Simulating “strategic” decisions for pedestrians’ evacuation

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Abstract

One of the main purposes of developing simulation models for indoor evacuations could be investigating the benefits various evacuation strategies that could be used for policy development and management. Here, we look at the effect of pedestrians’ reaction time variation on the evacuation efficiency. Using a relatively realistic simulation model, we investigate whether variability in the time that occupants take to make evacuation movement (i.e. waiting time) could result in a more orderly evacuation and thus less delay. Our simulated experiments did not support the idea. The simulation evidence showed that immediate response to the evacuation alert could be the most beneficial strategy as opposed to a strategy where various individuals start to evacuate at various times.

Introduction

The need for simulating evacuation process of pedestrians in crowded confined environments has been growingly appreciated given the applications that it offers for safety and disaster preparedness. The problem is highly multi-faceted and faces the major challenge of replicating the element of human behaviour in an accurate fashion in order to produce reliable estimates and thereby effective plans. For the purposes of tackling the human behaviour component, a simple categorisation of the general actions that evacuees can take (and thus, a microsimulation tool has to replicate) has been found useful and has received growing acceptance by researchers in the field. Each possible action of (a simulated) evacuee can arguably be classified under one of these three categories: (1) the decisions that they make before they initiate an escape movement (strategic decisions), (2) the decisions that determine their general evacuation path (tactical decisions); and (3) the momentary short-term (walking) decisions that they take while navigating through their chosen path (operational decisions). Despite the recognition of all three levels, it has been shown based on recent surveys that the literature has paid a noticeably imbalanced attention towards addressing these three aspects, with the higher levels of decisions (i.e. tactical and strategic) being far less understood than the lowest level (*1*). It has also been argued that the further one moves in the abovementioned hierarchy of three-level decision-making model, the more complicated the problem becomes. While walking actions are more about the physicality of the movement entailing minimum cognitive load, the upper level decisions entail more cognitive effort and thus pose more challenging phenomena to investigate.

It has however, been argued by recent studies that the simulation of upper level decisions may even have more meaningful impact on our aggregate estimates of evacuations (*2*). This calls for creating a balance in the accuracy of the evacuation prediction tools in terms of addressing these three phenomena (as opposed to fixing the walking aspect perfectly, and leaving the two other levels largely to speculation and intuition). Recent studies have attempted bridging this gap by conducting laboratory experiments and proposing tactical-level simulation models (*3*). The strategic decisions however, are yet to be adequately investigated. From prediction perspective, the most important question in relation with this level is the “reaction time” of evacuees (i.e. the decision that determines when an evacuee would choose to initiate their escape movement). Here, we work on this aspect of evacuation behaviour. In particular, we look at this aspect from an evacuation management perspective.

The idea that the rush of pedestrians towards exit routes may hinder the movement and further delay the process of evacuation has for long been circulating in the literature. In particular, the term “faster-is-slower” has been repeatedly used in this context conveying the idea that the rush of occupants during an evacuation scenario may counterintuitively be detrimental to the speed of evacuation (*4; 5*). On the other hand, however, new empirical evidence has recently emerged suggesting the idea that the notion that waiting or not rushing might be beneficial for evacuees in a crowded scenario could actually be inaccurate (*6*). As shown by a recent study, this effect could not be replicated in experimental settings (*6*).

This motivates us to look at this problem from a slightly different but relevant angle. Consider a scenario of evacuation in a crowded indoor environment. Further, consider two possible behavioural (response) scenario. Scenario 1, during which all evacuees respond to the threat in that environment and start evacuating immediately. Scenario 2, in which occupants has different response times. To further specify such scenario, we assume that while there is variability in reaction times (i.e. a probabilistic reaction time), occupants who are closer to exit points start their movement overall earlier than the occupants who are at further distance to exits at the onset of the evacuation. Is it possible that such behaviour results in a more efficient (i.e. quicker) evacuation? This is the question we investigate here, which we believe may have significant relevance to the management of evacuation processes.

Methods

To address the question raised in the previous section, we need to employ a simulation model that can replicate variability in reaction time in a probabilistic way. For this purpose, we developed a simulation model with multiple layers of modelling (i.e. operational, tactical and strategic) that can simulate various degrees of reaction time variability as part of the strategic-level modelling using various probabilistic (or econometric) methods.

The details of all layers of this simulation model would be beyond the scope of this paper, therefore, we solely focus on the simplest form of modelling reaction times. This method is based on sampling reaction times of individuals from exponential distributions (see Equation 1, for the probability density function) which is typically a suitable distribution for applications like this (i.e. duration models). In Equation 1, the parameter β is also the mean of the distribution (while the variance is β^2). As a result, the feature of "occupants closer to exits making quicker moves" can be represented through this parameter. In our specification, we define a distance R from the centre of the exit that has to be specified arbitrarily by the modeller in order to distinguish between the reaction time distribution of closer and further occupants. For the occupants whose distance to exit is less than R, we sample the reaction time from an exponential distribution with mean β_1, and for those whose distance to exit is bigger than R we sample the reaction time from an exponential distribution with mean β_2 ($\beta_2 > \beta_1$).

$$f(x) = \frac{1}{\beta} e^{\left(-\frac{1}{\beta}\right)x} \qquad (1)$$

We test the model on the physical setup shown in Figure 1. The setup consists of four rooms. At the onset of the evacuation, simulated occupants are randomly distributed in three lateral rooms. In each of the three lateral rooms, we generate 150 occupants at random positions. Therefore, in total we simulate the evacuation of 450 occupants. All occupants have to pass through the middle room in order to access the final gates in this room and thus complete their evacuation process.

We set R=2 metres and β_1=0.2 sec while changing the value of β_2 gradually (from 0 to 10). For each set of parameters (i.e. each β_2 value), we repeat the simulation procedure 50 times and calculate the average of total evacuation times and the average of average individual evacuation times over the repetitions.

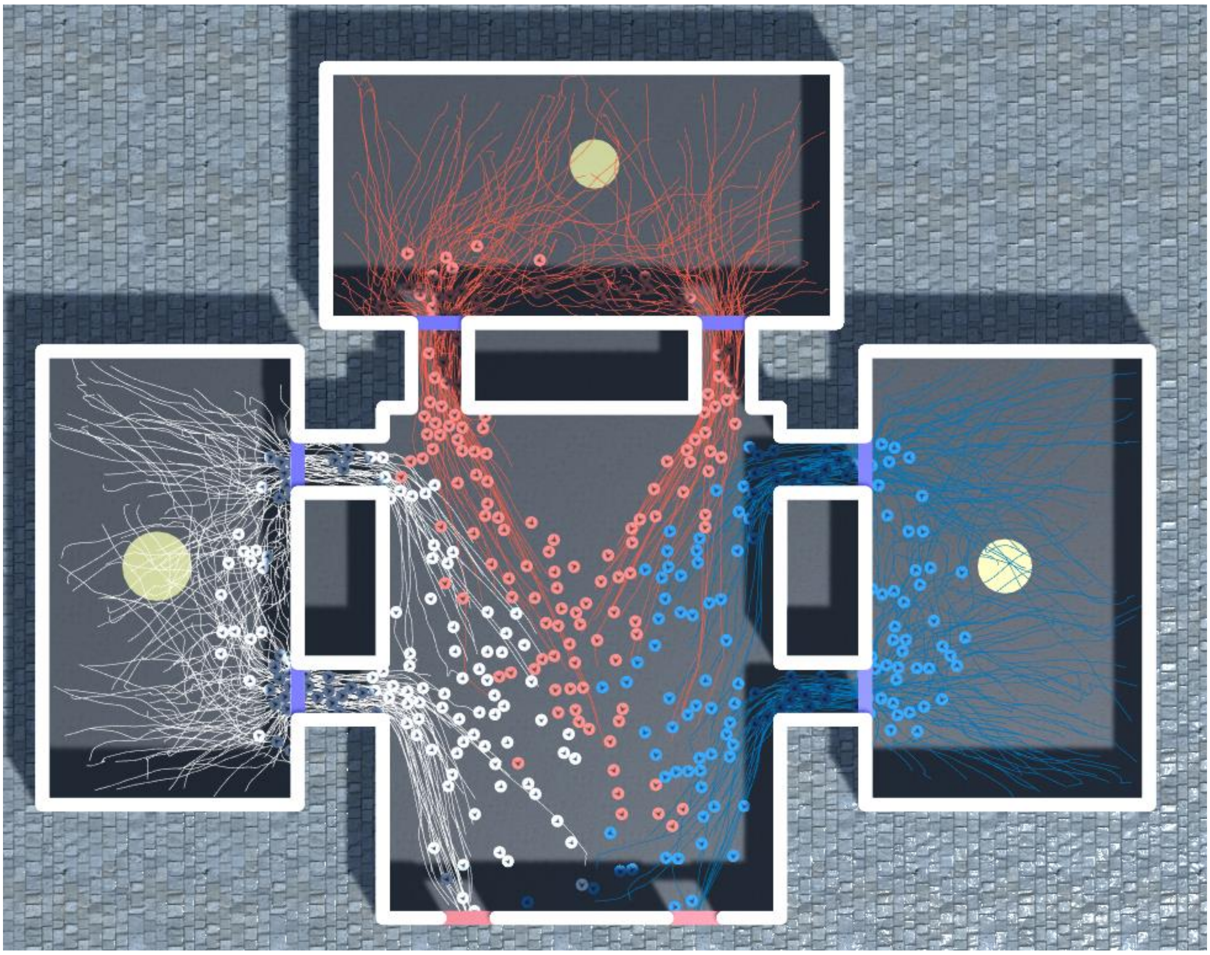
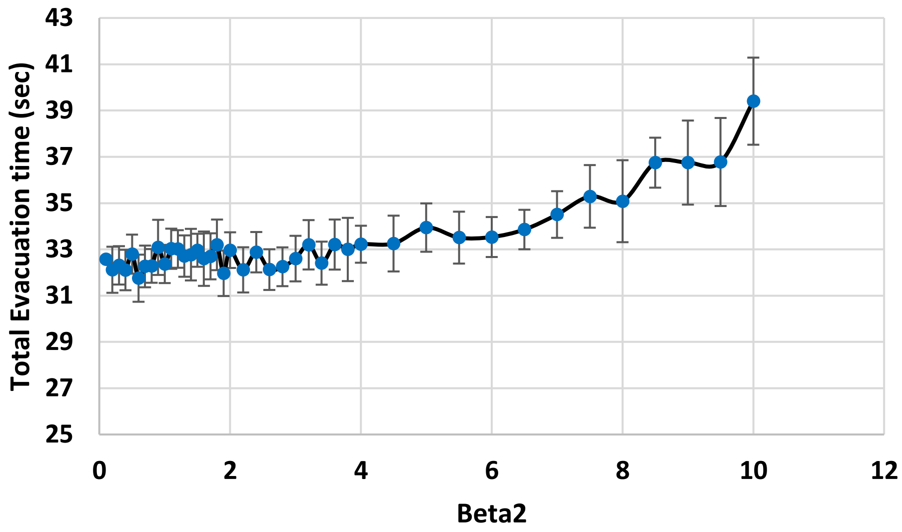


Figure 1 The physical setup used for the simulation experiments and the movement trajectory of simulated pedestrians as they evacuate the environment.

Results

For each run of the simulation, we calculated the Total Evacuation Time and Average of Individual Evacuation Times as measures of performance. We report on the variation of these two variables in response to changing the value of β_2. For Each value of the parameter, the average and standard deviation of these two variables were calculated over the 50 repetitions.

In Figure 2, we have visually presented these variations. According to these plots, both measures of performance indicate that heterogeneity in reaction time is not beneficial to the evacuation performance. As the mean of the reaction time for occupants that "far" from exit increases (while keeping the mean of reaction time for people that are "near" constant) both Total Evacuation Time and Individual Evacuation Time increases.



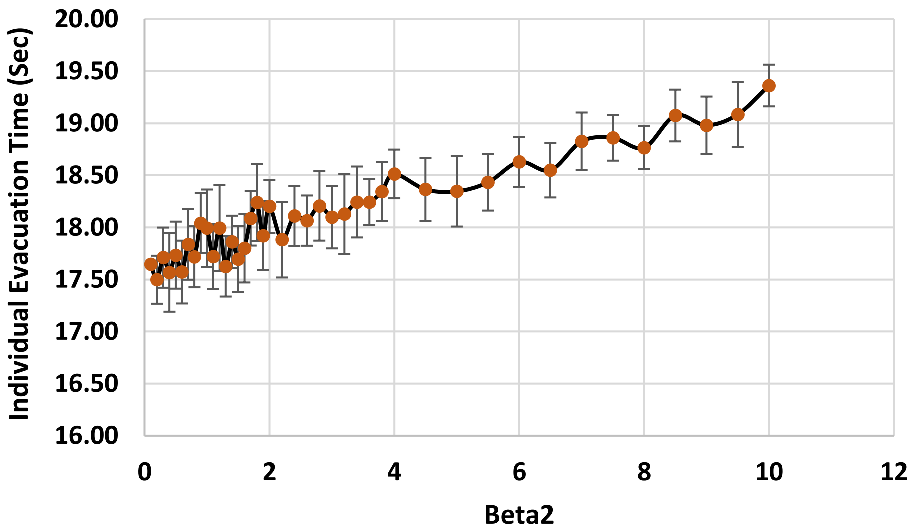


Figure 2 Variations of the Total Evacuation Time and Average Individual Evacuation Time in response to changing the value of the Mean Reaction Time (Beta2). The error bars represent the standard deviation of the simulated measurements.

Conclusions

We examined the effect of variation (or heterogeneity) in reaction time of occupants on the efficiency of the simulation process using computer simulated experiments. Our conclusion was that heterogeneity in reaction time does not benefit the process of evacuation and rather hinders it. The best strategy is for people to move immediately in order for a venue to evacuate quickly. They might experience more crowding during the process as a result of the sudden rush of occupants, but the results suggest that this accelerate the overall process of evacuation. This could be interpreted as further evidence into the inaccuracy of the idea that rushing in an evacuation scenario may backfire. As far as minimising the total evacuation time is concerned, people should not be advised to wait or slow down. This proposition, however, needs further testing under different simulated (or preferably experimental) scenarios).

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