Optimization for Community Resilience: Mitigation and Evacuation Planning under Multi-Hazard Risk

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Integrated building mitigation and evacuation

- Mitigation and evacuation decisions are highly interdependent.
- Poor mitigation can lead to increased evacuation demand, while inadequate evacuation planning can put pressure on mitigation efforts.
- Mitigation measures for buildings might not consider the capacity and condition of the local road networks.

Figure 1: Hazard evacuation zones [O.H. Hinsdale Wave Research Laboratory, Oregon State University]

Proposed framework for address mitigation and evacuation

Mitigation

Building-level mitigation

Minimize hazard impact

Evacuation Demand

Number of people to evacuate

Evacuation

Fair evacuation

Maximum evacuation

Figure 2: Representation of the model for mitigation and evacuation modeling

Objectives of the model: building mitigation

Objective functions:

- Minimize: Building value loss
- Minimize: Population dislocation
- Minimize: Building repair time and many more based on decision makers requirements.

$$\min \sum_{n \in N} \sum_{i \in Z} \sum_{k \in K} \varphi_{ik}^{n} x_{ik}$$

φ_{ik}^{n} = Impact of the natural hazards (e.g. economic loss, population dislocation, etc.)

x_{ik} = Decision variable for building retrofitting

Objectives of the model: evacuation planning

$$\min \sum_{a \in A} \sum_{d \in D} C_a \, f_{ansd}$$

Total travel distance

$$+ \sum_{n_s \in N_s} \sum_{d \in D} h^{+}_{nd} s^{+}_{nd}$$

Penalty of empty space

$$+ \sum_{d \in \mathcal{D}} \sum_{n_d \in N_d} s^{-}_{nd} g^{-}_{nd}$$

Penalty for not evacuating

$$+ \sum_{d \in \mathcal{D}} \sum_{i \in \mathcal{N}^s} \rho_{nd} \, \delta_{nd}$$

Penalty for not evacuating enough people

Constraints of the model

Constraints related to building mitigation:

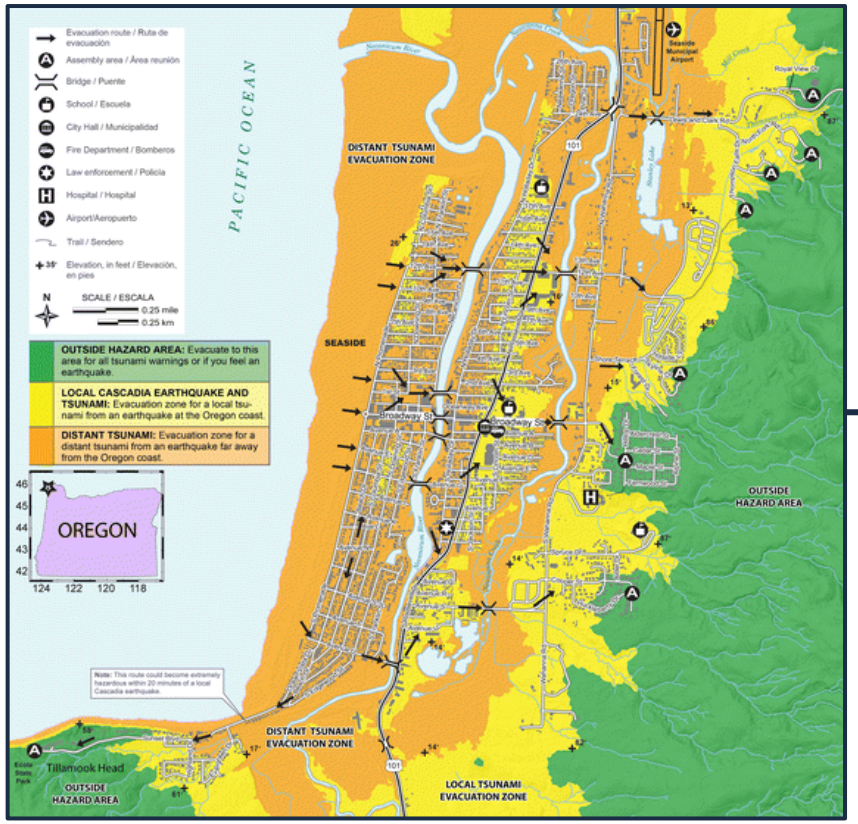
- Budget constraints
- Balance of buildings before and after retrofitting
- **Retrofitting feasibility constraints**

Constraints related to evacuation:

- Flow balance constraints
- Maximum travel distance constraints
- Transportation and evacuation capacity constraints
- Fair spatial distribution constraints

Constraints to calculate the evacuation requirement after mitigation

Seaside, OR as an illustrative example



There are eight assembly areas that are located outside the inundation zone.

Figure 3: Representation of the evacuation zones with transportation network

Trade-off analysis of different objectives

Table 1: Different mitigation measures for retrofitting buildings

Option	Description	Targeted Hazard
0	Do nothing (status quo)	-
1	Retrofit structure to high-seismic code	Earthquake
2	Relocate structure	Tsunami
3	Relocate and retrofit to high-seismic code	Earthquake and Tsunami

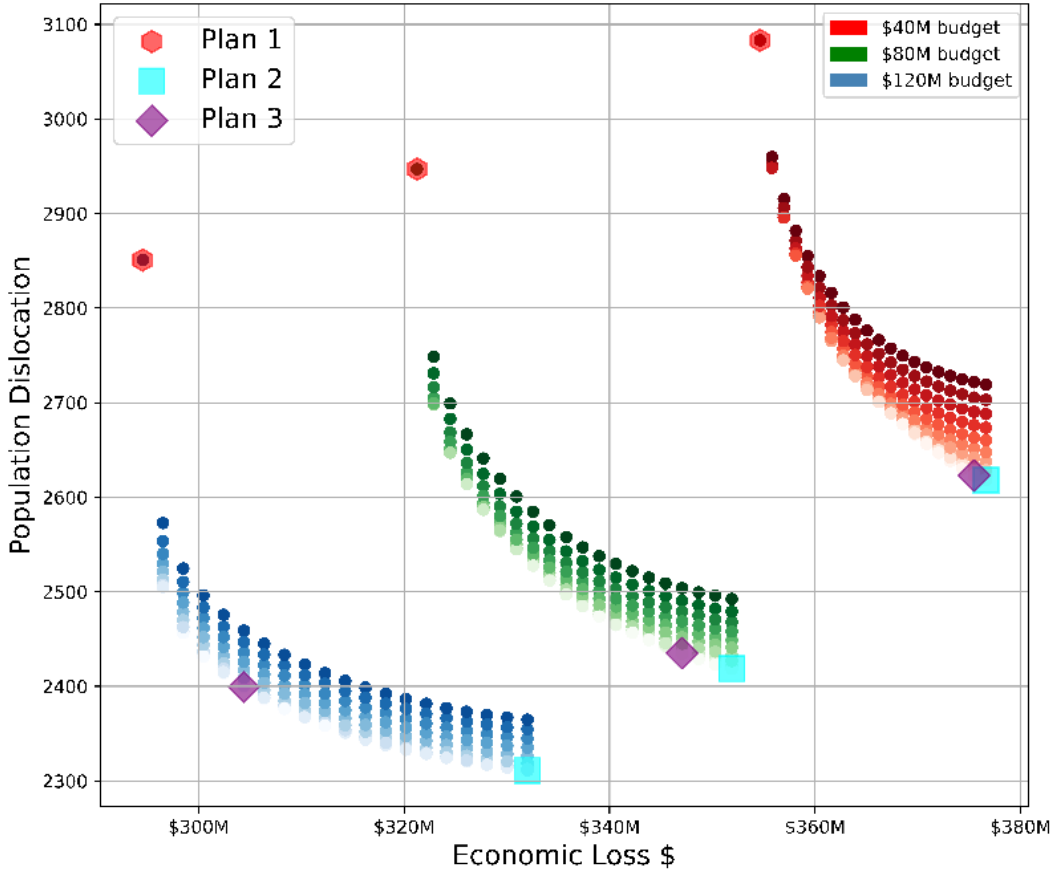


Figure 4: Pareto front of different objectives for building mitigation

Gupta, H.S., Adluri, T., Sanderson, D., González, A.D., Nicholson, C.D. and Cox, D., 2024. Multi-objective optimization of mitigation strategies for buildings subject to multiple hazards. International Journal of Disaster Risk Reduction, 100, p.104125.

Disruptions of the network due to the hazard impact

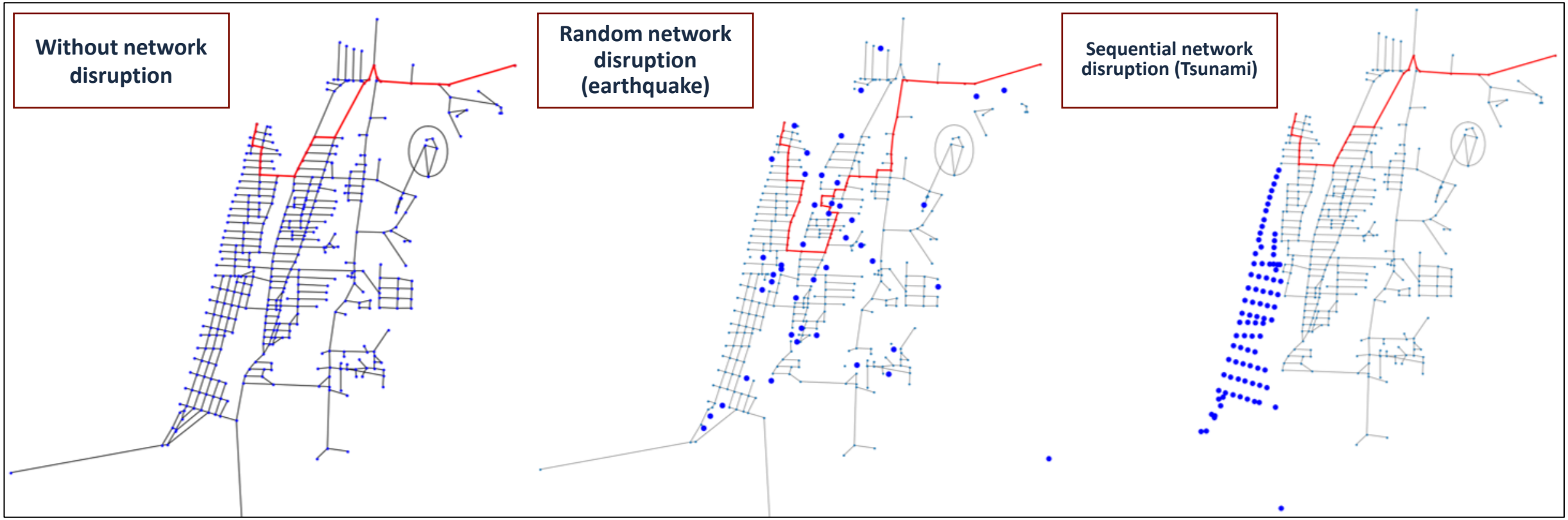


Figure 5: Example disruption scenarios (blue dots present disrupted node, red line present optimal evacuation route)

Gupta, H. S., Gonzalez, A.D., Jnad, R. and Kameshwar, S., 2024. Fairness-Driven Multi-Objective Optimization for Evacuation Planning in Natural Disasters. In International Conference on Transportation and Development 2024 (pp. 170-180).

Closing remarks and way forward

Prioritization of building mitigation based **on societal importance**.

Consideration of **fairness and equity** among social groups for allocation of resources for mitigation.

Consider **traffic congestion and blocked roads**, which would increase the overall distance and time required for the evacuation.

Human **behavior and social factors**.

THANK YOU

QUESTIONS?

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"While natural disasters capture headlines and national attention short-term, the work of recovery and rebuilding is long-term." - **Sylvia Mathews Burwell**