Supplementary information I of ResMapper: Functions and their models and assumptions

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This document explains the functions available in the ResMapper toolkit and the underlying models and assumptions (c.f. Figure 1). The authors welcome any modification of these functions and parameters to better reflect local conditions and data availability.

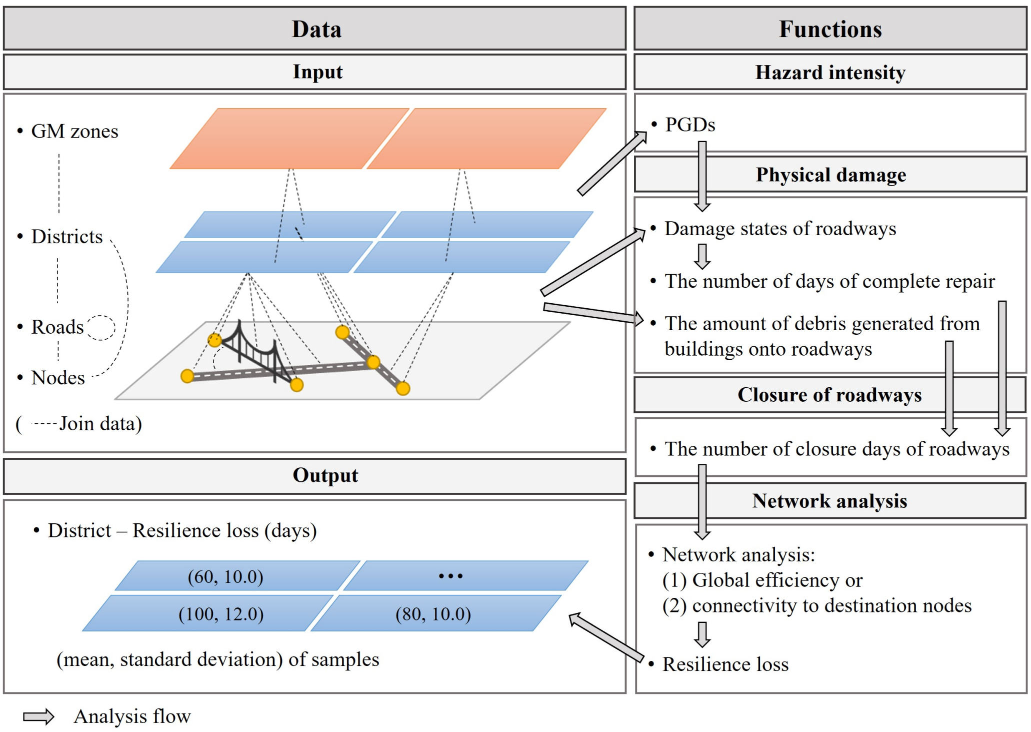

Figure 1: Architecture of the developed tool

1. Hazard intensity

1.1. Sampling permanent ground displacements

The function `samplePgdInInch.m` samples permanent ground displacements (PGDs) for each district. The function accepts an array of districts and that of ground motion (GM) zones. For sampling, the potential seismic hazards of each district is inferred by the join relationship between the two classes of objects. The function returns the array of districts with PGD samples attached as a property.

The function considers landslides as the cause of PGDs, following the model developed by the HAZUS-EQ model [1]. As the model considers 10 susceptibility categories, the proportion of these categories must be provided. The default value provided by HAZUS-EQ [1] is used for the benchmark example. For more detail, readers are referred to Chapter 4.2.2.2 of FEMA (2020) [1].

2. Structural damage of roadways

2.1. Damage states of roadways

The function `sampleRoadDamage.m` samples the damage states of roadways by referring to PGD samples and the intensity measures (IMs) of GM zones. The inputs are the arrays of roads, districts and GM zones. The function also utilises fragility curves. The function then returns the array of roadways with the samples of damage states added as a property.

Following the convention, paved roads are evaluated by PGDs, while bridges are evaluated by peak ground acceleration (PGA) and the spectral acceleration (Sa) at period 1 second.

2.2. The number of days taken for complete repair

The function `sampleNRecoveryDayByRoadDamage.m` samples the number of recovery days from the damage state of each roadway. For sampling, the function utilises recovery curves, which are defined as normal distributions with the provided means and standard deviations. In the benchmark example, the parameters are selected as provided by HAZUS-EQ [1].

2.3. The amount of debris generated from buildings onto roadways

Because of the large scale of analysis, the information of buildings is provided by being summarized as the expected number of damaged buildings for each district. Therefore, the function `evalNClosureDaysByBuilding.m` samples the the amount of damaged buildings onto each roadway by referring to the density of damaged buildings, the length of a road and the average length of buildings. Such amounts are calculated by assigning varying weights to different damage states. In the benchmark example, the weights are set 1, 0.75, 0.25 and 0.1 respectively for the four damage states, i.e. very heavy, heavy, moderate and slight.

While the function utilises a parameter of the average length of buildings, it is found to have a limited influence on the analysis results, incurring less than 3% of difference. In regard to the weights of damage states, users are referred to Section 3.3.

3. The number of clousure days of roadways

3.1. Closure by direct structural damage

The function `evalClosureDaysByRoadDamage.m` evaluates the number of closure days from a number of recovery days. To this end, the function requires a parameter of the ratio of the closure days to the recovery days. In other words, the number of closure days is evaluated by multiplying the ratio to that of recovery days. In the example, the ratio parameter is set 0.5. As readers may notice, this parameter plays an influential role as explained in the second supplementary document.

3.2. Closure by overpasses

Similar to Section 3.1, the function `evalClosureDaysByRoadDamage.m` evaluates the number of closure days by using a given ratio of the closure days to the recovery days of overpasses. In the example, the ratio parameter is set 0.1. Again, it plays an important role in the analysis result.

3.3. Closure by buildings

After sampling the generation of debris (c.f. 2.3), the function `evalNClosureDaysByBuilding.m` evaluates the number of closure days as the number of days until all debris on the roadway of interest is cleared. To this end, the function `evalRoadsClearPriority.m` first evaluates the clear priority of roads based on their proximity to the nodes where clearing works start (i.e. those having clearance priority). Then, the closure days are calculated by use of the clearing prioritisation, the total amount of debris and the daily clearing units (which is provided as a parameter).

There are two related parameters in the evaluation, i.e. the amount of debris generated by each damage state and the amount that can be cleared a day. In other words, the analysis result is governed by the ratio of the two parameters. In the second supplementary document, it is found that their ratio has a great influence on analysis results.

3.4. The final number of closure days

To decide the final number of closure days of each road, the function `evalMaxClosureDays.m` selects the longest closure days among those resulted by the three causes that are illustrated in Sections 3.1–3.3.

4. Network resilience

4.1. Network performance measure

Before calculating a resilience measure, a network performance measure needs to be evaluated. While various definitions are possible depending on an analysis purpose, this toolkit features two measures: the global efficiency and the connectivity to destination nodes. Both measures can be evaluated by performing network connectivity analyses.

First, the global efficiency follows what illustrated in [2], i.e.

$$E^{\text{glob}}(G) = \frac{1}{N(N-1)} \sum_{i \neq j \in \{1,\ldots,N\}} \frac{1}{d_{ij}} \tag{1}$$

where N is the number of nodes, G represents a given network, and the distance d_{ij} is 1 if the nodes i and j are connected and ∞ otherwise.

On the other hand, the connectivity to destination nodes is evaluated by the number of nodes connected to designated destination nodes (e.g. airports, entrances to highways and hospitals). Such performance can be measured either in terms of the absolute number of connected nodes or in terms of the ratio of those nodes compared to the total number of nodes in a district.

4.2. Resilience loss

Finally, for each sample, resilience loss value of each district needs to be calculated. Following the convention, a resilience loss is evaluated by considering two dimensions, i.e. a performance measure and time. As illustrated in Figure 2, the resilience loss is defined as the lost area from an occurrence of an earthquake to the full recovery. Then, the resilience loss is calculated as

$$RL = \sum_{t=0}^{T} (P^* - P_t) \tag{2}$$

where P^* is the performance measure evaluated without any damage, P_t is the performance measure at day t, $t = 0, \ldots, T$, and days 0 and T respectively represent an occurrence of earthquake and a full recovery. By definition, RL has its unit as days multiplied by the unit of network performance measure.

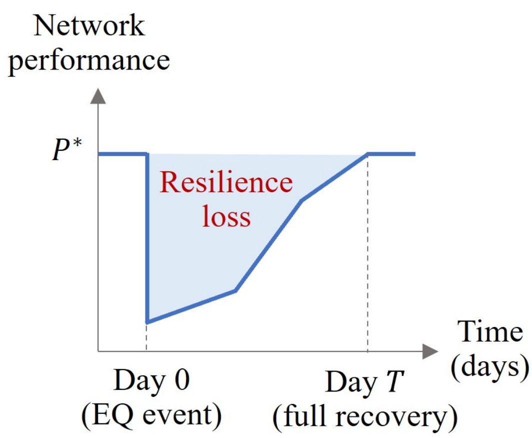

Figure 2: Illustrative definition of resilience loss

References

[1] FEMA, Hazus earthquake model technical manual (2020).

[2] S. Porta, P. Crucitti, V. Latora, The network analysis of urban streets: A primal approach, Environment and Planning B: Planning and Design 33 (5) (2006) 705–725.