# Failure and Recovery Database for a System of Interdependent Networks

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## Introduction

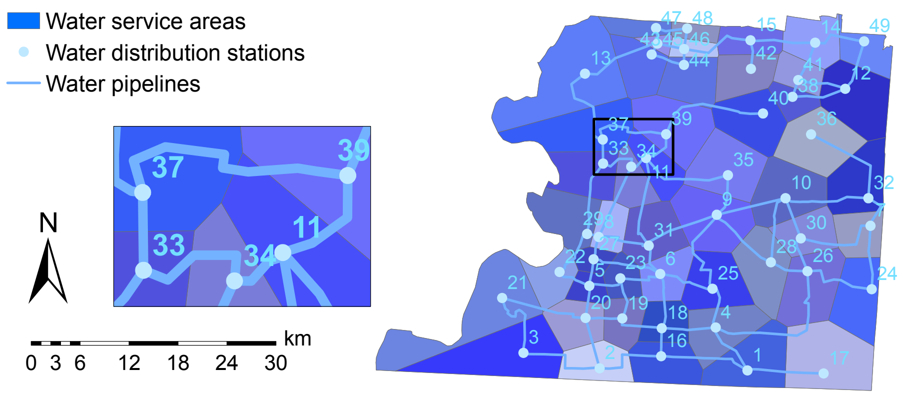
Considering the limited data available to perform recovery and resilience analysis on interdependent infrastructure networks, we have compiled relevant data to serve as a benchmark for such analyses. In particular, this database is developed using recovery strategies generated from the time-dependent Interdependent Network Design Problem (td-INDP) [1, 2]. To generate this database, we used Xpress-MP 7.9 solver, in a computer with Windows 7 Enterprise, 32GB of RAM, and processor Intel Core i7-4770. The database is organized into three different folders. **Folder 1** contains data with failure probabilities for each component in the studied system, **folder 2** contains the recovery strategies generated using the td-INDP model, and **folder 3** contains the input data necessary to to run the td-INDP model if desired. The studied system of systems includes stylized versions of the water, gas, and power networks for Shelby County, TN, USA. Figure 1 shows the utility networks used.

The rest of the document details the specific contents of each folder.

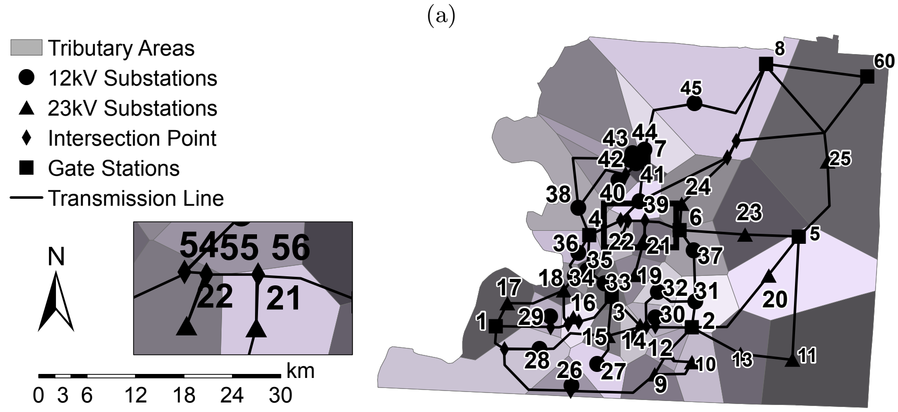
## Folder 1 - Failure probabilities

The probabilities of failure of each component (probM$\boldsymbol{\Xi}$.txt) are related to the magnitude of the disaster. File probM$\Xi$.txt has the probability of failure of each component for the gas, power and water networks in Shelby County, TN, given an earthquake with magnitude $\boldsymbol{\Xi} \in \{6, 7, 8, 9\}$. Below follows the list of parameters found in these files.

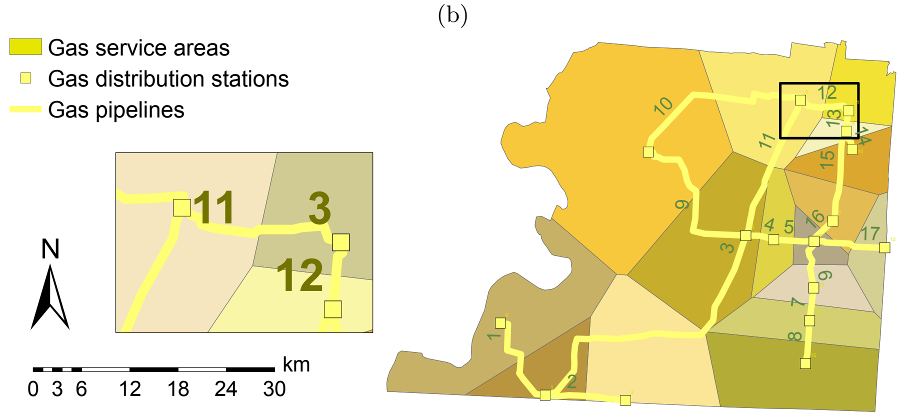
**proba** ← Probability of failure of each arc. Format: *(starting node, ending node, network) probability*




(a)




(b)




(c)

Figure 1: Water (a), power (b), and gas (c) networks in Shelby County, TN. (taken from [1])

**probn** $\leftarrow$ probability of failure of each node. Format: *(node, network) probability*

The numbering for the networks is 1 for water, 2 for gas, and 3 for power, for all the parameters described. The power and water networks were adapted from Hernandez-Fajardo and Dueñas-Osorio[3, 4], and the gas network from Song and Ok [5]. To calculate the failure probabilities, we also used the fragility curves and methods from Hazus [6], and the works by Adachi and Ellingwood [7, 8]

## Folder 2 - Failure and recovery scenarios

There are folders V$\boldsymbol{\Theta}$, where $\boldsymbol{\Theta} \in \{6, 12\}$ indicates the value of resources available used in the simulations. Inside each folder, there are files named M$\boldsymbol{\Xi}$V$\boldsymbol{\Theta}$T$\boldsymbol{\Psi}$RetCost200Iter$\boldsymbol{\Gamma}$.txt, where $\boldsymbol{\Xi} \in \{6, 7, 8, 9\}$ indicates the simulated earthquake magnitude, $\boldsymbol{\Theta} \in \{6, 12\}$ indicates the available resources, $\boldsymbol{\Psi}$ indicates the maximum time horizon (calculated for each simulation separately), and $\boldsymbol{\Gamma} \in \{1, 2, ..., 1000\}$ indicates the label associated to each random simulation (of damage and associated restoration) performed (for each possible configuration of magnitudes and resources). Below follows the list of parameters found in these files.

**M** $\leftarrow$ Moment magnitude

**V** $\leftarrow$ Resources available (in this case, # of components that can be recovered per period)

**TimeHorizon** $\leftarrow$ # of periods to perform the recovery process

**Iteration** $\leftarrow$ Randomly generated disaster scenario (based on **M** and the fragility of each component)

**ProblemStatus** $\leftarrow$ describes if the presented solution is the optimum

**bestObjValue** $\leftarrow$ best objective function found (obtained by using the provided recovery strategy)

**LB** $\leftarrow$ best lower bound found for the objective function (i.e., the optimal solution cannot be less that this value)

**gap** $\leftarrow$ The percentage difference between the current solution and the best bound

**time** $\leftarrow$ Time used by the optimizer to reach the provided solution

**soltFOa** $\leftarrow$ Flow cost. Format: *(period) value*

**soltFOb1** $\leftarrow$ Construction cost associated to arcs. Format: *(period) value*

**soltFOb2** $\leftarrow$ Construction cost associated to nodes. Format: *(period) value*

**soltFOb** ← Total construction cost. Format: *(period) value*

**soltFOc** ← Shared Construction cost. Format: *(period) value*

**soltFO** ← Objective function without unbalance cost. Format: *(period) value*

**soltFO2** ← Unbalance cost. Format: *(period) value*

**soltFOT** ← Total objective function. Format: *(period) value*

**soltsumarcs** ← Number of arcs recovered. Format: *(period) value*

**soltsumnode** ← Number of nodes recovered. Format: *(period) value*

**soltss** ← Number of components recovered. Format: *(period) value*

**solunsDem** ← Unsatisfied demand. Format: *(period) value*

**a** ← *functionality*= 0 indicates that the arc was destroyed in that earthquake simulation, 1 otherwise. Format: *(starting node, ending node, network) functionality*

**n** ← *functionality*= 0 indicates that the node was destroyed in that earthquake simulation, 1 otherwise. Format: *(node, network) functionality*

**solx** ← The flow of each commodity, through each arc, each time period. Format: *(starting node, ending node, network, commodity, period) flow*

**soly** ← *functionality*= 0 indicates that the arc is not functional, 1 otherwise. Format: *(starting node, ending node, network, period) functionality*

**soldy** ← *dfunctionality*= 1 indicates that the arc was repaired in that time period, 0 otherwise. Format: *(starting node, ending node, network, period) dfunctionality*

**solw** ← *functionality*= 0 indicates that the node is not functional, 1 otherwise. Format: *(node, network, period) functionality*

**soldw** ← *dfunctionality*= 1 indicates that the node was repaired in that time period, 0 otherwise. Format: *(node, network, period) dfunctionality*

**soldp** ← *excess* indicates the excess of commodity in each node, at each time period. Format: *(node, network, period) excess*

**soldm** ← *deficiency* indicates the deficiency of commodity in each node, at each time period. Format: *(node, network, period) deficiency*

## Folder 3 - INDP Input data

In this folder there is a unique file name INDP_data.txt, which contains all the data associated to the costs, capacities, network structures, and others necessary to solve the INDP (except for the initial disaster scenario to be studied) using the formulation presented in [1, 2]. The parameters shown in this file do not have a time index, since for the recovery strategies presented in **folder 2** it was assumed that these parameters did not depend on the time period, i.e., they were constant through the recovery process.

Below follows the list of parameters found in this file.

**v** ← Resource availability. Format: *(resource) value*

**c** ← Unitary flow costs. Format: *(starting node, ending node, network, commodity) cost*

**f** ← Reconstruction cost of link. *Format: (starting node, ending node, network) cost*

**q** ← Reconstruction cost of node. Format: *(starting node, network) cost*

**Mp** ← Oversupply penalty. Format: *(starting node, network, commodity) cost*

**Mm** ← Undersupply penalty. Format: *(starting node, network, commodity) cost*

**g** ← Cost of space preparation. Format: *(space) cost*

**b** ← Demand. Format: *(node, network, commodity) demand*

**u** ← Link capacity. Format: *(starting node, ending node, network) capacity*

**h** ← Resource usage when reconstructing link. Format: *(starting node, ending node, network, resource) value*

**p** ← Resource usage when reconstructing node. Format: *(node, network, resource) value*

**gamma** ← Physical interdependence between components. Format: *(starting node, ending node, network 1, network 2) value*

**alpha** ← Nodes belonging to each space. Format: *(node, network, space) value*

**beta** ← Links belonging to each space. Format: *(starting node, ending node, network,space) value*

**a** ← Arcs in the system. Format: *(starting node, ending node, network) value*

**n** ← Nodes in the system. Format: *(node, network) value*

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