TERRITORI APERTI

Definition of an enriched GIS network for evacuation planning

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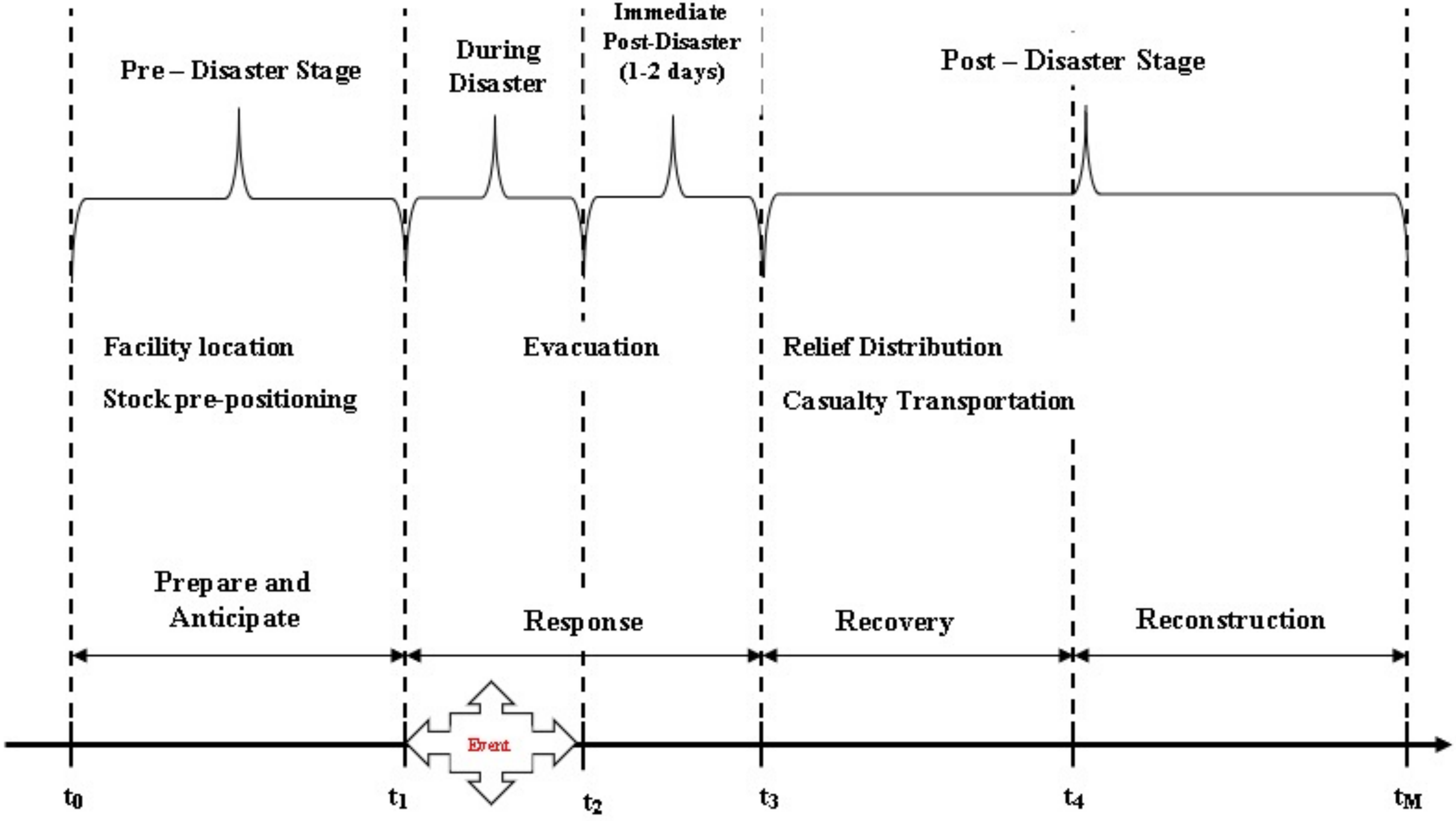
Introduction

- This paper leverages on two-steps modeling framework adopted for emergency evacuation planning
  - A method that extracts from an enriched GIS data a network description of the area to be evacuated.
  - A dynamic optimization model that evaluates the minimum time necessary to evacuate maximum people from an endangered zone/area to a pre-identified safe locations.
- Every year, more than 500 disasters are estimated to strike our planet, killing around 75,000 people and impacting more than 200 million others.
- L’Aquila earthquake in 2009

Disaster Management

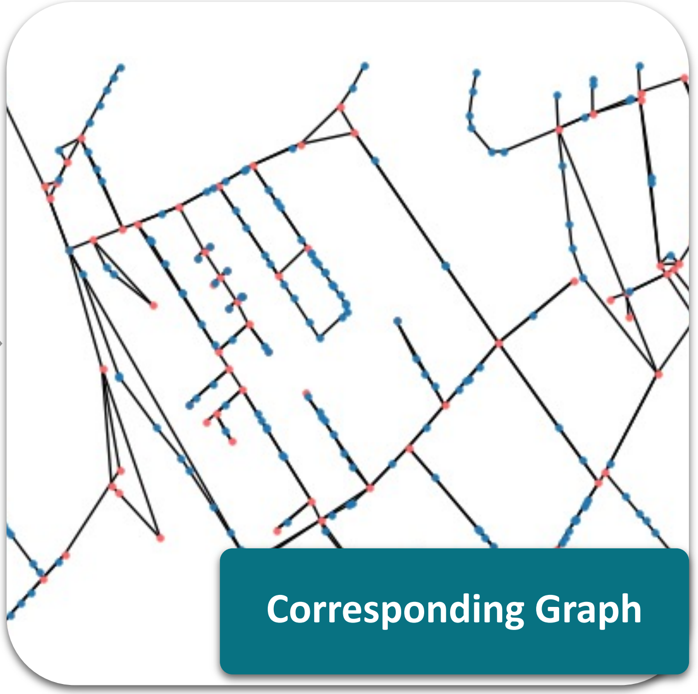


Network Definition

Extracting geographical data of the area to be evacuated in order to model it into a network

Google Earth Map

Shapefiles



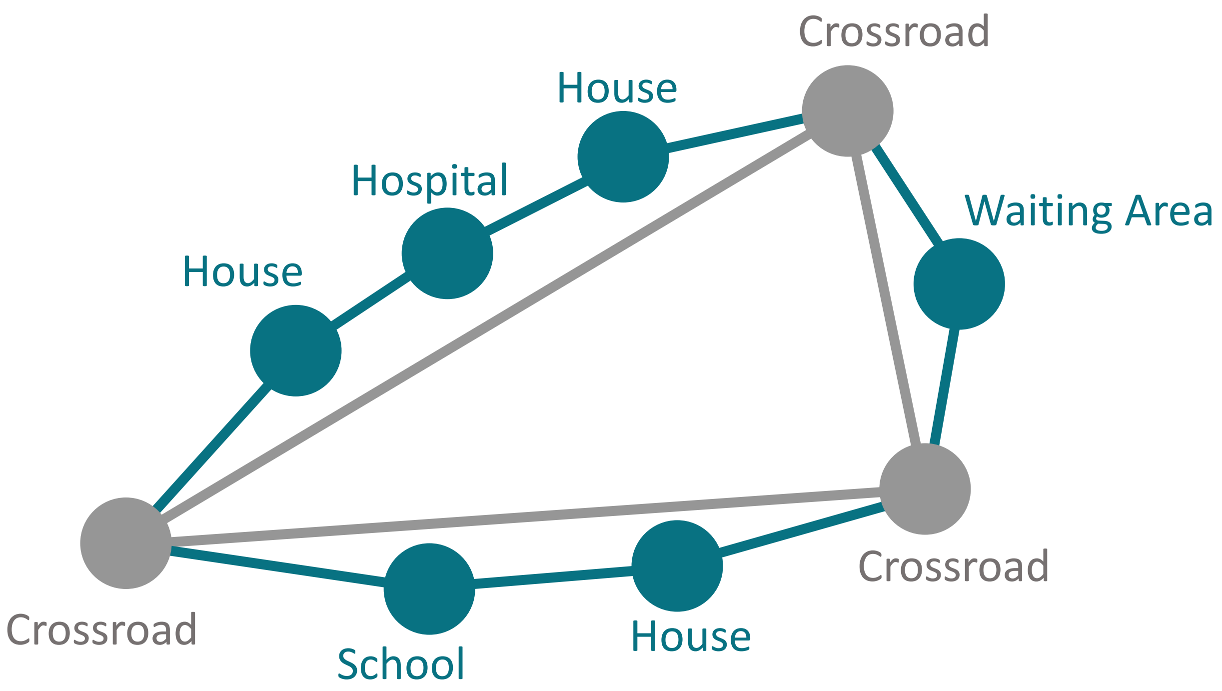
Corresponding Graph

Network Definition

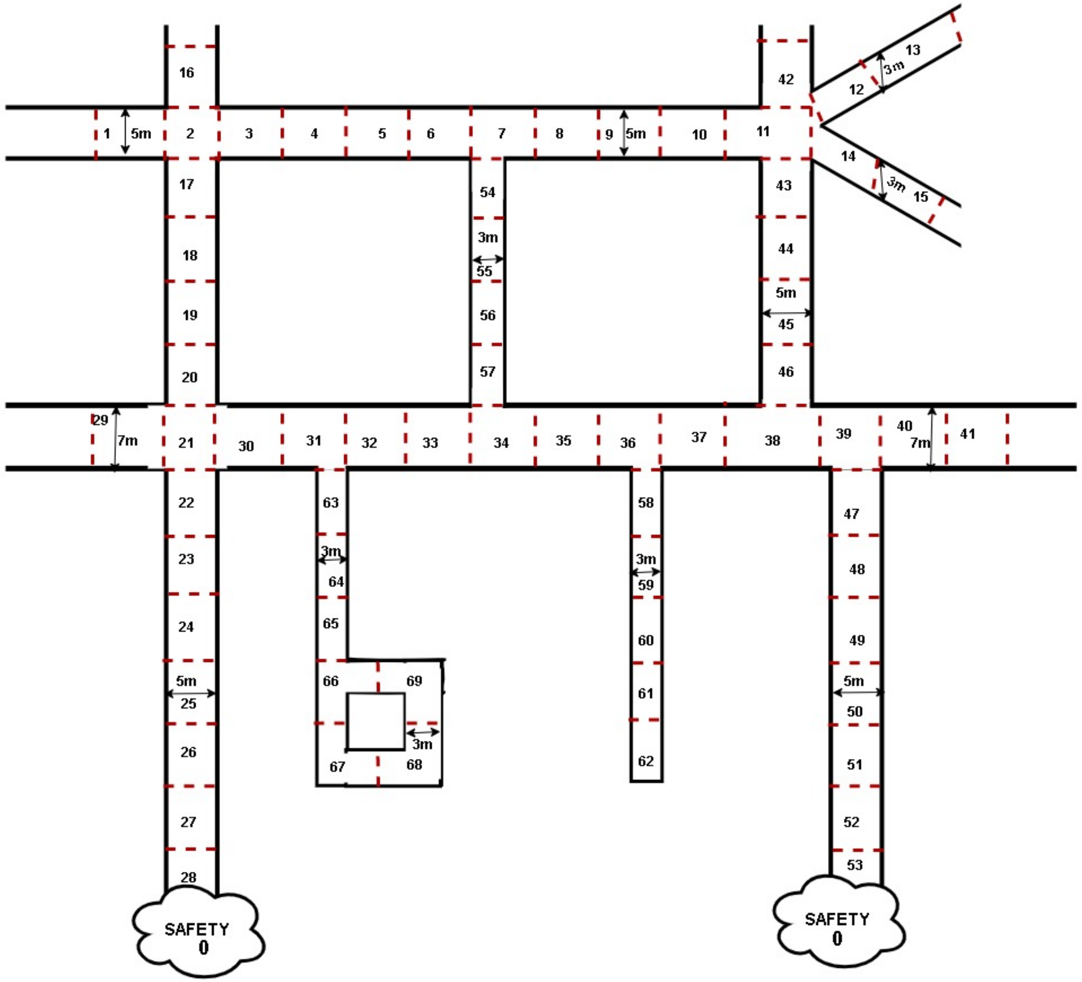
Network Definition

$G_D = (V, E) = (V_B \cup V_C \cup V_{WA}, E_S \cup E_{HS})$ where

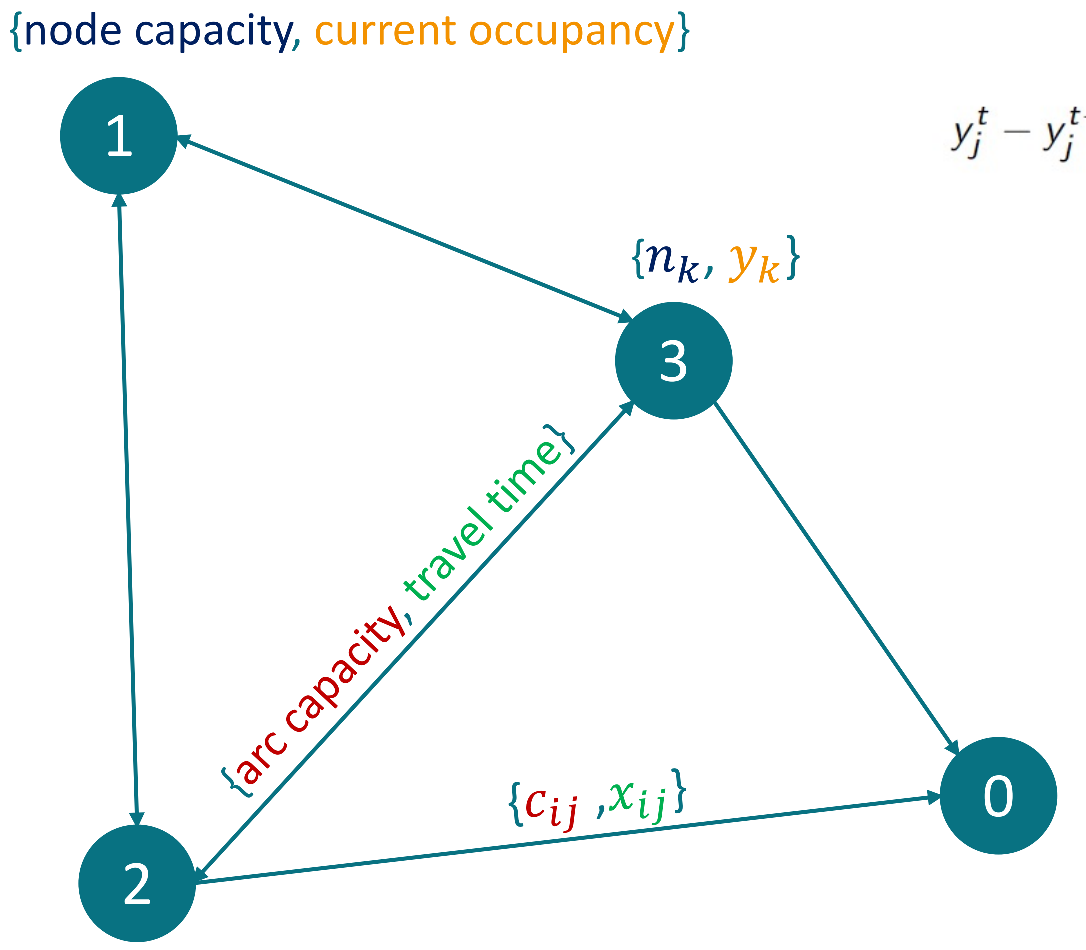
- V are the nodes:
  - V_C are the crossroads,
  - V_B are the buildings,
  - V_{WA} are the waiting areas
- E are the edges:
  - E_S are the streets
  - E_{HS} are the half-streets



Generating the Dynamic network for evacuation plan



Dynamic Model and Parameters



$$\max \{y_0^T\}$$

$$y_j^t - y_j^{t-1} - \sum_{i:ij \in A} x_{ij}^{t-1} + \sum_{i:ji \in A} x_{ji}^{t-1} = 0, \quad j \in V, t \in T, t > 0$$

$$0 \leq x_{ij}^t + x_{ji}^t \leq c_{ij}, \quad \forall (ij) \in A, t \in T$$

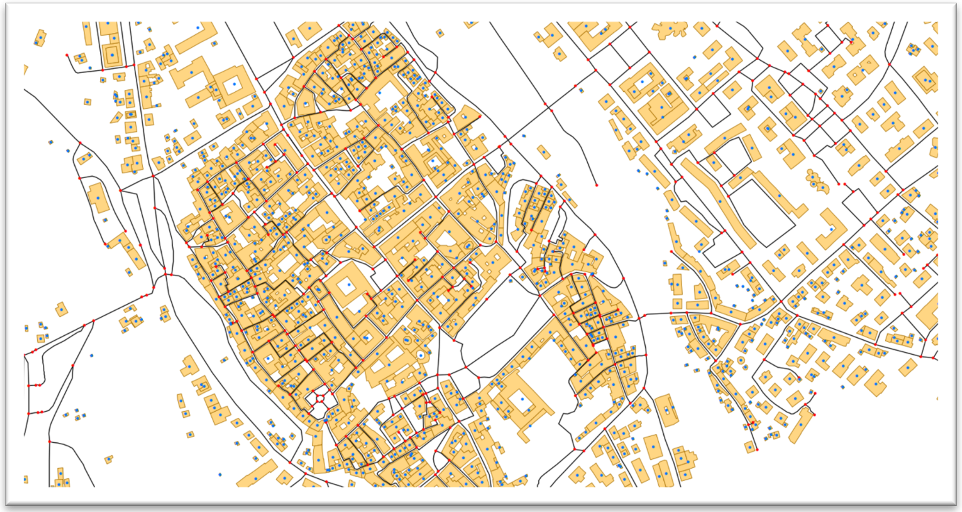
$$0 \leq y_i^t \leq n_i, \quad \forall i \in V, t \in T$$

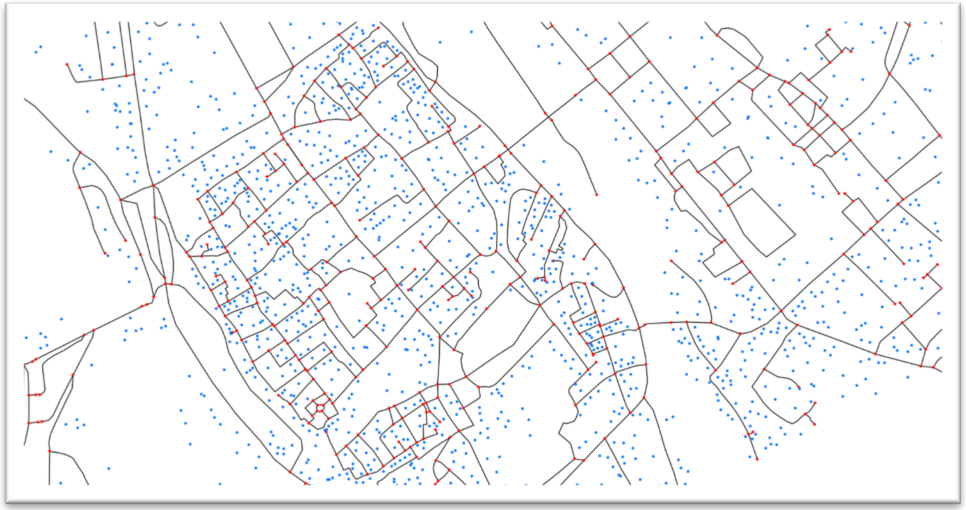
Setting model parameters

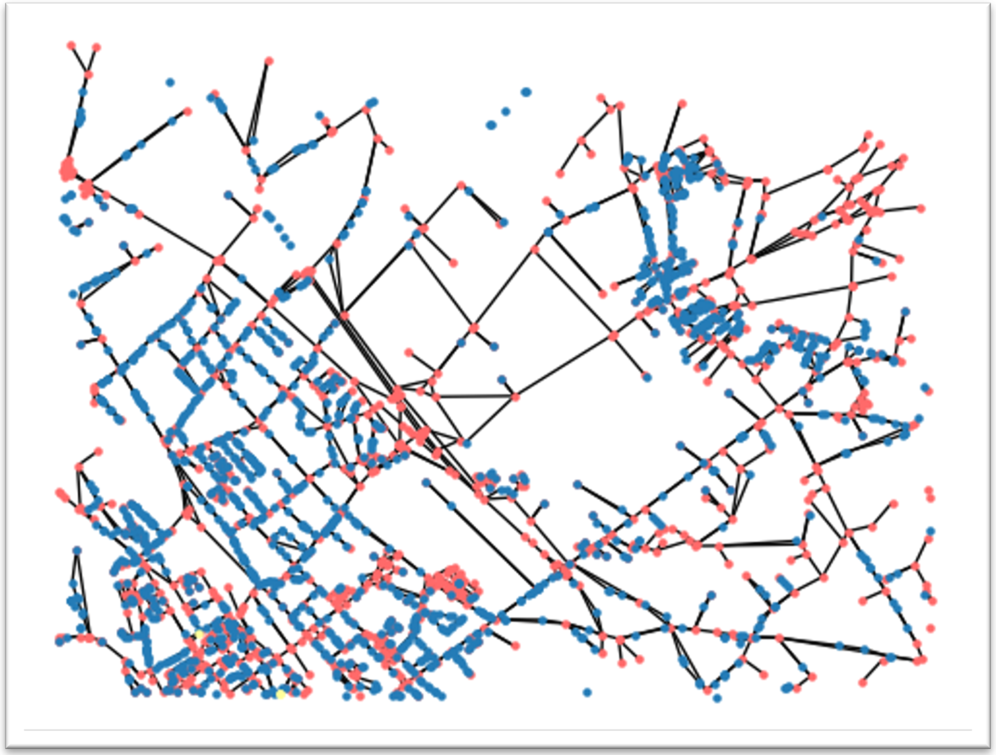
To get a reliable model, parameters were set to numbers that reflect reality in literature.

Parameters	Value
Model Granularity	Rectangular Grid
Walking Velocity	1.0 m/s
Cell Capacity	0.5 sq meters per evacuee
Street Capacity	1.8 persons per second per 1-meter door width

Experiments – Application to Sulmona



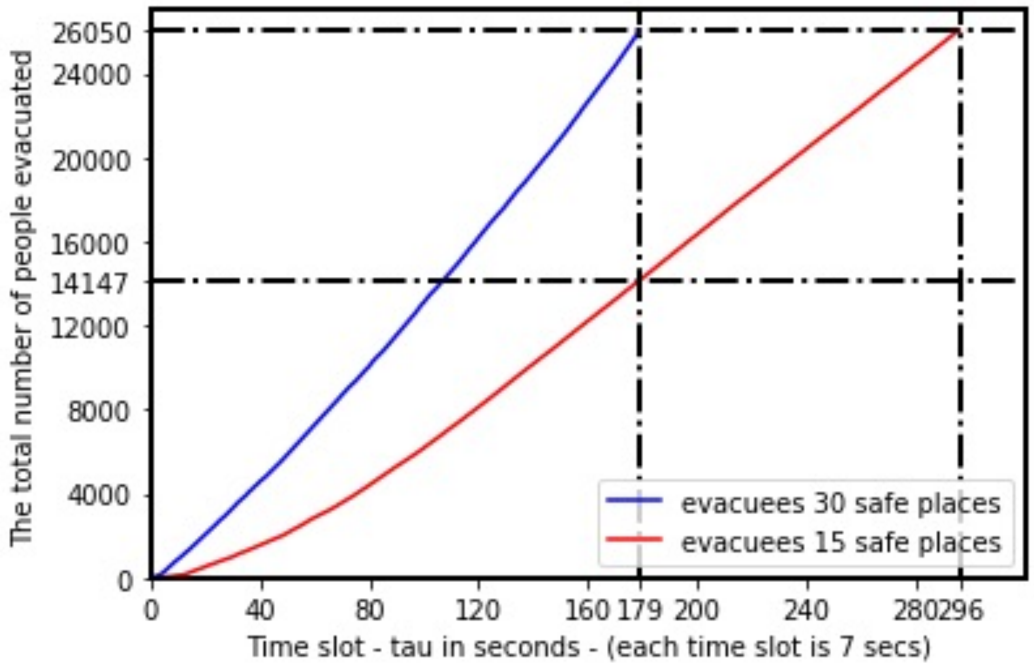




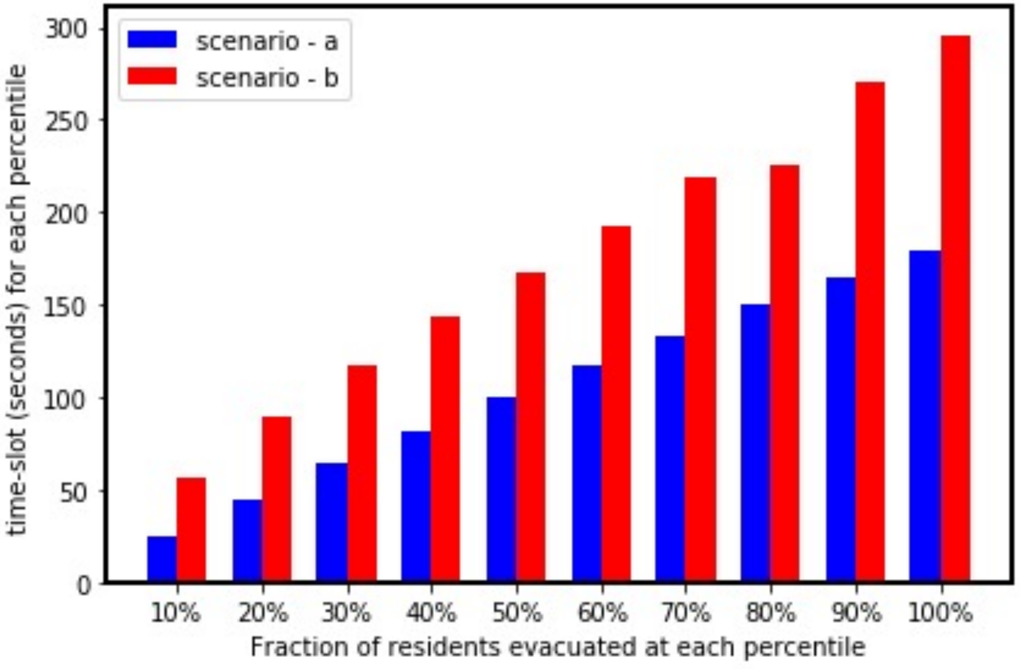
Experiments – Application to Sulmona

- We run the dynamic flow model to safely evacuate people from Sulmona in a case of a disaster.
- The cross-roads network was used with ***920*** junctions and ***1162*** interconnecting streets.
- The embedding resulted in a graph with ***12675*** nodes corresponding to the cells and including super sink node ***0*** as safe place.
- Adjacent cells were linked by ***25892*** arcs which allowed people traverse cells.
- Each unit time slot was obtained as ***7*** seconds
- Finally, we run the simulation with **26050** people randomly distributed in cells.

Results

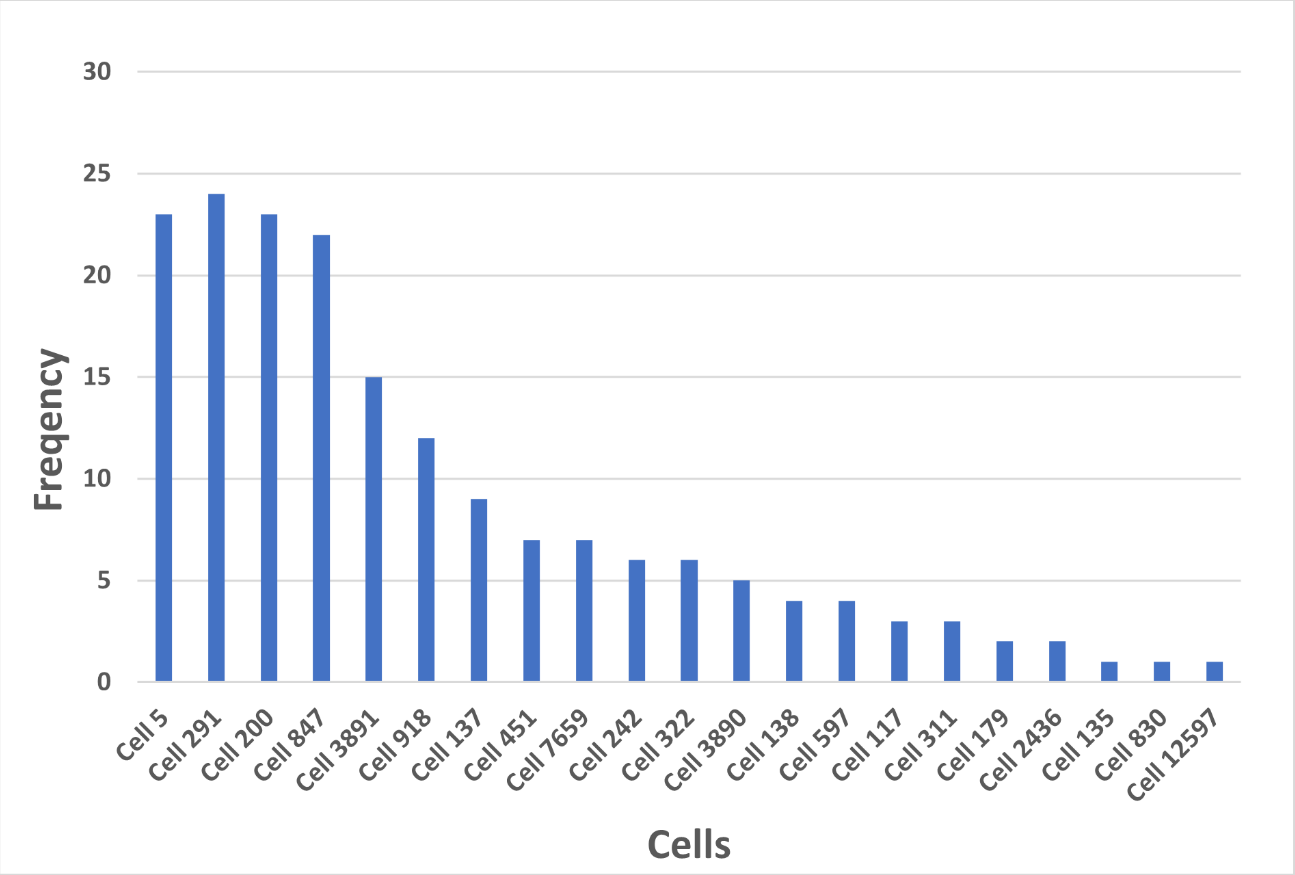


Total time taken to evacuate various fractions/portions of total evacuees for each scenario.



Total number of evacuees at each time slot for two scenarios - (a) 30 safe areas and (b) 15 safe places.

Results



The number of times a cell has the maximum capacity in all the time slots.

Conclusion

The contribution of this paper was threefold:

- The definition of a new algorithm able to generate an enriched network from GIS data, specifically tailored to include useful information for emergency management
- The adaptation of the optimization model developed by [1] to outdoor scenarios, that is the evacuation plan of a city in case of natural disaster;
- The validation of the previous step to a real case study, i.e., the historical center of Sulmona city in Italy.

[1] Arbib, C., Moghaddam, M. T., and Muccini, H. (2019). Iot flows: a network flow model application to building evacuation. InA View of Operations Research Appli-cations in Italy, 2018, pages 115–131. Springer

Future work

We plan to extend both the network construction and the optimization model in order to manage more real situations.

- Working to make more general the network to use it in other relevant problems, such as pre- and post-disaster facilities planning, and post-disaster reconstruction planning
- A more reliable estimation of people in a building.
- For the optimization model, we aim to add the congestion that will approximate the non-linearity of the arc capacities.
- Finally, we aim to make a trade-off analysis between the number of safe places and the total evacuation time.

THANK YOU FOR YOUR ATTENTION

ANY QUESTIONS?

Dynamic Model

- Following closing the CTM developed by [1, 2] the area to be evacuated is partitioned into cells embedded into an appropriate grid to get the graph $G = (V, A)$
- Nodes have 2 parameters: current population and maximum capacity
- Edges also have 2 parameters: capacity and travel time
- Model Parameters
    - $T = \{0,1,\ldots,\tau\}$:= the unit time slots
    - n_i:= capacity of cell *i*
    - c_{ij}:= capacity of arc $ij \in A$
    - y_i^t:= state of cell $i \in V$ at time $t \in T$
    - x_{ij}^t:= the flow that leave cell *i* at time *t* and reach adjacent cell *j* at time *t+1*
    - q_i:= initial number of evacuees in any cell

$$\max \{y_0^\tau\}$$

$$y_j^t - y_j^{t-1} - \sum_{i:ij\in A} x_{ij}^{t-1} + \sum_{i:ji\in A} x_{ji}^{t-1} = 0, \quad j \in V, t \in T, t > 0$$

$$0 \leq x_{ij}^t + x_{ji}^t \leq c_{ij}, \quad \forall (ij) \in A, t \in T$$

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