An emergency egress model based on a macroscopic continuous approach

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Objectives

Main objective of the study

Implementing a complete egress model including fire effects on persons

Characteristics of microscopic approaches

- Persons considered as individual entities, with own characteristics

- Statistical distributions to define input parameters

- Dependence on initial distribution of people

- Statistical treatment of output results to obtain representative data

Objectives

Main objective of the study

Implementing a complete egress model including fire effects on persons

Characteristics of our model

- <u>Output results significant for a large number of configurations</u>
  Results which do not depend on a particular initial distribution of persons

- <u>Fast computation</u>

- <u>Integration of fire stresses:</u>
  - thermal effects in terms of temperature and heat flux
  - low visibility

Modelling approach

Macroscopic approach in a continuous space and time

Summary

- ➢ **Assumptions and mathematical formulation**

- ➢ **MARCOE PAULO algorithm**

- ➢ **Validation / Comparison**

- ➢ **Integration of fire effects**

- ➢ **Conclusions**

- ➢ **Perspectives**

Assumptions and mathematical formulation
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Assumptions and mathematical formulation

Macroscopic approach → persons are represented by their **people density** ρ (persons per unit area)

Three basis assumptions

- Without constraint, people move at <u>preferred walking speed</u> (1)

- People density cannot exceed a <u>critical density</u> ρ_c (2)

- Flowrates through openings cannot exceed a <u>critical value</u> ψ_c

Mathematical formulation

$$\left[\begin{array}{l} \dfrac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0 \quad (1) \\[2ex] \vec{v} = P_{C\rho}\vec{V} \quad\quad\quad (2) \end{array}\right.$$

→ Numerical resolution by a finite volume method in a 2D computational domain

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Assumptions and mathematical formulation

3 cell types to describe the domain:

- Available cells

- Exit cells

- Wall cells

$$0 < \rho < \rho_C$$
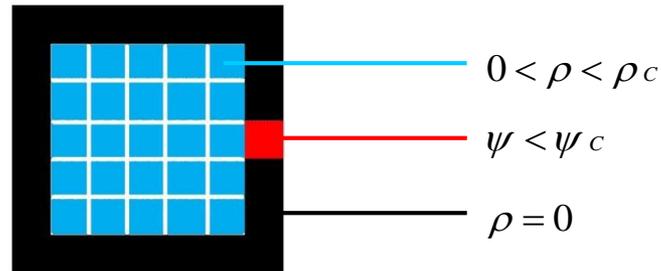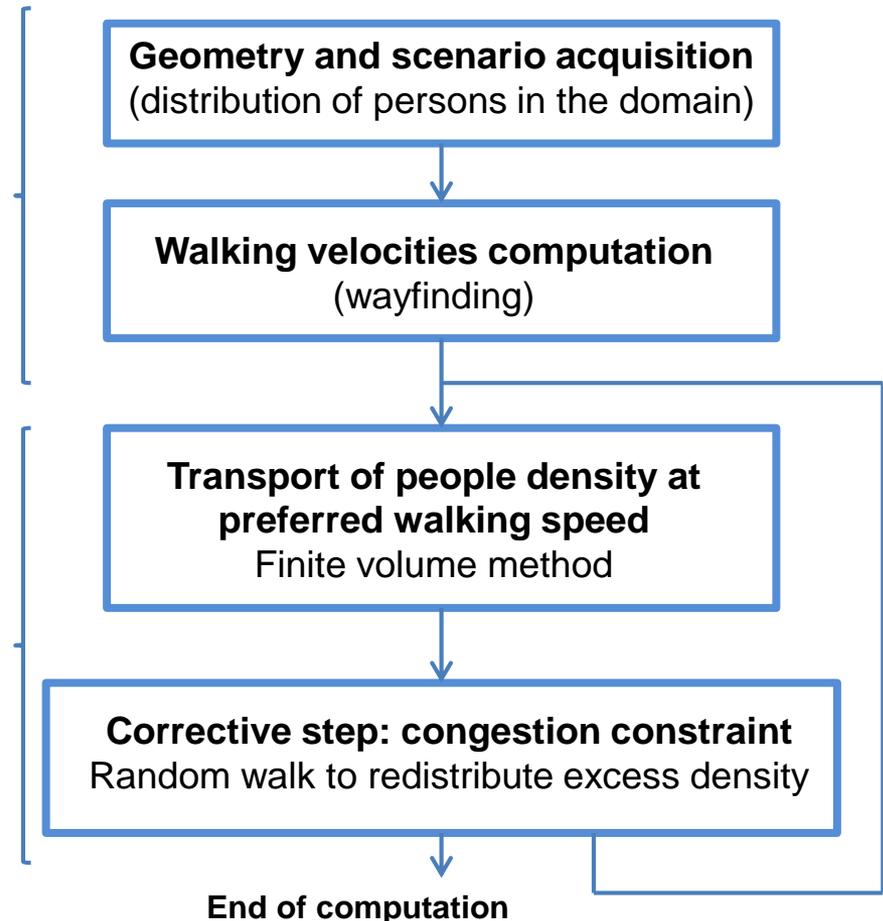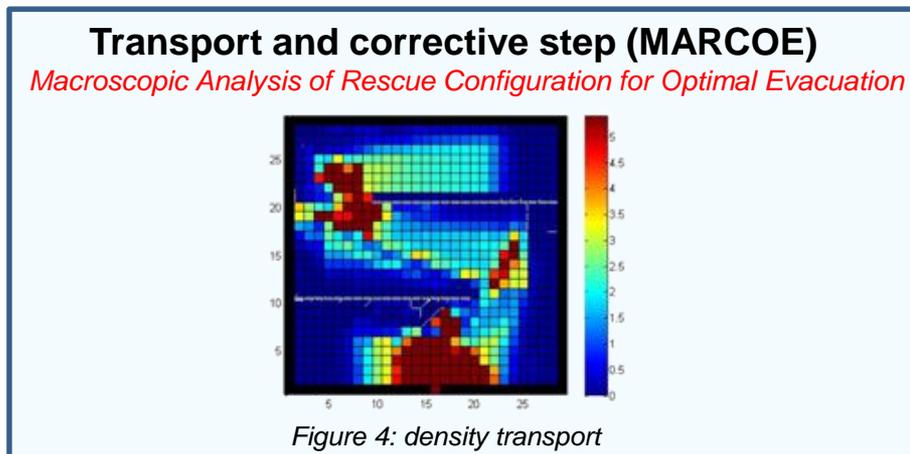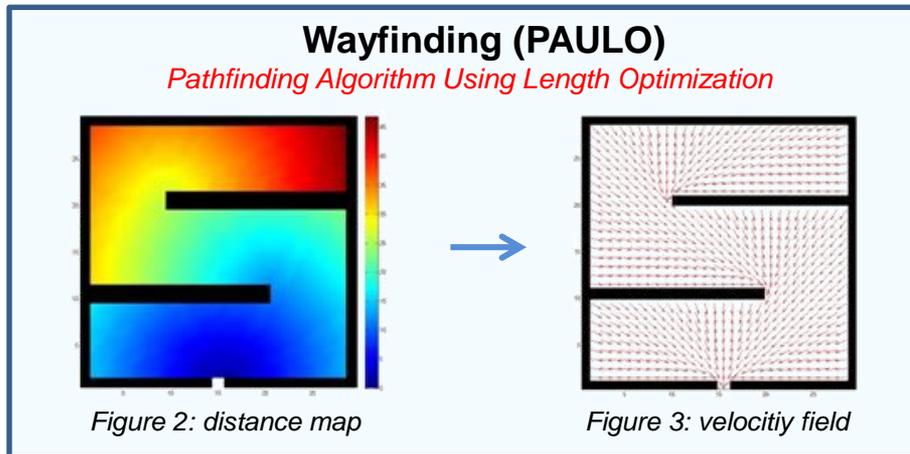
$$\psi < \psi_C$$

$$\rho = 0$$

Figure 1: 3 cell types

4 key parameters

- Preferred walking speed V_0 $\longrightarrow$ variable (age, genre, culture)
- Reaction time τ $\longrightarrow$ variable (risk perception)
- Critical people density ρ_C $\longrightarrow$ ~ 5.4 pers.m^{-2}
- Maximal flowrate through exits ψ_C $\longrightarrow$ ~ 1.1 pers.m^{-1}.s^{-1}

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MARCOE PAULO algorithm

Wayfinding (PAULO)
Pathfinding Algorithm Using Length Optimization

Figure 2: distance map

Figure 3: velocitiy field

Transport and corrective step (MARCOE)
Macroscopic Analysis of Rescue Configuration for Optimal Evacuation

Figure 4: density transport

Geometry and scenario acquisition
(distribution of persons in the domain)

Walking velocities computation
(wayfinding)

Transport of people density at preferred walking speed
Finite volume method

Corrective step: congestion constraint
Random walk to redistribute excess density

End of computation

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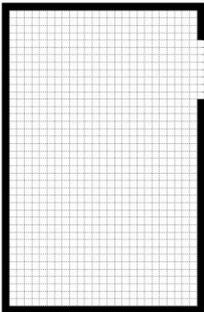# Validation / Comparison

Validation at a small scale

Figure 5: configuration of the room

➢ <u>First step:</u>
identification of free walking speed and reaction time of the sample of persons

$$\tau = 0,69 \; s$$
$$V_0 = 0,91 \; m/s$$

➢ <u>Second step:</u>
validation of the code against repeated tests

Characteristics of scenario

- 10 m^2 room with a single exit
- Test performed with 10 persons
- Random initial positions and orientations
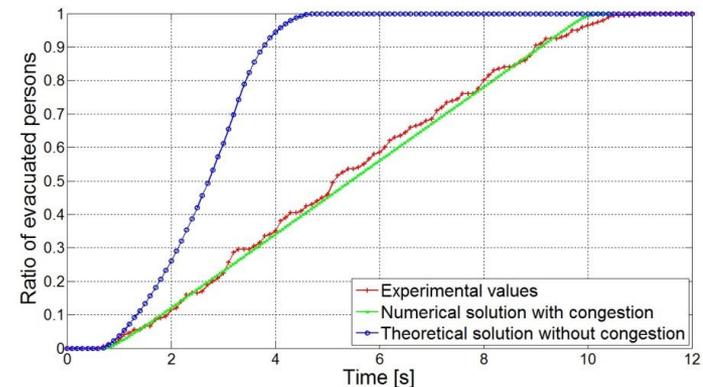- Start given by a beep
- 20 repeated tests

Figure 6: evacuation rate among time

➢ **Promising validation at a small scale**
➢ **Congestion situations properly handled**

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Validation / Comparison

Comparison between codes
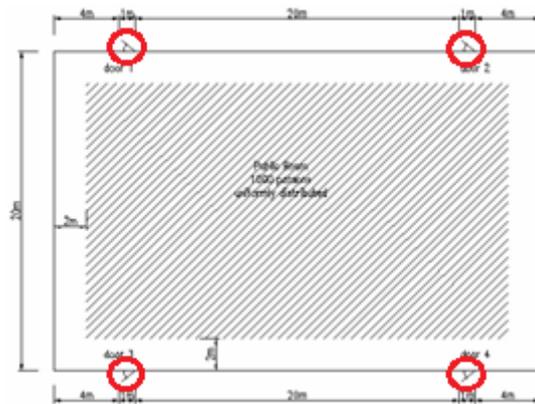
Figure 7: geometry of the test

Code	Egress time
EVAC	240,8 s
Pathfinder (Steering mode)	196,7 s – 199 s
Pathfinder (Steering+SFPE mode)	273,2 s – **283,2 s**
Pathfinder (SFPE mode)	264,7 s – 275,6 s
PedGo 2.5.0.7	**179 s**
Our model	**228 s**

Table 1: Comparison between models

Characteristics of the scenario

- Test 9 described in MSC.1/circ1238 of IMO
- 600 m² room (30 m x 20 m) with four one-meter-wide exits
- Evacuation of 1000 persons
- No reaction time

> **Ability to obtain coherent results by a single simulation with our model**

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Integration of fire effects

Three different ways to integrate fire

- Burning cells considered as <u>blocked cells</u>

- Introduction of threshold values to assess tenability in fire conditions

    Temperature: 60°C
    Heat flux: 2.5 kW/m²
    Extinction coefficient: 0.3 m^{-1}

    → Cells with constraints above thresholds are considered as <u>blocked cells</u>

- <u>Reduction of walking speed</u> according to extinction coefficient of smoke

    $$v(\beta) = \max(0.1\,V_0, (1 - a\,\beta)\,V_0)$$

> **Coupling with Fire Dynamics Simulator 6 to evaluate fire stresses**

Integration of fire effects

Characteristics of the comparison scenario

- Geometry of Test 10 described in MSC.1/circ1238 of IMO
- Group of 12 boat cabins (216 m^2) separated by a corridor
- Evacuation of 23 persons
- Uniform reaction time (30 s)
- Fire source placed in cabin n°9 (HRR=1MW with a medium growth according to NFPA 204 standard)
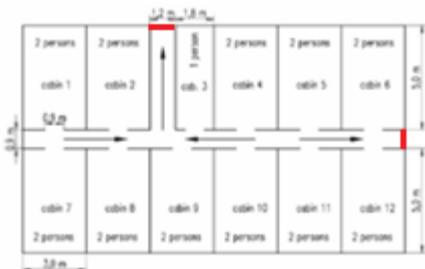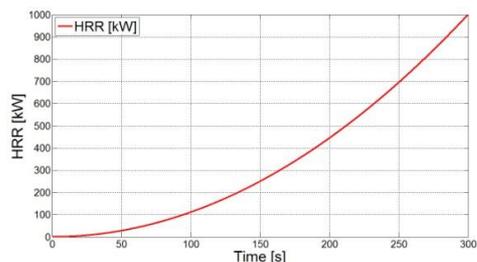

Figure 8: map of the geometry
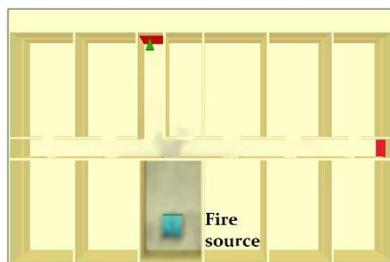

Figure 9: HRR among time

Figure 10: geometry of the test

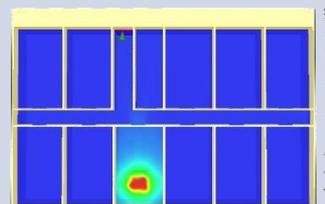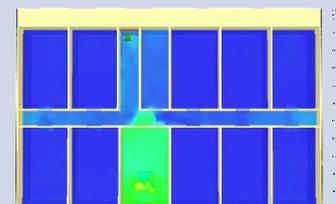## Evolution of fire constraints (t=120 s)

Figure 11:
heat flux field

Figure 12:
Temperature field
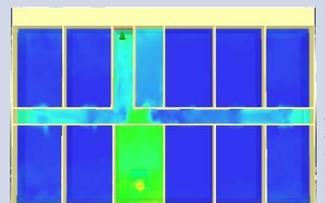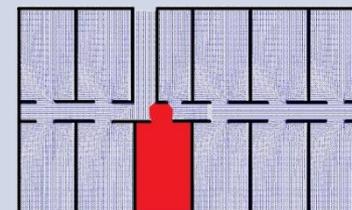

Figure 13: extinction
coefficient field

Blocked zone

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Comparison between our model and EVAC

- Free walking speed: 1.25 m.s⁻¹
- Reaction/premovement time: 30 s
- Fire-related data extracted each 5 s
- "Conservative" agents in EVAC
- Data averaged for 50 simulations in EVAC

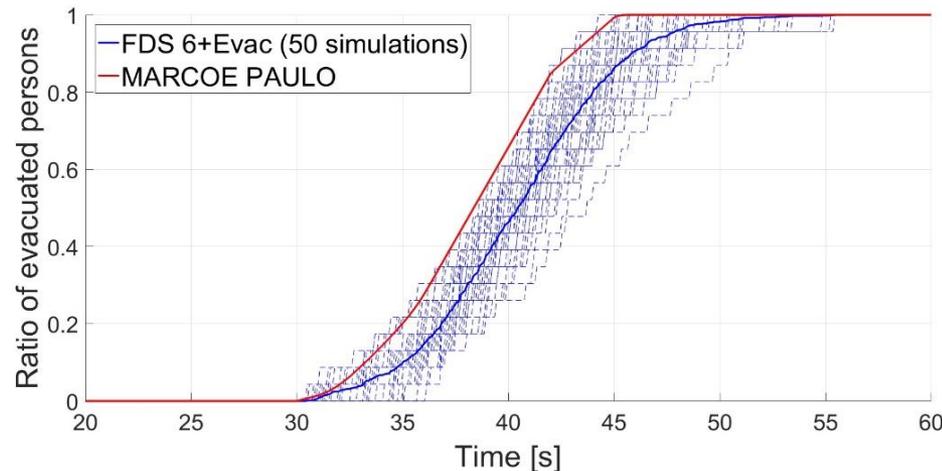|	$t_{50\%}$	$t_{75\%}$	$t_{90\%}$	$t_{95\%}$
EVAC	40.1 s	43.2 s	45.7 s	47.2 s
Our model	38.4 s	41 s	43.1 s	44.1 s

Table 2: comparison of intermediate egress times

Figure 14: comparison of exit rates

➤ **Comparison with EVAC on a simple fire scenario shows reveals a good agreement for egress times**

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Main conclusions

- New evacuation model based on a macroscopic continuous approach

- Promising validation at a small scale

- Output results coherent with those obtained with other egress tools

- Integration of fire effects in terms of threshold constraints and penalized velocities

➡ **Macroscopic continuous approach innovative in Fire Safety Engineering**

➡ **Model able to provide evacuation times significant for a lot of particular scenarios with a single simulation of a mean scenario with average input parameters**

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Perspectives and ongoing researches

- **A better way to integrate fire influence on egress conditions**
  Concept of threshold values for tenability not sufficient

- **The integration of visibility as a decision making process**
  Integration of exit signage into the simulation

- **The integration of several types of populations**
  Population with different characteristics
  different behaviors
  different exit preferences

- **Estimation of pre-evacuation times**
  Dependence on hazard perception

- **Validation with large-scale evacuation drills**
  Evacuation drills already conducted at medium and large scale