THUNDERHEAD ENGINEERING

Fire and Evacuation Modeling Technical Conference

September 12-14 2022
Brno, Czech Republic

Evacuation modelling – benchmark analysis of input parameter sensitivity of simulation software

Presented by Quentin JULLIEN

CSTB
le futur en construction

CSTB
le futur en construction

Table of contents

CSTB
le futur en construction

Context

Context

- Complexity of modern infrastructure, size of crowds
- … need for new tools

- No international standard, only guidelines in different countries
- In France, regulations are mainly prescriptive

RUGBY WORLD CUP™ FRANCE 2023

PARIS 2024

- However, context (JO24, Rugby 2023) -> changes

A collaborative approach

[1]CSTB
84, Avenue Jean Jaurès, Champs-sur-Marne
77447 Marne-la-Vallée cedex 2, France
quentin.jullien@cstb.fr

[2]EFECTIS France
Espace Technologique – Bât. Apollo,
Route de l'Orme des Merisiers
91193 Saint Aubin – France
virginie.drean@efectis.com

[3]STUDIO FAHRENHEIT
128 rue la Boétie, 75008 Paris, France
camille.lecompagnon@studio-fahrenheit.com

[4]CNPP
Route de la chapelle Réanville,
27950 Saint-Marcel
nicolas.trevisan@cnpp.com

[5]Université Paris-Saclay, CNRS, Laboratoire de Mathématiques d'Orsay, 91405, Orsay, France
bertrand.maury@universite-paris-saclay.fr

[6]LCPP
39bis Rue de Dantzig, 75015 Paris
jean-luc.paillat@interieur.gouv.fr

[7]Movement Strategies, A GHD Company
10, Fetter Lane, London EC4A 1BR, UK
bachar.kabalan@ghd.com
steve.gwynne@ghd.com

- Inventory of models
- Appropriate input parameters
- Analysis methodology

Objectives of the study

PREVIOUS STUDY:
DISPERSION OF RESULTS WITH THE SAME COMMON PARAMETERS AND TOOL-SPECIFIC INPUT PARAMETERS SET TO DEFAULT

➔ each tool impacts congestion differently

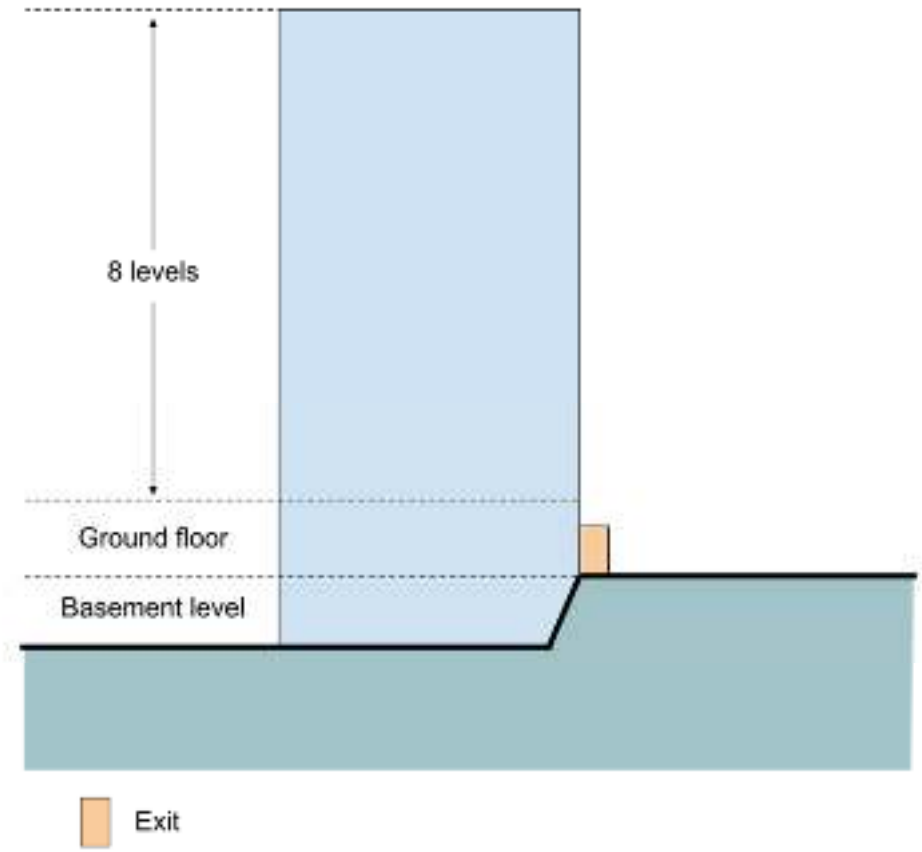
Objectives:

- Conduct a sensitivity analysis on 3 common input parameters using 4 different egress models
- Study the influence of these parameters on congestion and hence the egress time

CSTB
le futur en construction

Experiment setup

Evacuation drill



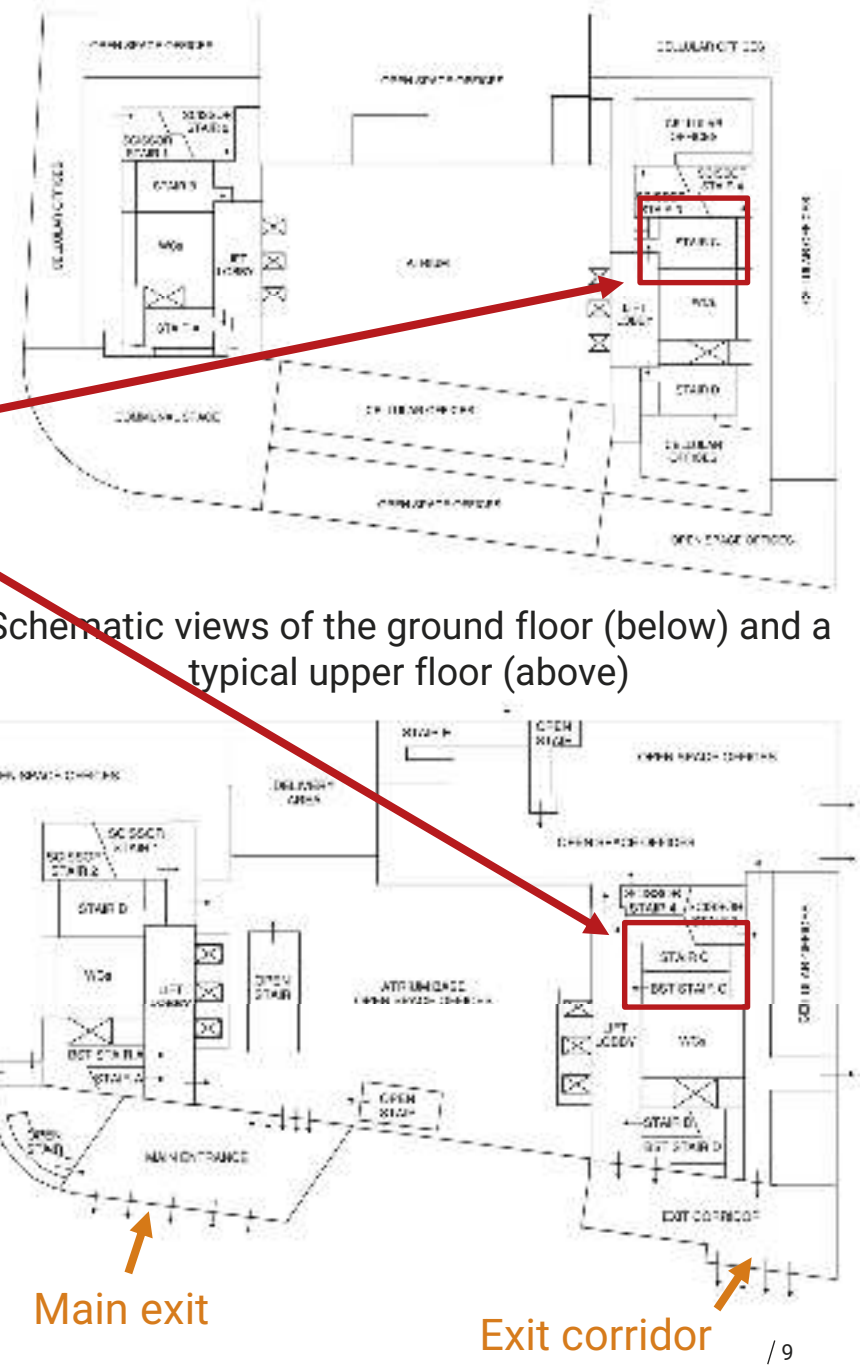
- S_{floor} ≈ 61 m x 44 m
- S_{total} = 20 600 m^2
- 8 egress stairs
- 40% of the total accommodation capacity

Occupancy during the drill

Level 8	133	Level 7	169
Level 6	193	Level 5	249
Level 4	218	Level 3	146
Level 2	0	Level 1	137
Ground floor	65	Basement	39

Evacuation drill

- 20 members on site
- 3 cameras installed in stair C
- CCTV throughout (except in stairs)
- Very large single assembly point at rear



Schematic views of the ground floor (below) and a typical upper floor (above)

Evacuation times:

- To outside: 7 min
- To assembly point: 8,5 min

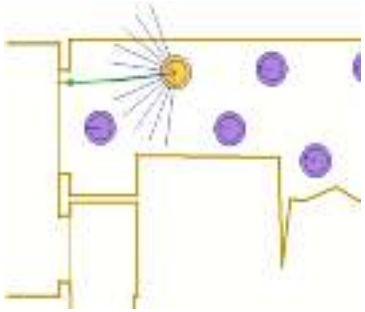
CSTB
le futur en construction

Sensitivity study

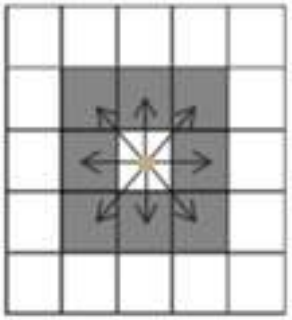
Software overview

	Pathfinder	buildingEXODUS	FDS+EVAC	Cromosim compartment model
Micro/Macro	Micro	Micro	Micro	Macro
Space representation	Space grid mesh (triangular)	Space grid mesh	Space grid mesh (rectangular)	Network (skeleton of the building)
Agent representation	Cylinder	One agent per cell (0.5 m x 0.5 m)	Ellipsis*	N.A.
Characteristic dimension of agent	Diameter	Cell size	Major axis length	Via door capacities

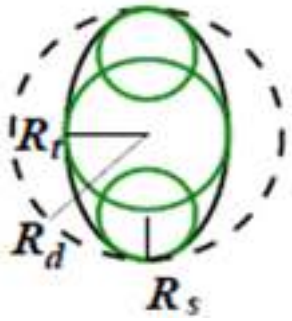
**: The shape of the human body is approximated by a combination of three overlapping circles.*

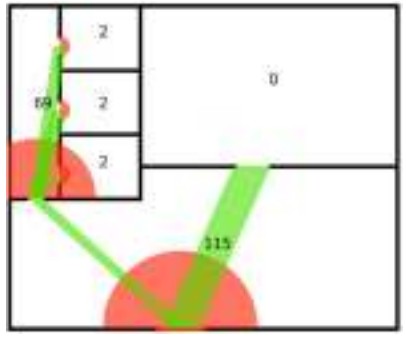


Pathfinder Steering mode



The Moore neighbourhood





CSTB
le futur en construction

Input parameters

Parameter	Values	Reference value
Velocity in m/s*	0.6, 0.8, 1.0, 1.2, 1.4	1
Diameter of a person in m	0.40, 0.45, 0.50, 0.55, 0.60	0.5
Premovement time interval in s**	0, [0-5], [0-15], [0-30], [0-60]	0

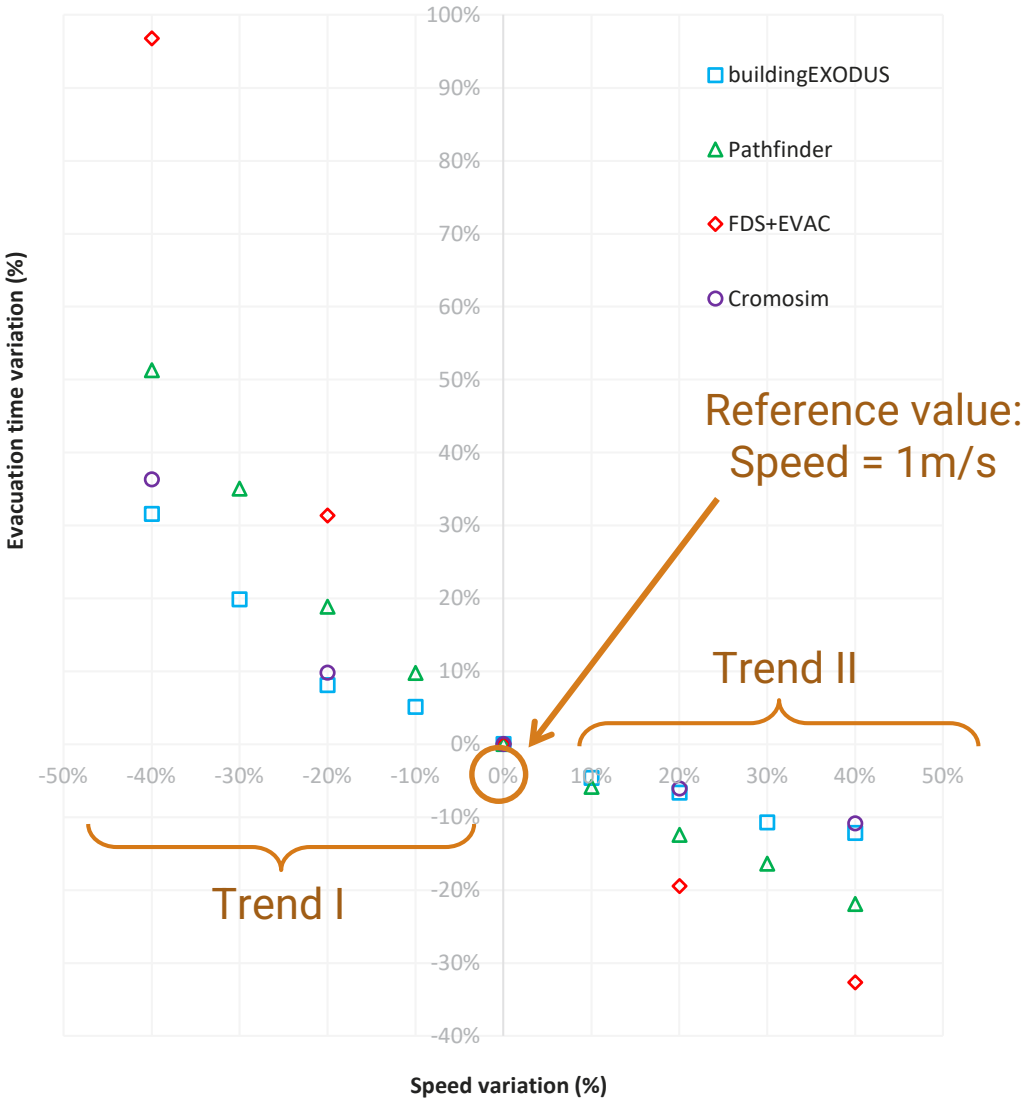
*: Speed does not follow any distribution and is fixed for all agents.
**: Values are attributed to occupants using a uniform distribution over the time intervals.

CSTB
le futur en construction

Sensitivity study

General sensitivity analysis

Individual impact of variables on total evacuation time: speed



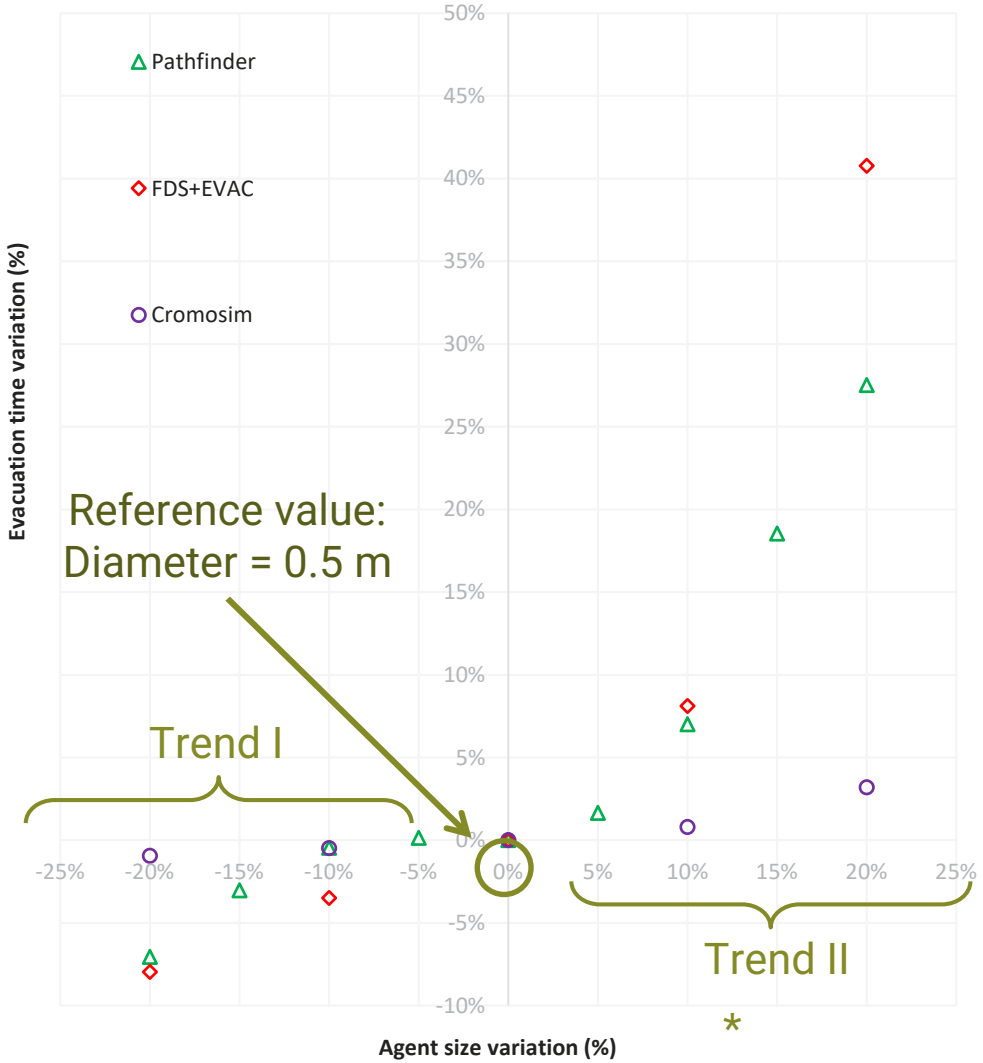
- Two global trends
- Almost linear
- Magnitude varies between tools ➔ difference in management of staircases & interactions
- Slope steeper for lower speeds (trend I)

➢ Congestions might disrupt the evacuation

  - Higher speeds ➔ more occupants in the stairwell at the same time
  - Evacuation governed by congestion instead of speed

Individual impact of variables on total evacuation time: agent size

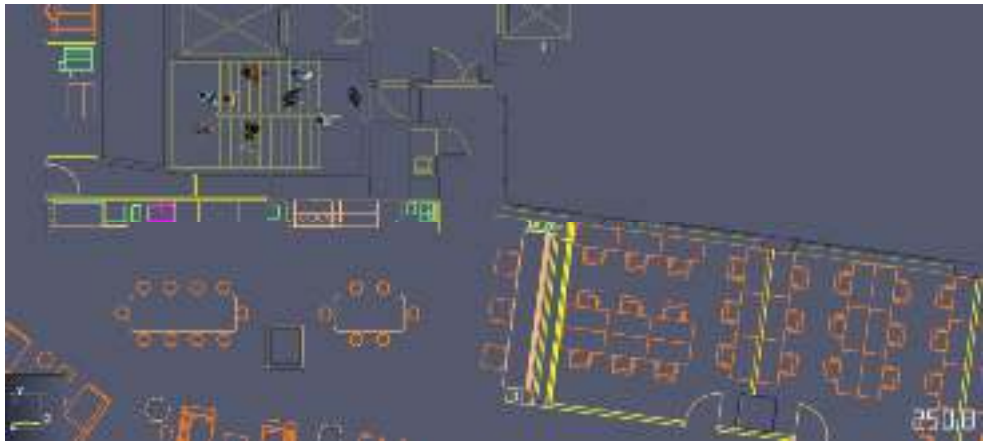
- Sensitivity is low for small diameters ➔ flow through doors near max
- In Cromosim conflicts are managed differently ➔ sensitivity to agent diameter is low



** In buildingEXODUS size is not a tunable parameter and hence it is not included here*

Individual impact of variables on total evacuation time: agent size

- For FDS+Evac and Pathfinder, high sensitivity for larger diameters (0.5m to 0.6m)
  ➔ higher space requirements
- Increase in agents' size generates congestion in the stairs



View of the Pathfinder simulation with [speed, size]=[1 m/s, **0.4 m**] at t=250 s, floor 6, staircase A

View of the Pathfinder simulation with [speed, size]=[1 m/s, **0.6 m**] at t=250 s, floor 6, staircase A

Individual impact of variables on total evacuation time: premovement time

- Low sensitivity (~5%) to premovement time for all tools [0-60] s

➢ Egress time governed by the flow in the stairs (bottlenecks)

➢ The delayed occupants will eventually reach the stair that is already jammed

CSTB
le futur en construction

Sensitivity study

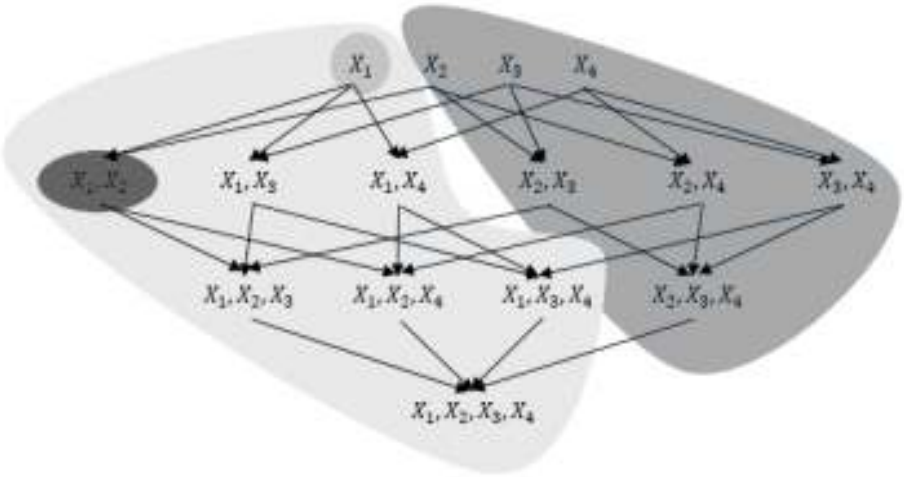
Sobol's sensitivity indices

Sobol indices

Input
$x_1, x_2, x_3, x_4 \ldots$

Mathematical model
$f(x_1, x_2, x_3, x_4 \ldots)$

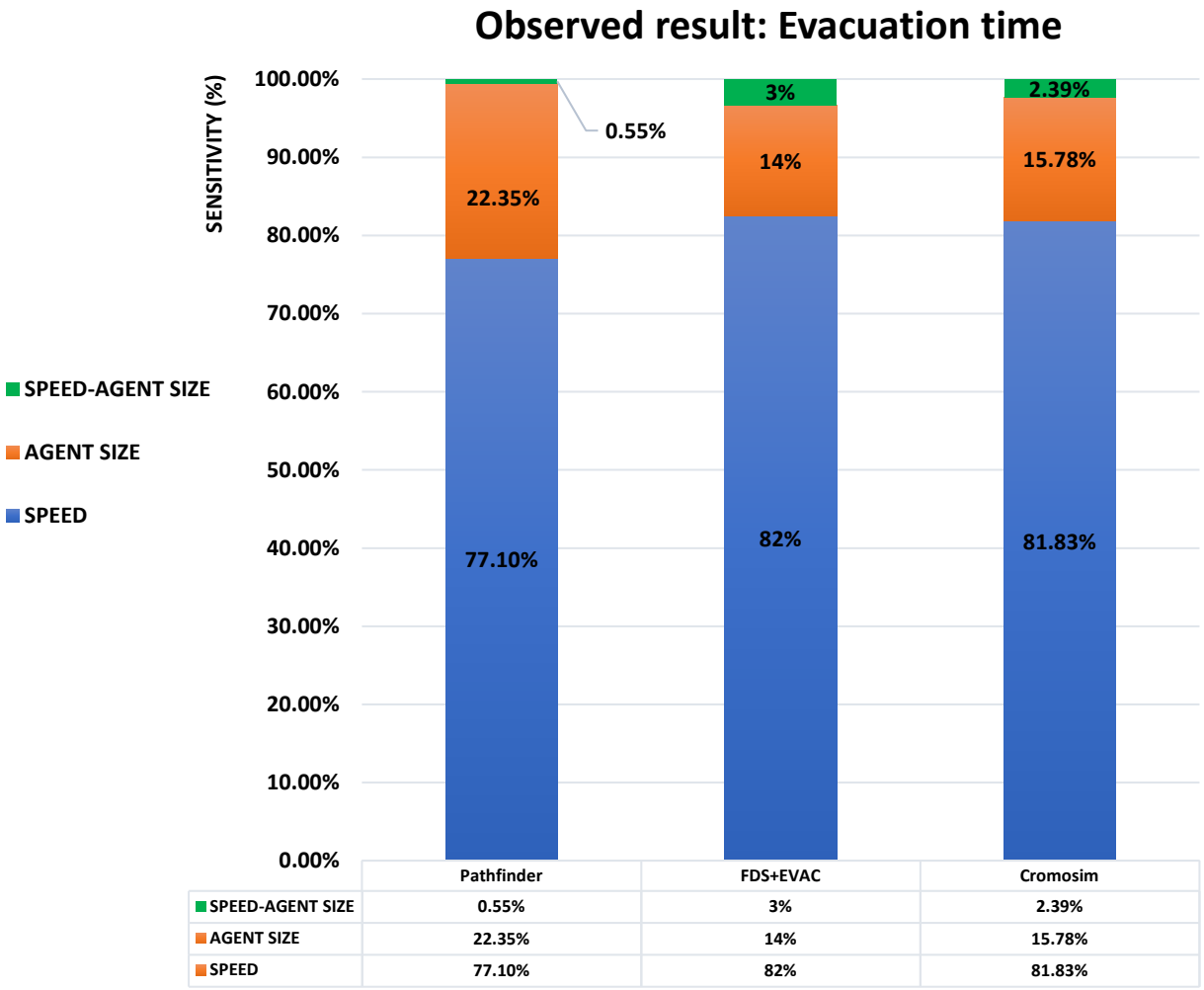
Output
y_n



- Main effect of X_1
- Interaction between X_1 and X_2
- Total effect of X_1
- Main effect of X_2, X_3 and X_4

Different kinds of Sobol indices

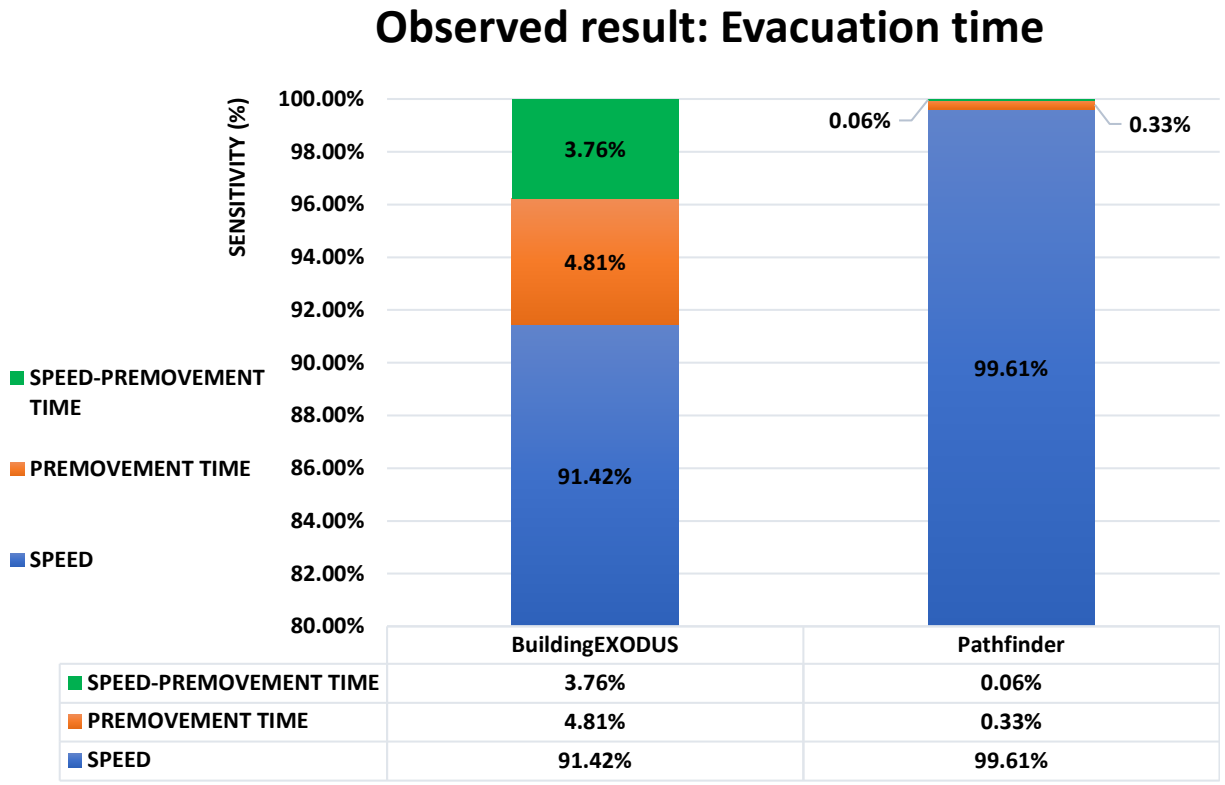
Influence of speed, agent size and their second-order interactions on evacuation time



- ~80% of egress time variation is due to **speed**
- Effect of the occupant's speed on the output does not depend on agent's size and vice versa

Sensitivity of the total evacuation time to the speed, premovement time and their interactions

- Influence of **speed** is predominant (~90% of the variations)
- In Pathfinder, the effect of premovement time or of its interaction with speed is negligible
- Speed and premovement time are independent variables as well



CSTB
le futur en construction

Conclusions & perspectives

Conclusions

- Preponderant influence of **speed**
  - Congestion limits the egress time for higher speeds
- Micromodels are much more sensitive to **size** variations than macromodels
- Negligible influence of **premovement time** within the [0; 60]s interval ➔ Congestions seems to outweigh the delay of premovement time
- Differences in amplitude between tools – at doors and merging points (eg **staircases**)
- **Quantification of congestion and knowledge of conflict resolution are crucial**
- The results are valid for the intervals and the case studied

Avenues for future research

- Modelling of the **stairwells**
  - Correct way to discretize the space, adjust conflict resolution etc.
- Take **congestion** into account, not only evacuation time
  - Personal egress efficiency (PEE), individual waiting time…
- Other **drills** to compare the observations

Thank you for your attention

Acknowledgements:

- *The building hosts*
- *Fire brigade officers: Paris Fire Brigade & SDIS 39*

CSTB
le futur en construction