

SFPE EUROPE



Q2 2020 ISSUE 18



AN OFFICIAL PUBLICATION OF SFPE

USE OF CROWD EVACUATION MODELS IN TIMES OF PANDEMIC

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The COVID-19 pandemic has led to dramatic changes in building usage. Governments around the world have adopted different measures to contain the spread of the SARS-CoV-2, ranging from strict lockdowns prohibiting building access to recommendations on physical distancing (also called social distancing). As countries around the world gradually re-open and restrictions are removed, building safety should be assessed in light of multiple threats, including virus transmission and fire. This paper analyzes the use of evacuation models in times of pandemic by discussing:

1. Development of new outputs for the analysis of occupant exposure
2. Needed changes in crowd evacuation models to produce such outputs and the need for re-assessing crowd movement and behaviour in times of pandemics

Need for New Crowd Modelling Outputs

Crowd evacuation models are widely used in fire safety engineering in the context of performance-based design. This involves assessment of evacuation times against a time in which untenable conditions occur. The most important evacuation time is the time corresponding to the last person reaching a safe place, namely the Required Egress Safe Time (RSET). To perform a safety assessment of a building, this information is often coupled with the analysis of emergent behaviour (e.g. congestion levels in the building, etc.). It should be noted that crowd evacuation models are based on the representation of crowd movement, and that the most used computer evacuation models in fire safety engineering are generally microscopic, i.e., models are able to represent each individual person in the simulation and track their movement in space/time.^[1] This opens up several opportunities to use crowd evacuation models to assess aspects related to pandemics, as users know the location of the occupants in the building over time during the evacuation process.

In fact, pandemics such as COVID-19 pose new safety objectives for buildings linked to the concurrent threat of spread of disease, thus ensuring that adequate fire safety design should be

achieved in parallel with minimizing the risk of infecting the evacuating population. This is translated into assessment of the distances that occupants keep during their egress and what (procedural and/or design) solutions could be adopted to ensure physical distancing prescriptions for the building are not violated. New outputs are needed from crowd evacuation models for this purpose. This includes outputs linked to the so-called proximity analysis, i.e., the assessment of occupant exposure to other building occupants in relation to their location in the building based on the physical distancing concept.

An important aspect to be considered is the need to produce metrics that can be changed over time to account for variability in virus transmission mechanisms. Research studies^[2] have suggested that SARS-CoV-2 may be transmitted similarly to SARS, namely through (1) physical contact, (2) droplets, and (3) airborne routes. Nevertheless, the research community is still debating the exact mechanisms of virus transmission among humans.^[3] Therefore, given the current uncertainty, there is no universally accepted metric to quantify occupant exposure. Crowd evacuation models should therefore be ready to consider different mechanisms of transmission and embed enough flexibility to provide different outputs in relation to assumptions adopted for occupant exposure.

A recent attempt to address this issue has been performed. It relates to an occupant exposure sub-model called EXPOSED^[4] that was developed to retrofit existing microscopic crowd models regardless of the virus transmission mechanism assumption. EXPOSED generates a set of metrics on occupant exposure based on the simulated movement trajectories of people.

Re-assessing Crowd Movement and Behaviour

Crowd evacuation models are generally based on assumptions regarding crowd movement and behaviour that are based on data collected without any ongoing pandemic. Therefore, an application of a model to assess occupant exposure (e.g. performing proximity analysis assessing physical distancing) may lead to misleading results if the user does not carefully evaluate the evacuation model inputs and modelling assumptions. In particular, the underlying algorithms of crowd evacuation models may not be explicitly designed to account for changes in movement and behaviour driven by the fear of virus transmission. Two examples can be used to explain this issue.

One example is route choice, which is often solved by evacuation models with optimization algorithms aimed at minimising evacuation times or based on shortest-distance criteria.^[5] The second issue is that a crowd might behave differently during a pandemic, and people may attempt to keep larger physical distances than usual. In other words, the whole process of queuing might be different, as people may (or not) tend to keep larger distances. This change in behaviour might affect the relationships between the fundamental variables driving occupant movement (e.g. speed/flow and density) and lead to the need to re-evaluate the underlying assumptions adopted by models as the expected change in behaviour may lead to longer evacuation times. In fact, achievable density levels will directly be affected by physical distancing.

An example of a hypothetical change in the speed-density and flow-density relationships in a corridor (adopting as benchmark the curve calculated using the hand-calculations method presented in the SFPE handbook^[6]) is provided in Figure 1 under the assumption of uniform packing (see Figure 2); 1 or 2 m (3.3 or 6.56 ft) physical distancing; and a linear trend (i.e. max density of 1 pers/m²).

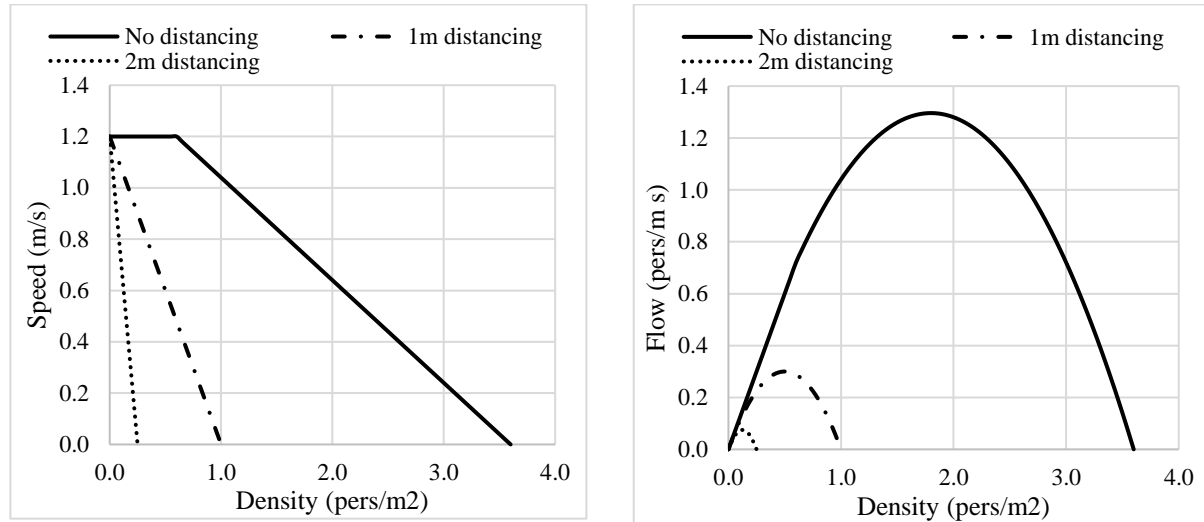


Figure 1. Example of Change in Speed-Density Relationship from Current SFPE Curve (solid line) in a Corridor to Hypothetical Relationships (dashed) during a Pandemic

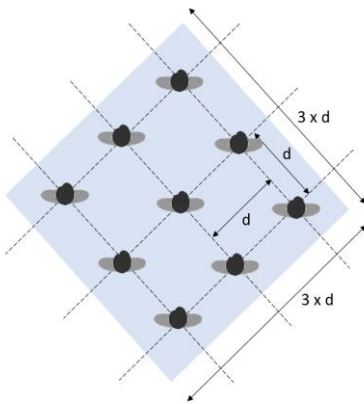


Figure 2. Hypothetical Uniform Distribution of Pedestrians Keeping Physical Distance for Density Calculations

These are hypothetical relationships, which should be revised in line with three different issues:

1. The speed might be kept unimpeded until the same value of density adopted in the SFPE hand-calculations method (e.g., 0.54 pers/m² in a corridor) decreases linearly from the value of unimpeded speed or starts decreasing from a given intermediate value.

2. The actual packing of people might not correspond to the prescribed physical distance, i.e. people might need a higher physical distance prescription to keep the desired physical distance.
3. Groups (e.g. family, friends) might not keep the physical distance, thus affecting the maximum density in a given area.

Figure 3 shows how maximum density may vary in accordance to the physical distance kept by people under the uniform pedestrian packing assumed in Figure 2. This will subsequently affect the fundamental relationships between speed/flow and density, with a likely reduction of flow and subsequent longer evacuation times. All those assumptions are currently hypothetical and need to be investigated, i.e., pedestrian packing, collision avoidance, speed-density, and flow-density relationships during a pandemic should be obtained from real world data.

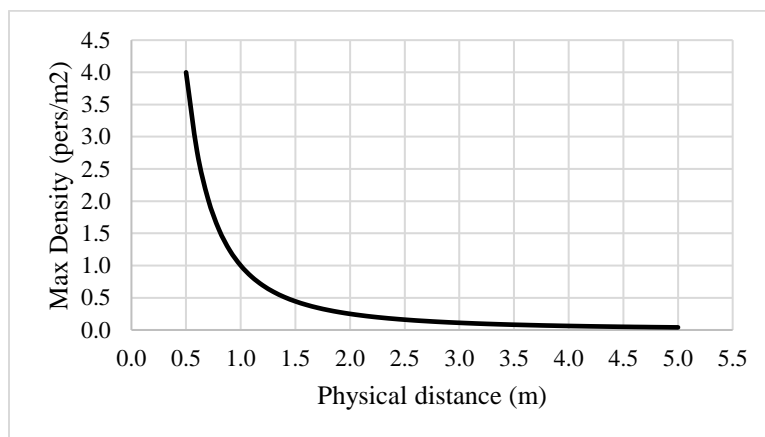


Figure 3. Relationship between Maximum Density and Physical Distance Kept by People under Assumed Hypothetical Packing.

As in fire scenarios, crowd movement and behaviour will be affected by risk perception.^[7] A model user should therefore define the inputs in light of the population under consideration, the phase of the pandemic, and the information provided to the occupants. Crowd evacuation model inputs and assumptions may be revised depending on the modelling approach adopted, for example, a social force, a comfort distance, or the opportunity to customize the fundamental relationships between flows, speeds and density, etc.^[5] As crowd evacuation models were not originally designed for this type of behaviour and movement, a user would have to always check that the implemented inputs would produce the expected behaviour. This analysis is needed to reproduce credible movement and behavioural scenarios until more data are collected and implemented in evacuation models.

Summary

In times of pandemic, a safety analysis should not focus on assessing each individual threat in isolation. This is important as physical distancing might impact evacuation given lower flows and longer associated egress times. It is therefore necessary to identify tools able to analyse the impact of concurrent threats, such as virus transmission and fires. The potential use of crowd evacuation models for the assessment of occupant exposure during a pandemic has been

presented along with the issues associated with input calibration. An example of a sub-model called EXPOSED, which is available to retrofit crowd evacuation models, has been presented. Further information on the metrics produced by the model and its potential uses for proximity analysis are provided in the full article associated with this work.^[4] Future studies could investigate the full coupling of crowd movement models and epidemiological models to perform an even more accurate assessment of transmission risk.^[8]

References

- [1] R. Lovreglio, E. Ronchi, and M. J. Kinsey. "An Online Survey of Pedestrian Evacuation Model Usage and Users," *Fire Technology*, November 2019, doi: 10.1007/s10694-019-00923-8.
- [2] I. T. Yu *et al.* "Evidence of airborne transmission of the severe acute respiratory syndrome virus," *New England Journal of Medicine*, Vol. 350, No. 17, pp. 1731–1739, 2004.
- [3] D. Lewis. "Is the coronavirus airborne? Experts can't agree," *Nature*, Vol. 580, No. 7802, pp. 175–175, April 2020, doi: 10.1038/d41586-020-00974-w.
- [4] E. Ronchi and R. Lovreglio. "EXPOSED: An occupant exposure model for confined spaces to retrofit crowd models during a pandemic," *Safety Science*, doi: 10.1016/j.ssci.2020.104834.
- [5] E. Ronchi. "Developing and validating evacuation models for fire safety engineering," *Fire Safety Journal*, 2020.
- [6] S. M. V. Gwynne and E. R. Rosenbaum. "Employing the Hydraulic Model in Assessing Emergency Movement," *SFPE Handbook of Fire Protection Engineering*, M. J. Hurley, D. T. Gottuk, J. R. Hall, K. Harada, E. D. Kuligowski, M. Puchovsky, J. L. Torero, J. M. Watts, and C. J. Wieczorek, Eds. New York, NY: Springer New York, 2016, pp. 2115–2151.
- [7] R. Lovreglio, E. Ronchi, and D. Nilsson. "An Evacuation Decision Model based on perceived risk, social influence and behavioural uncertainty," *Simulation Modeling Practice and Theory*, Vol. 66, pp. 226–242, August 2016, doi: 10.1016/j.simpat.2016.03.006.
- [8] L. Goscé, D. A. Barton, and A. Johansson. "Analytical modelling of the spread of disease in confined and crowded spaces," *Science Report*, Vol. 4, p. 4856, 2014.

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