Analyzing Interdependent Critical Infrastructure in Post Earthquake Urban Reconstruction

Saeed Nozhati

June, 2018
Motivations

✓ Develop a framework to guide the management of community recovery following disasters.

✓ The framework must support policymakers with computing optimal or near-optimal recovery strategies.

✓ The framework must treat a community as a system of system and optimize several networks at the same time.
Properties of a *comprehensive* decision-making framework

- Treat different sources of uncertainties;
- Computationally manageable;
- Be able to consider multi-objectives and constraints;
- Look-ahead property.
Dynamic Programming

\[ x^*_1 \in \arg \min_{x_1} J_1 (x_1) \]

\[ J_1 (x_1) = \min_{x_2, \ldots, x_N} F(x_1, x_2, \ldots, x_N) \]

\[ \ldots \]

\[ x^*_k \in \arg \min_{x_k} J_k \left( x^*_1, x^*_2, \ldots, x^*_{k-1}, x_k \right) \]

where \( J_k \) is defined by recursion:

\[ J_k (x_1, x_2, \ldots, x_k) = \min_{x_{k+1}} J_{k+1} (x_1, x_2, \ldots, x_{k+1}) \]
Curse of Dimensionality

\[ M: \text{Damaged Comps.} \quad \prod_{i=0}^{K} \binom{M-i}{N} \quad \text{s.t.} \quad M - K > N \]

\[ N: \text{Resource of Units} \]

\[ M >> N \]
In the rollout approach, $J_k$ is approximated by a function that is more easily calculated and does not require excessive storage.

If $H_k(x_1, \ldots, x_k)$ denotes the corresponding approximately optimal value, the rollout algorithm obtains a suboptimal solution by replacing $J_k$ with $H_k$:

$$\tilde{x}_k \in \arg \min_{x_k} H_k (\tilde{x}_1, \ldots, \tilde{x}_{k-1}, x_k)$$
How to define the base heuristic $H_k$?

- The current recovery policy of regionally responsible public and private entities;
- The importance analyses;
- The greedy algorithms;
- A random policy without any pre-assumption.
The total number of people benefiting from the network once \( \kappa_i \) is implemented.

Denote the total time elapsed between completion of repair action \( \kappa_{i-1} \) and \( \kappa_i \).

\[
F_2(X) = \frac{1}{k_{\text{end}}} \sum_{t=1}^{t_{\text{end}}} h_i \times k_i
\]

\[
X^*_2 := \arg \max_{X \in \Omega} F_2(X)
\]
Base heuristic vs. Rollout algorithm (EPN):
**Smart Base heuristic vs. Rollout algorithm (EPN):**

![Graph showing comparison between Base Heuristic, Rollout with 1-step Heuristic, and Rollout with N-step Heuristic over time. The x-axis represents time in days, and the y-axis represents the number of people with electricity.]
Smart Base heuristic vs. Rollout algorithm (WN):
Base heuristic vs. Rollout algorithm (EPN + WN):
Conclusion

✓ Rollout has the mentioned paramount properties;

✓ Rollout can adopt and improve different base heuristics and current entities’ policies;

✓ Rollout is adaptable to other infrastructure systems and hazards.
ACKNOWLEDGEMENTS

• Professor Bruce R. Ellingwood (Advisor)
• Professor Hussam N. Mahmoud (co-advisor)
• Professor Edwin K.P. Chong
• Professor John W. van de Lindt