Procedure for Resilience Assessment Exposed to Hazard Events

Jie Zhao[a] and Ji Yun Lee[b]

[a]*Graduate Research Assistant, Washington State University, Pullman, WA 99164, USA, E-mail: jie.zhao2@wsu.edu*
[b]*Assistant Professor, Washington State University, Pullman, WA 99164, USA, E-mail: jiyun.lee@wsu.edu*

The primary purpose of this document is to illustrate quantitative simulation process for assessing the resilience of a supply chain system exposed to a scenario hazard event. First, a scenario hazard analysis is performed in HAZUS-MH software to obtain the damage state probabilities of facilities and bridges. The effects of physical/structural damages on supply chain performance can be represented by the time-varying capacity of each facility and edge following a hazard event. Based on the post-hazard-event recovery process, supply chain resilience can be assessed at each time step until system achieves its pre-hazard-event functionality.

1. Data and Files Needed for FTOT Risk and Resilience Assessment

In order to assess supply chain performance following a hazard event, several types of data and files are required. This section lists all the data and files needed for the FTOT risk and resilience assessment package.

- Geographical network: HAZUS-MH bridge network (HighwayBridge_3state.txt) can be obtained directly from HAZUS-MH and will be used to measure the edge capacity reduction due to a hazard event. This dataset should be related to the FTOT network dataset (MiddlePoint_Road.txt) to utilize data available on both of them: the HAZUS-MH dataset includes bridge fragility curves, repair times, and restoration functions, while the FTOT dataset contains information on edges (e.g., edge capacity, traffic volume). In this context, the new file (Relationship_BridgeRoad_3state.txt) has been developed.
- Physical damage estimation (Facility_DS.txt and Bridge_DS.txt files): Damage state probabilities of facilities and edges induced by a specific hazard event are the outputs of HAZUS-MH hazard analysis.
- Risk and recovery assessment (Risk_ResileinceAssessment.py): Based on the physical damage estimation, supply chain performance immediately following the hazard event and the associated restorative activities can be assessed.
- Time-varying variables: Time-varying capacities of facilities and edges (facility_time_varying_cap.npy and edge_time_varying_cap.npy) can capture the changes in their capacities from the time of hazard occurrence to the completion of post-disaster recovery processes, which are the outputs of risk and recovery assessment.
- Post-disaster recovery parameters: After the simulation of system recovery processes following a hazard event, two parameters are obtained, which are the total recovery time (total_recovery_week.npy) and repair costs for damaged facilities (repair_costs.npy). These two parameters are subsequently used in the resilience assessment.
- Resilience assessment (FTOT_SCR folder): Some of the existing FTOT codes are modified to assess the resilience of a supply chain system exposed to a scenario hazard event.

In order to assess the supply chain resilience exposed to hazard events, several modifications are required, which are located in two FTOT Python files: (a) ftot.py and (b) ftot_pulp_weekly.py. The first file controls the overall steps for supply chain analysis. It is modified to incorporate the iterative structure of optimization step for each simulation time interval, aimed to track the supply chain performance from earthquake occurrence to the completion of recovery activities. Then, resilience calculation equations are added after the iteration of optimization step, to quantify the supply chain resilience following the scenario hazard event. The purpose of modifications on the second file is to run the supply chain optimization based on the time-varying capacity variables. Thus, the facility and edge capacity are adjusted at each simulation time step based on the outputs from risk and recovery assessment. The facility capacity is changed in the table generation function in o1 step, while the edge capacity is redefined in the constraint of maximum route capacity in o2 step. Furthermore, the objective function is modified to incorporate the restoration cost of damaged facilities and facility operation cost as two additional components of the total cost.

The simulation procedure using these data and files is presented in Figure 1. After performing a "scenario hazard analysis" in HAZUS-MH software, the damage state probabilities of facilities and bridges can be obtained. The remaining capacities of supply chain components due to their damages and related recovery activities can be estimated through the process of risk and recovery assessment and subsequently used to generate a set of time-varying variables as well as the recovery parameters. Finally, by incorporating these variables and parameters into the modified FTOT simulation, we can assess the supply chain resilience following a scenario hazard event. It should be noted that the process in the current version of the FTOT resilience assessment package can only quantify the effect of earthquake event on supply chain performance, while simulation method should be modified for other types of hazards. The detailed steps for the seismic risk and resilience assessment are illustrated in Section 2.

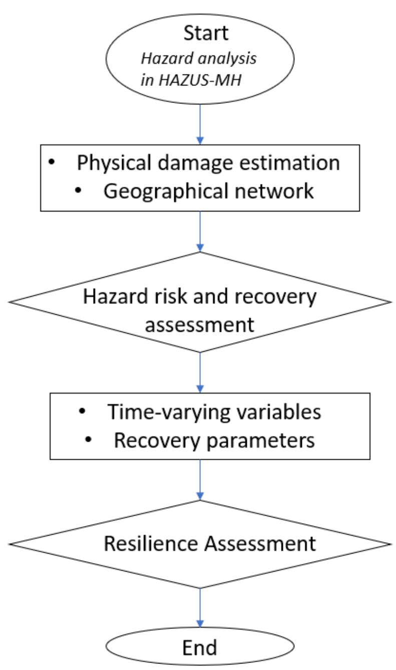
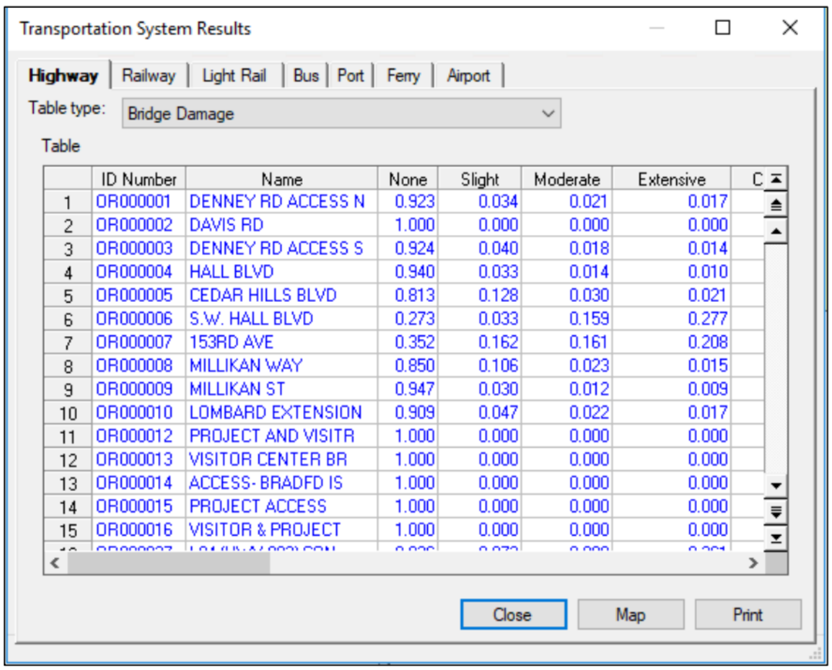


Figure 1. Simulation process for supply chain risk and resilience assessment

2. Simulation Steps: Seismic Hazards

Step 1: *Conduct a scenario hazard analysis in HAZUS-MH software to obtain facility/bridge damage state probabilities*

HAZUS-MH software supports a “scenario hazard analysis”. After conducting a hazard analysis, the facility and bridge damage state probabilities can be directly obtained. For example, as presented in Figure 2, the table lists the probability of each damage state (Slight, Moderate, Extensive, and Complete damage states) for every individual bridge. Finally, the damage states of facilities and bridges can be generated by using Monte Carlo Simulation method.



	ID Number	Name	None	Slight	Moderate	Extensive	C
1	OR000001	DENNEY RD ACCESS N	0.923	0.034	0.021	0.017	
2	OR000002	DAVIS RD	1.000	0.000	0.000	0.000	
3	OR000003	DENNEY RD ACCESS S	0.924	0.040	0.018	0.014	
4	OR000004	HALL BLVD	0.940	0.033	0.014	0.010	
5	OR000005	CEDAR HILLS BLVD	0.813	0.128	0.030	0.021	
6	OR000006	S.W. HALL BLVD	0.273	0.033	0.159	0.277	
7	OR000007	153RD AVE	0.352	0.162	0.161	0.208	
8	OR000008	MILLIKAN WAY	0.850	0.106	0.023	0.015	
9	OR000009	MILLIKAN ST	0.947	0.030	0.012	0.009	
10	OR000010	LOMBARD EXTENSION	0.909	0.047	0.022	0.017	
11	OR000012	PROJECT AND VISITR	1.000	0.000	0.000	0.000	
12	OR000013	VISITOR CENTER BR	1.000	0.000	0.000	0.000	
13	OR000014	ACCESS- BRADFD IS	1.000	0.000	0.000	0.000	
14	OR000015	PROJECT ACCESS	1.000	0.000	0.000	0.000	
15	OR000016	VISITOR & PROJECT	1.000	0.000	0.000	0.000	

Figure 2. HAZUS-MH output: bridge damage state probabilities

Step 2: *Estimate reduced capacities of structures immediately following a scenario hazard event*

Capacity of each facility type is a function of damage state, while edge capacity can be related to the bridge damage state. Detailed description is presented in Step 3 of the document titled “Procedure for Estimating Capacity Reduction”.

Step 3: *Capture time-varying capacities of facilities and edges*

Please refer to the document titled “Procedure for Resilience Assessment” for following process:

- Estimate the delay times of damaged facilities and bridges
- Estimate the recovery times of damaged facilities and bridges
- Calculate the repair costs of damaged facilities
- Modify facility and edge property tables

Step 4: *Modify the objective function of the FTOT optimization*

The objective function of the optimization is to minimize the total supply chain costs per product ($cost(t)$) and is mathematically expressed by:

$$cost(t) = \frac{cost_0 + w_R \cdot (cost_R\,(t))}{product(t)} \tag{1}$$

where $cost_0$ = the business-as-usual supply chain costs consisting of transportation cost and operation cost; $cost_R\ (t)$ = the resilience cost at time *t*; and $product(t)$ = the amount of the final product at time *t* under; w_R = the weighting factor determined by a decision-maker based on the relative importance of the resilience cost/reward in total cost calculation. In this example, the equal weights are assigned to $cost_0$, and $cost_R\ (t)$. More specifically, $cost_R(t)$ comprises four cost components, including unmet demand penalty (c_{UDP}), facility restoration cost in the aftermath of hazard events ($c_{restoration}$), and changes (Δ) in transportation cost ($c_{transportation}$) and operations cost ($c_{operation}$) due to seismic event. The resilience cost can be summarized in the following equation:

$$cost_R(t) = c_{UDP}(t) + c_{restoration}(t) + \ \Delta(c_{transportation}(t) + c_{operation}(t)) \tag{2}$$

Step 5: *Run optimization simulation at each time step*

By incorporating the time-varying capacities of facilities and edges that represent both the structural damages immediately following a hazard event and the recovery processes, supply chain analysis should be simulated at every time step t_n (where t_n is the time interval considered during the recovery process; user defined). This process is repeated until supply chain performance achieves its pre-hazard-event functionality (or any other pre-defined functionality level). This example utilizes week as a time interval to assess the effect of a hazard event on supply chain performance.

Step 6: *Calculate the supply chain resilience*

The resilience of supply chain can be computed as follows:

$$R = \int_{t_h} cost_R(t_h)dt_h \tag{3}$$

where t_h = the time period from the hazard occurrence to the completion of recovery processes.

In conclusion, the simulation processes for Steps 2 and 3 are generated in the part of risk and recovery assessment (Risk_ResileinceAssessment.py file), while the modified FTOT resilience assessment (FTOT_SCR folder) includes Steps 4 – 6 to assess the effect of a seismic hazard event on supply chain performance.