Engineering Analysis of Implementing Pedestrian Scramble Crossing at Traffic Junctions in Singapore

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Summary

A computational model based on the modified Discrete Element Method (DEM) was developed and utilized for computer simulations of pedestrian behaviors at simple and scramble crossing junctions in this study. The computational model was calibrated based on field observations of pedestrian behaviors at simple junctions in Singapore and good qualitative agreement between simulation results obtained from the model and these field observations was achieved. The computational model was then applied for simulations of scramble crossing to predict pedestrian behaviors that would likely be observed if scramble crossing were implemented in Singapore. There was a tendency for jamming to occur at the center of a scramble crossing junction especially if the number of pedestrians was large. Nevertheless, the time required for all pedestrians to reach diagonally opposite corners of the junction was less than twice that required for pedestrians to reach opposite ends of a simple junction. From the point of view of enhancing pedestrian flow rates, it may thus be concluded that it would likely be beneficial to implement scramble crossing at busy junctions in Singapore.

Introduction

The population of Singapore is projected to increase over the next few decades. Along with this, the numbers of vehicles and pedestrians on the road are expected to increase and so traffic congestion problems are likely to become more acute. One potential approach to improve pedestrian flow rates at large or busy junctions is to implement scramble crossing. During scramble crossing, vehicles approaching a junction from all directions stop and pedestrians are allowed to cross the junction in any direction they wish, including diagonally. Scramble crossing has been implemented in many countries throughout the world, including the United States, United Kingdom and Japan. For example, scramble crossing was implemented at one of the busiest traffic junctions in London, called the Oxford Circus, in 2009. It may also be beneficial to implement scramble crossing in Singapore. However, as pedestrians in different countries exhibit different behaviors, it is difficult to extrapolate the effects of implementing scramble crossing in other countries to predict the effects and potential benefits of implementing scramble crossing in Singapore. This deficiency in our knowledge provided the motivation for this research project. The objective of this project was thus to develop an engineering tool that could be applied to simulate pedestrian behaviors at simple and scramble crossing junctions. The simulation model developed would be calibrated according to pedestrian behaviors in Singapore so that it can be utilized to predict pedestrian flow rates and crossing time at busy junctions if scramble crossing were implemented in Singapore. The long term vision of this project is to provide decision-makers, such as the relevant authorities and government agencies, with a reliable tool that can be applied to support informed decision-making on whether scramble crossing should be implemented in Singapore.

Field Work

During the initial phase of this project, field work studies were conducted to capture video recordings of pedestrian behaviors at busy junctions in Singapore. Figure 1 shows an example of one of the video recordings captured at a junction in the Central Business District (CBD). The pedestrians were mostly office workers going for lunch or returning to their offices from lunch. Figure 2 shows the snapshots of video recordings captured at a different junction in Singapore. This was obtained at a shopping district on a weekend and so the demography of the pedestrians was different from that of the pedestrians in the previous figure. These pedestrians were generally younger and engaging in leisure activities such as shopping. In contrast to the office workers captured in the previous set of video recordings, there were many pedestrians who moved as groups because they were family members or couples. Consequently, the overall behaviors of the two groups of pedestrians shown in the two figures were observed to be different. These video recordings were used as field data against which to calibrate the simulation model developed in this study. This was in line with the objective of developing a model that would be customized to pedestrian behaviors in Singapore, and that could then be applied to predict pedestrian behaviors if scramble crossing were implemented in Singapore.

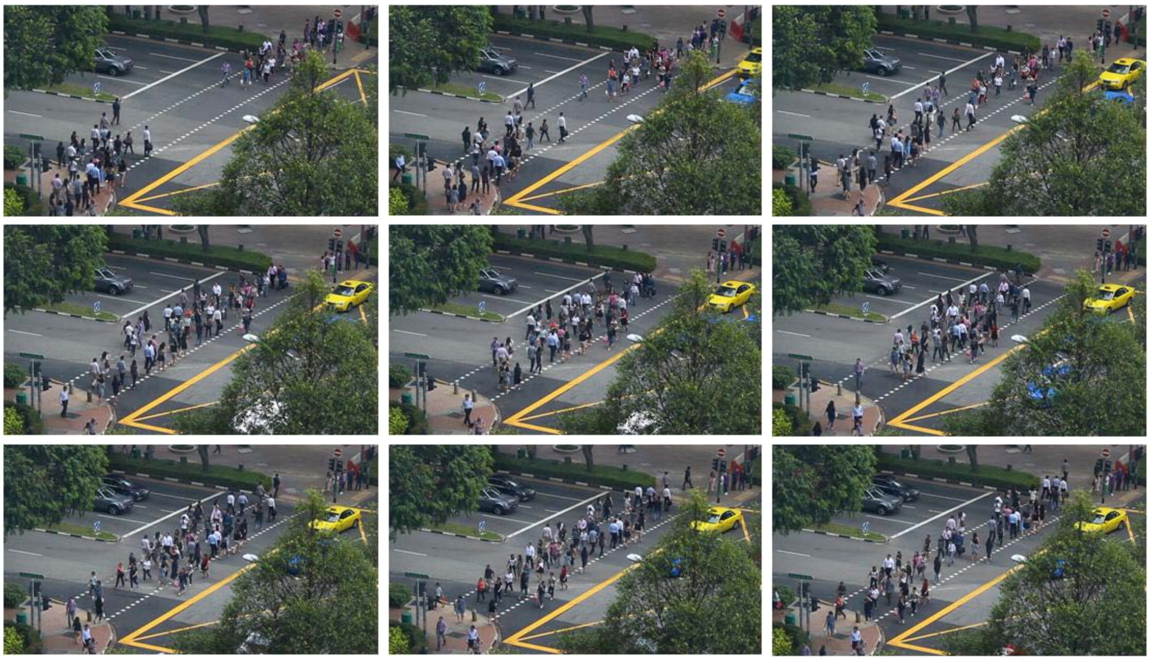

Figure 1. Snapshots of video recording showing pedestrian behavior at a busy junction in the Central Business District (CBD) of Singapore.

Figure 2. Snapshots of video recording showing pedestrian behavior at a busy junction in a shopping district of Singapore.

Simulation Model

A pedestrian flow model was developed based on a particle dynamics approach known as the Discrete Element Method (DEM) in which individual pedestrians were modeled as particles. The translational and rotational motions of individual pedestrians are governed by Newton's laws of motion:

$$m_i \frac{dv_i}{dt} = \sum_{j=1}^{N} \left(f_{c,ij} + f_{d,ij} + f_{s,ij} \right) \quad (1)$$

$$I_i \frac{d\omega_i}{dt} = \sum_{j=1}^{N} T_{ij} \quad (2)$$

where m_i and v_i are the mass and velocity of i^{th} particle respectively, N is the number of particles in contact with i^{th} particle, $f_{c,ij}$, $f_{d,ij}$ and $f_{s,ij}$ are the contact, damping and social forces respectively, I_i is the moment of inertia of i^{th} particle, ω_i is its angular velocity and T_{ij} is the torque arising from contact forces which causes the particle to rotate. A linear spring-and-dashpot model was implemented for the calculation of contact and damping forces while an inverse square law was applied for the calculation of the social force.

Results and Discussion

Several DEM simulations of pedestrians crossing a simple junction were conducted in the next phase of this study. The various parameters of the DEM model as well as operational conditions such as the number of pedestrians were varied. The objective of this phase of study was to fine-tune the parameters in the model so as to achieve good agreement between the pedestrian behaviors simulated and those observed during the field work studies. Figure 3 shows an example of pedestrian behaviors predicted by the DEM model in which two groups comprising 50 pedestrians each moved towards opposite ends of the simple junction. The arrows and color contours indicate directions of motions and magnitudes of the social force experienced by the pedestrians during crossing. It may be seen that some extent of jamming occurred near the center of the junction when the number of pedestrians was large and magnitudes of social force were generally high, indicating that some level of crowdedness or discomfort was felt by almost all pedestrians. In general, good qualitative agreement between the simulation results and field work observations was achieved. The calibrated simulation model was then applied for predictions of pedestrian behaviors at a scramble crossing junction.

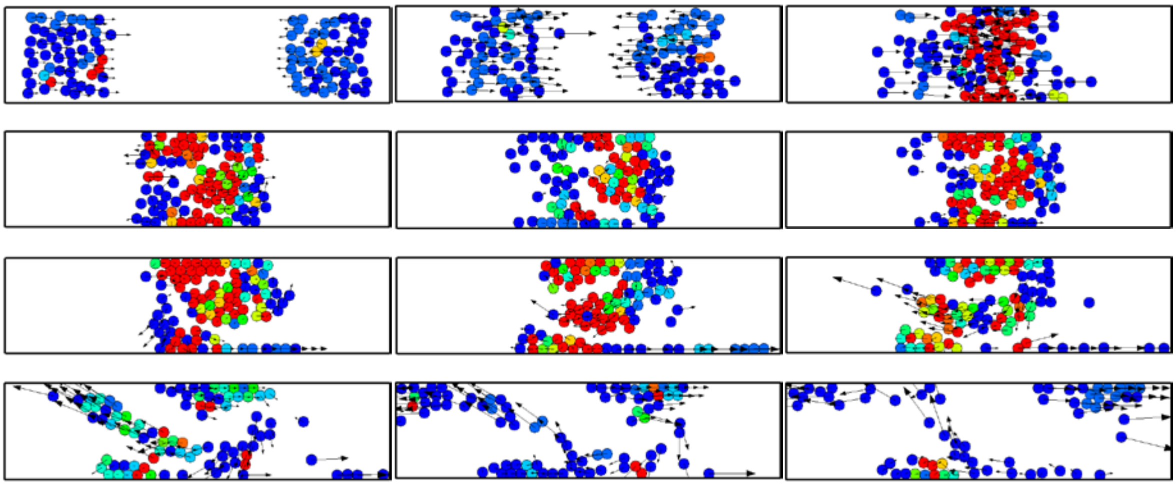

Figure 3. DEM simulation of pedestrian behavior at a simple junction. The color contours indicate the strength of the social force experienced by each pedestrian and can be interpreted to be a measure of crowdedness or level of discomfort felt during crossing.

Figure 4 shows snapshots of a DEM simulation of pedestrian behaviors during scramble crossing obtained from the calibrated simulation model. Four groups comprising 50 pedestrians each moved from the four corners of the cross junction towards their respective diagonally opposite ends of the junction. It may be seen that jamming of the pedestrians occurred near the center of the junction where the four groups converged and the high magnitudes of social force indicated fairly high levels of crowdedness or discomfort experienced by many pedestrians. The limiting factor for the total time for all pedestrians to reach their respective destinations and the junction to clear was the speed at which individual pedestrians were able to meander slowly through the pedestrian jam. This was a common phenomenon observed in all simulations of scramble crossing conducted in this study. The extent of jamming was lower, but never completely absent, in cases where the total number of pedestrians was smaller. Nevertheless, it was also observed that the time required for pedestrians to reach their destinations at the diagonally opposite corners of the junction was less than twice the time required for pedestrians to cross a simple junction, such as those shown in the previous figure. Despite the jamming phenomenon, this would imply that scramble crossing was still more efficient in allowing pedestrians to reach diagonally opposite ends of a cross junction than simple crossing. In the latter, pedestrians would have to do simple crossing twice in order to reach the diagonally opposite end of a cross junction and the time taken, based on the two types of crossing simulations conducted in this study, would be longer. From the point of view of improving pedestrian flow rates, it may thus be concluded that it would be beneficial to implement scramble crossing in Singapore.

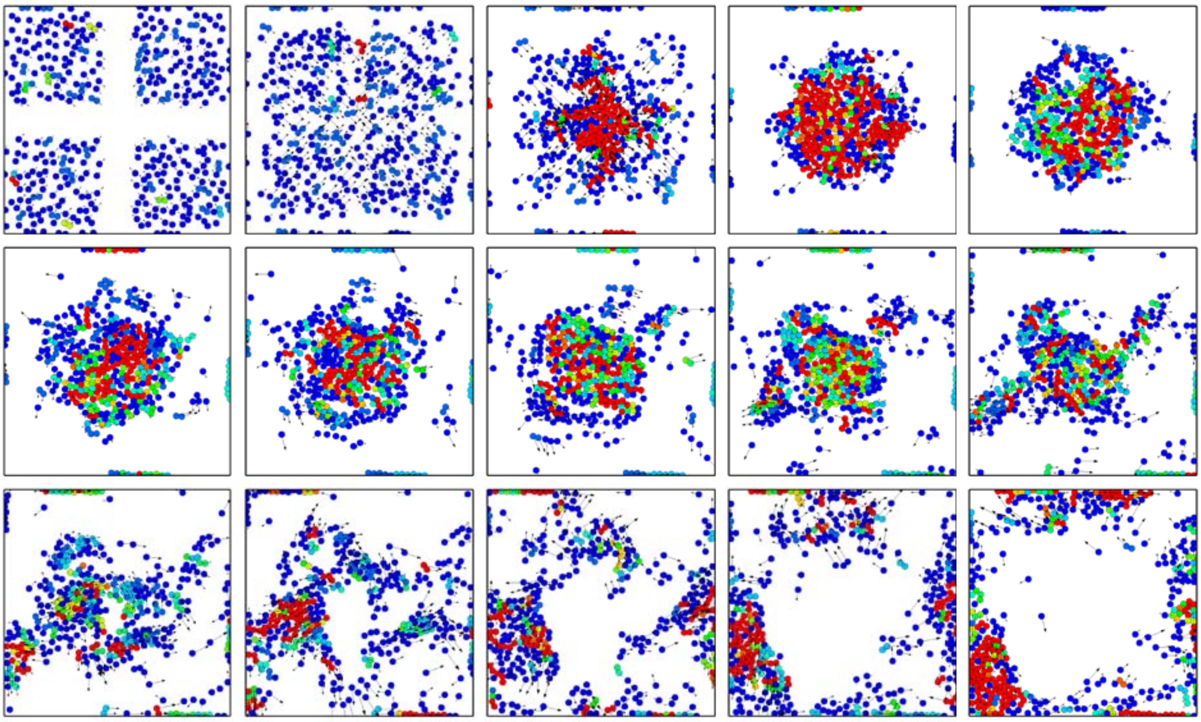

Figure 4. DEM simulation of pedestrian behavior at a scramble crossing junction where each group of pedestrians wished to reach the diagonally opposite corner of the junction. The color contours indicate the strength of the social force experienced by each pedestrian and can be interpreted to be a measure of crowdedness or level of discomfort felt during crossing.

Conclusions

The conventional Discrete Element Method (DEM) was modified by incorporating a social force model and applied for simulating pedestrian behaviors at simple and scramble crossing junctions. The simulation model was calibrated against field observations of pedestrian behaviors at different simple crossing junctions in Singapore by fine-tuning various parameters in the model and good qualitative agreement was achieved. Based on this calibrated model, simulations of scramble crossing were conducted. It was observed that jamming always occurred at the center of the junction during scramble crossing and this placed a limit on pedestrian flow rates that could be achieved. Nevertheless, the time required for pedestrians to reach diagonally opposite corners of the scramble crossing junction was less than twice that required for pedestrians to reach opposite ends of a simple junction. It could thus be concluded that it would likely be beneficial to implement scramble crossing at busy junctions in Singapore to achieve higher pedestrian flow rates. It would be pertinent to continue this study to conduct further parametric analyses of the effects of various operational conditions on crowding behaviors and crossing time for potential scramble crossing junctions in Singapore. Further research studies can also be conducted to explore possible modifications to the conventional scramble crossing practice with the objective of addressing the issue of jamming during scramble crossing. A successful resolution of this issue may potentially lead to further enhancements of pedestrian flow rates as well as level of comfort during scramble crossing at busy junctions.

Acknowledgements

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