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Empirical study on pedestrian crowd behaviour in right angled junction

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Abstract

Bottleneck formed due to complex architectural configurations can create hazardous situations as have been noted from the previous documented studies of crowd disasters. There have been numerous fatalities and serious injuries in the past around the world due to stampedes at those bottleneck points. One of the critical bottlenecks that is common in major public infrastructure is the right angled junction (also called as T-Junction). Although computer simulations have been used to study the pedestrian crowd movement in T-junction, complementary empirical data required for model calibration and validation is limited in the literature. Specifically, the impact of 'flow directions' on the performance of pedestrian flows at T-junction is missing in the literature.

In this paper, a series of controlled experiments were conducted to study the pedestrian flows at T-junction under faster walking conditions and with two different 'flow directions'. In one setup, two inflows of pedestrians approached each other in straight (0 degree) path before merging together at 90 degree (referred as T1). In the other setup, two inflows of pedestrians approach each other at 90 degree before merging together in straight path (referred as T2). The relevant macroscopic and microscopic crowd dynamics parameters were extracted and analysed. It was observed that 'T1' was over 51% efficient in terms of outflow of the pedestrians as compared to the 'T2'. There were less short headways and more long headways at exit segment of setup 'T2' as compared to 'T1' and were statistically significant. The results from our study demonstrate that it is very important to consider the 'flow direction' when designing any public infrastructure where large number of pedestrians can be expected or for crowd control. These results are also valuable inputs for the pedestrian crowd dynamics model development and validation.

1. Introduction

Planning and designing of amenities for efficient, comfortable and safe walking in public places is a great challenge to planners seeking to create liveable communities and sustainable travel behaviour. Particularly, the movement of large numbers of pedestrians in complex built environment such as major train stations, stadiums, shopping malls and open events is important from safety and daily operations point of view. There have been numerous fatalities and serious injuries in the past around the world due to stampedes and trampling (Shiwakoti et al. 2008). As such understanding of pedestrian crowd dynamics is crucial for development of design solutions to minimise the negative consequences such as stampedes and delays to our daily activities.

There exist several simulation models and software packages for simulating pedestrian motion. Those models can be classified based on their space representation (continuous / grid based / network structure), purpose (specific purpose / general purpose), and level of detail (macroscopic / microscopic) (Shiwakoti et al., 2008, Shiwakoti et al. 2013, Duives et al., 2013). Complementary data are required to test the theoretical models quantitatively for their validity and reliability and also to compare the performance of alternative models.

However, a major shortcoming of the existing models is the lack of appropriate validation with empirical data especially with the crowd movement in major public infrastructure. Complex crowd movements like turning, merging, and crossing occur in those major public infrastructure (Shiwakoti et al., 2011a; Gorrini et al. 2013, Dias et al., 2012, Shiwakoti et. al. 2015).

A common example of complex crowd movement is at right angled junction (T-junction) where two streams of pedestrian crowd merge together. Such movement can be observed frequently in major train stations or other public infrastructure. Previous studies on documented crowd disasters have highlighted that such architectural configuration act as bottleneck and potentially lead to trampling and stampedes as people rush to escape (Chertkoff and Kushigian, 1999). However, quantitative study on the effect of T-junction to pedestrian walking operations is limited in the literature.

Tajima and Nagatani (2002) applied a lattice-gas model of biased random walkers to simulate the pedestrian merging flows in a T-shaped channel. They found that clogging can occur at either channel or both channels. In another research, cellular automata based simulation procedure was adopted by Peng and Chou (2011) and verified the congestion conformation and phase transitions at T-junction. Zhang et al. (2011) and Boltes et al. (2011) performed a series of controlled experiments with human participants in straight corridor and T-junction and established fundamental diagrams of the two geometrical layouts separately and then illustrated the discrepancies between them. Later, Craesmeyer and Schadschneider (2014) applied a floor field cellular automaton model to simulate merging crowd flows at T-junctions and found the simulation results agreed well with the experimental data provided by Zhang et al. (2011). With respect to non-human organisms approach, a series of experiments with panicking ants have been investigated in the past to explore the efficiency (in terms of outflow) and safety at turning, merging and crossing architectural features during collective dynamics (Shiwakoti et al. 2014a, Shiwakoti et al. 2014b, Dias et al. 2013). With respect to the studies on interaction angle of multiple directions pedestrian flows, Wong et al. (2010) examined an oblique intersecting angle to study bidirectional pedestrian steams and subsequently developed an improved model in Xie et al. (2013). Wu and Lu (2013) conducted a series of laboratorial experiments to derive features of weaving pedestrians and its impact on the crowd behaviour. Influence of merging angle and walking speed on pedestrian crowd behaviour was recently investigated by Shiwakoti et al. (2015). All these studies demonstrated the significance of architectural layout and the local interactions towards the efficiency and safety of pedestrian crowds in public infrastructure.

Based on literature review, there are two shortcomings in the study of crowd behaviour at T-junctions. First, existing studies have focused mainly on simulation studies and there is lack of empirical analysis that considers both macroscopic and microscopic features of crowd flow at T-junction. Second, there is no existing study that has considered the impact of ‘flow directions’ at T-junction. This study aims to analyse those two gaps via controlled laboratory walking experiments.

In the next section, we provide a description of the experiments at T-junction. Results are described and conclusions are presented including a summary of key findings and a discussion of their implications for future research.

2. Experiment

2.1 Experiment setup

The experiments were performed at an open ground in a college in Suqian (China) in 25 May 2014. A total of 70 college students (46 males and 24 females) were selected as participants for the experiment. For the experiment, two experimental setups were designed:

(i) A T- junction with two inflows of pedestrians approaching each other in straight (0 degree) path before merging together at 90 degree (Figure 1a). This setup will be referred as 'T1' throughout the paper. The dimensions of the setup are also shown.

(ii) Same T-junction as in (i) above but with different direction of inflows of participants as shown in Figure 1(b). In this setup, two inflows of pedestrians approach each other at 90 degree before merging together in straight path. This setup will be referred as 'T2' throughout the paper.

Corresponding snapshot from the experiments can be seen in Figure 1 (c & d). These experimental setups have been designed to enable us to observe the effect of 'direction of flow' in an identical T-junction layout. The 1.5 m width of the corridor was sufficient for 3 people to walk side by side and with 70 participants walking under limited space; it was enough to create a stable and congested flow situation at Level of Service (LOS) E (Highway Capacity Manual, 2010). A solid boundary material was created through the use of stable traffic barrier as shown in Figure 1 (c & d). With the height of the wall set at 1.9 m, a blocked vision condition could be created as encountered in real life situation at major public infrastructure.

2.2 Conduction of experiment

In order to create homogeneous flows, two groups of 35 participants were held separately behind a waiting line (3 m away from the entrance of each inflow corridor) before walking into the corridors. Participants were divided considering uniformity in gender and body size in two groups. Each group of participants were provided with yellow and red hats for better visualization during data extraction.

Before the start of the experiments, participants were instructed where to gather, when to start walking and where to walk. However, no information was provided to the participants regarding the research aims of the study. Few warm up walking trials were conducted to ensure that participants were comfortable in walking through the corridor and follow the instruction.

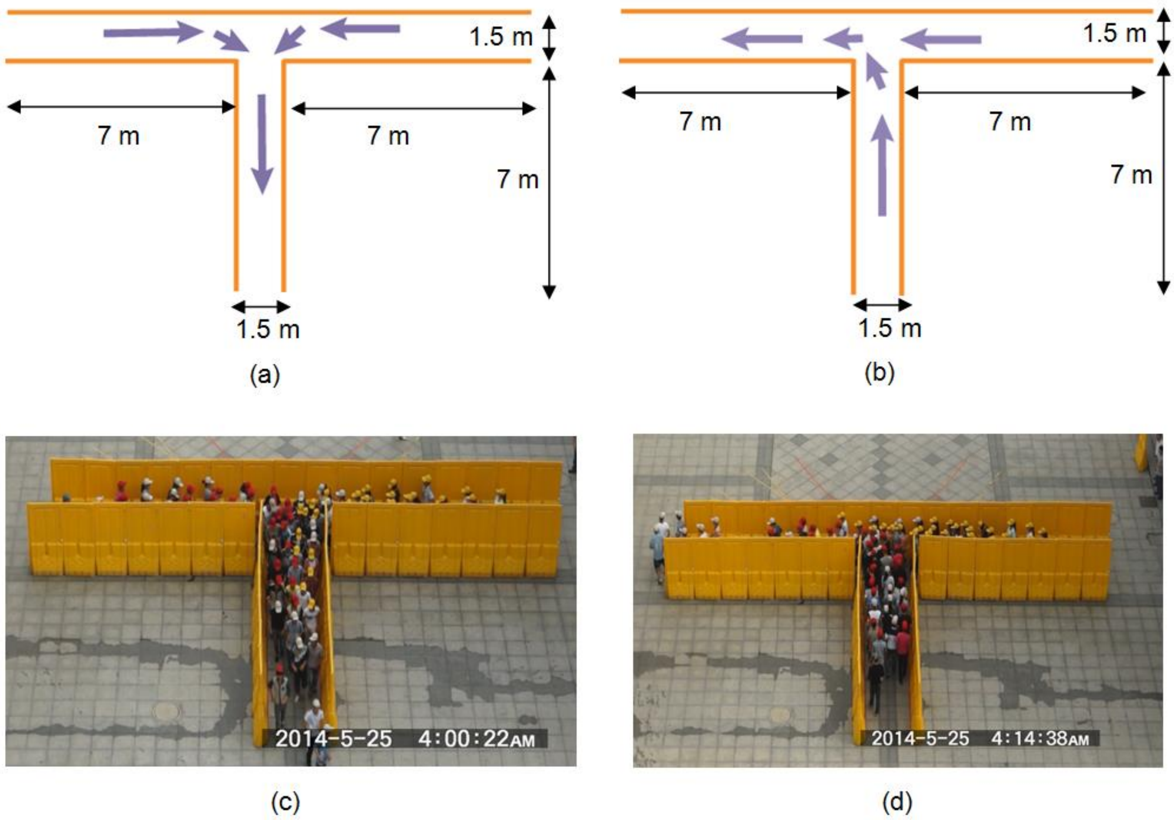
The free flow speed of each participant was measured by recording the walking time and distance in the experiment site, and the averaged speed for normal walking was $v_{nw0} =$ = 1.33 ± 0.21 m/s while slow running (or faster walking) was $v_{nw0} =$ = 2.35 ± 0.65 m/s.

Each set of experiment was repeated for three times so as to ensure adequate sample size. With two desired speed for walking operations (normal and faster walking), total of 12 experimental trials were conducted. Although higher number of repetitions may be desirable for statistical analysis; considering resource and cost constraints, three to five repetitions have been sufficient to conduct relevant analysis for laboratory walking experiments (Asano et al., 2007, Kretz 2007).

A whistle signal was used to initiate the walking and the participants returned to the waiting area for next repetition after passing through the exit corridor. To minimise the cumulative learning behaviour of participants, the position of the individuals within the group was randomly located for the next trial.

Participants were first asked to walk with their normal walking speed and the experiments were conducted for three repetitions. After that, participants were asked to walk faster (slow running) and the experiments were repeated three times similar like normal walking. While normal walking would be relevant to the congested situation in day to day pedestrian activities or special events, slow running or faster walking may be more representative when people are in hurry (as observed during peak hour in train stations) or in normal evacuation process (Daamen, 2004). The experiments were recorded via video cameras.

Figure 1: Schematic diagram showing dimensions and direction of flows in the T-junction (a & b) and corresponding snapshot from experiments (c & d)



2.3 Data extraction

Trajectories of pedestrian movements were extracted (semi-automatic) using a video tracking software named Tracker (Brown, 2014). This software has been widely used in video modeling and analysis researches. Coordinates of pedestrian's movement were extracted from the image sequences at the frame rate of 25 frames per second of recorded videos. The pixel coordinates were obtained by tracking the head of moving pedestrians frame by frame. Since the camera position was not perpendicular to the ground surface, it is necessary to convert the pixel coordinates to physical coordinates so as to obtain real world trajectories. Pixel coordinates were transformed to physical coordinates using the 2-dimensional simultaneous projective transformation method (Wolf and Dewitt, 2000).

Although some errors do occur in the coordinate transformation method, we tried to obtain reasonable accuracy for the actual and estimated coordinates (R-squared value as 0.97) which is sufficient for our analysis. The detailed procedure on coordinate transformation method has been discussed in Shiwakoti et al. (2015). Based on these trajectories, macroscopic parameters like density, flow rate, speed as well as microscopic properties such as headway could be extracted.

3. Results

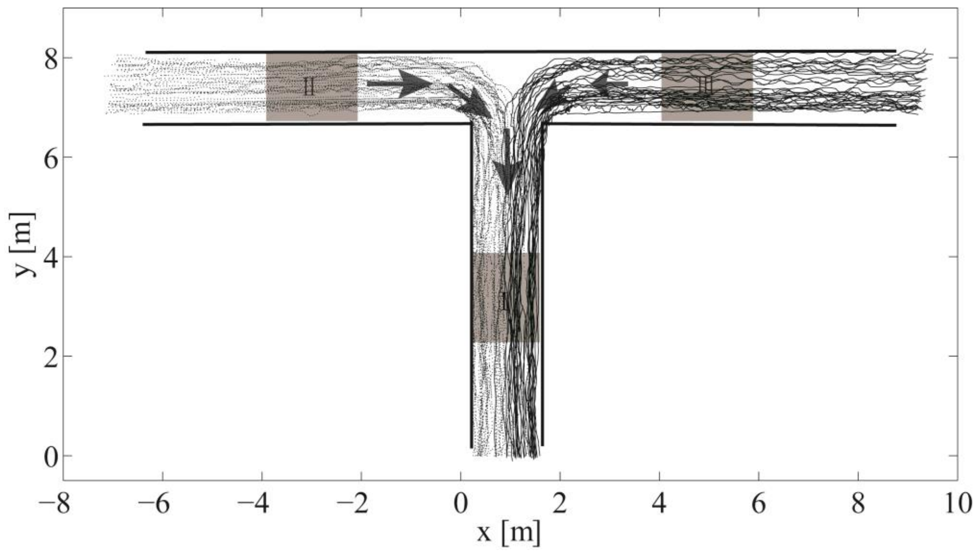
In this paper, we present only the results based on faster walking as it relates closely to the emergency evacuation. In the next section, we present the trajectory analysis followed by extraction of macroscopic and microscopic parameters.

3.1 Trajectory analysis

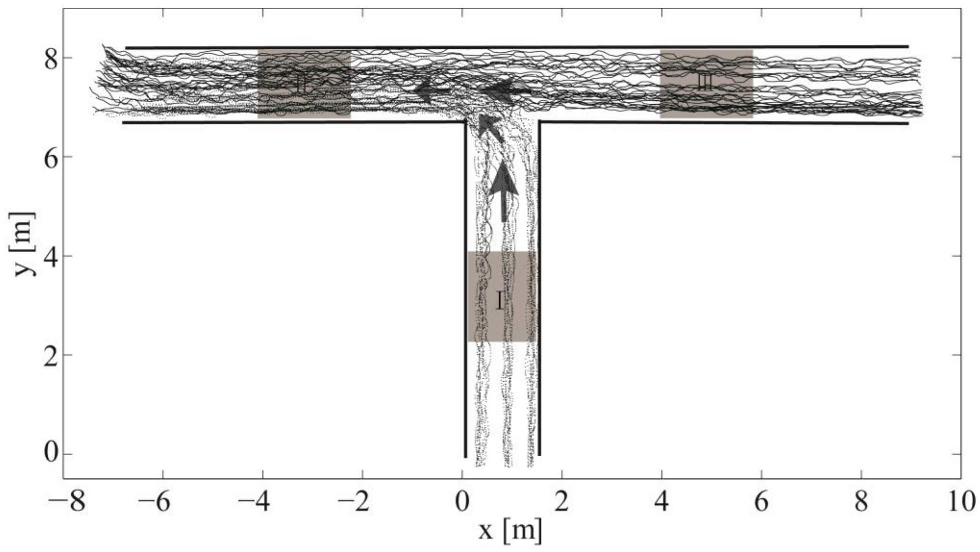
Figure 2 shows the sample of two dimensional trajectories (based on x and y coordinates).The figure also shows the rectangular measurement regions of 2 m in length (and 1.5 m width) labelled as I, II and III respectively. These regions were chosen at the middle of each corridor where the flow was stable for our microscopic and macroscopic parameters measurements.

It was observed that pedestrians try to exhibit self-organized behaviour by avoiding conflicts with other pedestrians and minimising their walking efforts when a change of direction was required. For example, for setup 'T1', when pedestrians merge, two distinct lane formations were observed (dotted line and the solid lines, Figure 1a).

Figure 2: Sample trajectory for setup T1 (a) and T2 (b)



(a)



(b)

Pedestrians tried to minimise their walking efforts and potential conflicts during the turning manoeuvre by staying close to their nearest edge (of the wall) as possible. Despite their desire to stay on their current path, local interactions occurred at the merging point (demonstrated by the mix of trajectories) which may potentially slow down the crowd movement at merging point as compared to the movement in a straight path.

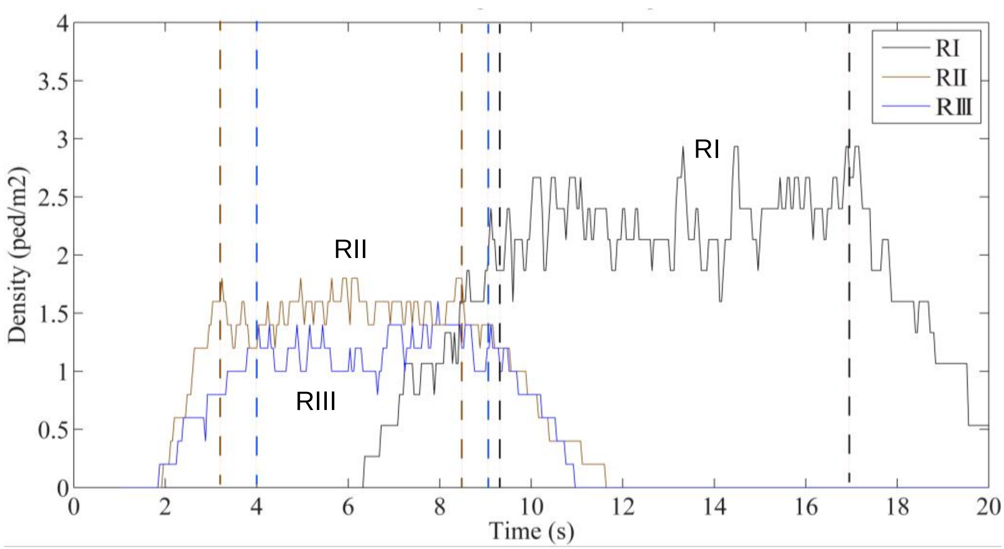
As can be seen from the Figure 2, the crowd turbulence (occurred due to mix of trajectories) at merging point is comparatively higher in the setup ‘T2’ (Figure 2b) as compared to ‘T1’ (Figure 2a) suggesting the direction of inflows may have an effect on the speed and outflow of pedestrians. This higher crowd turbulence in ‘T2’ could be potentially due to blocked vision. In case of ‘T1’, two approaching group of pedestrians can see each other and are able to adjust their speed to avoid potential conflicts before merging together. However, in case of ‘T2’, it is difficult to gauge each other movements due to blocked vision until they meet at the merging point. This abrupt need of speed adjustment at the merging point leads to more crowd turbulence in ‘T2.’

In the next section, we analyse the macroscopic and microscopic parameters to further verify this observation.

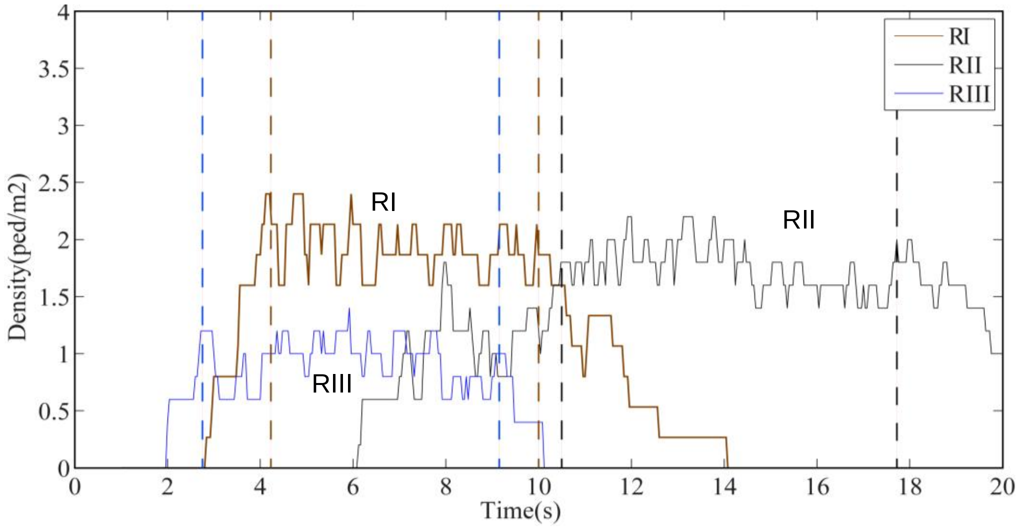
3.2 Macroscopic parameters

Macroscopic parameters of pedestrian crowds include the density, speed and flow. By processing the trajectories of the crowd, the density and speed transition in measuring regions could be obtained. Figure 3 and 4 shows the density and speed transition for ‘T1’ and ‘T2’ setups.

Figure 3: Density transition with time for setup T1 (a) and T2 (b)



(a)



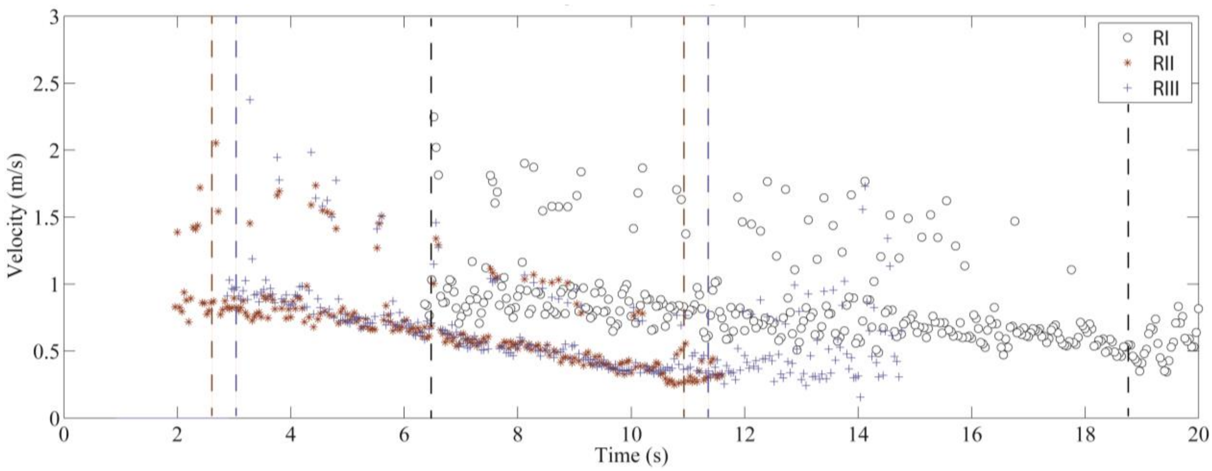
(b)

Density and speed values tend to increase from zero point (i.e. no pedestrian was in the measuring region) and then reached a relative stable level and kept that level for certain time period (i.e. the measuring time range). When all pedestrians dissipated through the measuring region, the relevant values reached zero again. In Figure 3 and 4, we captured the transitions for the three measuring regions (as defined earlier in section 3.1) with boundary of measuring regions defined by corresponding dotted line.

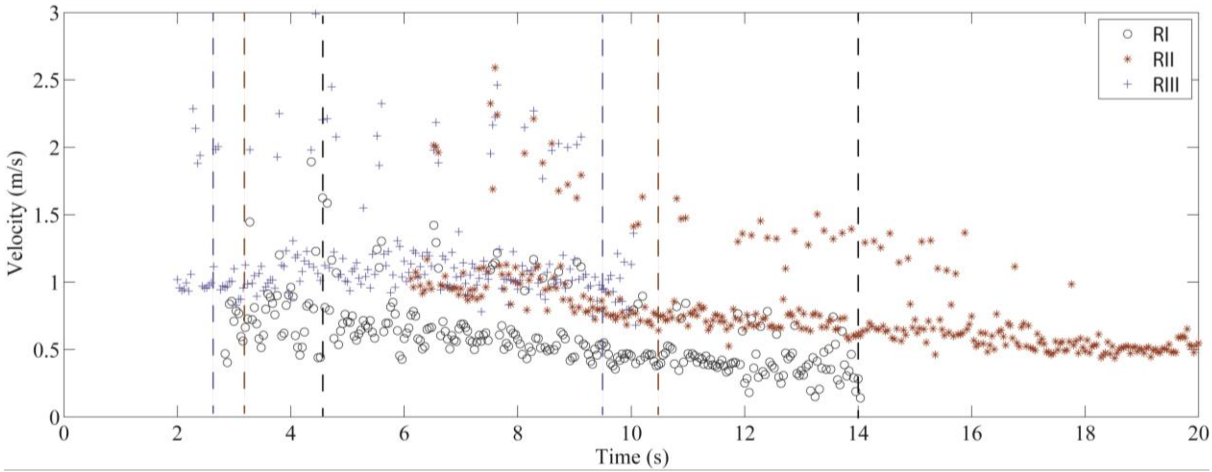
From Figure 3, it can be observed that the density transition at the downstream measurement area is efficient for 'T1' (Region I) as compared to 'T2' (Region II). Within nearly same time interval, higher density transition is being achieved in 'T1' (Figure 3a) as compared to 'T2' (Figure 3b). The lower density transition in 'T2' could be due to the relative higher crowd turbulence at merging areas as observed in the trajectory analysis.

Further as seen from the speed transition in Figure 4, the corresponding speed of pedestrians in downstream measurement area in 'T2' (Figure 4b) is lower than 'T1' (Figure 4a).

Figure 4: Speed transition with time for setup T1 (a) and T2 (b)



(a)



(b)

The mean speed, density and flow rate as observed in the three measurement regions are shown in Table 1. It is interesting to note that although the participants were instructed to walk faster (slow running), the mean speed over the measuring region is significantly less than the free flow speed observed for faster walking (v_{nw0} = = 2.35 ± 0.65 m/s, see section 2.2 above).

The low speed observed in the measuring regions may be due to the local interactions among pedestrians. As can be seen from the speed transition in Figure 4, the initial speed is quite high (around the free flow speed), but as time elapses and the group of pedestrians approaches other group of pedestrians, there is tendency to slow down to avoid potential conflicts and dangerous situations like pushing manoeuvre.

The average flow rate in the downstream of ‘T1’ is 2.28 ped/s/m while to that of ‘T2’ is 1.10 ped/s/m suggesting ‘T1’ is over 51% efficient (in terms of outflow) than ‘T2’.

Table 1: Macroscopic parameters obtained for the two experimental setups

Experimental Setup	T1			T2		
Measuring region	I*	II	III	I	II*	III
Mean density (ped/m^2) (S.D.)	2.35 (0.28)	1.53 (0.15)	1.19 (0.17)	1.62 (0.33)	1.94 (0.23)	0.92 (0.21)
Mean velocity (m/s) (S.D.)	0.97 (0.42)	0.74 (0.33)	0.93 (0.32)	0.61 (0.24)	0.57 (0.25)	1.23 (0.43)
Mean flow (ped/s/m) (S.D.)	2.28 (0.83)	1.13 (0.42)	1.11 (0.34)	0.99 (0.36)	1.10 (0.41)	1.13 (0.39)

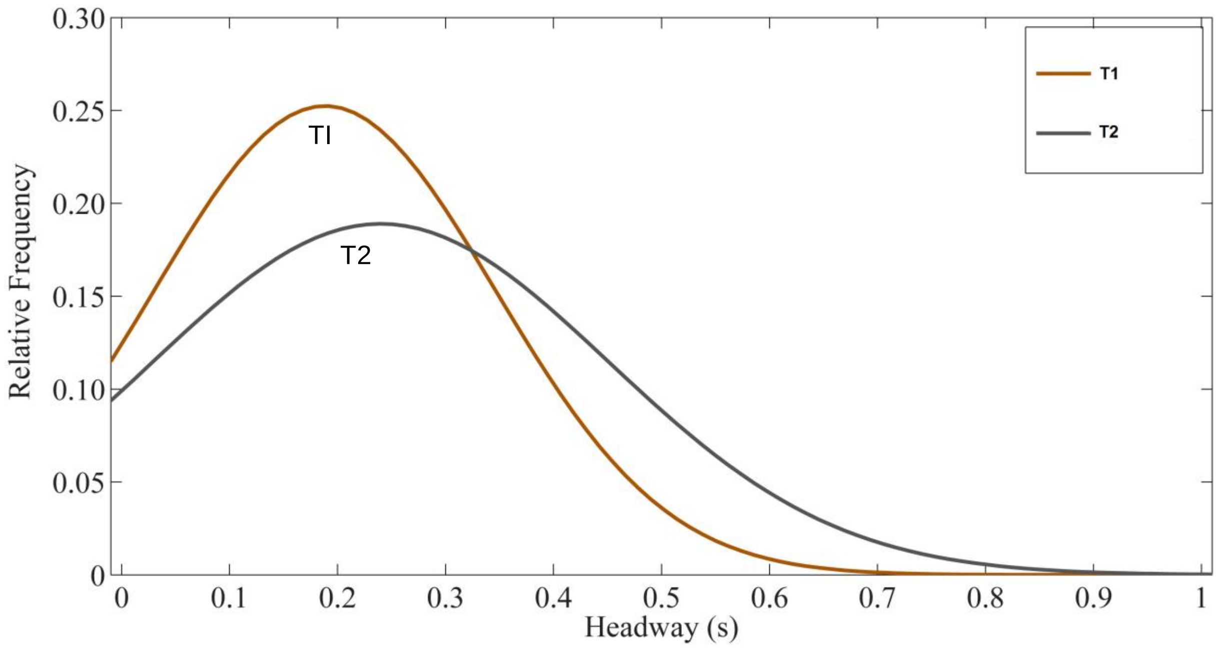
Note: “*” represent the measuring region is located in the downstream merging corridor.

3.3. Microscopic parameter

Headway distributions of exit corridor are important for the evaluation of emergency egress strategies as it reflect the time and space gap between pedestrians crowd (Shiwakoti et al, 2011b). For a given measuring downstream segment, by recording the time point when a pedestrian was passing the segment in a time series, headway distribution of pedestrian crowd could be calculated. Figure 5 shows the plot of headway and relative frequency for the two setups.

As can be observed in Figure 5, there were less short headways and more long headways at exit segment of setup ‘T2’ as compared to ‘T1’ suggesting the inefficiency of ‘T2’ in terms of outflow of the pedestrian crowd as compared to ‘T1’. The mean headway at the downstream segment for ‘T1’ and ‘T2’ were 0.19s (±0.16) and 0.24s (±0.21) respectively and were statistically significant (p-value <0.05)

Figure 5: Plot of headway and corresponding relative frequency for setup T1 and T2



4. Conclusion

T-junction forms an important component in floor plans of any major public infrastructure such as transit stations. Such architectural configuration has been identified as a critical bottleneck from documented case studies of several pedestrian's crowd disasters. However, in literature very little data exists on the efficiency of T-junction on the outflow of pedestrians and its impact on the overall efficiency and safety of the crowd movement. Specifically, the impact of 'flow directions' on the performance of pedestrian flows at T-junction is missing in the literature. This study attempted to fulfil that gap by identifying 'flow directions' as a key variable to evaluate the operation of pedestrian flows at T-junction.

In this paper, a series of controlled experiments were conducted to study the pedestrian flows at T-junction under faster walking conditions and with two different 'flow directions'. In one setup, two inflows of pedestrians approached each other in straight (0 degree) path before merging together at 90 degree (referred as T1). In the other setup, two inflows of pedestrians approach each other at 90 degree before merging together in straight path (referred as T2). The number of participants and the dimensions of the experimental corridor were same for both setups.

Although the participants were instructed to walk faster, their speed decreased as the time elapsed. This was due to the tendency of pedestrians to avoid potential conflicts and dangerous situations when approaching other pedestrians. Bottleneck created at the merging point had an effect on the outflow of the pedestrians. It was observed that 'T1' was over 51% efficient in terms of outflow of the pedestrians as compared to the 'T2'. There was less crowd turbulence in the merging area of T1 and higher density transition with respect to time was achieved.

In future studies, there are several improvements that can be followed up. One area that could be improved is to consider the diverse range of participants in the experiments. In this study we considered only the college adults. However in real world, pedestrian crowd is heterogeneous and consists of children, teenage, elderly and disabled people which may have an influence on the outflow of pedestrians.

Moreover, in this study, we conducted equal number of participants in the two inflows. However, experimental design can be developed that includes different proportion of flow (for e.g. 20:80, 40:60, 50:50, 30:70). It would be interesting to observe how the minor flow in one merging corridor has an effect on the major flow in other corridor or vice versa. Likewise, the experiment can be repeated for different corridor lengths and widths and greater number of participants to observe the sensitivity of outflow with respect to corridor and crowd size.

Nevertheless, the results from our study demonstrate that it is very important to consider the 'flow direction' when designing any public infrastructure where large number of pedestrians can be expected or for crowd control. As such, architects and planners/managers of emergency response need be made aware how small crowd movement feature in an escape area can make a big difference in terms of outflow and safety of crowd management and evacuation process. Some of the results from the experiment reported in this paper can be used in future to inform the quantitative metric for an appropriate LOS measure, or set of LOS measures. Also the efficiency obtained in terms of outflow of pedestrians from this study can be used to test pedestrian crowd simulation model's prediction.

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References

Asano, M, Kuwahara, M and Tanaka, S (2007) Multi-Directional Pedestrian Flow Model Based on Empirical Data, CD-Rom Papers of the *World Conference on Transport Research 11* Berkeley: WCTR

Brown, D (2014) Tracker V4.86. < www.cabrillo.edu/~dbrown/tracker/>, accessed on April 2015

Boltes, M, Zhang, J, Seyfried, A and Steffen, B (2011) T-junction: Experiments, trajectory collection, and analysis, pp 158-165 of Papers of the Proceedings of IEEE International Conference on Computer Vision (ICCV Workshops) Barcelona

Chertkoff, J M, Kushigian, H R (1999) *Don't panic: the psychology of emergency egress and ingress* (first ed) Connecticut: Praeger Publishers

Craesmeyer, M and Schadschneider, A (2014) Simulation of merging pedestrian streams at T-junctions *Transportation Research Procedia 2*, 406–411

Daamen, W (2004) *Modelling passenger flows in public transport facilities* Ph.D. Thesis, Delft University of Technology, Delft, the Netherlands.

Dias, C, Sarvi, M and Shiwakoti, N, and Burd, M (2012) Turning angle effect on emergency egress: experimental evidence and pedestrian crowd simulation *Transportation Research Record 2312*, 120-127

Dias, C, Sarvi, M, Shiwakoti, N, Ejtemai, O and Burd, M (2013) Investigating collective escape behaviours in complex situations *Safety Science 60,* 87–94.

Duives, D C, Daamen, W and Hoogendoorn, S P (2013) State-of-the-art crowd motion simulation models *Transportation Research Part C: Emerging Technologies 37,* 193–209.

Gorrini, A, Bandini, S, Sarvi, M, Dias, C and Shiwakoti, N (2013) An empirical study of crowd and pedestrian dynamics: the impact of different angle paths and grouping, *Papers of the Transportation Research Board Annual Meeting 92* Washington D.C.: TRB

Highway Capacity Manual (HCM) (2010). Transportation Research Board (TRB), National Research Council, Washington.

Kretz, T (2007) *Pedestrian traffic: simulation and experiments*. *PhD thesis*, University of Duisburg-Essen, Germany

Peng Y C and Chou, C I (2011) Simulation of pedestrian flow through a 'T' intersection: a multi-floor field cellular automata approach. *Computer Physics Communications 182(1),* 205–208.

Shiwakoti N, Sarvi, M and Rose, G (2008) Modelling pedestrian behavior under emergency conditions – State-of-the-art and future directions, Papers of the Australasian Transport Research Forum 31 Gold Coast : ATRF

Shiwakoti, N, Sarvi, M, Rose, G and Burd, M (2011a) Consequence of turning movements during emergency crowd egress *Transportation Research Record 2234*, 97-104

Shiwakoti, N, Sarvi, M, Rose, G and Burd, M (2011b) Animal dynamics based approach for modelling pedestrian crowd egress under panic conditions *Transportation Research Part B: Methodological 45(9),* 1433-1449.

Shiwakoti, N and Sarvi, M (2013) Understanding pedestrian crowd panic: A review on model organisms approach *Journal of Transport Geography 26*, 12-17

Shiwakoti, N, Sarvi, M, Dias, C and Burd, M (2014a) Understanding crowd panic at turning and intersection through model organisms, pp 1175-1186 of Papers of the *Pedestrian and Evacuation Dynamics 6* Switzerland: PED

Shiwakoti, N, Sarvi, M, and Burd, M (2014b) Using non-human biological entities to understand pedestrian crowd behaviour under emergency conditions *Safety Science 66, 1-8*

Shiwakoti, N, Gong, Y, Shi, X and Ye, Z (2015) Examining influence of merging architectural features on pedestrian crowd movement *Safety Science 75*, 15-22

Tajima, Y and Nagatani, T (2002) Clogging transition of pedestrian flow in T-shaped channel. *Physica A: Statistical Mechanics and its Applications 303*, 239–250

Wolf, P R and Dewitt B A (2000) *Elements of photogrammetry with applications in GIS* (3rd ed), McGraw-Hill Publishers : New York

Wong, S C, Leung, W L, Chan, S H, Lam, W H K, Yung, N H C, Liu, C Y and Zhang, P (2010) Bidirectional pedestrian stream model with oblique intersecting angle *Journal of Transportation Engineering 136(3),* 234-242.

Wu, J R and Lu, S G (2013) The features analysis and operation evaluation of pedestrian weaving zone *Transportation Research Record 2393,* 66-74

Xie, S, Wong, S, Lam, W and Chen, A (2013) Development of a bidirectional pedestrian stream model with an oblique intersecting angle *Journal of Transportation Engineering*, *139(7)*, 678-685

Zhang, J, Klingsch, W, Schadschneider, A and Seyfried, A (2011) Transitions in pedestrian fundamental diagrams of straight corridors and T-junctions *Journal of Statistical Mechanics: Theory and Experiment 6*, P06004