
**Introducing PRIISM:
Probabilistic Resilient Interdependent
Infrastructure System Modeling**

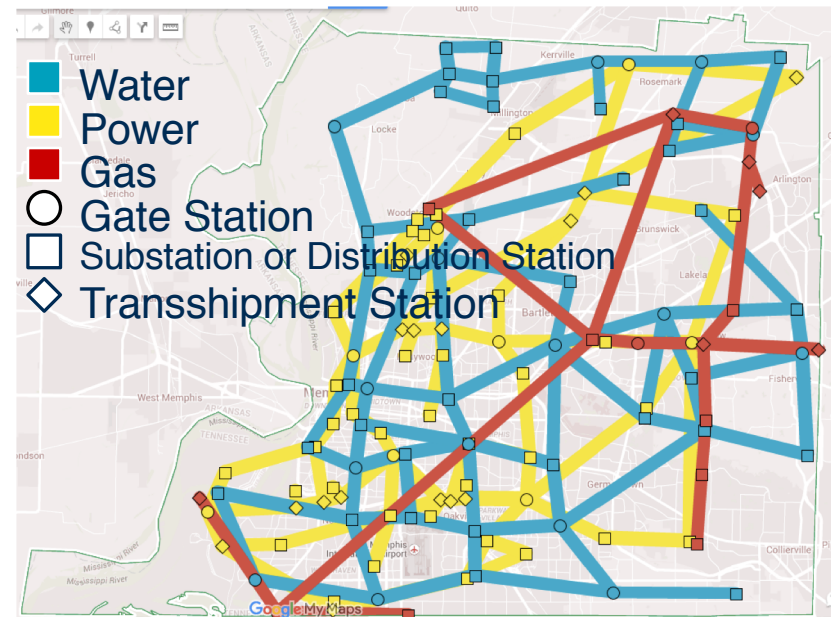
Iris Tien, Ph.D.

Williams Family Associate Professor
School of Civil and Environmental Engineering
Georgia Institute of Technology

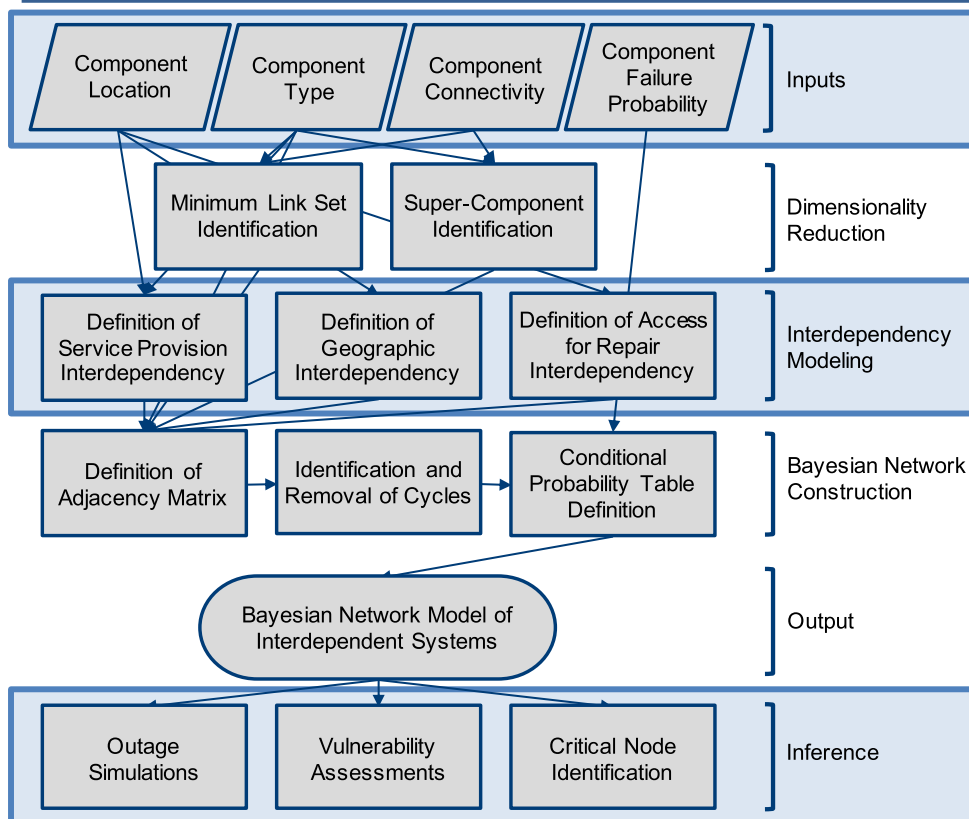
Critical Infrastructure Resilience Institute (CIRI) Webinar
November 12, 2020

Motivation

- Increasing connectivity of critical infrastructure systems and dependencies across national critical functions
- Single → multiple infrastructure systems
- Capture interdependencies between systems
 - Threat of cascading failures
 - Geographical hazards
 - Dependence for recovery



Methodology



Multi-step process and algorithm

- Individual component characteristics
- Define interdependencies across system (3)
- Analyses across range of threat and outage scenarios

✧ **Applegate and Tien**, "Framework for Probabilistic Vulnerability Analysis of Interdependent Infrastructure Systems," *JCCE*, 2019

Define infrastructure system interdependencies

- Comprehensive, generalized interdependencies (3)

Service Provision Interdependency

- One component depends on service outputs of another to function

Geographic Interdependency

- Two or more components in same geographical area may fail together

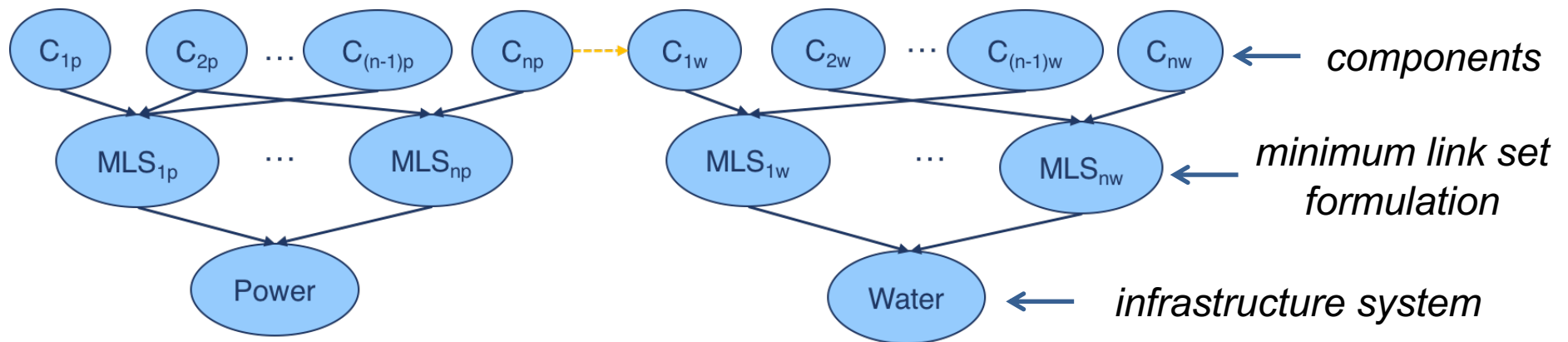
Access for Repair Interdependency

- Infrastructure components must be functional for cyber or physical access to failed components
- Methods for *quantitative probabilistic* modeling of each interdependency type

✧ Johansen and Tien, "Probabilistic Multi-Scale Modeling of Interdependencies between Critical Infrastructure Systems for Resilience," *SRI*, 2018

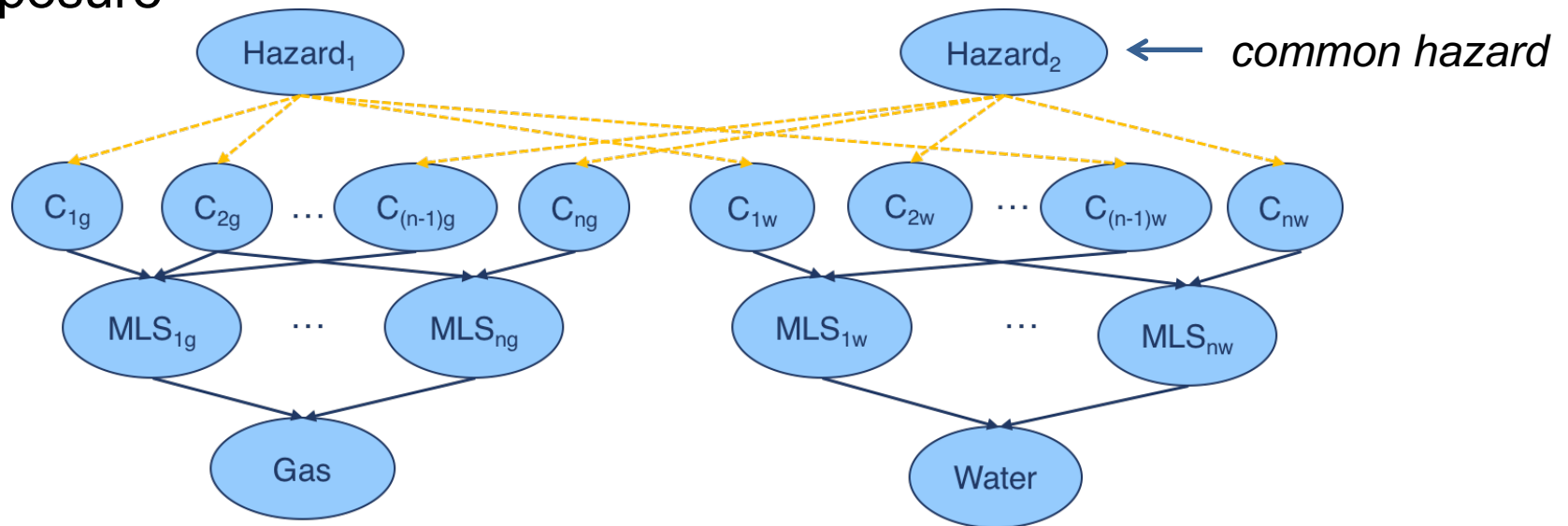
Service provision interdependency

- Functioning of one infrastructure depends on service outputs of another
- e.g., fuel supply for power generation, electricity for water pumps



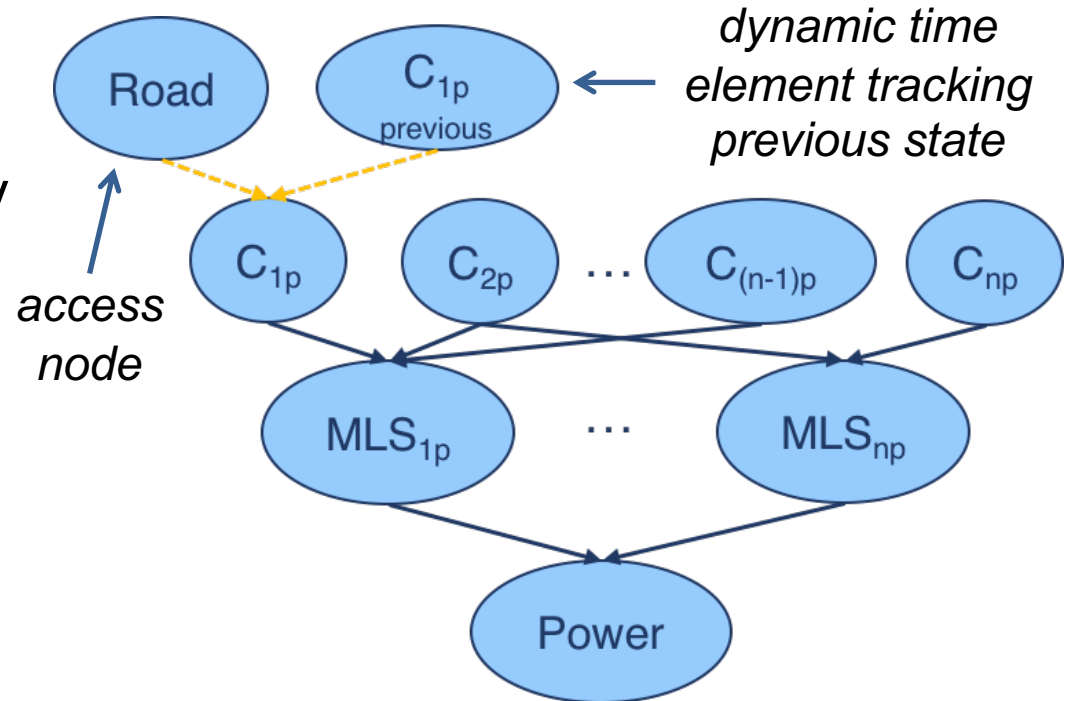
Geographic interdependency

- Functioning of one infrastructure connected to functioning of another due to physical similarity, geographic proximity
- e.g., collocated gas lines and water mains, common hazard exposure



Access for repair interdependency

- Ability to repair one infrastructure affected by access (physical, remote/cyber) provided by another infrastructure
- Addresses post-disaster recovery for resilience
- e.g., communications for controls, transportation systems for repair



PRI

- In

Component
character
of conn
infrastru
system

- Junction (pair network)
- Pipe
- Con
- Cool
- local

PRIISM - Probabilistic Resilient Interdependent Infrastructure System Modeling Tool

PRIISM

Probabilistic Resilient Interdependent Infrastructure System Modeling Tool

Data Inputs Analysis Options Run

Open and load file for junctions/pipes Export contents as new file

Junctions ID	Supply	Latitude	Longitude
16	<input type="checkbox"/>	79263	27508
17	<input type="checkbox"/>	85798	26816
18	<input type="checkbox"/>	79293	28636
19	<input type="checkbox"/>	77704	29027
20	<input type="checkbox"/>	76226	29046
21	<input type="checkbox"/>	72876	29847
22	<input type="checkbox"/>	75184	30895
23	<input type="checkbox"/>	77624	30638
24	<input type="checkbox"/>	87731	30203
25	<input type="checkbox"/>	81333	30219
26	<input type="checkbox"/>	85151	30924
27	<input type="checkbox"/>	76551	31404
28	<input type="checkbox"/>	83678	31285
29	<input type="checkbox"/>	76287	32420
30	<input type="checkbox"/>	84878	32247
31	<input type="checkbox"/>	78767	31954

Pipes ID	Pipes node 1	Pipes node 2
1	1	17
2	16	1
3	4	1
4	3	2
5	2	16
6	21	3
7	20	21
8	16	18
9	19	18
10	18	4
11	26	4
12	20	19
13	23	19
14	2	20
15	4	25
16	20	5

Two example analysis scenarios

- 1) Pipes analysis, upstream simulation of pipe breaks in a hazard, include service provision interdependencies, vulnerability assessment to cascading failures
- 2) Junctions analysis, include service provision interdependencies, and hazard nodes and access nodes (for geographic and access for repair interdependencies), interdependent system risk assessment

1) Pipes analysis

The screenshot displays the PRIISM (Probabilistic Resilient Interdependent Infrastructure System Modeling Tool) software interface. On the left, a Microsoft Excel spreadsheet is open, showing a column of numerical values under the heading 'Pipes pf'. A red box highlights this column, with an arrow pointing to the 'Pipe Component' radio button in the software's 'Junction/Pipe' settings.

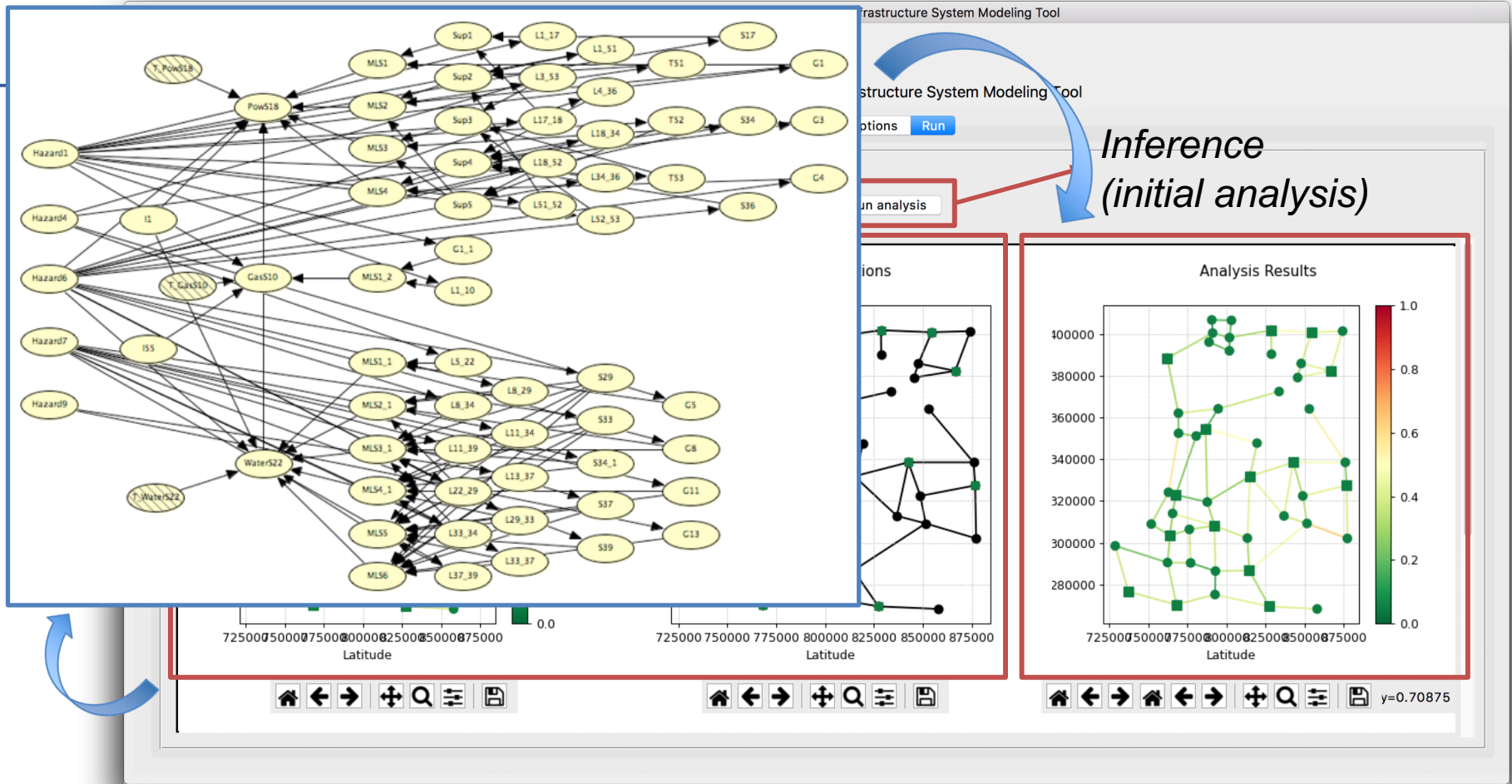
The main software window shows the 'Analysis Options' tab. The 'Junction/Pipe' section has 'Pipe Component' selected. The 'Configure Pfs and Interdependencies' section has 'No Hazard Nodes' and 'No Access Nodes' selected. The 'Configure supply interdependencies' button is visible. Below this is a table for 'Supply Interdependencies' with 9 rows of input fields.

On the right, a network graph shows a complex network of nodes and edges. The nodes are represented by squares and circles, and the edges are lines connecting them. A color scale on the right of the graph ranges from 0 (green) to 1 (red), indicating a probability or risk level. The graph is plotted against Latitude on the x-axis (ranging from 750000 to 850000) and an unlabeled y-axis (ranging from 80000 to 200000).

Iris Tien, Ph.D.

PRIISM: Probabilistic Resilient Interdependent Infrastructure System Modeling



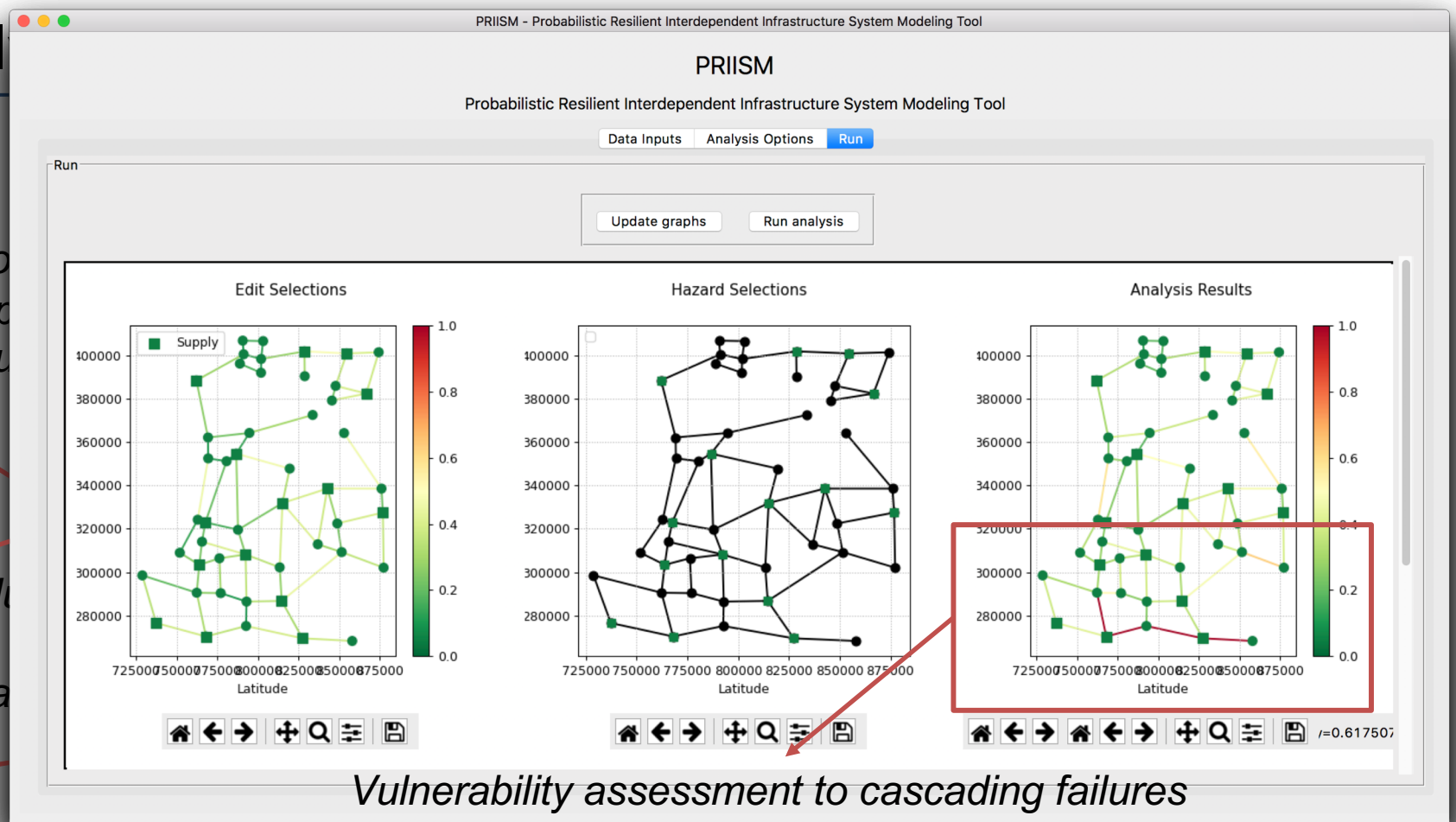


Anal

Select nodes
from graph
input failure
scenario

Node failure
scenario
and update

Update



Vulnerability assessment to cascading failures

2) Junctions analysis with added interdependencies

PRIISM - Probability of Failure

Configure probability of failure

Junctions/Pipes

Junctions

Open and load file for Pf

OR

Pf given hazard
uniform value:

0

Pf given no
hazard uniform
value:

0

Populate uniform value

Pipes

Open and load file for Pf

OR

Pf given hazard
uniform value:

0

Pf given no
hazard uniform
value:

0

Populate uniform value

Power/Access components

Power components

Open and load file for supply

OR

Pf given hazard
uniform value:

0.0

Pf given no
hazard uniform
value:

0.0

Uniform # of
power
components/
supply:

0

Populate uniform value

Access components

Open and load file for Pf

OR

Pf given hazard
uniform value:

0.0

Pf given no
hazard uniform
value:

0.0

Uniform # of
access
components/
supply:

0

Probability of
repair

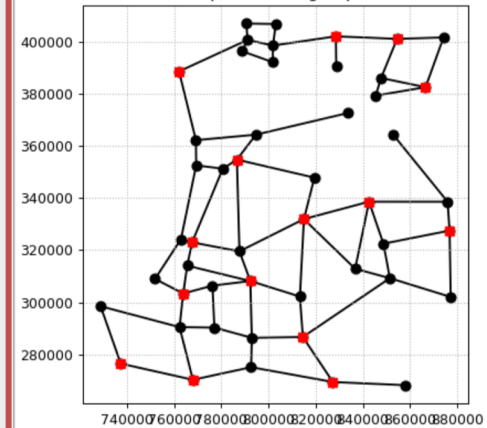
0.0

Populate uniform value

Hazards

Hazard node selection

Press enter to accept selected group of hazard nodes.



Probability of hazard

Hazard Group	Hazard Occurrence
0	0.0
0	0.0
Update	

*Power and Access
Components for
service provision and
access for repair
interdependencies*

*Hazards Selection
for geographic
interdependencies*

Configure probability of failure

Junctions/Pipes

Junctions

Open and load file for Pf

OR

Pf given hazard uniform value:

0

Pf given no hazard uniform value:

0

Populate uniform value

Pipes

Open and load file for Pf

OR

Pf given hazard uniform value:

0

Pf given no hazard uniform value:

0

Populate uniform value

Power/Access components

Power components

Open and load file for supply

OR

Open and load file for Pf

Pf given hazard uniform value:

0.01

Pf given no hazard uniform value:

0.0001

Uniform # of power components/supply:

1

Populate uniform value

Access components

Open and load file for Pf

OR

Pf given hazard uniform value:

0.01

Pf given no hazard uniform value:

0.0001

Uniform # of access components/supply:

1

Probability of repair

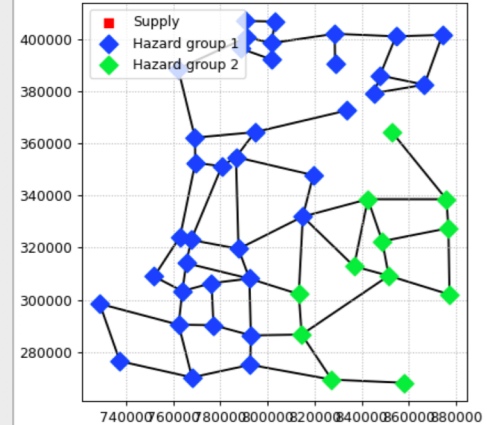
0.8

Populate uniform value

Hazards

Hazard node selection

Press enter to accept selected group of hazard nodes.



Probability of hazard	
Hazard Group	Hazard Occurrence
1	0.01
2	0.02
Update	

Interdependency inputs

PRIISM - Probabilistic Resilient Interdependent Infrastructure System Modeling Tool

PRIISM

Probabilistic Resilient Interdependent Infrastructure System Modeling Tool

Data Inputs Analysis Options Run

Analysis Options

📄
📊

Junction/Pipe

Junction Component
 Pipe Component

Configure Pfs and Interdependencies

Hazard Nodes
 No Hazard Nodes
 Access Nodes
 No Access Nodes

Configure supply interdependencies

Supply Interdependencies

ID	# of power components	Pf given hazard	Pf given no hazard	# of access components	Pf given hazard	Pf given no hazard	Probability of repair
1	1	0.01	0.0001	1	0.01	0.0001	0.8
2	1	0.01	0.0001	1	0.01	0.0001	0.8
3	1	0.01	0.0001	1	0.01	0.0001	0.8
4	1	0.01	0.0001	1	0.01	0.0001	0.8
5	1	0.01	0.0001	1	0.01	0.0001	0.8
6	1	0.01	0.0001	1	0.01	0.0001	0.8
7	1	0.01	0.0001	1	0.01	0.0001	0.8
8	1	0.01	0.0001	1	0.01	0.0001	0.8
9	1	0.01	0.0001	1	0.01	0.0001	0.8

Latitude

Run analyses

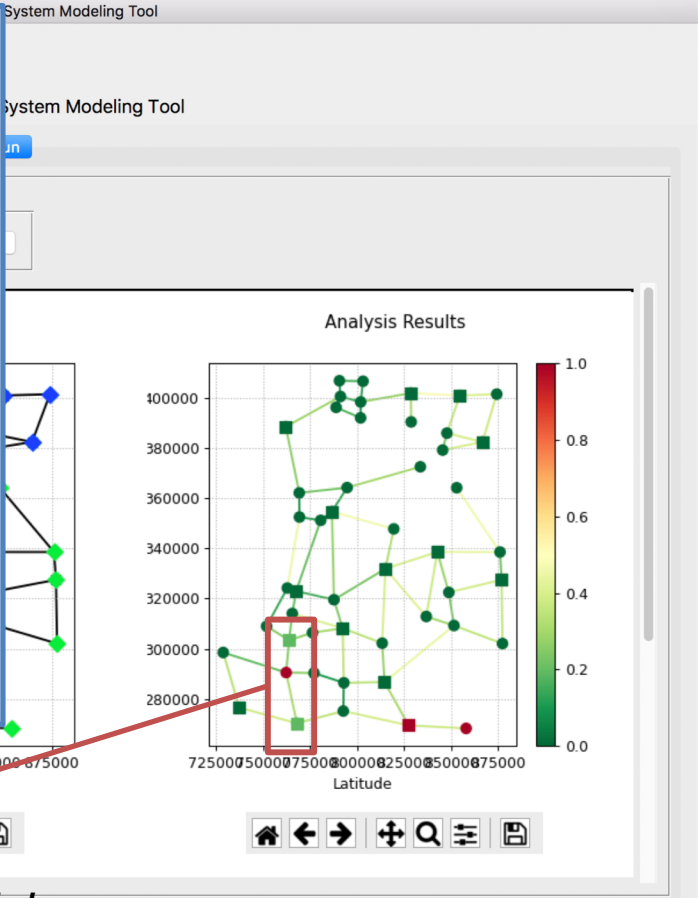
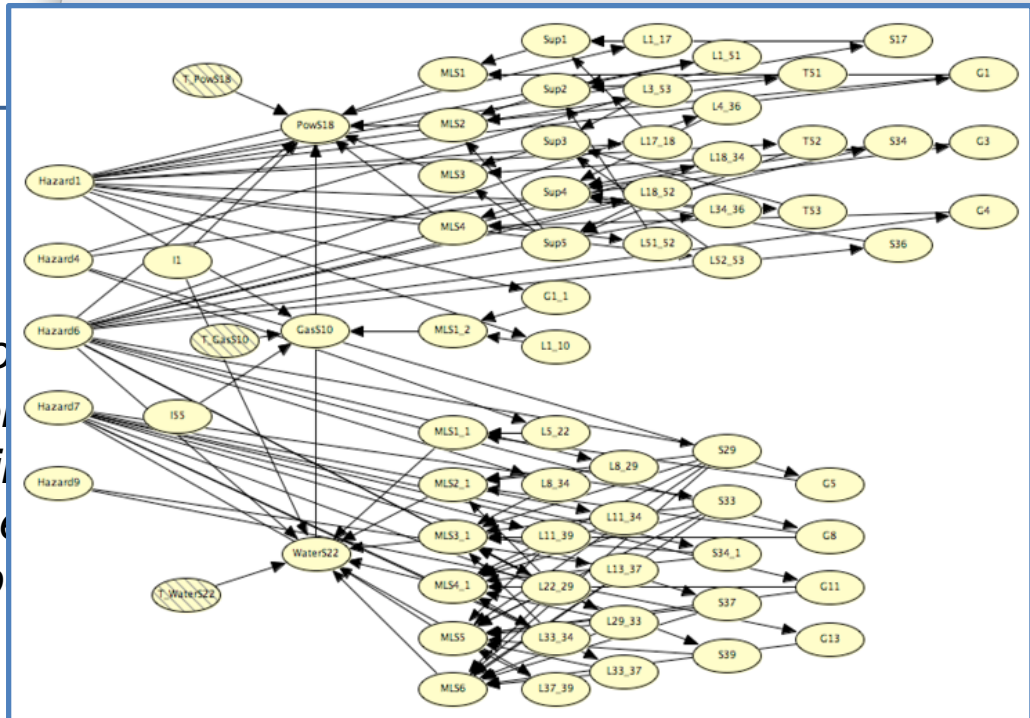
The screenshot displays the PRIISM software interface. At the top, the title bar reads "PRIISM - Probabilistic Resilient Interdependent Infrastructure System Modeling Tool". The main window title is "PRIISM Probabilistic Resilient Interdependent Infrastructure System Modeling Tool". Below the title, there are three tabs: "Data Inputs", "Analysis Options", and "Run". The "Run" tab is active, and a red box highlights the "Run" button. Below the tabs, there are two buttons: "Update graphs" and "Run analysis", both highlighted with red boxes. Red arrows point from the text "Run analyses" to the "Run" button and from "Update graphs and Run initial inference analysis" to the "Update graphs" and "Run analysis" buttons. The main area contains three plots: "Edit Selections", "Hazard Selections", and "Analysis Results". Each plot shows a network of nodes and edges on a grid. The "Edit Selections" plot has a legend with a green square labeled "Supply" and a color scale from 0.0 to 1.0. The "Hazard Selections" plot has a legend with blue diamonds and green diamonds labeled "Hazard group" and a color scale from 0.0 to 1.0. The "Analysis Results" plot has a color scale from 0.0 to 1.0. Each plot has a toolbar with navigation icons and a status bar at the bottom showing $r=0.939901$.

Run analyses

Update graphs and Run initial inference analysis

No
se
fail
sc
up

Non-
supp
node



Backward inference for comprehensive risk assessment (causes), including interdependencies

PRIISM

- Simple inputs
 - Component characteristics (location, function, vulnerability, connectivity)
- Outputs
 - System vulnerability assessments
 - Cascading failure impacts
 - Including service provision, geographic (hazard areas), and access for repair interdependencies
- Component-level information → system-level outcomes for comprehensive critical infrastructure risk assessments
- Quantitative probabilistic analysis capabilities accounting for interdependencies across systems and functions, uncertainties in component outcomes and threat scenarios

Acknowledgements:

- Chole Applegate, Ph.D.
- Cynthia Lee, Ph.D.
- Shirling Xu

Department of Homeland Security Award #2015-ST-061-CIRC01

Contact: itien@ce.gatech.edu