Comparing Different Metrics Quantifying Pedestrian Safety

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Why?

Analysis of crowd disasters

- Hajj (2006, 2009) [1]
- Love Parade (2010) [2]

Calibration and safety

- NIST 1822 [3]
- Fundamental diagrams [4]
- Level of Service [5]

Improving safety

- Simulations of the Hajj [6]
- Evacuations of concerts [7]
- Crowd flow optimization of the Grand Départ [8]

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[1] Dridi, "Tracking Individual Targets in High Density Crowd Scenes Analysis of a Video Recording in Hajj 2009"

[2] Helbing and Mukerji, "Crowd disasters as systemic failures: analysis of the Love Parade disaster"

[3] Ronchi et al., "NIST Technical Note 1822: The process of verification and validation of building fire evacuation models"

[4] Zhang et al., "Transitions in pedestrian fundamental diagrams of straight corridors and T-junctions"

[5] Fruin, *Pedestrian planning and design*

[6] Khan and McLeod, "Managing Hajj crowd complexity: Superior throughput, satisfaction, health, & safety"

[7] Wagner and Agrawal, "An agent-based simulation system for concert venue crowd evacuation modeling in the presence of a fire disaster"

[8] Zwan, "The Impact of Density Measurement on the Fundamental Diagram"

Classifying safety

Density ρ

The number of pedestrians (N) located in a unit area (A).

- $\rho = \frac{N}{A}$

Velocity $\vec{\mathbf{v}}$

The average direction and speed of pedestrians.

Flow $\vec{\mathbf{q}}$

The number of pedestrians crossing a virtual line.

- $\vec{q} = \rho \times \vec{v}$

Pressure p

The amount of pressure a pedestrian experiences.

- $p = Variance(\vec{v}) \times \rho$

How to measure density for pedestrians?

Many choices

- 7 different categories [1]
  All give different results...
- For each category, different methods exist
  And each is supposed to be better than its predecessor...

We implemented:

- A grid-based method [2]
- A Voronoi-based method [3]
- The Gaussian-based method
- An improved Gaussian-based method [4]

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[1] Duives, Daamen, and Hoogendoorn, "Quantification of the level of crowdedness for pedestrian movements"

[2] Fruin, *Pedestrian planning and design*

[3] Steffen and Seyfried, "Methods for measuring pedestrian density, flow, speed and direction with minimal scatter"

[4] Plaue, Bärwolff, and Schwandt, "On measuring pedestrian density and flow fields in dense as well as sparse crowds"

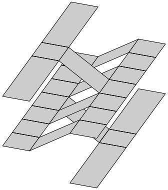
Flat-world

Are these methods suitable for pedestrians?

No, because some ignore obstacles.

No, because these methods are only defined for flat worlds.

Possible solution: Geodesic distance



This world is not flat (unless you really like maths)

Geodesic distance

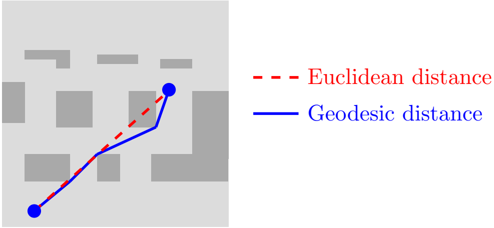
In this situation, the **geodesic distance** is the shortest walking distance.

Advantages:

- Defined for any surface
- Takes obstacles into account

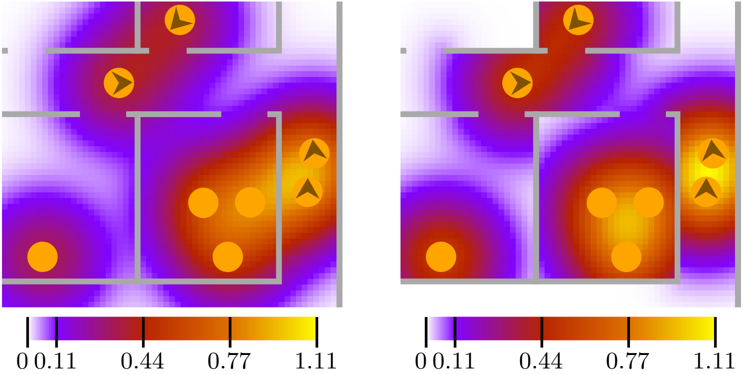
Disadvantage:

- Computationally expensive



Impact on different metrics

Density:



Using Euclidean distance

Using geodesic distance

Impact on safety?

What we see:

- It looks different
- We get different/higher peaks
- No “values” are crossing obstacles

What we don’t see:

- Does it affect safety decisions?
- Are these differences significant?

Measuring impact on safety

We propose new ways of comparing methods.

Old:

- Peaks
- Biggest difference

New:

- Quadratic score
- Bin difference

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Definition (Quadratic score)

The quadratic score (qs) is the maximum divided by the local value squared, normalized over the area.

$$qs(M) = \frac{1}{A_R} \sum_{i=1}^{N} \left(\frac{v(C_i, M)}{\max(M)} \right)^2 A_i$$

Measuring impact on safety

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Old:

- Peaks
- Biggest difference

New:

- Quadratic score
- Bin difference

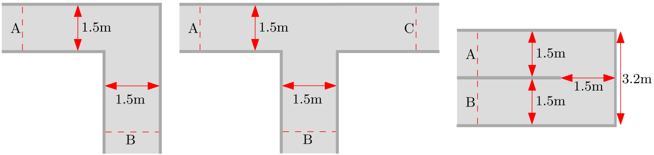
Definition (Bin difference)

The bin difference is the weighted difference in misprediction of safety levels (for example Level of Service).

$$bd(M_1, M_2) = \frac{1}{A_R} \sum_{i=1}^{N} \left(bin(C_i, M_1) - bin(C_i, M_2)\right)^2 A_i$$

Experiments

Basic environments



Scenarios

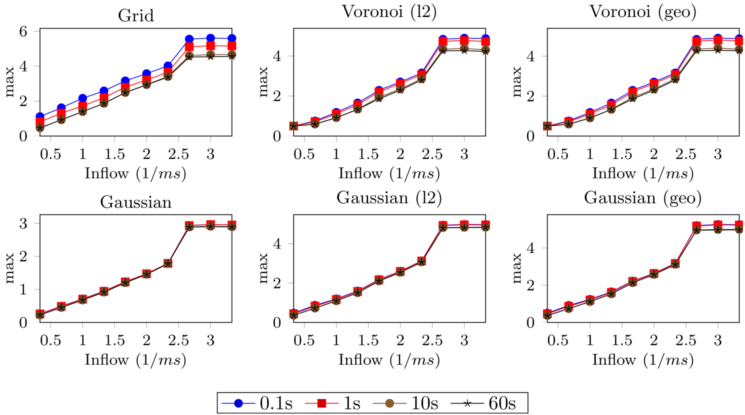
- Spawn agents every x seconds
- Let the agents move from **start** to **goal**
- After the first agent reaches the **goal**, start a timer (120 seconds)
- When the timer runs out, measure for 10 minutes

Here, x is one of 2, 1, $\frac{2}{3}$, $\frac{1}{2}$, $\frac{2}{5}$, $\frac{1}{3}$, $\frac{2}{7}$, $\frac{1}{4}$, $\frac{2}{9}$, $\frac{1}{5}$.

Averaging windows: Instantaneous, 1s, 10s and 60s

Results (windows)

U-turn environment; density:



Conclusion: An averaging window of 10s is enough

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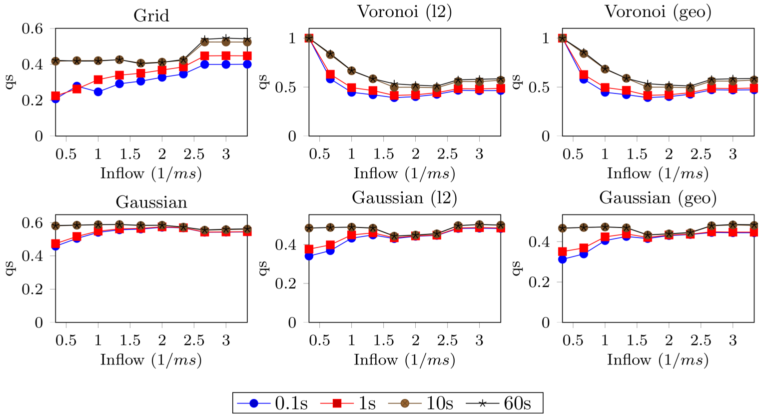

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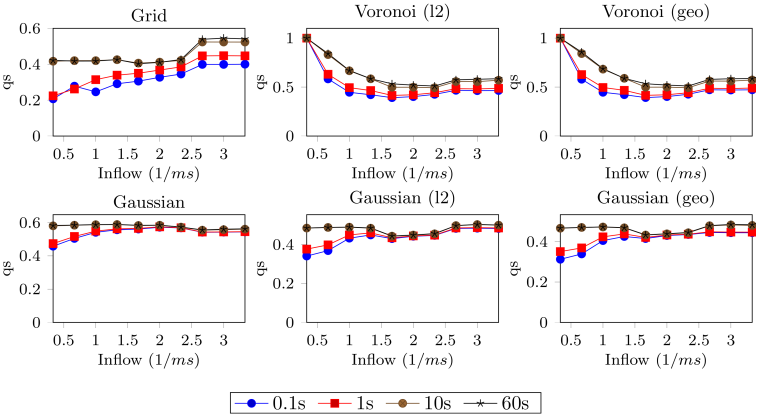
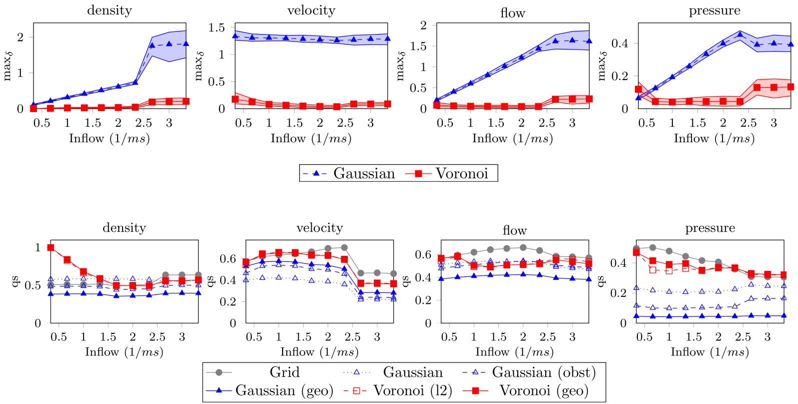


Conclusion: An averaging window of 10s is enough

Results (Comparing)



Conclusion: Different ranges and different trends

Open questions

- Are these comparisons enough?
  More research required
- Can we efficiently calculate geodesic distances in 3d environments?
  Depends on what you call efficient
- Do we really need the geodesic distance for accurate threat assessment?
  Probably not for all situations

Thanks!

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