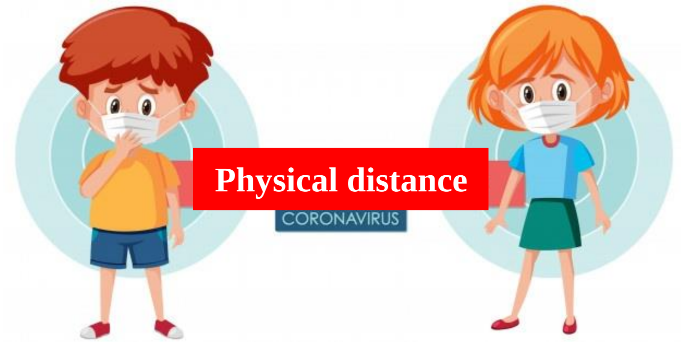
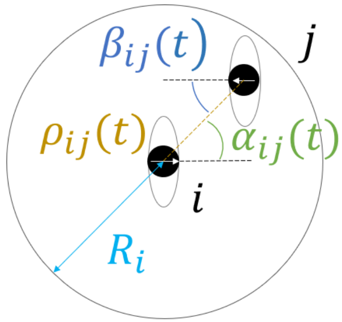
Fire and Evacuation Modelling Technical Conference
FEMTC2020
September 9-11, 2020, online



Evacuation modelling and Covid-19



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Sponsor and collaborators

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Outline

- Evacuation and COVID-19
- The implications of physical distancing
- Proximity analysis vs exposure assessment during evacuation
- The EXPOSED model
- A methodology for evacuation model usage

Evacuation and COVID-19

Dealing with concurrent threats

- **Pandemic** affects crowd dynamics
- Still **scarce empirical research** available (first crowd movement data soon coming) but so far only in **normal** situations
- Other threats (e.g. fire) do not **“disappear”**
- Evacuation models can be of great help to analyse **concurrent threats** (Covid-19+fire)

The implications of physical distancing

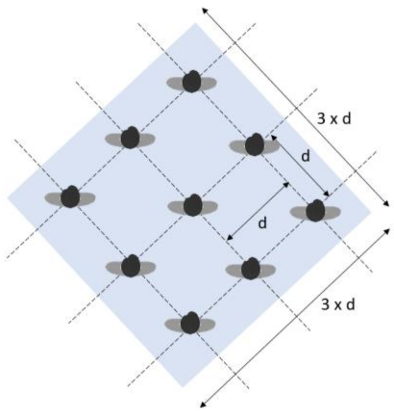
Physical distancing: psychological implications

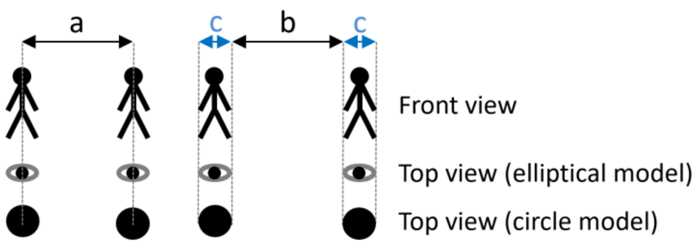
- **Self-organization** mechanisms of crowds change as perception of others change
- Evacuation modellers can look at the field of **proxemics**
- **Personal space** (PS) → buffer zone, others are now seen as intruders
- Limitation → PS looks mostly at individuals rather than **collective groups** → Social Identity Theory (Tajfel & Turner, 2004) can help interpretation

The implications of physical distancing

Physical distancing: physical implications

Change of **space usage**





- Different assumptions for **occupant load** in evacuation scenarios

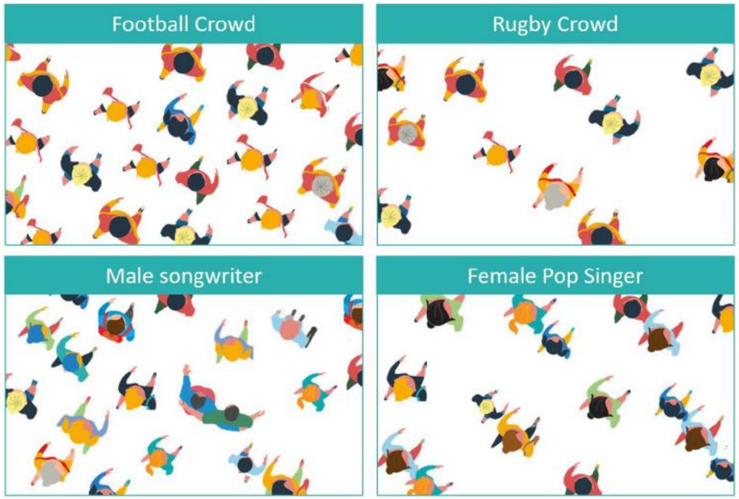
(physical distancing provisions are prone to interpretation)

The implications of physical distancing

Physical distancing: physical implications

- **Fundamental** speed/flow vs density **relationship** may depend on:
  - Assumptions on **unimpeded speed** (comparable to SFPE hydraulic model, e.g. decrease starts at 0.54 pers/m2 in a corridor?)
  - To which extent people **comply** to physical distance recommendations

  - Nature of **groups** and their dynamics →

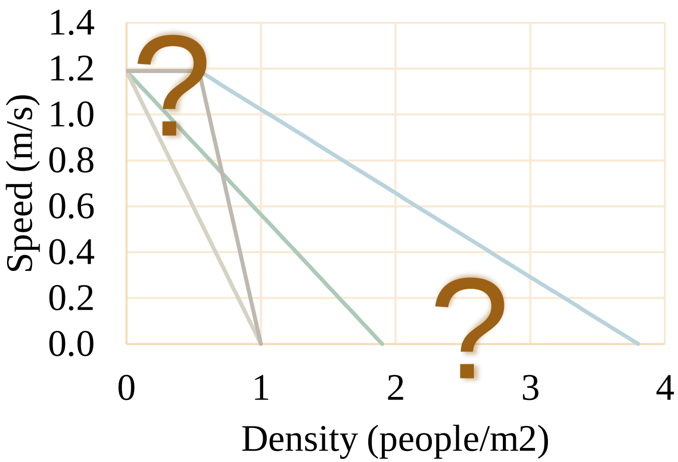


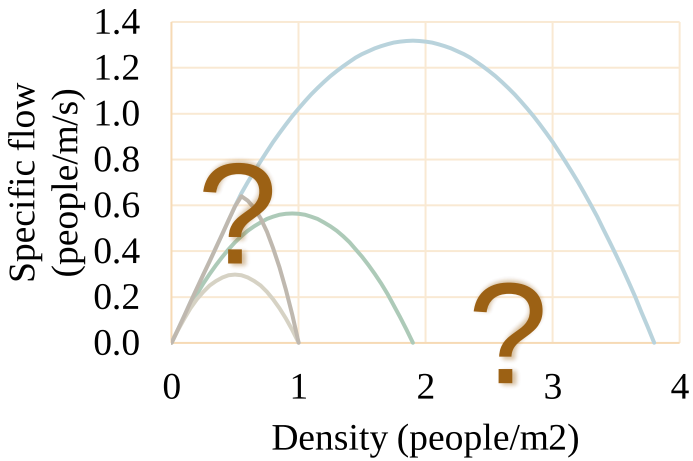
Larsson et al, 2020

The implications of physical distancing

Physical distancing: physical implications

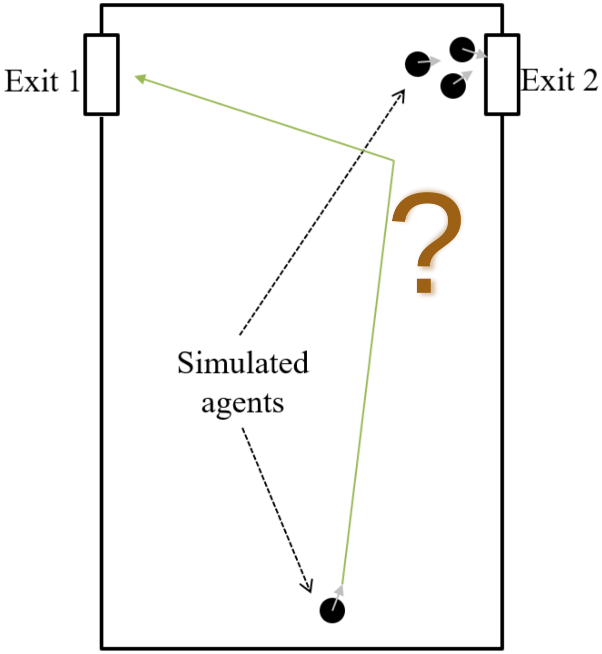
- **Fundamental** speed/flow vs density **relationship** possible changes → Examples





The implications of physical distancing

Physical distancing: physical implications



Route choice and **collision avoidance** changes

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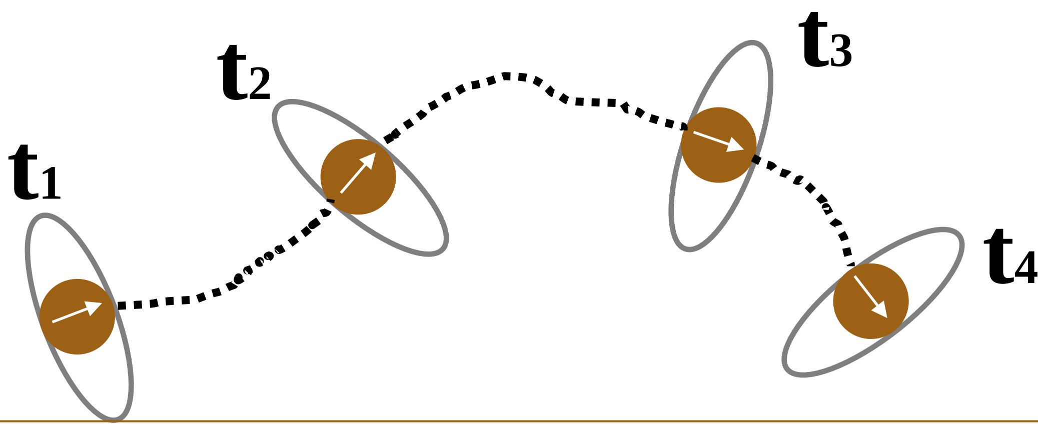
Proximity analysis vs exposure assessment

Evacuation models generally provide the information concerning the **location** of people in space during the passage of time (e.g. parametric equations of movement)

For each simulated evacuees, 2D (or 3D) **coordinates** are available at each time

x,y,(z),t



Proximity analysis vs exposure assessment

Two approaches

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NEWS

Is the coronavirus airborne? Experts can't agree

The World Health Organization says the evidence is not compelling, but scientists warn that gathering sufficient data could take years and cost lives.

- Ongoing debate on mechanisms of virus transmission

Proximity analysis

Assumption that risk increases with proximity

Exposure assessment

Risk does not depend only on distance criteria

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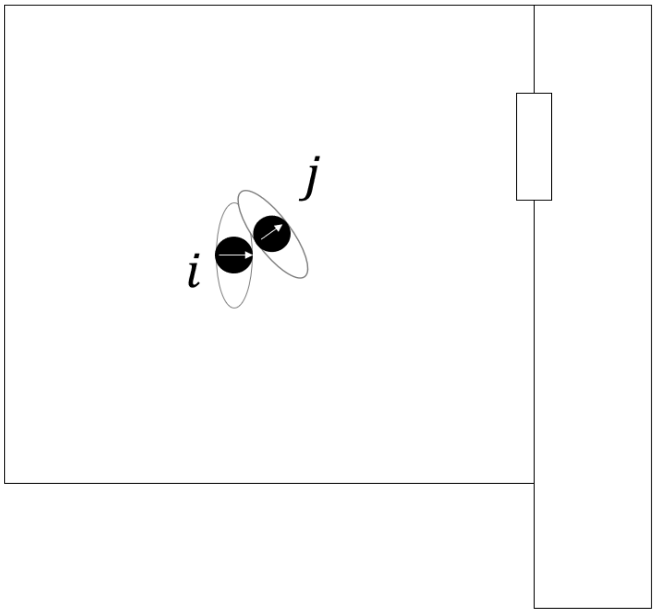
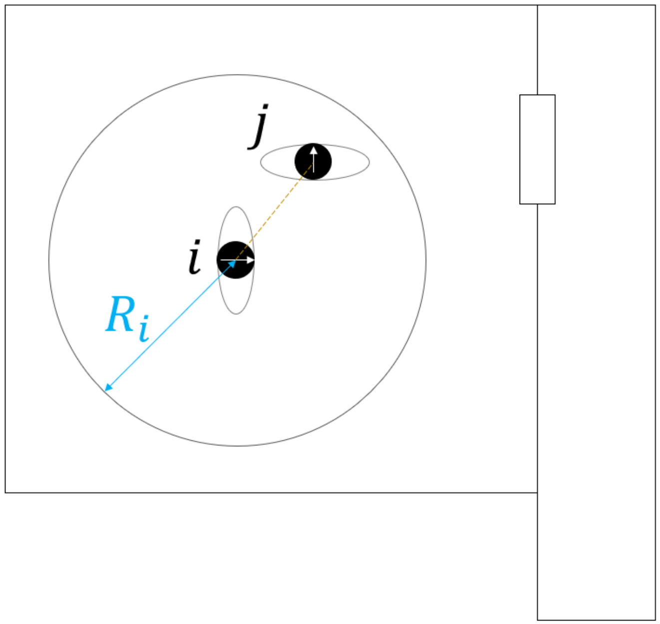
Proximity analysis vs exposure assessment

Examples of exposure/proximity

Physical contact



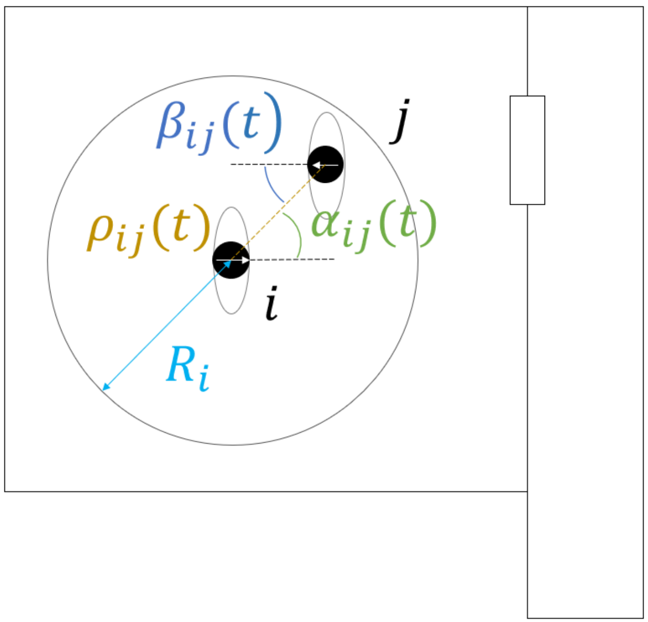
Physical distance radius



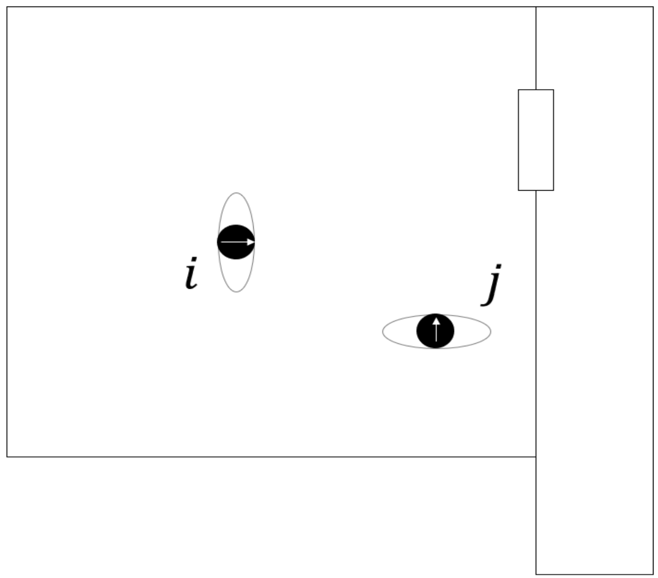
Proximity analysis vs exposure assessment

Examples of exposure/proximity

«face-to-face» contact
in a physical distance radius

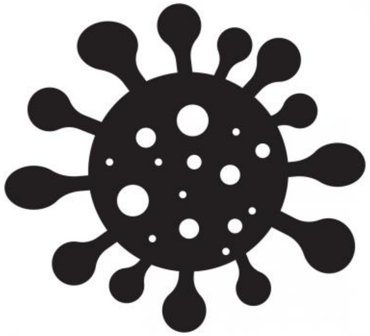


Same room or building



Proximity analysis vs exposure assessment

Why exposure assessment?

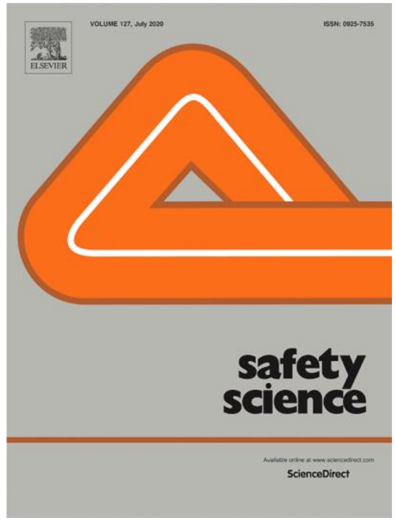


- Evacuation models have started implementing **sub-models** to represent or measure physical distancing → mostly focusing on **proximity analysis**
- Recommendations on **physical distancing change** between countries and between phases of the pandemics.
- Still **uncertainty** on the exact mechanisms of SARS-CoV-2 virus transmission

The EXPOSED model

An occupant exposure model for confined spaces → **EXPOSED**

Published in *Safety Science*, ”*EXPOSED: An occupant exposure model for confined spaces to retrofit crowd models during a pandemic*” by Ronchi E, Lovreglio R.



- Simple sub-model, designed to **retrofit** any crowd evacuation models
- It works with **any exposure assumption**

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The EXPOSED model

Every simulated agent *i* in the model is potentially **exposed** to a given number of people in every time-step

This information can be represented as a set including the **number of people** to which each individual is exposed to at a given time interval

$$\boldsymbol{E^i} = \left\{e_{t0}, e_{t1}, \dots, e_{tq}, \dots, e_{tf}\right\} \quad \forall\, i$$

Where e_{tq} is the k number of people j to which each person i *is* exposed at a given time interval t_q

The EXPOSED model

Considering the exposure of each individual person within a given scenario, we can represent this information with a matrix $\boldsymbol{E_t^i}$

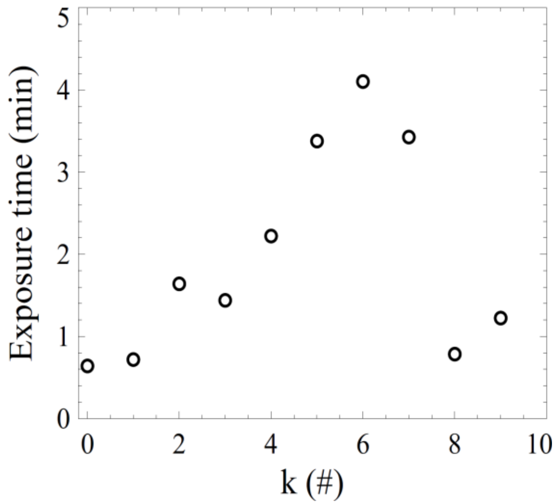
$$\boldsymbol{E_t^i} = \begin{pmatrix} E^1 \\ \vdots \\ E^i \\ \vdots \\ E^n \end{pmatrix} = \begin{pmatrix} \mathrm{e}_{\mathrm{t0}}^{1} & \cdots & \mathrm{e}_{\mathrm{tq}}^{1} & \cdots & \mathrm{e}_{\mathrm{tf}}^{1} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \mathrm{e}_{\mathrm{t0}}^{\boldsymbol{i}} & \cdots & \mathrm{e}_{\mathrm{tq}}^{\boldsymbol{i}} & \cdots & \mathrm{e}_{\mathrm{tf}}^{\boldsymbol{i}} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \mathrm{e}_{\mathrm{t0}}^{\boldsymbol{n}} & \cdots & \mathrm{e}_{\mathrm{tq}}^{\boldsymbol{n}} & \cdots & \mathrm{e}_{\mathrm{tf}}^{\boldsymbol{n}} \end{pmatrix}$$

The EXPOSED model

It is possible to obtain information concerning the time T_k^i to which an individual *i* is exposed to a given number of people *k*. This represents the time of exposure of each individual person to 0 persons, 1 person, … *m=n-1* persons).

$$T_k^i = \sum_{t_0}^{t_f} t_q^i \ \forall\, i, k$$

Example considering 10 people

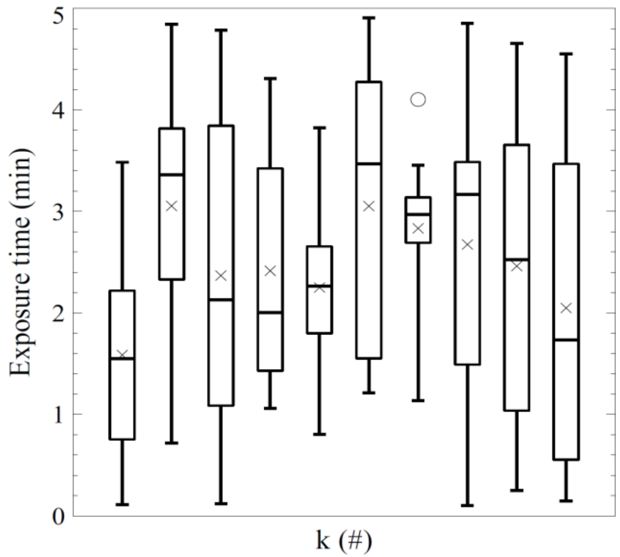


The EXPOSED model

Considering the total time t_f spent by people in a given space, we can obtain a set of distributions T_k of exposure times which correspond to a given number of people $k \geq 0$

$$T_k \ (\mu_k, \sigma_k^2)$$

Example considering 10 people



We can therefore obtain for example:

1) Max number of agents that people are exposed at the same time
2) The longer exposure time to each given number of agents
3) The average and variance of exposure times to a given number of agents

The EXPOSED model

The sum over the data-points available for each of the exposure values to a given number of people allows us to obtain a **cumulative exposure** measure C_k to a given number of people k. The case $k=0$ corresponds to the time in which agents were exposed to nobody else C_0 (the higher this value, the better it is).

$$C_k = \sum_{i=1}^{n} T_k^i$$

The sum of all C_k (normalized as a function of the number of people to which you are exposed to and/or other variables such as mask use) with $k > 0$ allows to perform a **global evaluation** of exposure G in a given space

$$G = \sum_{k=1}^{m} \gamma_k \, C_k$$

Potential issue

Need to ”discount” groups?

A methodology for evacuation model usage

Workflow for combined use of evacuation model and exposure assessment model

- *Step 1* — Definition of crowd movement scenarios
- *Step 2* — Simulation of people movement with a crowd model
- *Step 3* — User's choice of modelling assumption(s) on occupant exposure
- *Step 4* — Obtainment of outputs from crowd model of each agent i based on the chosen assumption(s)
- *Step 5* — Calculation of time each agent i has been exposed to a given number of occupants k
- *Step 6* — Calculation of a set of distributions T_k (μ_k, σ_k^2) of exposure times corresponding to a given discrete number of agents $k \geq 0$ and associated metrics
- *Step 7* — Calculation of cumulative exposure C_k to a given number of people
- *Step 8* — Calculation of global assessment of occupant exposure G
- *Step 9* — Risk assessment on building usage based on occupant exposure metrics

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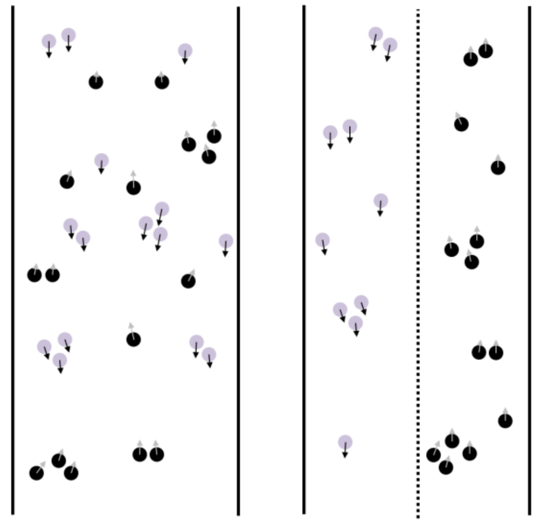
A methodology for evacuation model usage

The use of exposure assessment model outputs together with evacuation models

- Evaluation of **design solutions** (geometric layout, temporary obstacles) to minimize exposure → how does this affect evacuation?
- Evaluation of **crowd management** solutions which consider both fire evacuation times and occupant exposure



Conclusions

- Crowd dynamics field under the **spotlight**
- Crowd movement and behaviour **change** due to pandemic → we need to re-evaluate evacuation model assumptions (e.g. fundamental relationships, route choice, individual/group behaviour)
- Until data on crowd dynamics during COVID-19 are available, **conservative** assumptions are needed
- Proximity analysis and exposure assessment can be **combined** with fire safety engineering to evaluate concurrent threats

THANK YOU!

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References

- Larsson, Anna, Elin Ranudd, Enrico Ronchi, Aoife Hunt, and Steve Gwynne. “The Impact of Crowd Composition on Egress Performance.” *Fire Safety Journal*, May 2020, 103040. https://doi.org/10.1016/j.firesaf.2020.103040.
- Ronchi, Enrico, Ruggiero Lovreglio, Rugiada Scozzari, and Michele Fronterrè. “Use of Crowd Evacuation Models in Times of Pandemic.” *SFPE European Magazine*, 2020.
- Ronchi, Enrico, and Ruggiero Lovreglio. “EXPOSED: An Occupant Exposure Model for Confined Spaces to Retrofit Crowd Models during a Pandemic.” *Safety Science* 130 (October 2020): 104834. https://doi.org/10.1016/j.ssci.2020.104834.
- Ronchi, Enrico. “Developing and Validating Evacuation Models for Fire Safety Engineering.” *Fire Safety Journal*, May 2020, 103020. https://doi.org/10.1016/j.firesaf.2020.103020.
- Tajfel, Henri, and John C Turner. “The Social Identity Theory of Intergroup Behavior.,” 2004.