

Capacity, Entropy, and Safety: A Metric-Based Framework for Urban Airspace structure Evaluation

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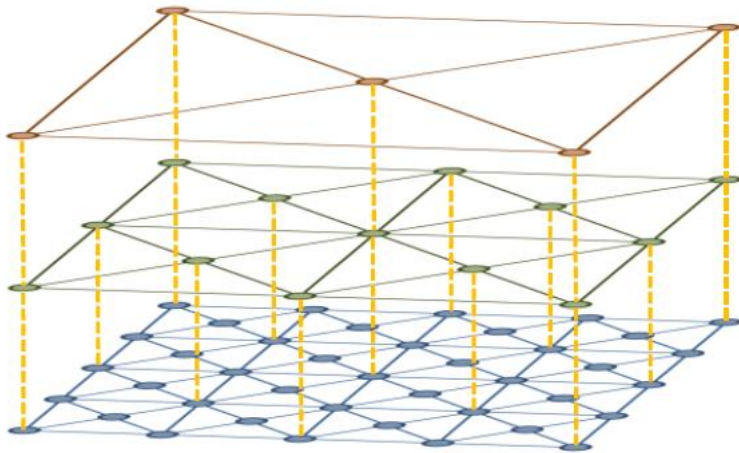
UAB

Universitat Autònoma
de Barcelona

Objectives

- UAM -> Contingency procedures
- Contingency procedures -> Services and infrastructure
- How do we determine the scale of services and infrastructure needed? Can we know the scale of operations in an airspace? What do we measure? Can we avoid simulations?

Modelling



Source [1]

Airspace structure is based on corridors:

- Can be represented with graphs.
- Too many obstacles/restricted areas can lead to corridors.
- Predictable trajectories for strategic planning.
- Social acceptance corridors.

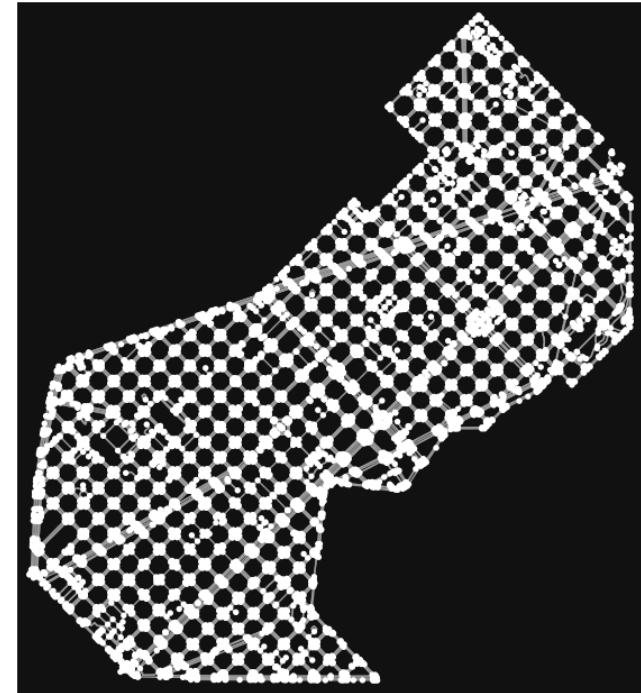
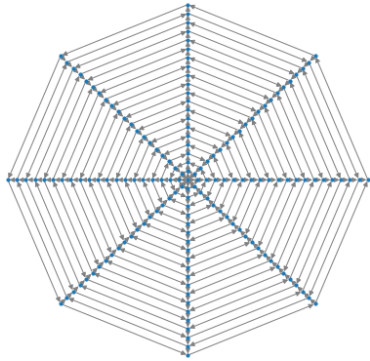
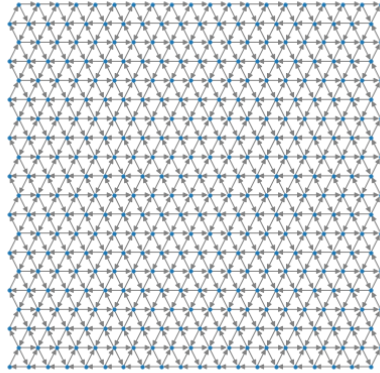
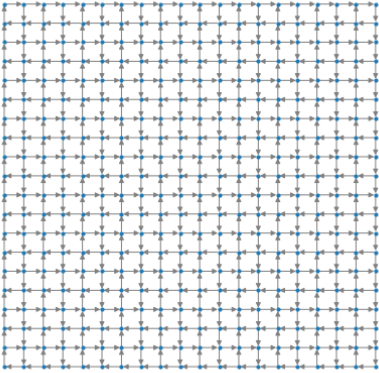
Other considerations and simplifications:

- Focus on 2D layers.
- Nodes as vertiports (main hubs) and vertistops (smaller).
- Constant velocity.

To evaluate performance:

- **Capacity:** Number of simultaneous missions.
- **Safety:** Number of conflicts in a contingency situation.

Layouts



Eixample, Barcelona

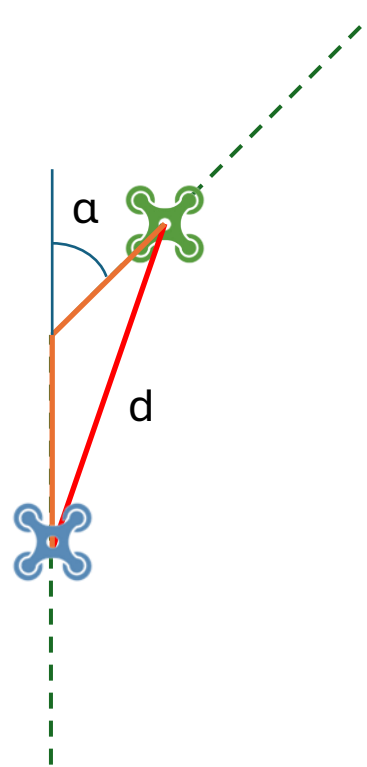
Entropy

$$I_f(G) := - \sum_{i=1}^{|V|} \frac{f(v_i)}{\sum_{j=1}^{|V|} f(v_j)} \log \left(\frac{f(v_i)}{\sum_{j=1}^{|V|} f(v_j)} \right)$$

Source [2]

$$f(v) = \frac{\sin(\pi - \alpha)}{2 \sin \frac{\alpha}{2}}$$

$v \rightarrow$ node $V \rightarrow$ total number of nodes

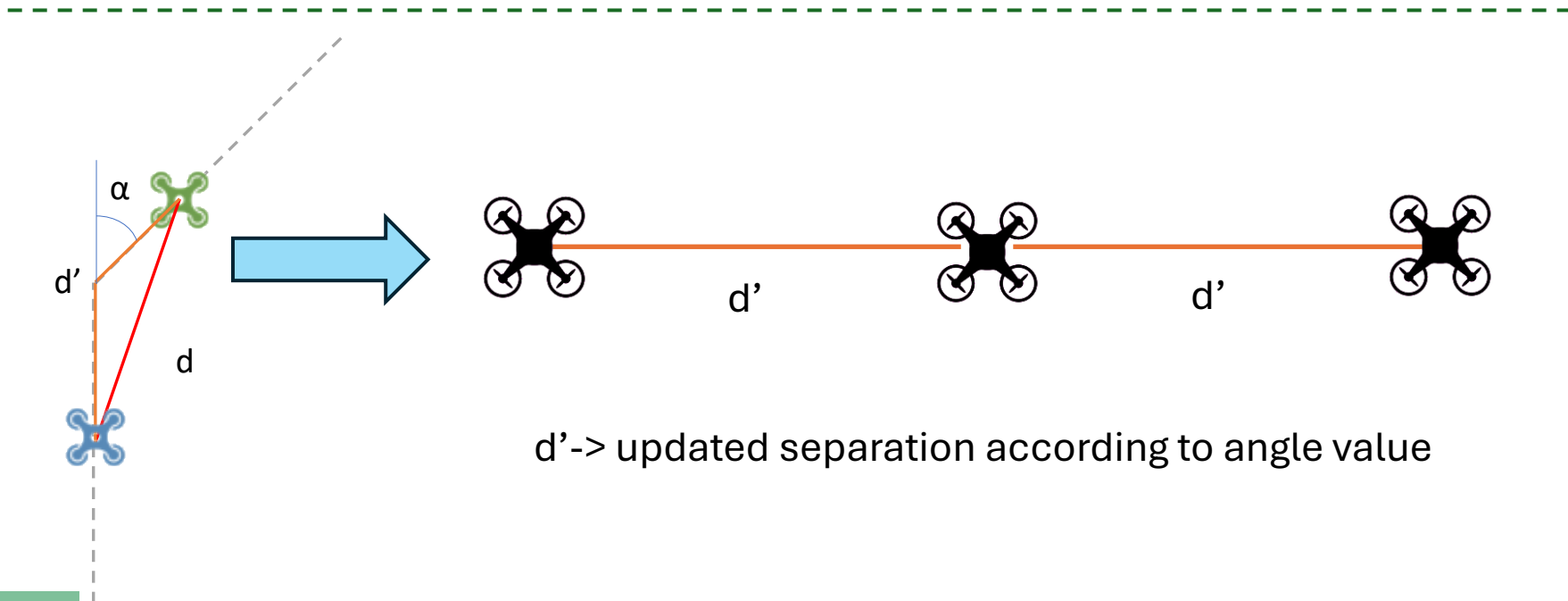
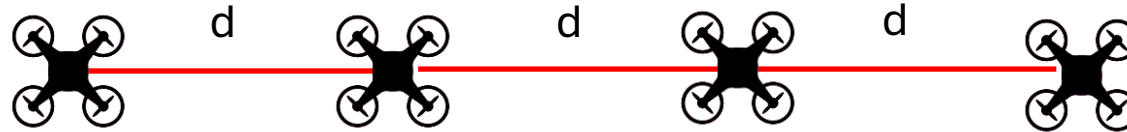


- Aims to capture complex geometrical information.
- Depends on size.
- Difficult to interpret.

Higher Entropy $\rightarrow$ More information needed to describe the state of a system

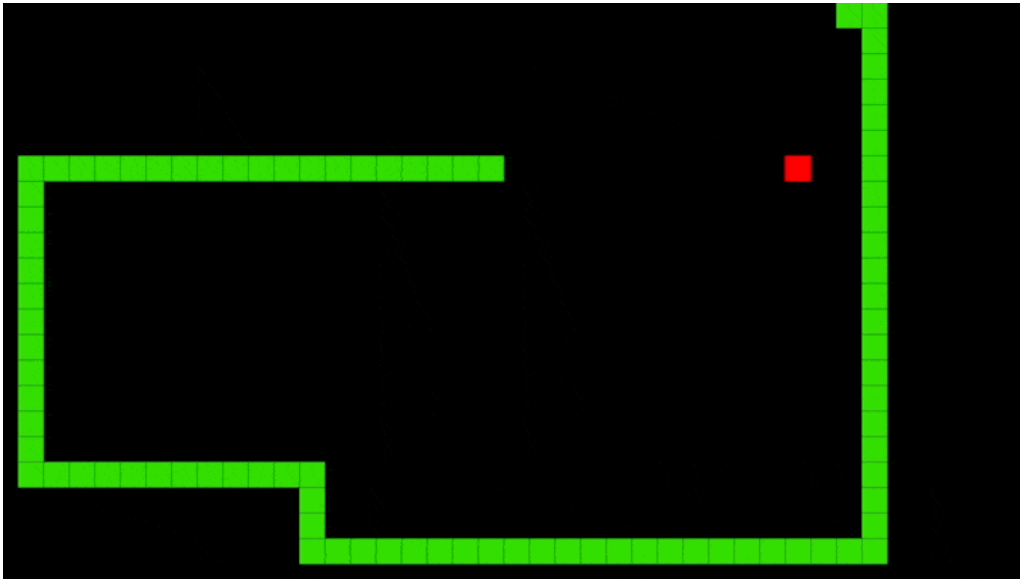
Capacity

$d \rightarrow$ minimum separation



$d' \rightarrow$ updated separation according to angle value

Capacity



Source [4]

$\text{Tolerance} \times \text{velocity} > \text{Edge length}$

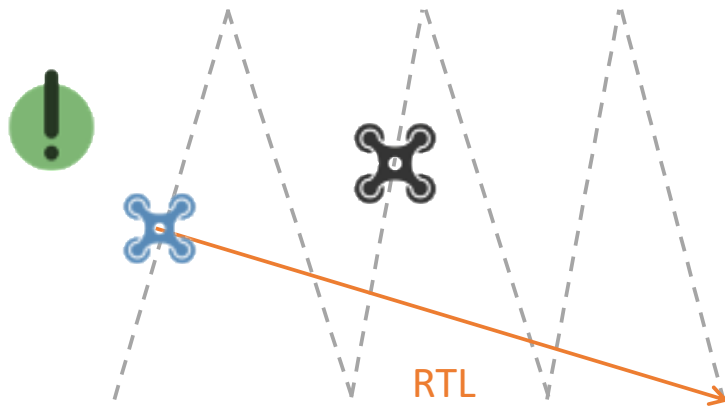
Multiple 'snakes'

Contribution per edge < 1

Some edges cannot be used at the same time and their contribution is 0

Safety

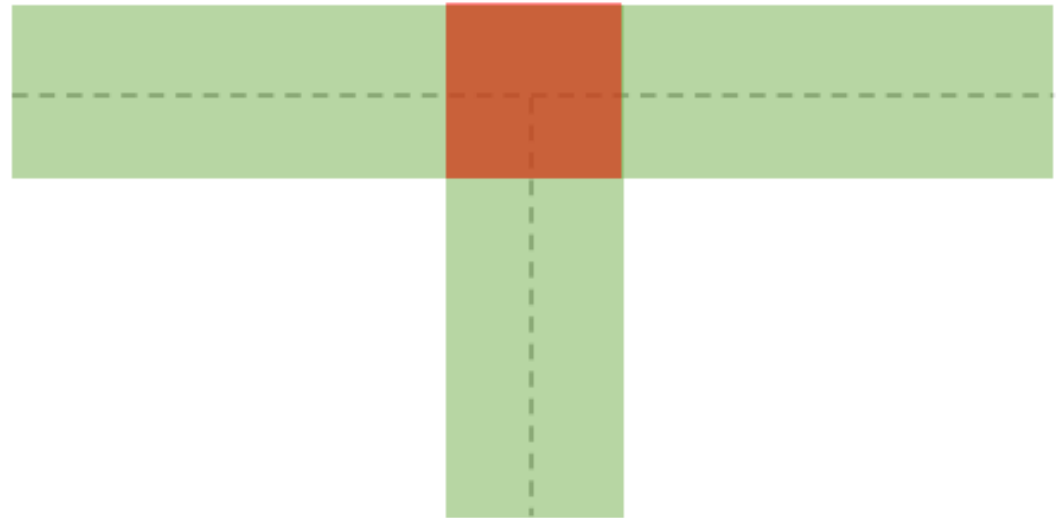
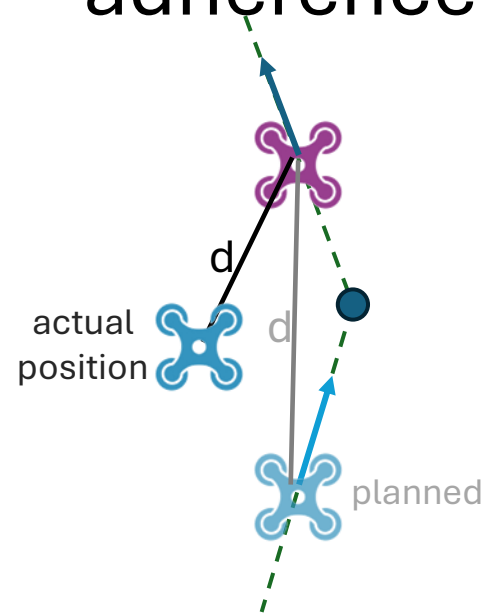
Contingency



- The graph is divided using a Voronoi diagram based on vertiport location
- For each edge, the number of crossings to its corresponding vertiport is counted

Safety

Loss of
adherence



Validation

- The validation of these metrics need to be done using simulations.
- Mission design, traffic generation and DCB have done using DroneAs as U-space service provider (USSP). [Source \[3\]](#)

Capacity simulations:

- Each run has vertiports allocated randomly.
- Mission could be freely allocated within 1h window.
- Maximum accepted demand.
- The final result is the average maximum simultaneous capacity for each layout.

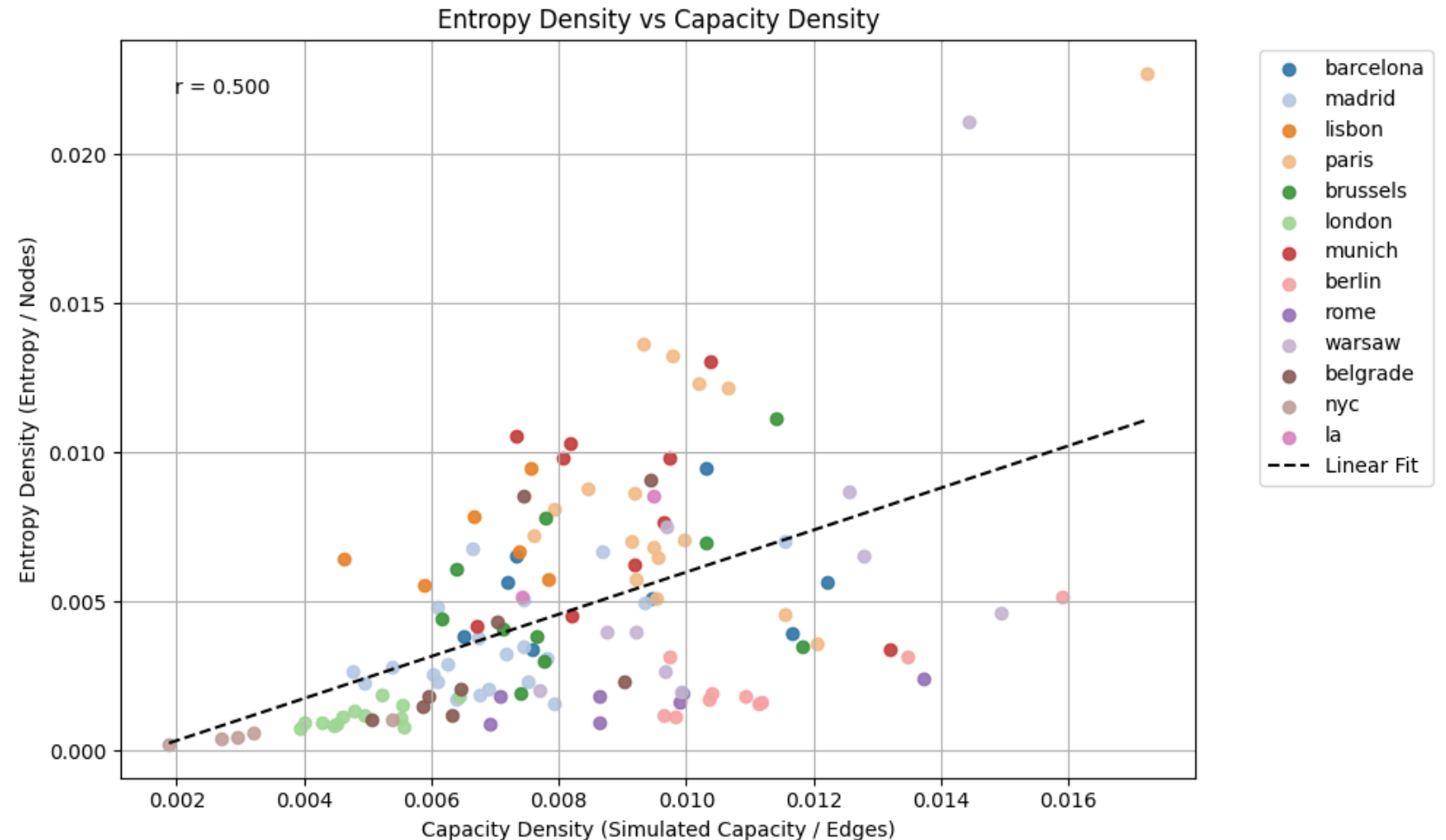
Safety simulations:

- Traffic scenarios from capacity simulation were used.
- 5% of missions had an RTL/loss of adherence for each run.
- Final result is average number of conflicts over 200 runs.

Capacity Results – Using Entropy

There is a plausible relationship

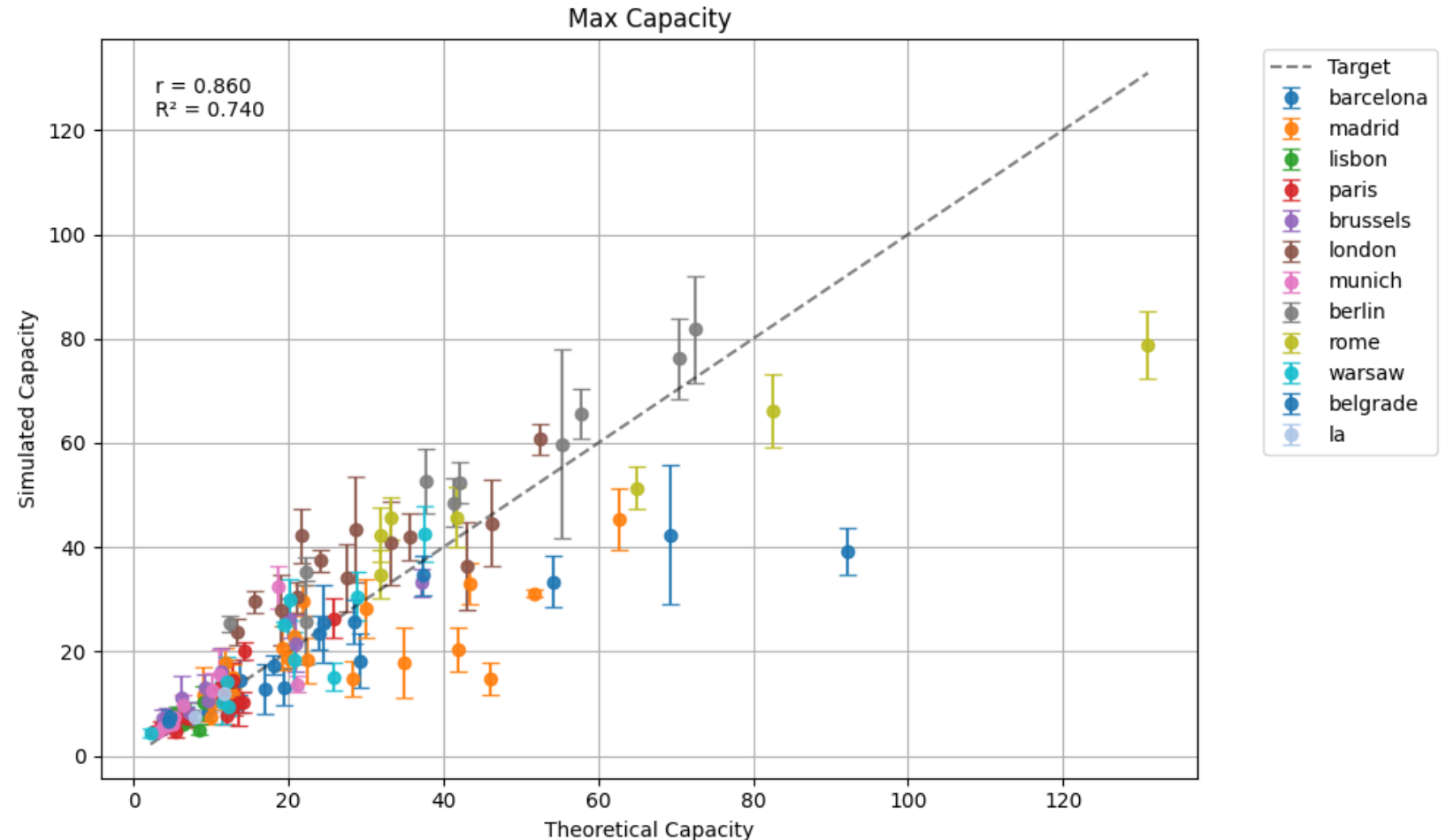
Better models are needed to explain the variance



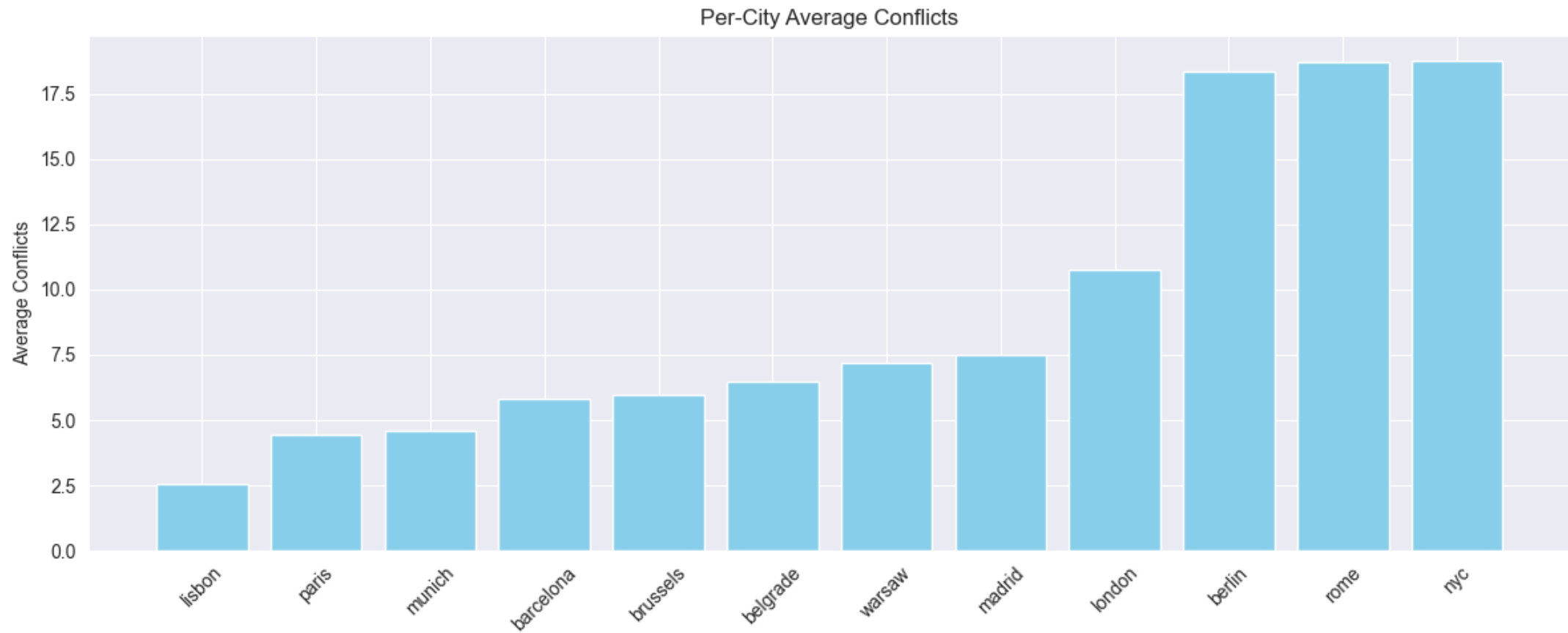
Capacity Results – Using Capacity metrics

Stronger
correlation

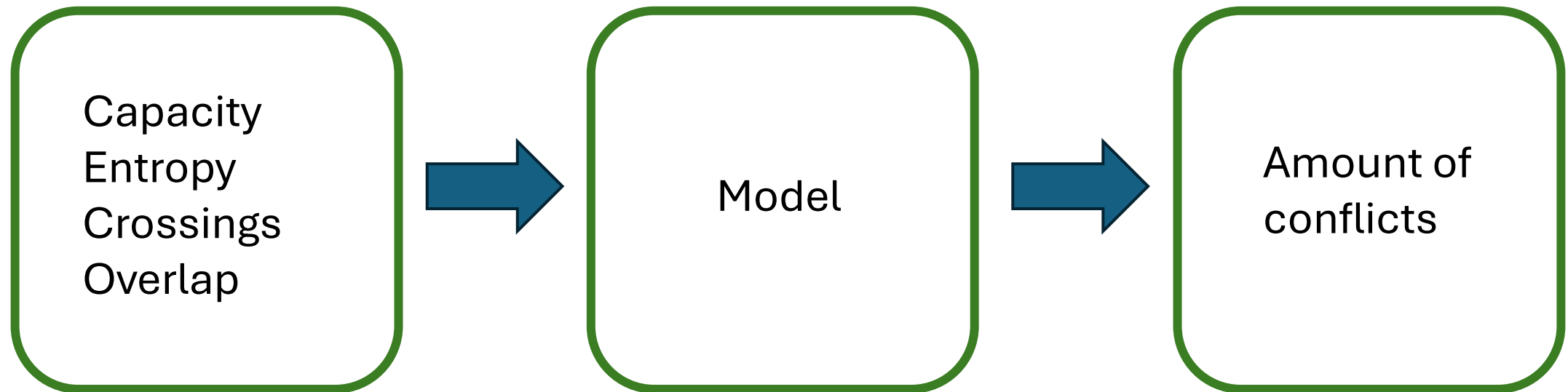
Higher
uncertainty for
larger values



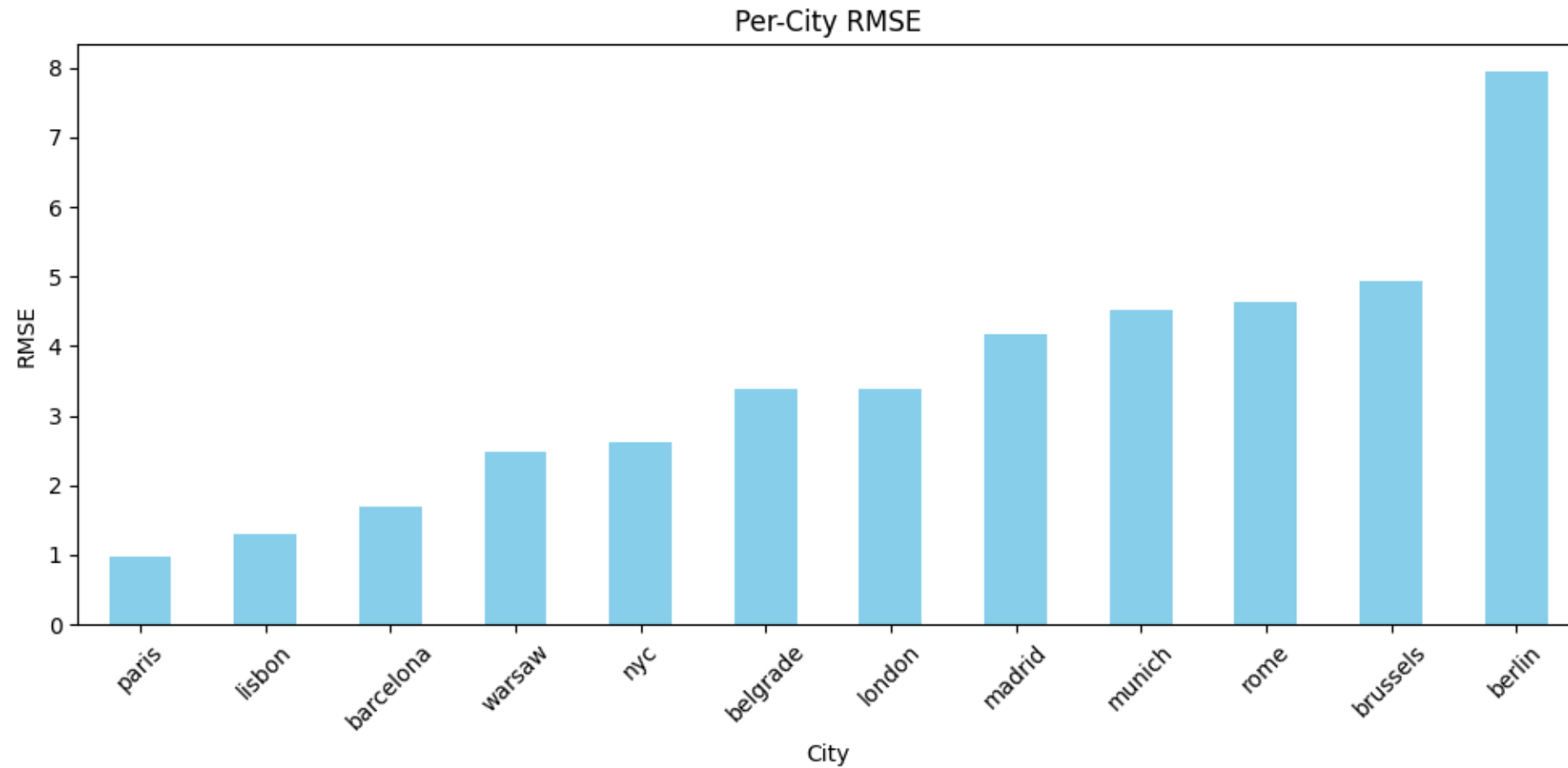
Safety Results



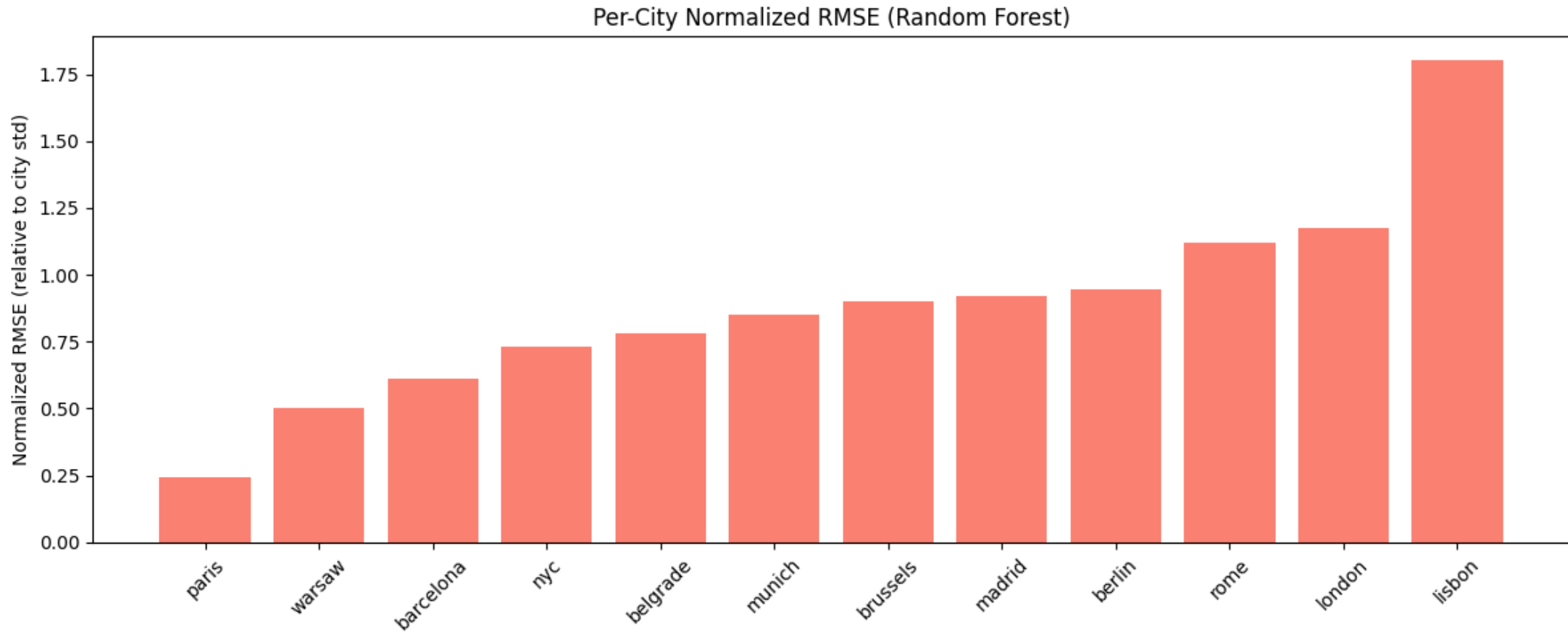
Safety Results



Safety Results



Safety Results



Conclusion and Discussion

- The capacity metric seems to perform well. Could be used to determine maximum load of the airspace.
- Safety is far more difficult to replace with a single metric and still requires simulations. RTL pretty much guarantees a conflict. Dedicated contingency corridors and services could mitigate their impact.
- How can we improve our analysis of the simulation results? Is there any scenario that should be studied more thoroughly?

References and sources

- [1] Emmanuel Sunil, Jacco Hoekstra, Joost Ellerbroek, Frank Bussink, Dennis Nieuwenhuisen, et al.. Metropolis: Relating Airspace Structure and Capacity for Extreme Traffic Densities. ATM seminar 2015, 11th USA/EUROPE Air Traffic Management R&D Seminar, FAA & Eurocontrol, Jun 2015, Lisboa, Portugal. hal-01168662
- [2] Mowshowitz, A., & Dehmer, M. (2012). Entropy and the Complexity of Graphs Revisited. *Entropy*, 14(3), 559-570. <https://doi.org/10.3390/e14030559>
- [3] Muñoz-Gamarra, J.L., Ramos, J.J., Liu, Z., \& Sobejano, A. Impact of USSPs performance in shared U-space volumes.
- [4] <https://www.coolmathgames.com/es/blog/la-historia-de-snake-el-juego>

Thank you for listening!

Questions, doubts and feedback would be appreciated!