Agent-based Probabilistic Tsunami Evacuation Modeling and the potential future EPOS integration

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Introduction

Timely evacuation is the most effective measure to reduce tsunami fatalities, making the coastal populations' evacuation capability a key factor to assess during major events. Agent-based modeling is a multidisciplinary simulation approach that can simulate human responses to tsunami inundation.

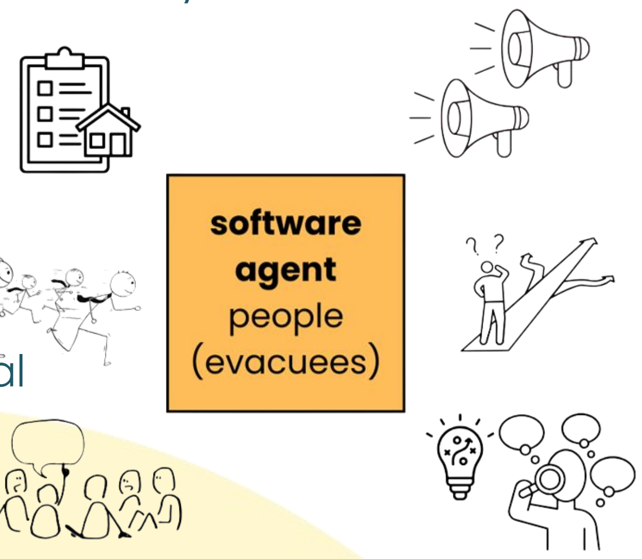
In this approach, evacuees interact with their inundated environment based on predefined rules that replicate complex real-world behaviors.

Our simulation model, built on the GAMA platform (Taillandier et al., 2018), integrates geospatial, demographic, and social data into a high-resolution digital framework. It incorporates detailed tsunami simulation scenarios derived from site-specific PTHA results using various DDSS from TCS Tsunami. Results from execution of selected scenarios with simple human behavior (baseline model) show that tsunami scenario parameters such as magnitude and tsunami impact (e.g., flow depth), can significantly influence the probability of safe evacuation.

Methodology

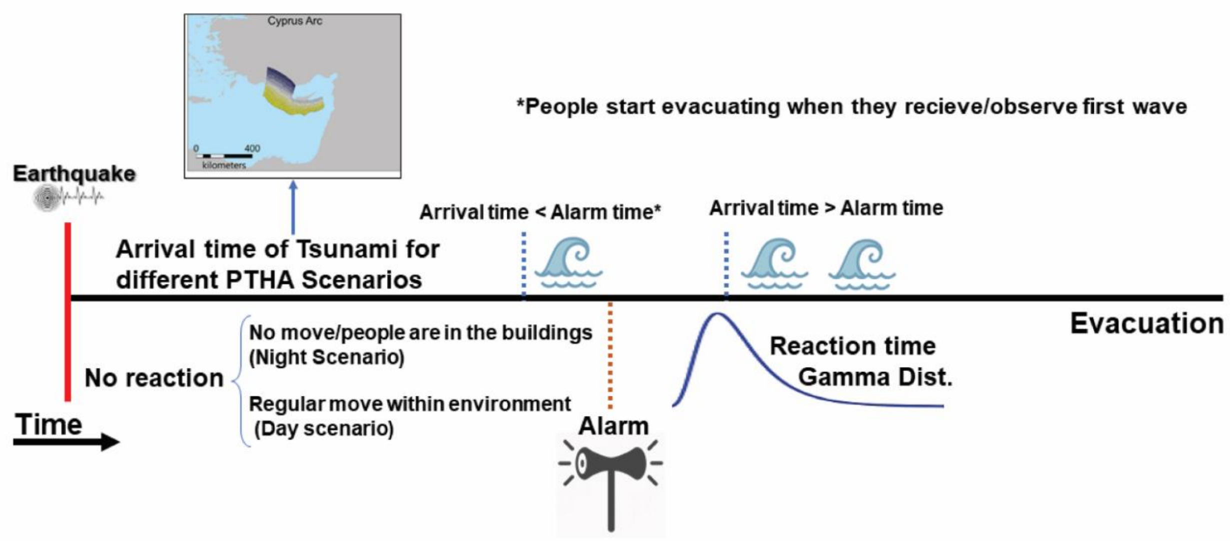
This study presents a probabilistic simulation-based framework for evacuation modeling in GAMA open-source platform optimized for large-scale agent-based simulations. GAMA features a high-level programming language, built-in GIS support, and BDI (Belief-Desire-Intention) core for human behavior modeling.

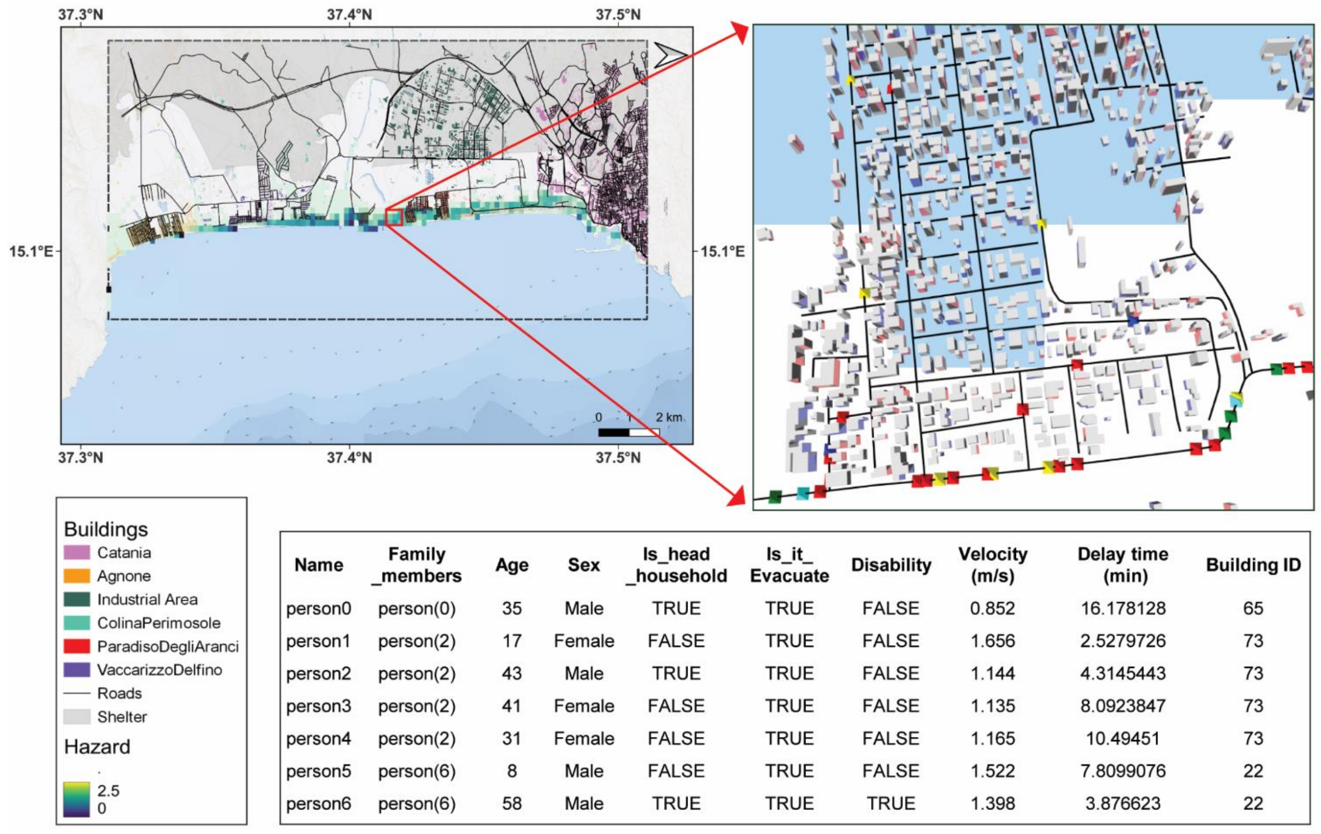
In GAMA, human Agents possess characteristics (age, speed, household type,..), perform actions (running, walking, freezing,..), communicate to each other, process environmental cues (e.g., sirens), and adapt behaviors based on immediate stimuli or long-term goals.



Agent Based modeling in eastern Sicily

Agent-Based Modeling in Eastern Sicily followed four key steps: **Input Parameters:** High-resolution digital evacuation model incorporating building and road exposure, Shelters(Tonini et al., 2021), site-specific PTHA scenarios(Gibbons et al., 2020), and human exposure and behavioral models sampled from surveys, literature, and statistical databases. **Modeling & Interaction:** Definition and diagrams illustrating agent behaviors and interactions. **Simulation Execution:** Dynamic simulation runs based on input parameters. **Validation:** Expert assessments, literature reviews, and past event data verification.





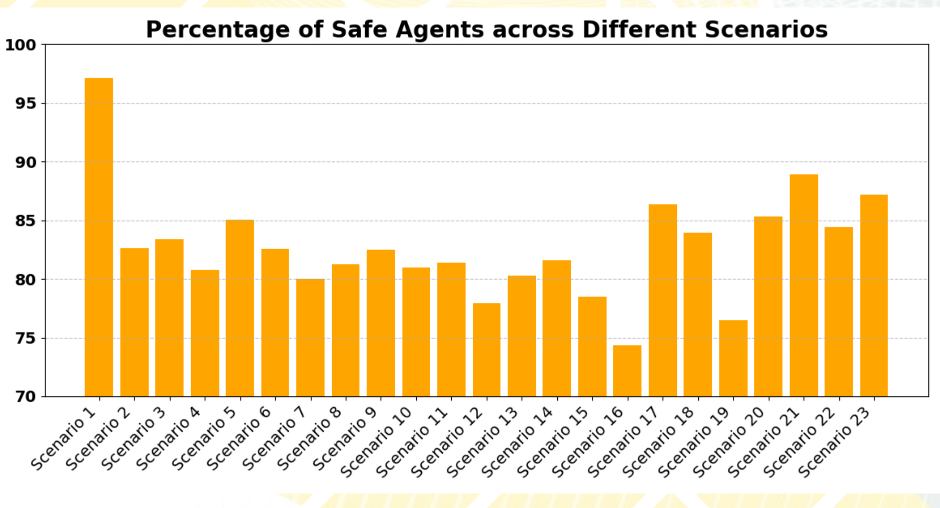
Name	Family _members	Age	Sex	Is_head _household	Is_it_ Evacuate	Disability	Velocity (m/s)	Delay time (min)	Building ID
person0	person(0)	35	Male	TRUE	TRUE	FALSE	0.852	16.178128	65
person1	person(2)	17	Female	FALSE	TRUE	FALSE	1.656	2.5279726	73
person2	person(2)	43	Male	TRUE	TRUE	FALSE	1.144	4.3145443	73
person3	person(2)	41	Female	FALSE	TRUE	FALSE	1.135	8.0923847	73
person4	person(2)	31	Female	FALSE	TRUE	FALSE	1.165	10.49451	73
person5	person(6)	8	Male	FALSE	TRUE	FALSE	1.522	7.8099076	22
person6	person(6)	58	Male	TRUE	TRUE	TRUE	1.398	3.876623	22

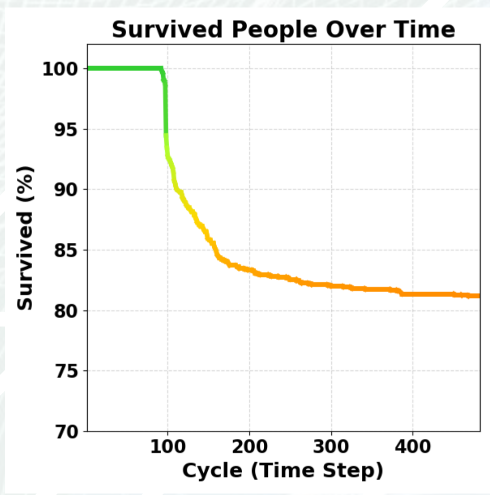
Results and Future Plans

The simulations are currently running under four conditions: nighttime/daytime, each with or without an alarm.

Preliminary results from selected PTHA scenarios, based on the baseline "nighttime/no alarm" case (Figure 4), suggest a possible influence of Tsunami magnitude and impact (e.g., flow depth) on probability of safe evacuation. However, to accurately estimate evacuation probability within the Probabilistic Tsunami Evacuation Analysis framework using Monte Carlo Simulation (Eq. 1), additional scenarios must be simulated.

$$P(E|I) = \int_{\Omega_\theta} P(E|\boldsymbol{\theta}, I)p(\boldsymbol{\theta}|\boldsymbol{I})d\boldsymbol{\theta} \approx \frac{\sum_{i=1}^{N} P(E|\theta_i)}{N} \quad eq.\ 1$$





Building on this work, future efforts will focus on expanding capabilities and further aligning with EPOS visions.

Key directions include:

- **Enhancing Cross-TCS Collaboration:** Integrating multi-hazard impacts such as earthquake-damaged buildings, debris-blocked roads, and bridges with impaired viability due to the damage by tsunami triggering events (e.g., earthquakes leading to tsunamis) within the ABM framework.
- **Potential ICS-D Use Case:** Establishing a tsunami evacuation modelling platform.
- **Vision for the Future:** Pioneering the development of a Digital Twin for Tsunami Evacuation, enabling real-time multi-channel data fusion, adaptive updating of the evacuation environment, predictive analytics, scenario planning, and dynamic decision-making to protect communities against tsunami threats.

References:

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Gibbons, S. J. et al. (2020) Probabilistic tsunami hazard analysis: high performance computing for massive scale inundation simulations. Front. Earth Sci. https://doi.org/10.3389/feart.2020.591549

Tonini, R. et al. (2021) Testing inundation maps for evacuation planning in Italy. Front. Earth Sci. 9, 628061, https://doi.org/10.3389/feart.2021.628061

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