Identification and Classification of Restoration Interdependencies after Hurricane Sandy

Thomas C. Sharkey Joe H. Chow John E. Mitchell Huy Nguyen Sarah G. Nurre William A. Wallace

Rensselaer Polytechnic Institute

June 5, 2013

1 Overview

2 Classes of Restoration Interdependencies

3 Analysis and Discussion

Restoration Interdependencies

- **Definition**: A *restoration interdependency* occurs when a restoration task, process, or activity in an infrastructure is impacted by a restoration task, process, or activity in a different infrastructure.
- These are distinct from *operational interdependencies* which occur when when a component of one infrastructure requires services provided by another infrastructure in order to properly function.
- Our work to date has focused on a classification scheme and analysis from articles in major newspapers in areas affected by Hurricane Sandy.

Comparison of Operational and Restoration Interdependencies

- The subway system has an operational interdependency on the power system.
  - Damage to a substation that feeds a subway line causes a disruption to subway services.
  - Subway services will not resume until power is restored but its restoration efforts were not impacted.
- The repairs needed to flooded subway lines had a restoration interdependency with the power system.
  - Damage to a substation that feeds a subway line prevents test trains from running on the line.
  - Subway services will not resume until power is restored and test trains are run.
  - Therefore, the timeline of subway restoration can be affected by power restoration efforts.

Why think about Restoration Interdependencies?

- Infrastructure managers can plan their restoration efforts based on damage reports.
- The planned restoration efforts help to project out the set of operational components in the infrastructure and thus predict the level of service provided by the infrastructure.
  - However, operational interdependencies can affect this prediction due to the cascading failures of disruptions in other infrastructures.
- The *predicted timeline* of the restoration efforts provides the set of operational components in the infrastructure.
  - However, restoration interdependencies will affect this predicted timeline due to the impacts of other infrastructures' restoration efforts.

Methodology for Identifying Restoration Interdependencies

- We examined news articles related to Hurricane Sandy published in four major newspapers.
  - The New York Times - New York City.
  - Newsday - Long Island.
  - The Star Ledger (and other nj.com partners) - New Jersey.
  - The Philadelphia Inquirer - Philadelphia and South Jersey.
- Each of these newspapers had sections or tags that listed all articles related to Hurricane Sandy.
- A database of quotes were collected and a coding scheme to classify them was developed.

1 Overview

2 Classes of Restoration Interdependencies

3 Analysis and Discussion

Identified Classes of Restoration Interdependencies

1. Traditional Precedence.
2. Effectiveness Precedence.
3. Options Precedence.
4. Time-Sensitive Options.
5. Competition for Resources.

Traditional Precedence

- **Definition**: A restoration task in infrastructure B cannot be started until a restoration task in infrastructure A is complete.
- **Observed Frequency**: 48
- **Examples**:
  - Test trains in the subway cannot be run until power is restored to the line.
  - Assessment activities to determine damage to equipment cannot begin until power is restored to the facility.
  - Distribution of gas to restore normal levels of reserves cannot start until debris is cleared from ports.
- **Comments**:
  - Power had a precedence over a restoration task in 7 other infrastructures.
  - Three other infrastructures had a precedence over a task in the power system.

Effectiveness Precedence

- **Definition**: A restoration task in infrastructure B is not as effective (for example, it requires a longer processing time or more resources dedicated to it) until a restoration task in infrastructure A is complete.
- **Observed Frequency**: 8
- **Examples**:
  - Pumping floodwaters from an area is slowed by electrical outages to pumps in the area.
  - Gas stations can only accept cash from customers due to disruptions in their credit lines.
- **Comments**:
  - Only the power and telecommunications infrastructures served as infrastructure A in our observations.

Options Precedence

- **Definition**: A restoration task in infrastructure B can be completed by accomplishing a restoration task in one of a set of possible infrastructures, A_1, A_2, ..., A_n.
- **Observed Frequency**: 20
- **Examples**:
  - A senior care facility or a hospital, after losing backup generators, can either wait for power restoration or order an evacuation of its patients from the facility.
  - A gas station could reopen by either having its power restored or receiving a generator (or hand-pumping gas out of its tank).
- **Comments**:
  - In most situations, infrastructure B will appear as one of the infrastructures that can complete the task.

Time-Sensitive Options

- **Definition**: A restoration task in infrastructure B must be completed only if a restoration task in infrastructure A is not completed by a certain (unknown) deadline. Therefore, the restoration task in A must be completed by its deadline or the task in B must be completed.
- **Observed Frequency**: 11
- **Examples**:
  - Power is not restored to a cell tower before a generator powering it runs out of fuel, thus creating a refueling task.
  - Flooding or debris prevents the access of firefighters to the location of a fire, thus creating more residential cleanup tasks.
- **Comments**:
  - The refueling issue was not frequently reported but probably frequently occurred.

Competition for Resources

- **Definition**: Restoration tasks in infrastructures A_1, A_2, ..., A_n compete for the same set of scarce resources.
- **Observed Frequency**: 9.
- **Examples**:
  - Power generators brought into an area could assist with providing electricity to hospitals, the water system, or waste water treatment plants.
  - Emergency vehicles and power restoration crews both require fuel for their restoration activities.

1 Overview

2 Classes of Restoration Interdependencies

3 Analysis and Discussion

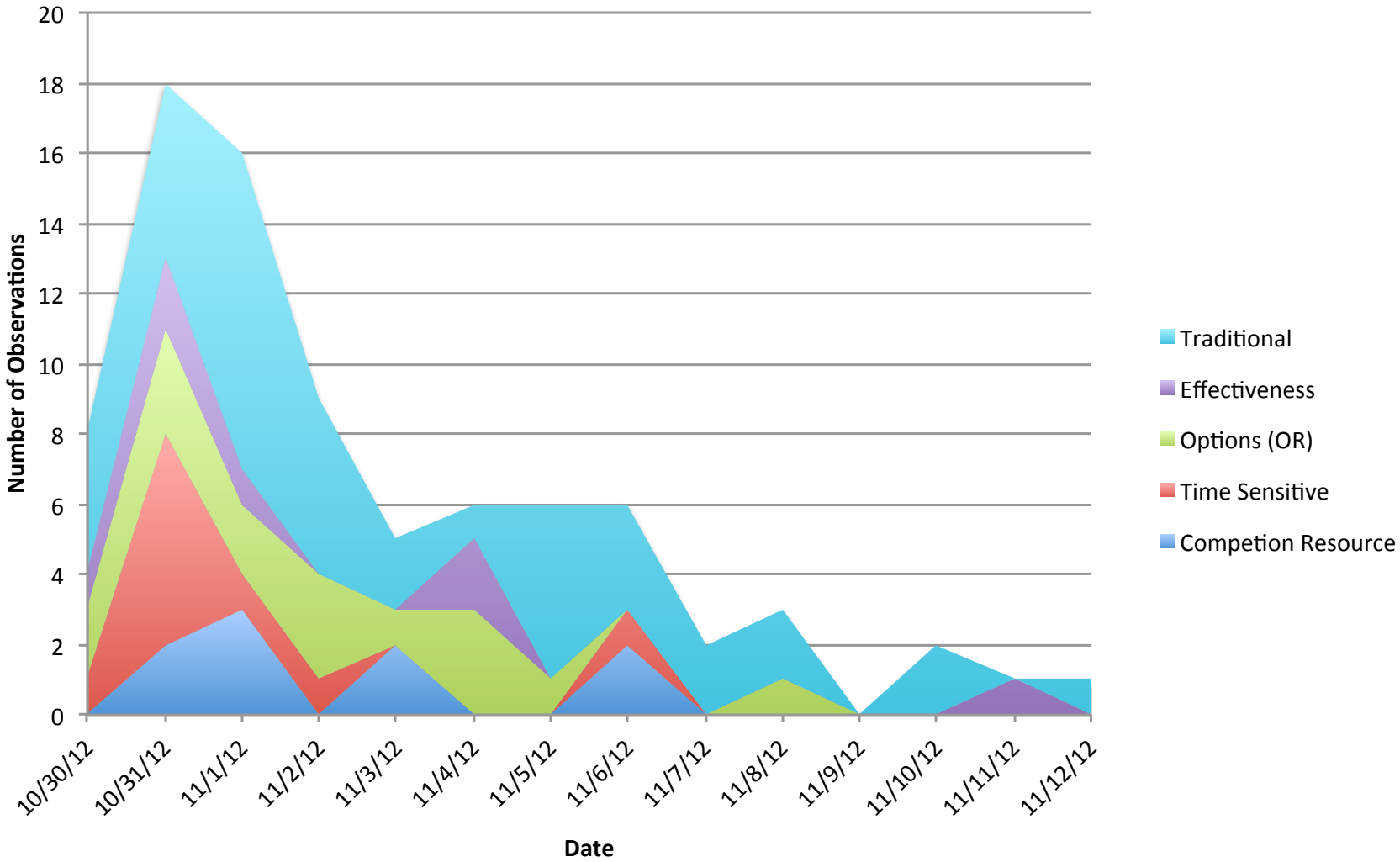
Frequency Summary

	NYT	Newsday	Star Ledger	Other NJ	PI	Total
Traditional Precedence	16	9	10	11	2	48
Effectiveness Precedence	5	0	1	2	0	8
Options Precedence	6	2	2	10	0	20
Time-Sensitive Options	2	1	4	4	0	11
Competition for Resources	3	1	1	2	2	9
Total	32	13	18	29	4	96

Restoration Interdependencies by Critical Infrastructure Sector

	Chemical	Commercial Facilities	Communications	Critical Manufacturing	Dams	Defense Industrial Base	Emergency Services	Energy	Financial Services	Food and Agriculture	Government Facilities	Healthcare	Information Technology	Nuclear	Transportation	Water and Waste Water
Chemical																
Commercial Facilities								TR	OP							
Communications				EF				TR, EF, CR		EF						
Critical Manufacturing				OP												
Dams																
Defense Industrial Base																
Emergency Services							OP	CR		CR	CR	CR				CR
Energy			TR, TS	TR, OP			TR, OP, CR	TR, OP		TR, EF, TS	TR, OP	OP			TR, EF, CR	CR
Financial Services									OP							
Food and Agriculture							CR									
Government Facilities							CR				OP					
Healthcare							CR			CR						
Information Technology																
Nuclear																
Transportation		TS		TR			TR	TR, OP, CR								
Water and Wastewater							CR	CR								

Temporal Analysis: Timeline for Observations



Information-Sharing

- It may be possible to mitigate the impact of restoration interdependencies by coordinating or sharing information between infrastructures during their restoration efforts.
- For example, knowledge of *when* power would be restored to subway lines and stations would help better plan:
  - when test trains could run and
  - how to locate generators to pump water out of the system.
- Full coordination is unlikely; therefore, it is necessary to explore possible coordination and information-sharing mechanisms.

Next Steps

- Confirmation of restoration interdependencies with infrastructure managers.
- Discussions with infrastructure managers about potential coordination and information-sharing mechanisms.
- Quanitfying the impact of coordination and information-sharing to mitigate restoration interdependencies.