Probabilistic **R**esilience **A**ssessment of **I**nterdependent **Sys**tems (**PRAISys**): *User Manual*

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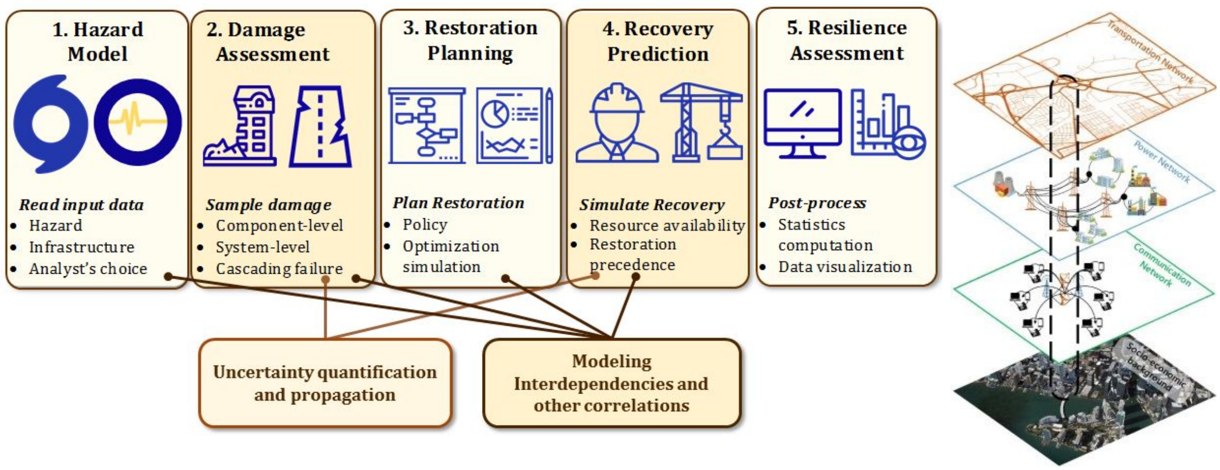
1 Introduction

After extreme events, a community's socio-economic recovery depends on the recovery of its infrastructure systems, such as power and water distribution systems, transportation networks, communications systems, and critical buildings. We need to build resilient infrastructure systems to support the national economy and wellbeing of citizens, resist extreme events, and ensure their capacity to rapidly recover to full service afterwards.

PRAISys, standing for Probabilistic Resilience Assessment of Interdependent Systems,is a comprehensive platform for resilience assessment of communities under given hazard scenarios. It can address stochastic interdependencies among infrastructure systems in a probabilistic manner. In the current implementation, PRAISys can handle two types of hazards: earthquake, and hurricane; it can consider three infrastructure systems: power, communication, and transportation. It is worth noting that the socioeconomic background of a community is incorporated in the resilience assessment.

As shown in the following figure, PRAISys consists of five major steps. In *Step 1*, PRAISys reads input data on the given hazard scenario and infrastructure system(s) of interest, as well as the analyst's choices for setting up different decision options. In *Step 2*, PRAISys uses fragility curves to perform initial damage assessment for every structural component under the given hazard scenario and conducts cascading failure analyses. After that, PRAISys develops the restoration plan for the given damage scenario (*Step 3*). Following the restoration plan, PRAISys simulates the recovery process of the infrastructure system(s) (*Step 4*). Based on recovery curves, PRAISys assesses the infrastructure system resilience in a probabilistic manner (*Step 5*).



Website: http://www.praisys.org/; Email: praisys@lehigh.edu

2 Requirements

2.1 Operation System Requirements

PRAISys can operate on MAC, Linux and Windows. The application doesn't require access to the Internet.

2.2 Software Requirements

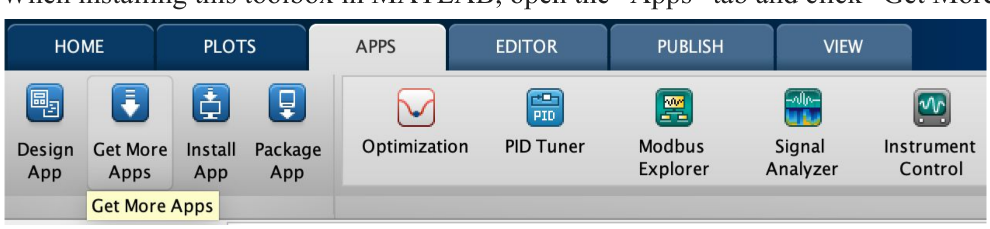
To run the program, the following software/packages are required.

(1) MATLAB R2019a (or newer)

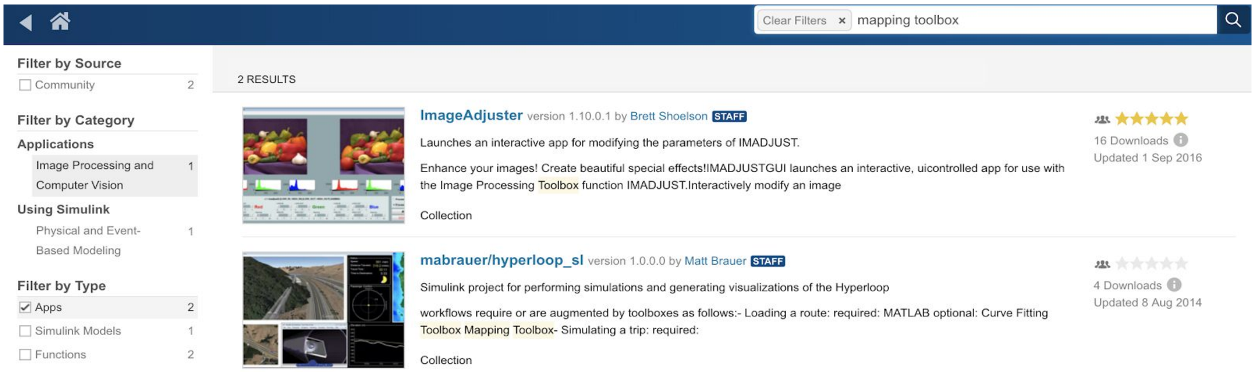
Two additional packages in MATLAB are required.

(1.1) *Mapping Toolbox*

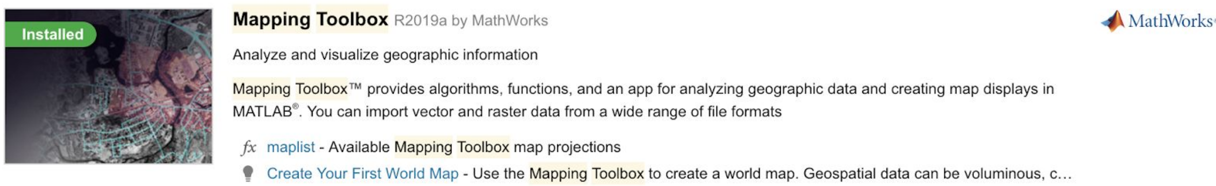
When installing this toolbox in MATLAB, open the "Apps" tab and click "Get More Apps".



Then, type "Mapping Toolbox" in the search bar. Deselect "Apps" in the "Filter by Type" category.



After deselecting this button, the correct toolbox should appear:



(1.2) *bioinformatics toolbox 4.11*

Following a similar procedure as that in (1.1) shown above, the "*bioinformatics toolbox 4.11*" package can be installed as well. This toolbox is required when using the function related to computing network functionality based on graph theory at step 4. Please find more details with the following link. https://www.mathworks.com/products/bioinfo.html

(2) Gurobi Optimizer (optional, only required for optimization-related computations)

For Gurobi, please follow the instructions from the link below to set it up in MATLAB after installation:
http://www.gurobi.com/documentation/8.0/quickstart_mac/matlab_setting_up_gurobi_f.html

(3) yalmip (optional, only required for optimization-related computations)

This is an open-source package, based on ".m" files, for the optimization formulation at step 3. To properly use yalmip, solvers, such as Gurobi and Cplex, should be installed, and the solver's path should be added to MATLAB. Otherwise, when you run "yalmiptest" in the MATLAB command window, an error message of "the gurobi solver cannot be found." would come up.

- Download the package of yalmip from the website, extract the zip file, and save it to a directory. https://yalmip.github.io/download/
- Read the following link to set up the path from MATLAB to yalmip. https://yalmip.github.io/tutorial/installation/

% Note: type "addpath(genpath(yalmiprootdirectory))" in your matlab.
remember to change the directory of "yalmiprootdirectory" in the above path to the directory of the yalmip folder.

3 Input

There are three types of input data required for the PRAISys platform.
(1) **Hazard scenario data** are in the form of the ".mat" file, presented in the subfolder named "InputHazard". PRAISys only reads infrastructure data in this folder.
(2) **Infrastructure data** are in the form of ".csv/.xlsx" files, presented in the subfolder named "Input". PRAISys only reads infrastructure data in this folder. Note that the socioeconomic background of a community is considered in the infrastructure data.
(3) **Analysts' choices** can be easily set up via the graphical interface of PRAISys.

A brief explanation of the required infrastructure data is presented as follows.

3.1 Input Data for the Power System

In PRAISys, a power system consists of power plants, electric substations, power lines, and transmission towers.

3.1.1 Power plant

Required attributes for a power plant are the following:

- Power Plant ID
- Name
- Longitude
- Latitude
- Fuel Type
- Generation Capacity (mW)
- Type (optional, representing the type of this power plant by following the classification of power plants in the HAZUS-Earthquake Technical Manual in the current implementation)
- TotalPop (representing the total population served by this power plant)
- TotalHH (representing the total number of households served by this power plant)

Here is a screenshot of an example table of "PowerPlants.csv".

	A	B	C	D	E	F	G	H	I	J	K	L
1	Power pla	Name	Longitude	Latitude	Fuel Type	Generatio	Generate	Generatio	Type	ServRange	TotalPop	TotalHH
2	1	Bethleher	-75.3135	40.61831	Gas	1134	0	0	EPP3	28	732026	279761
3	2	Martins Cr	-75.1062	40.80177	Gas	2310	0	0	EPP3	28	431965	161595

3.1.2 Substation

In PRAISys, the object of an electric substation is named as "Bus". The current implementation of PRAISys only considers electric substations at transmission-level, not at distribution-level. Required attributes for an electric substation include the following:

- Substation ID
- Name
- Max Voltage Served (kV)
- Latitude
- Longitude
- TotalPop (representing the total population served by this electric substation)
- TotalHH (representing the total number of households served by this electric substation)

Here is an example table of "Substations.csv".

	A	B	C	D	E	F	G	H	I	J	K
1	Substatio	Name	Max Volta	Type	Longitude	Latitude	Estimated	Real powe	Reactive p	TotalPop	TotalHH
2	1	Hosensacl	500	Transmiss	-75.507	40.45595	17763			1158	453
3	2	Wescosvil	500	Transmiss	-75.5606	40.57359	17763			14772	5887
4	3	Steel City	500	Transmiss	-75.3078	40.6196	17763			2701	1008

3.1.3 Power line (along with transmission towers)

In PRAISys, the object of a power line is named as "Branch". The power lines are power conductors at transmission-level for connecting substations and power plants, along with transmission towers distributing at a certain distance interval along power lines. In the current implementation of PRAISys, electric conductors at distribution-level are not considered. Required attributes for a power line include the following:

- Branch ID
- Branch Node 1
- Branch Node 2
- Voltage (kV)
- Tower type (i.e., the structural type of transmission towers carrying this power line)

Here is an example table of "Power_Line.csv".

	A	B	C	D	E	F
1	Branch ID	Branch Node 1	Branch Node 2	Voltage (k	Tower Type	
2	4	Bethlehem Gas	Steel City	500	Lattice	
3	11	Martins Creek Gas	Siegfried	230	Lattice B	
4	12	Martins Creek Gas	Quarry	230	Lattice A/Monopole	
5	13	Martins Creek Gas	Northwood	230	Lattice A	

3.1.4 Transmission Tower

As PRAISys considers that transmission towers are distributed at a certain distance interval along power lines, PRAISys does not require the input data of transmission towers.

3.2 Communication System

In PRAISys, a communication system consists of central offices, communication towers, and communication lines.

3.2.1 Central office

Required attributes for a central office include the following.

- Central office ID
- Latitude
- Longitude
- TotalPop (representing the total population served by this central office)
- TotalHH (representing the total number of households served by this central office)

Here is an example table of "CentralOffices.csv".

	A	B	C	D	E	F	G	H	I	J	K	L
1	Central of	Latitude	Longitude	Label	Company	Structure	Height (m	Built year	Address	Service Ra	TotalPop	TotalHH
2	1	40.639	-75.4494	ALTWPAA	XO PENNS	C2L	10	2000		8	250066	95680
3	2	40.6031	-75.4765	ALTWPAA	CTSI, INC.	S1L	15	1990		8	230823	89278
4	3	40.6023	-75.4707	ALTWPAC	CCCPA, INC. DBA CONNECT!					8	234695	90135
5	4	40.5867	-75.6114	ALTWPAC	CHOICE ONE COMMUNICATIONS, INC.					8	69982	26546

3.2.2 Communication Tower

Required attributes for a communication tower include the following.

- ID
- Tower Structural Type
- Longitude
- TotalPop (representing the total population served by this communication tower)
- TotalHH (representing the total number of households served by this comm. tower)
- Height (optional)

Here is an example table of "CommunicationTowers.csv".

	A	B	C	D	O	P	Q	R	S	T	U
1	ID	UtilFcltyCl	Tract	Name	BackupPo	Latitude	Longitude	Comment	Height (m	TotalPop	TotalHH
2	CT1	Monopole		CT1		40.46439	-75.4463		42.7	6906	2395
3	CT2	Lattice_3leg		CT2		40.49528	-75.5098		45.4	15284	6285
4	CT3	Monopole		CT3		40.51364	-75.5888			28875	10989
5	CT4	Lattice_3leg		CT4		40.51953	-75.4888		57.9	23764	9903

3.2.3 Communication line

Due to reasons of national security and commercial competitiveness, we do not know actual locations of cables and optical fibers (i.e, communication lines) that connect central offices and communication towers. To build the network connectivity, we have made two assumptions. (1)

Every central office is connected to 3 adjacent central offices with communication lines. (2) Every communication tower is connected to 2 adjacent central offices via communication lines. As a result, PRAISys does not require the input of communication lines; instead, it will read the input data of central offices and communication towers to automatically build communication lines based on the aforementioned two assumptions.

3.3 Transportation System

In PRAISys, a transportation system consists of road segments, bridges, and traffic lights (optional). Road segments are defined by road nodes and road links.

3.3.1 Road Node

Road nodes are intersections and highway interchanges in a road network. Required attributes of a road node include the following.

- NodeID
- Latitude
- Longitude
- Road description (optional)

Here is an example table of "RoadNode.csv".

	A	B	C
1	NodeID	Latitude	Longitude
2	1	40.57893	-75.6238
3	2	40.58241	-75.6255
4	3	40.6813	-75.6947

3.3.2 Road Link

Required attributes of a road link include the following.

- LinkID
- FromNodeID
- ToNodeID
- AADT (representing annual average daily traffic)
- Length
- Number of Lanes (optional)

Here is an example table of "RoadLink.csv".

	A	B	C	D	E	F	G	H
1	LinkID	FromNodeName	ToNodeName	FromNodeID	ToNodeID	AADT (201	Number o	Length (m
2	1	22_e1	22_e2	43	44	42000	2	1.1
3	2	22_e2	22_e3	44	45	42000	2	3.3
4	3	22_e3	22_e4	45	46	42000	2	1.7

3.3.3 Bridge

Bridges related to a transportation network are classified into two types: bridges carrying road segment(s), and bridges crossing road segment(s) from above. Required attributes of a bridge include the following:

- BridgeID
- Latitude
- Longitude
- No. of CarryRoadLinkID
- CarryingRoadLinkID1
- CarryingRoadLinkID2
- CarryingRoadLinkID3
- No. of CrossRoadLinkID
- CrossingRoadLinkID1
- CrossingRoadLinkID2
- CrossingRoadLinkID3
- SkewAngle
- No. of Spans
- Width
- Length
- MaxSpanLength
- Structural Type (in the form of “HWBx”, x = 1, 2, …, 28, by following the classification method of highway bridges in the HAZUS-Earthquake Technical Manual, shown as Table 3.13 on Page 3-33, with a screenshot also presented below.)
- AADT (representing annual average daily traffic)
- Year (optional, representing the year of building this bridge, or reconstructing this bridge)

Here is an example table of “Bridges.csv”.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
											Bridges			
bridgeID	Latitude	Longitude	Icon	IconColor	IconHeading	Name	NoOfCarryL...	CarryLinkID1	CarryLinkID2	CarryLinkID3	NoOfCrossL...	CrossLinkID1	CrossLinkID2	CrossLinkID3
Number	Number	Number	Number	Categorical	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number
bridgeID	Latitude	Longitude	Icon	IconColor	IconHeading	Name	NoOfCarry...	CarryLinkID1	CarryLinkID2	CarryLinkID3	NoOfCross...	CrossLinkID1	CrossLinkID2	CrossLinkID3
1	40.5891	-75.5895	12	green	Bridge1	brg1	0	0	0	0	2	75	58	0
2	40.5893	-75.5907	12	green	Bridge2	brg2	1	191	0	0	0	0	0	0
3	40.5932	-75.5813	12	green	Bridge3	brg3	1	191	0	0	0	0	0	0

R	AC	AD	AE	AF	AG	AH	AI	AJ	DW	EE	EF
							Bridges				
BridgeClass	YEARBUILT	YEARRECON	SERVTYPON	SERVTYPU...	MAINSPANS	APPSPANS	LENGTH	DECKWIDTH	SKEW	ADTTOTAL	ADTYEAR
Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number	Number
BridgeClass	YEARBUILT	YEARRECON	SERVTYPON	SERVTYPU...	MAINSPANS	APPSPANS	LENGTH	DECKWIDTH	SKEW	ADTTOTAL	ADTYEAR
HWB12	1988	0	1	1	3	0	337	43.5	38	24772	2018
HWB12	1958	1988	1	1	3	0	103	46.5	71	24677	2018
HWB15	1958	1988	6	1	1	0	101	71.5	26	58694	2017

Here is the structural classification table for bridges (Table 3.13 on Page 3-33 in the HAZUS-Earthquake Technical Manual).

Table 3.13: Highway System Classification

Label	Description
	Hignhway Roads
HRD1	Major Roads
HRD2	Urban Roads
	Highnway Bridges
HWB1	Major Bridge - Length > 150m (Conventional Design)
HWB2	Major Bridge - Length > 150m (Seismic Design)
HWB3	Single Span – (Not HWB1 or HWB2) (Conventional Design)
HWB4	Single Span – (Not HWB1 or HWB2) (Seismic Design)
HWB5	Concrete, Multi-Column Bent, Simple Support (Conventional Design), Non-California (Non-CA)
HWB6	Concrete, Multi-Column Bent, Simple Support (Conventional Design), California (CA)
HWB7	Concrete, Multi-Column Bent, Simple Support (Seismic Design)
HWB8	Continuous Concrete, Single Column, Box Girder (Conventional Design)
HWB9	Continuous Concrete, Single Column, Box Girder (Seismic Design)
HWB10	Continuous Concrete, (Not HWB8 or HWB9) (Conventional Design)
HWB11	Continuous Concrete, (Not HWB8 or HWB9) (Seismic Design)
HWB12	Steel, Multi-Column Bent, Simple Support (Conventional Design), Non-California (Non-CA)
HWB13	Steel, Multi-Column Bent, Simple Support (Conventional Design), California (CA)
HWB14	Steel, Multi-Column Bent, Simple Support (Seismic Design)
HWB15	Continuous Steel (Conventional Design)
HWB16	Continuous Steel (Seismic Design)
HWB17	PS Concrete Multi-Column Bent, Simple Support - (Conventional Design), Non-California
HWB18	PS Concrete, Multi-Column Bent, Simple Support (Conventional Design), California (CA)
HWB19	PS Concrete, Multi-Column Bent, Simple Support (Seismic Design)
HWB20	PS Concrete, Single Column, Box Girder (Conventional Design)
HWB21	PS Concrete, Single Column, Box Girder (Seismic Design)
HWB22	Continuous Concrete, (Not HWB20/HWB21) (Conventional Design)
HWB23	Continuous Concrete, (Not HWB20/HWB21) (Seismic Design)
HWB24	Same definition as HWB12 except that the bridge length is less than 20 meters
HWB25	Same definition as HWB13 except that the bridge length is less than 20 meters
HWB26	Same definition as HWB15 except that the bridge length is less than 20 meters and Non-CA
HWB27	Same definition as HWB15 except that the bridge length is less than 20 meters and in CA
HWB28	All other bridges that are not classified (including wooden bridges)
	Highwnay Tunnels
HTU1	Highway Bored/Drilled Tunnel
HTU2	Highway Cut and Cover Tunnel

3.3.4 Traffic light

Traffic light data are optional. Required attributes for a traffic light include the following.

- Traffic light ID
- Latitude
- Longitude
- AssociatedRoadLinkID (representing on which road segment this traffic light controls traffic)

Here is an example table of “TrafficLights.csv”.

	A	E	F	G	H
1	TrafficLigh	Name	Link	Latitude	Longitude
2	1	TL1	87	40.58184	-75.4569
3	2	TL2	86	40.58184	-75.4569
4	3	TL3	86	40.60296	-75.4609

4 Output

Outputs are generated in the form of “.mat/.txt/.jpg” files, presented in the subfolder named “Output”. A list of output files are presented as follows.

Name	Directory	Description
Functionality.mat[1]	PRAISys/hostname/mat/[2]	Total functionality changes for each system in every sample
Schedule.mat		The system generated schedule for reconstruction for each run of each sample.
Data_Sample_x_Run_y.mat		Sampling results for each run of each example
Original_Data.mat		The original data from input files.
Communication/ Power/ systemName.jpg	PRAISys/hostname/plot/	Plots for system functionality vs. time using system generated recovery schedule.
data/ functionality/ schedule.txt	PRAISys/hostname/txt/	Log files for input data, functionality change for each run and schedule information.

Note:
1. For “.mat” files, open with MATLAB and their contents will be imported as variables.
2. For location, “hostname” is the name of your network provider.