 4a	1.5	4000
Scenario 4b	1.5	5000

Table 3. Walking distance and transit times for the different experiments conducted

Radius of roundabout: m	None	0.5	1.0	1.5
Volume: (p/h)/m		Walking distance: m		
4000	11.95	12.82	13.07	14.34
5000	12.16	12.49	12.98	14.83
6000	12.03	12.32	13.00	15.07
		Passing time: s		
4000	28	27	24	27
5000	24	22	21	23
6000	20	21	17	20

Before the formal experiments were carried out, three trial experiments were conducted to compare the coherence of pedestrian characteristic factors between the pedestrian flow in the experiment and actual pedestrian flow in a subway. Video footage from a real subway hallway with intersecting pedestrian streams was analysed using SIMI Motion. Trial experiments were conducted according to the traffic volume/number of pedestrians obtained from these subway videos. One-way analysis of variance (Anova, where *p* < 0.05 represents a significant difference and *p* > 0.05 represents no significant difference) was conducted for the three factors of passing time, speed and acceleration and the significance is shown in Table 1. In this study, the passing time was taken as the total time from the first person entering the experiment area until the last person walked out of the experimental area. Results indicate that there was no

Table 4. Descriptive statistics of speed under different traffic volumes (STD, standard deviation)

Volume of pedestrian traffic: (p/h)/m	Radius of roundabout: m	Mean: m/s	Medium: m/s	Max.: m/s	Min.: m/s	STD: m/s
4000	None	1.18	1.16	1.72	0.57	0.40
	0.5	1.26	1.21	1.70	0.63	0.38
	1.0	1.29	1.26	1.74	0.60	0.32
	1.5	1.30	1.27	1.85	0.66	0.24
5000	None	1.09	1.08	1.70	0.42	0.47
	0.5	1.18	1.10	1.74	0.64	0.41
	1.0	1.23	1.16	1.82	0.62	0.30
	1.5	1.25	1.16	1.73	0.65	0.16
6000	None	0.89	0.85	1.72	0.40	0.49
	0.5	0.99	0.85	1.69	0.42	0.33
	1.0	1.08	1.03	1.86	0.66	0.29
	1.5	1.13	1.07	1.65	0.61	0.23

significant difference between the trial experiments and the real-world subway hallway. This finding demonstrates that the experiment could mimic a real-world scenario.

3. Investigating impact of roundabout settings on pedestrian streams

3.1 Design of pedestrian experiment

The aim in this section is to investigate the impact of different roundabout designs on intersecting pedestrian streams. Three aspects are explored: (a) whether the existence of the roundabout has an impact on a weaving stream and, if so, what this impact is; (b) the influence of the size of the roundabout on intersecting pedestrian streams; and (c) the performance of the roundabout under different volumes of pedestrian traffic. Hence, experiments consisting of different combinations of pedestrian traffic volumes and roundabout sizes are developed.

According to the Transportation Research Board's (TRB's) Transit Cooperative Research Program (TCRP) Report 100, the *Transit Capacity and Quality of Service Manual*, the standard one-way passageway capacity is 5000 (persons/h)/m (unit (p/h)/m is used in the rest of this paper) (Kittelson & Associates *et al.*, 2003). In this study, as any potential conflict may vary according to different traffic volumes, three levels of pedestrian volumes were investigated: 4000 (p/h)/m, 5000 (p/h)/m and 6000 (p/h)/m, indicating that there were six, seven and eight experimental participants randomly assigned to a row, respectively. The experimental stream ratio is 1:1 in this study. Based on this assumption, three sizes of roundabout were designed, of radius 0.5 m, 1.0 m and 1.5 m, as seen in Figure 2. Thus, in total, 12 scenarios were designed and the experiments were conducted for analysis, as listed in Table 2.

3.2 Data analysis

3.2.1 Walking distance and transit time

Three pedestrian experiments were conducted for each scenario and the average measurement was taken from these. Table 3 shows the average walking distance and transit time under

Figure 3. Rate of increase in mean speed after installing roundabout

different combinations of traffic volume and roundabout settings. It was found that for the same size roundabout the average walking distances for different traffic volumes vary little, which demonstrates that the pedestrian volume has barely affected the route selection. However, with the increase of roundabout size, the average walking distance increases. This is evident because the pedestrians have to walk around the roundabout to reach their destinations. The larger the roundabout is, the larger is the detour distance and hence the total walking distance.

As regards transit time, the comparison between a 'no-roundabout' scenario and scenarios with different sizes of roundabout is of interest. When the roundabout's radius is 0.5 m, the change in path of movement has little effect on travel distance and, therefore, there is only a small change in transit time. A maximum of 2 s change is observed for the three different volumes. When the roundabout's radius is increased to 1.0 m, an average of about 3–4 s drop in transit time is seen, which is about 15% reduced when compared with the no-roundabout scenario. However, when the roundabout's radius is increased to 1.5 m, where the walking distance is the largest, the transit time is less than or the

Figure 4. Frequency of acceleration in pedestrian traffic volume of: (a) 4000 (p/h)/m; (b) 5000 (p/h)/m; (c) 4000 (p/h)/m

same as the situation where no roundabout has been added. This observation suggests that a large roundabout has some positive effect on walking for intersecting streams. Overall, although walking distance increases when a roundabout is inserted, the transit time decreases. Thus, the transit efficiency of whole pedestrian streams increases. It should also be noted that, because the number of pedestrians in each experiment is the same, the transit time decreases with increase of pedestrian traffic volume.

3.2.2 Speed

The descriptive statistics regarding speed under different volumes of pedestrian traffic are listed in Table 4. Compared with the scenarios without a roundabout, the installation of a roundabout

leads to an increase in pedestrian speed and a decrease in the standard deviation of speed for all traffic volumes. This phenomenon indicates that the installation of a roundabout could improve the traffic condition in general. For an identical traffic volume, the mean and median speeds increase and the standard deviation decreases with the expansion of the roundabout radius. However, this observation does not support a conclusion that the larger roundabout is, the better the pedestrian walking condition is. The size of roundabout could not be infinitely large, and should depend on the size of the area of intersection.

To investigate the influence of roundabout size on pedestrian speed under different traffic volumes, the rate of increase of

mean speed is analysed in Figure 3. It can be seen that the greater the experimental traffic volume is, the greater is the rate of increase in speed. It is clear that the rate of increase in pedestrian mean speed at 6000 (p/h)/m is significantly higher than that for the other pedestrian traffic volumes.

3.2.3 Acceleration

Frequent acceleration and deceleration is one of the hazard factors in vehicular traffic; it is also undesirable in pedestrian traffic (Hediyeh *et al.*, 2012). The acceleration data were extracted to investigate the influence of roundabout installation on change in speed. Figure 4 shows the distribution of pedestrian acceleration for different traffic volumes and roundabout installations. It is apparent that, after installing the roundabout, a more centred distribution of acceleration is found for all traffic volumes. This demonstrates that installing a roundabout could effectively reduce the occurrence of changes in acceleration.

In summary, the installation of a roundabout is beneficial to intersecting traffic. However, the improvement depends on the size of the roundabout. In the three sizes of roundabouts used in the current study, the largest one at 1.5 m radius shows the best overall traffic condition (no significant increase in transit time, but higher speed and less acceleration). In addition, the improvement in speed is the most significant at the largest experimental pedestrian traffic volume (6000 (p/h)/m).

Figure 5. Experimental scenarios with traffic-guiding signage added

4. Evaluating the effect of traffic guiding signage

4.1 Design of pedestrian experiment

After a roundabout has been installed, pedestrians can walk around it in either a clockwise or counterclockwise direction. In highway regulation, only one-way traffic is allowed at roundabouts. Guiding signs are installed in front of roundabouts to direct drivers. This study also introduced guiding signage for pedestrian management at roundabouts. According to the law and custom in China, cars and pedestrians should travel on the right-hand side of thoroughfares. Therefore, signage to direct users in a counterclockwise direction was installed in front of the roundabout (Figure 5). A separate experiment was conducted to observe the effect of the traffic sign. In this experiment, a pedestrian volume of 5000 (p/h)/m and roundabout radius of 1.0 m were employed.

4.2 Data analysis

Speed, acceleration, walking distance and transit time as derived from the new experiments (shown in Table 5) are compared with those derived from scenario 3b. Figure 6 shows the pedestrian walking tracks for both experiments. Each line represents a pedestrian's walking track. Gradients are given according to speed and represented by symbols, where solid circles indicate the lowest speed and open squares the highest (see key). The speed can represent the degree of conflict between pedestrian traffic flows. The lower the speed is, the more severe is the conflict. Overall, the positions of lower speed are mostly distributed in and before intersecting areas, especially those areas where there are the most serious conflicts of pedestrian traffic.

It is evident that the traffic guiding signs elicited a walking distance that was increased by 5.70%. From Figure 6 it can be seen that almost all of the pedestrians walk in a counterclockwise direction, which leads to detours for some pedestrians. However, the transit time is decreased by 14.28% compared with the scenario without guiding signs. In addition, the average speed is increased and the standard deviation is decreased by 3.25% and 26.70%, respectively. With respect to acceleration, a 12.20% reduction of standard deviation can be observed for the scenario with signs. All the parameters point to the finding that guiding signage plays a positive role in improving traffic efficiency at roundabouts.

In particular, the conflict points, as represented on Figure 6, are worth noticing. Without the guidance of the traffic signs, pedestrians would choose either to turn left or right at the

Table 5. Parameters analysis under different traffic guiding signage

Traffic guiding sign	Transit time: s	Walking distance: m	Mean of speed: m/s	STD of speed: m/s	STD of acceleration: m/s ²
No signs (new experiment)	21	12.98	1.23	0.30	0.41
Signs included (scenario 3b)	18	13.72	1.27	0.22	0.36

Figure 6. Comparison of pedestrian tracks with walking speed: (a) no guiding signage for two streams; (b) guiding signage added

roundabout. The entering and merging conflict of two streams is significant. By responding to the traffic signs, the pedestrians walk in the same direction. The bidirectional conflict on entry is eliminated and the merging conflict is alleviated. In summary, the benefit of adding auxiliary guiding signage has been observed through the experimental study.

5. Case of three intersecting streams

5.1 Design of pedestrian experiment

A three-stream intersection, which is a more complicated traffic phenomenon, is also observed at some subway stations. In this section, three additional experiments are described

which studied the influence of a roundabout on such three-stream intersections.

The experimental scenarios were established as in Figure 7. All the designs were the same as for the two-stream intersection flow, except that numbers of entrances and exits were changed to three. Three comparative experiments were designed as follows: the first one (scenario 5a) was a three-stream intersection with no roundabout; the second (scenario 5b) was a three-stream intersection with a roundabout; and the last one (scenario 5c) included both a roundabout and traffic guiding signage. A pedestrian volume of 5000 (p/h)/m and roundabout radius of 1.0 m were employed in these experiments.

Figure 7. Experimental scenarios for three intersecting pedestrian traffic streams

5.2 Data analysis

The same set of performance indicators was used for the analysis. Speed, acceleration, walking distance and transit time for the three new scenarios are summarised in Table 6. The walking distance for scenarios 5b and 5c was increased 7.54% and 10.65%, respectively, when compared with scenario 5a. As regards transit time, there was no change between scenarios 5a and 5b; a 9.09% decrease was seen for scenario 5c. The mean speed for scenarios 5b and 5c was significantly higher compared with that for scenario 5a. The rates of increase were 22.35% and 34.12%, respectively. In terms of the standard deviation of the speed, taking scenario 5a as the basis, decreases of 37.74% and 49.06% are seen for scenarios 5b and 5c, respectively. With respect to the standard deviation of acceleration, scenarios 5b and 5c show decreases of 41.82% and 52.73%, respectively, compared with scenario 5a. Overall, the walking efficiency is improved in scenarios 5b and 5c. Furthermore, scenario 5c shows higher efficiency than scenario 5b, which consolidates the finding from the previous section – namely, that the signs have a positive impact in terms of improving pedestrian traffic flow. The three-stream scenarios were also compared with the two-stream scenarios. For all the performance indicators, the effect of the roundabout was more significant in the three-stream scenarios.

Figure 8 shows the pedestrian walking tracks for the three pedestrian streams scenarios. Conflict points (darkest areas) can be observed on all three scenarios. In terms of quantity of conflict points, it can be clearly seen that scenario 5a has the most and the scenario 5c has the least. When there is no roundabout (scenario 5a), three streams intersect near one point, which is near the centre of the experimental field. For scenario 5b, pedestrians walk around the roundabout and conflicts are separated into different locations. For scenario 5c, where signs are posted, the only merging conflict is observed for the one-way counterclockwise flow. In this scenario, the conflict is minimised because the walking direction is the same.

In summary, the experimental results obtained from three pedestrian streams consolidate the findings from the experiments with two pedestrian streams. Adding a roundabout and guiding signs is useful to improve the traffic efficiency. This improvement is more significant for three pedestrian streams than for two pedestrian streams.

6. Conclusions and recommendations

In this study, the influence of installing a roundabout on the characteristics of pedestrian flow is investigated by conducting a series of experiments on pedestrians. It was found that installing a roundabout at a pedestrian intersection improves the traffic efficiency and reduces conflict for both two streams and three streams of pedestrian traffic flow. The size of the roundabout designed shows a positive relationship with the traffic efficiency in this study. In addition, the role of the roundabout is more important when the volume of pedestrians is large. Furthermore, setting guiding signs in front of the roundabout leads to the pedestrians walking in the same direction, which eliminates the initial bidirectional conflicts and reduces merging conflicts. Overall, it is recommended for subway management to install roundabouts at pedestrian intersections. However, it should be noted that this study has focused only on a balanced flow scenario. In other words, the volume of each stream of pedestrians in a multiple stream has been assumed as the same. To mimic the real-world situation fully, additional study using an unbalanced flow ratio is recommended. In addition, the characteristics of four intersecting pedestrian streams are significantly more complicated than for those in the current study, so it would be useful to analyse the effect of a roundabout in the case of four intersecting streams.

Table 6. Parameters analysis for different roundabout designs and traffic guiding signage

Scenario	Facility setting		Transit time: s	Walking distance: m	Mean speed: m/s	STD speed: m/s	STD acceleration: m/s ²
	Radius of roundabout: m	Traffic guiding signage					
Scenario 5a	None	None	22	12.20	0.89	0.53	1.10
Scenario 5b	1	None	22	13.12	1.04	0.33	0.64
Scenario 5c	1	Included	20	13.50	1.14	0.27	0.52

Figure 8. Pedestrian tracks with walking speed of: (a) scenario 5a; (b) scenario 5b; (c) scenario 5c

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