Introduction

- Post-disaster restoration planning for a water supply system is important but very difficult.

- Difficulties in restoration planning:
  1. Situation awareness in dynamic and uncertain situation
     → Technical problem
  2. Prioritization in restoration process
     → Socio-technical problem

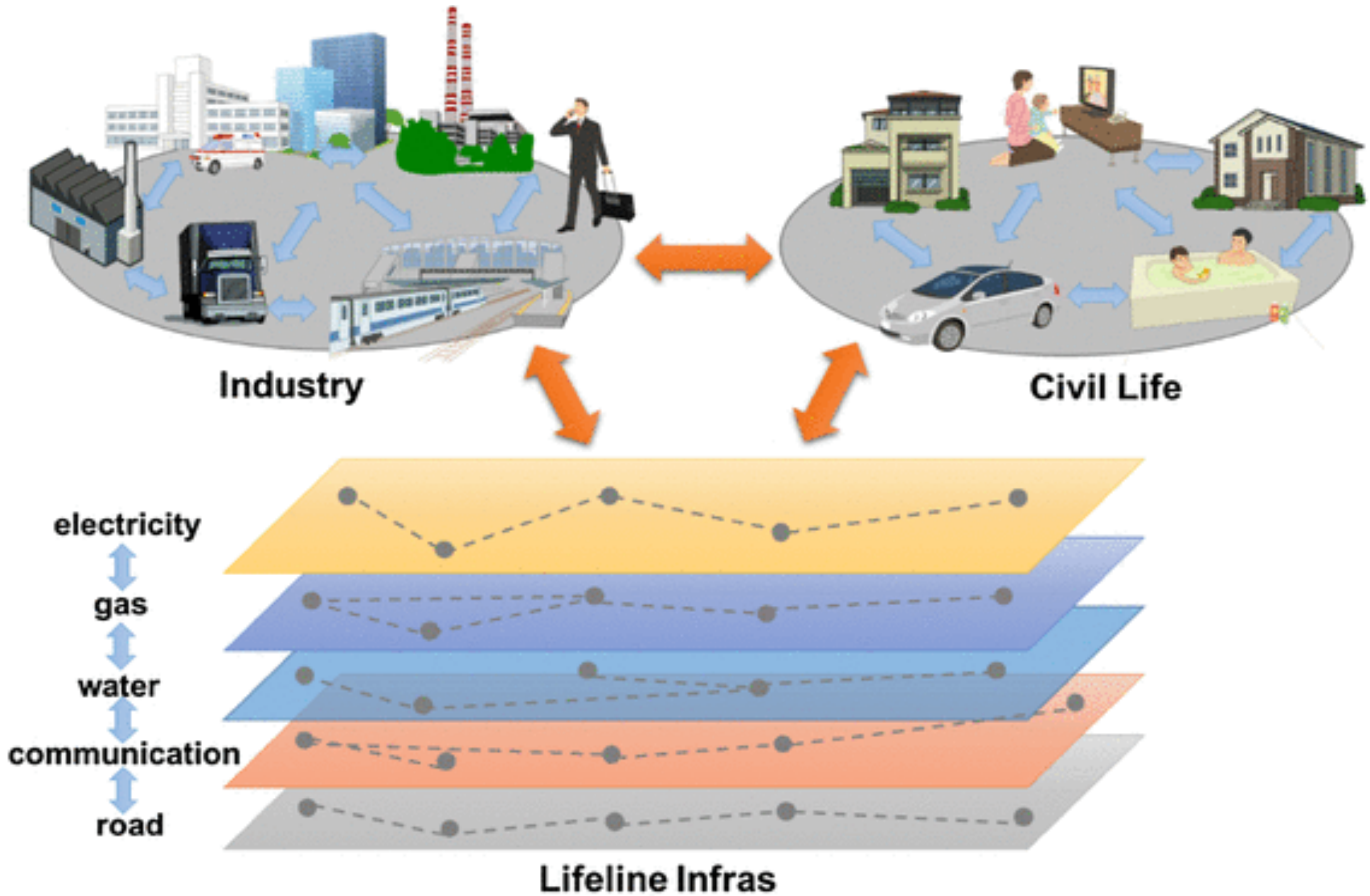
- Great need for a high-fidelity simulation of water supply system restoration for testing and comparing various prioritizations

Objective

1. To develop a high-fidelity simulation of water supply system restoration
   - Considering multiple interdependencies underlying urban systems
   - Implementing a realistic restoration task
   - Considering hydrodynamic behavior of water distribution system
   - Using the actual city data

2. To apply this simulation to practical decision-making support
   - Restoration planning reflecting the priority in restoration process

Modeling Framework



[1] Kanno, T., Koike, S., Suzuki, T., & Furuta, K. (2018). Human-centered modeling framework of multiple interdependency in urban systems for simulation of post-disaster recovery processes. Cognition, Technology & Work, 1-16.

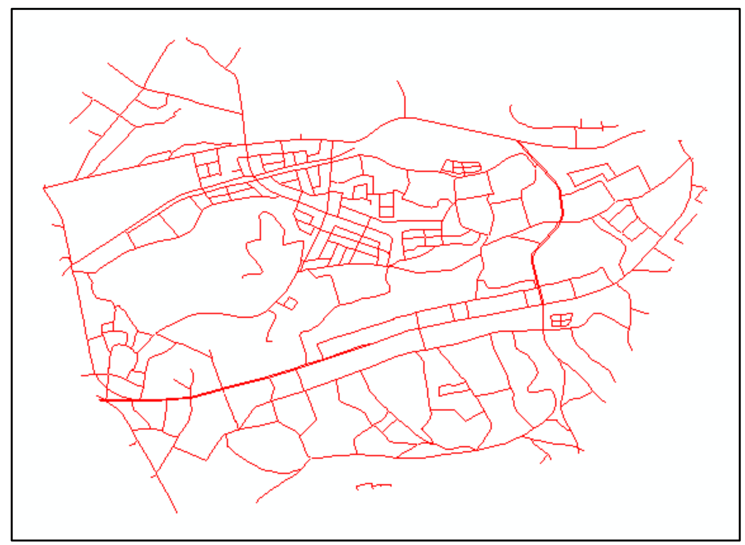
Multiple Interdependencies

		On		
		Civil Life	**Industry**	**Lifeline**
Dependence Of	**Civil Life**	1) Between civil life ● Means-ends ● Resource conflict ● Geographical	2) Civil life on industry ● Supply ● Geographical	3) Civil life on lifeline ● Supply ● Geographical
	Industry	4) Industry on civil life ● (Labor) Supply ● Geographical	5) Between industry ● Supply ● Demand ● Alternative ● Geographical	6) Industry on lifeline ● Supply ● Geographical
	Lifeline	7) Lifeline on civil life ● Demand ● (Labor) Supply ● Geographical	8) Lifeline on industry ● Demand ● Supply ● Geographical	9) Between lifeline ● Supply ● Demand ● Alternative ● Geographical

Simulation Model

- Agent-based model
  - Citizen: daily activity
  - Company: production process
  - Restoration Squad: restoration process

- Network model
  - Lifeline Infrastructures
  - Power grid, water supply, sewage, gas, road, waste disposal, telecommunication, etc.



Restoration Task

- Restoration procedure
  1. Get the resources for restoration from the warehouse
  2. Move to the damaged pipeline
  3. Repair by using the resources

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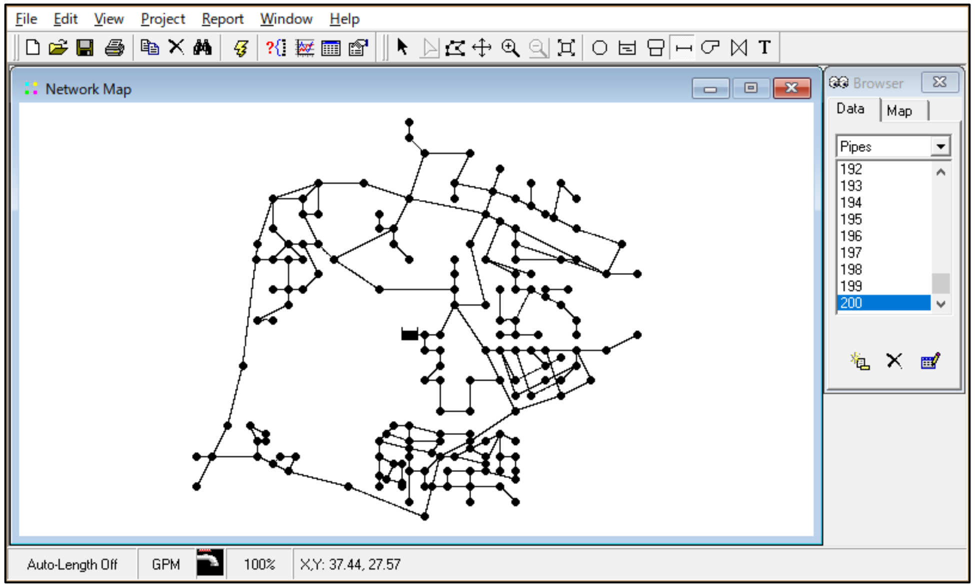
- Realistic restoration operations
  - Operate valves
  - Use a heavy machinery
  - Partition the affected area and repair in block units
  - Distribute water tank trucks
  - Receive the support from outside the city

Hydrodynamic Behavior

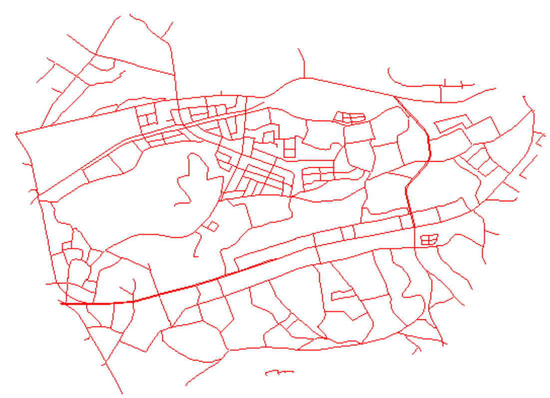
- Hydrodynamic Analysis API (EPANET)
  - Calculate the water demand, flow, pressure, and so on
  - Evaluate the water availability of each residence / company
  - https://www.epa.gov/water-research/epanet



City Model

- Target area under this study
  - Arao city
  - In Kumamoto prefecture, Japan
  - With a population of about 50,000 people

- City model considering:
  - Population and its distribution
  - Number of companies
  - Location of impportant facilities such as hospitals and evacuation centers
  - Road network topology from OSM
  - Water supply network topology



Optimization of Restoration Plan

- Genetic Algorithm (GA)
  - Chromosome: restoration plan
    - the order of restoration for damaged pipelines
    - the squad in charge of the restoration

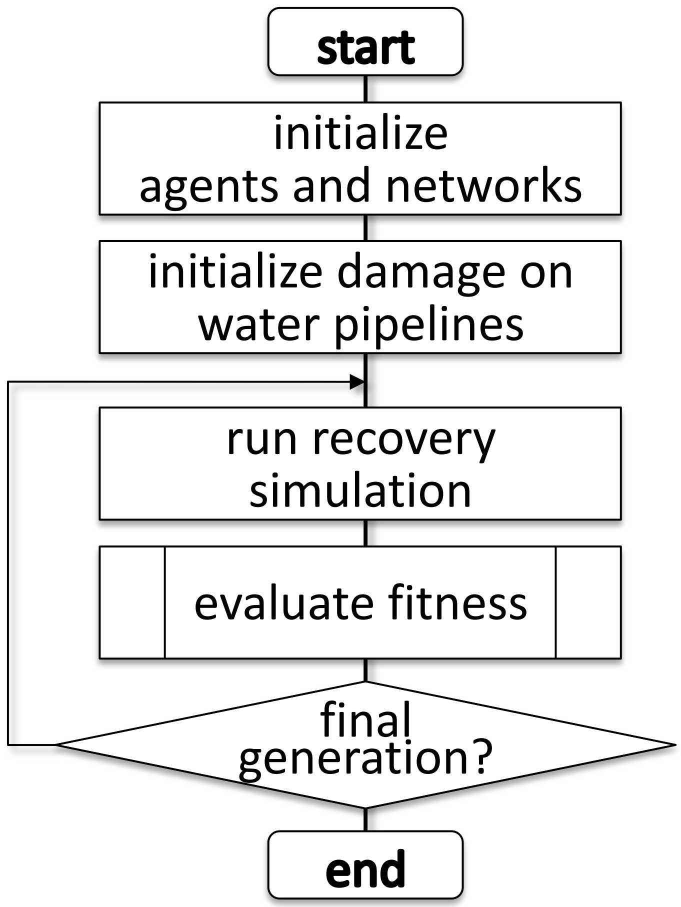
$$fitness = \alpha \times fitness_L + \beta \times fitness_I + \gamma \times fitness_C$$

$fitness_L$ $(Lifeline)$	Restoration rate
$fitness_I$ $(Industry)$	Operation rate
$fitness_C$ $(Civil\ Life)$	Quality of life

  - Weight coefficients (α, β, γ) = the priority of each subsystem

Simulation

- Simulation Procedure



- Simulation Setting

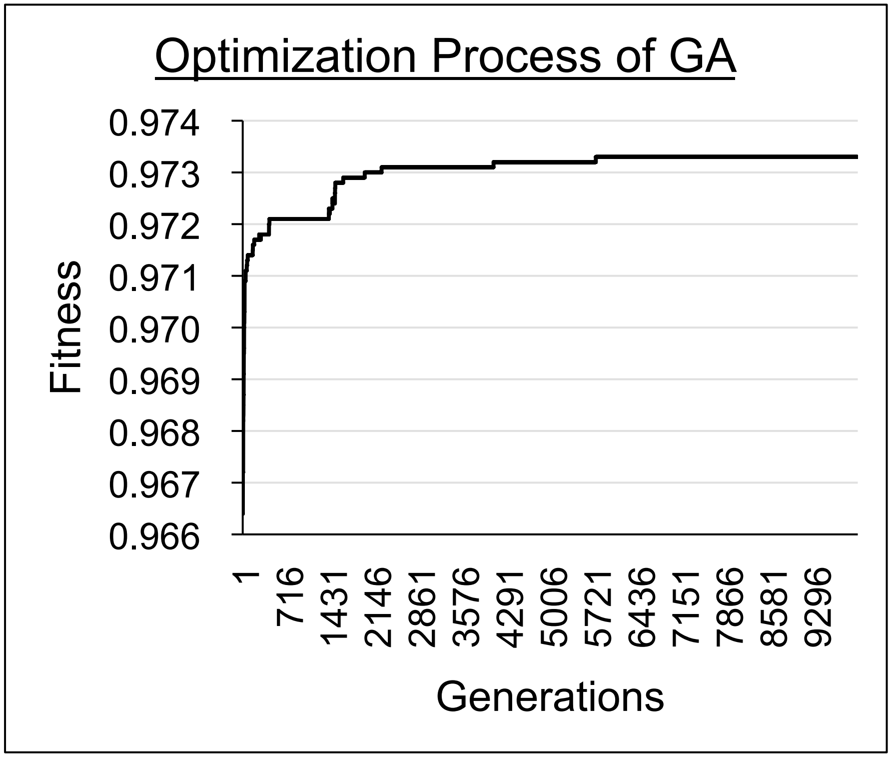
Network (*1)	Nodes	173
	Links	199
	Damaged Links (*2)	40
Agent	Company	153
	Residence	257
	Citizen / Worker (*3)	1540
GA	Population	100
	Generations	10000
	Selection Rate	0.5
	Crossover Rate	0.3
	Mutation Rate	0.1

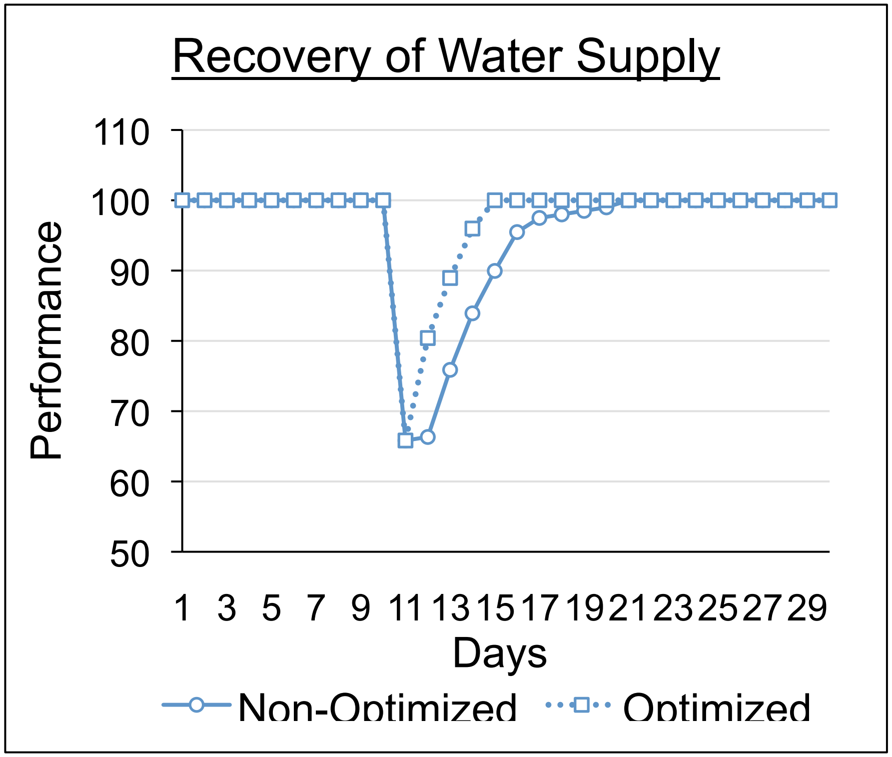
(*1) only the central part of Arao city

(*2) estimated by potential earthquake damage

(*3) 1 agent representing approx. 11 people

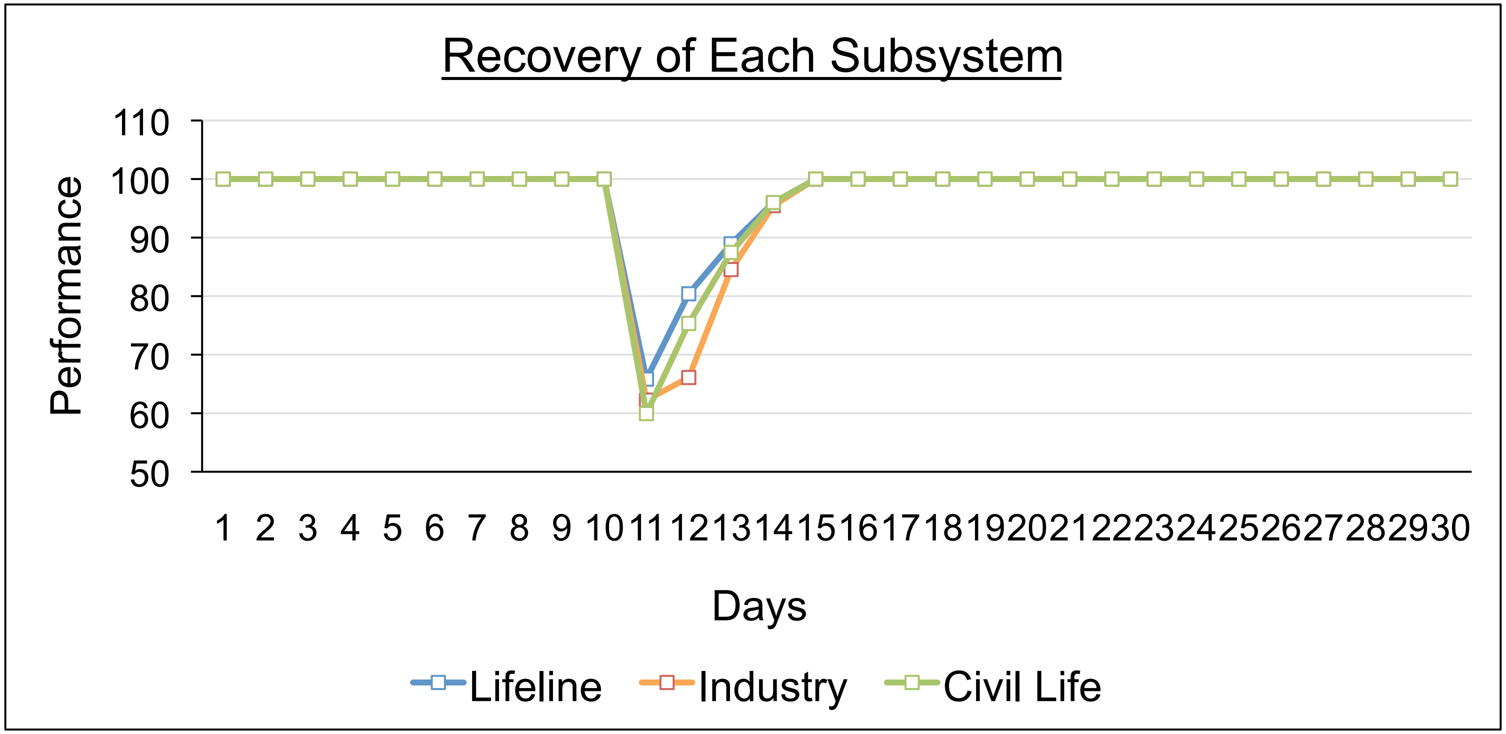
Simulation Results (1)





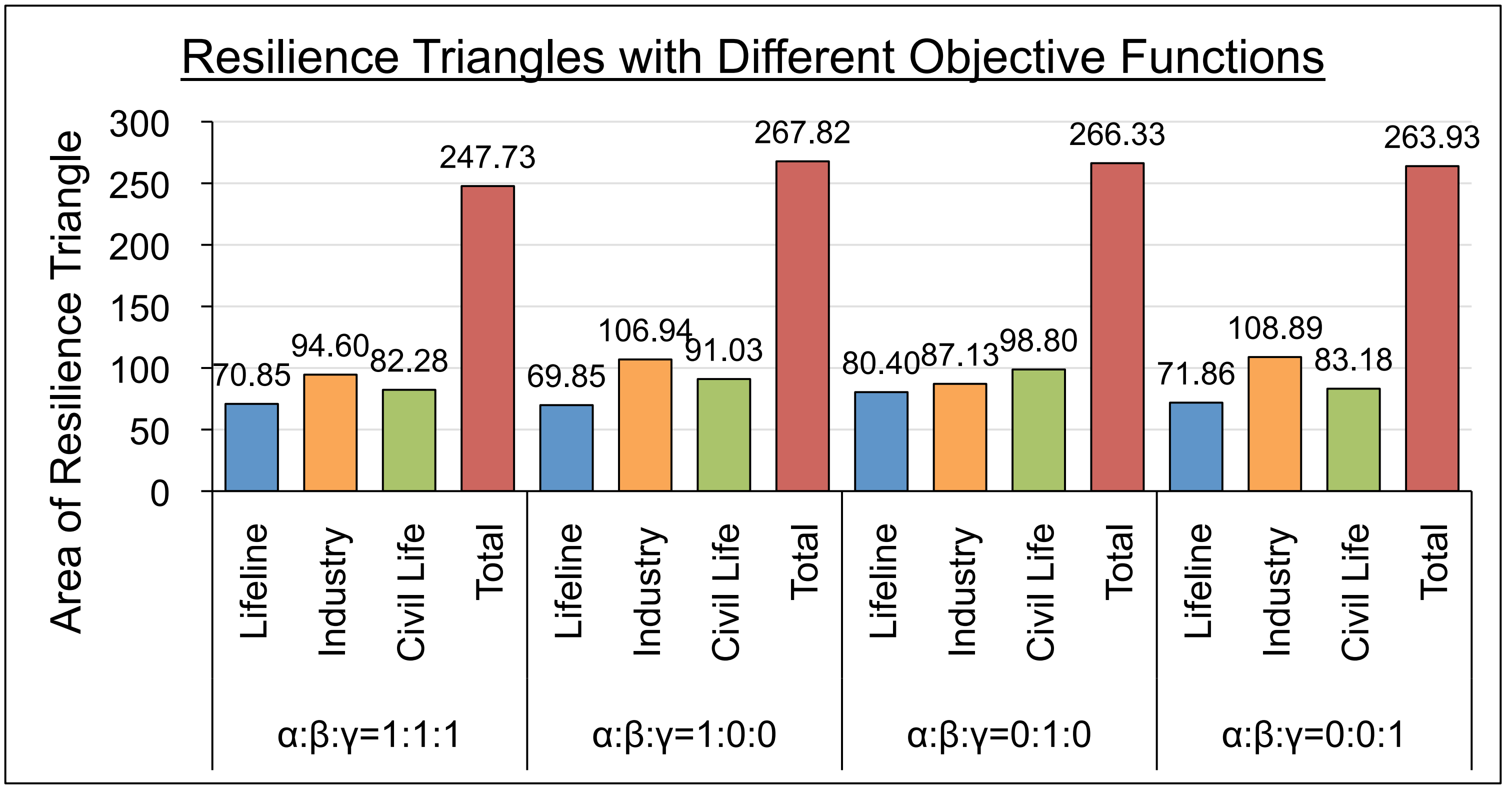
- As the number of generations increases, the fitness value becomes higher.
- The optimized plan was 5 days shorter than non-optimized plan.
- GA optimization works appropriately.

Simulation Results (2)



- We can observe and evaluate the restoration process of each three subsystem.

Simulation Results (3)



- The different objective functions provide slightly different results.
- We can compare the optimized restoration under various prioritizations.

Conclusion

- A high-fidelity simulation of water supply system restoration was developed.
  - Considering multiple interdependencies underlying urban systems
  - Implementing a realistic restoration task
  - Considering hydrodynamic behavior of water distribution system
  - Using the actual city data

- Optimization of restoration plan using GA was conducted.
  - GA optimization works appropriately.
  - We can observe the restoration process of each three subsystem.
  - We can compare the optimized restoration under various prioritizations.

Thank You!

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