INSPECTION AND RESTORATION SCHEDULING OF ROADWAY AND OTHER LIFELINE SYSTEMS FOR IMPROVED POST-DISASTER INFRASTRUCTURE SYSTEMS RECOVERY

This document is a technical summary of the Federal Highway Administration report, *Inspection and Restoration of Roadway and Other Lifeline Systems for Improved Post-Disaster Infrastructure Systems Recovery*, FHWA-HRT-TBD.

INTRODUCTION

Hazards pose significant issues for the performance of critical lifelines, and the post-disaster performance of roadway networks, in particular, is crucial, as roadways, including pavements and bridges, are key links used in completing infrastructure repairs. The performance of roadways depends on an ability to quickly assess roadway facility conditions through inspection, for which access along the same pavement and bridge system that is under examination is required. Thus, some restoration activities to the roadway elements may need to be completed before inspections of other roadway network elements or elements of other infrastructure lifelines can even begin. The order in which these inspection and restoration activities take place can greatly affect the time until services from critical lifelines are restored, and the simultaneous consideration of the restoration needs of multiple lifelines given their reliance on the roadway network facilitates faster overall recovery of the communities they serve.

This project led to the development of a multi-stage stochastic programming formulation for jointly devising post-disaster inspection and restoration activity schedules to minimize roadway downtime and maximize opportunities for timely completion of repairs to other lifelines over the recovery period. Each lifeline is presumed to have dedicated inspection and repair crews, but no crew can access its lifeline element if no pathway to them exists. The formulation presumes the occurrence of a randomly arising disaster event whose impact may damage roadway links or other critical lifeline components, and that its effects are only revealed at the time of inspection. That is, the status of the infrastructure links and nodes are known only with uncertainty. The status of the links and nodes is revealed only after an inspection decision is taken and implemented, and restoration cannot take place until inspection is complete.

Since inspection decisions are outcomes of the mathematical model and inspection actions reveal the state of the links and nodes, uncertainty in this problem context is decision-dependent or endogenous. This work recognizes the decision dependence of information realization from optimally scheduled inspections in the state of the lifeline elements, capturing the key elements of this endogeneity in uncertainty.

METHODOLOGY

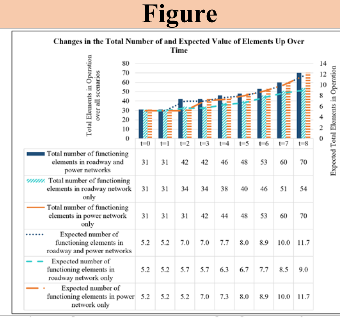
A multi-stage, stochastic, integer formulation of the problem of determining an optimal inspection-repair schedule of elements of infrastructure lifelines damaged in a disaster event was developed, implemented, and applied on an illustrative network involving both roadways and a co-located power distribution network. The formulation involves the use of conditional nonanticipativity constraints to capture how inspection decisions impact the timing of the realization of random information.

DATA SUMMARY

Data on the test network, including roadways, substations, and transmission lines of Arlington, Virginia were extracted from (County Board, 2010) and used to illustrate the developed method's application and assess the benefits of coordinating inspection and restoration actions across multiple lifelines.

EVALUATION RESULTS

Numerous observations can be made for the test application, as given in the table.

<table>
<tr><th></th><th>Description</th><th>Figure</th></tr>
<tr><td>1</td><td>The percent of total lifeline elements that are functioning at the end of the study horizon over all scenarios compared with immediately post-disaster is 56% (67% of roadway and 36% of power elements). When focusing only on restoring the power network, only 43% (54% of roadway and 22% of power elements) of the elements were restored.</td><td>


</td></tr>
<tr><td>2</td><td>When actions are focused entirely on bringing the power network back up, the repair of roadway links not required to support inspection and/or repairs in the power network will be postponed.</td><td>
<table>
<tr><th></th><th>$t = 0$</th><th>$t = 1$</th><th>$t = 2$</th><th>$t = 3$</th><th>$t = 4$</th><th>$t = 5$</th><th>$t = 6$</th><th>$t = 7$</th><th>$t = 8$</th></tr>
<tr><td>Roadway and Power Network</td><td>0</td><td>NA</td><td>1</td><td>2</td><td>2</td><td>4,5,6,8</td><td>3,8</td><td>NA</td><td>NA</td></tr>
<tr><td>Roadway Network Only</td><td>0</td><td>NA</td><td>1</td><td>2</td><td>2</td><td>5,6,8</td><td>3,4</td><td>NA</td><td>NA</td></tr>
<tr><td>Power Network Only</td><td>0</td><td>NA</td><td>1</td><td>2</td><td>2,8</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td></tr>
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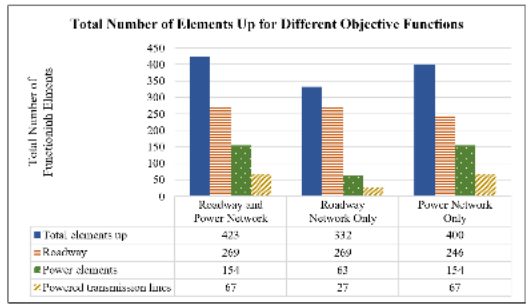
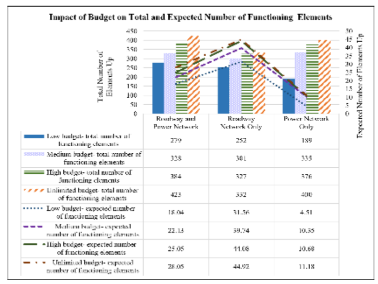
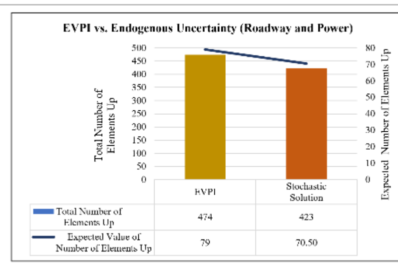
3	Coordination between lifelines led to a greater number of paths created from the depot to power network elements over time, and more of these paths were open earlier.	
4	Relaxing inspection and restoration budget restrictions can have a sizeable impact on the recovery of all lifelines.	
5	A gain of 12% in the expected number of elements that can be returned to full functionality over the considered time horizon resulted from perfect information of the future.	

CONCLUSIONS AND IMPLEMENTATION

The problem of determining optimal inspection and repair decisions of infrastructure lifelines in the aftermath of a disaster event impacting a geographic area is modeled as a multi-stage, stochastic integer program with endogenous uncertainty capturing that inspection and repair decisions impact the timing of network element status realization. Inspections reveal which links of the networks are in need of repair or are otherwise functioning. Repair actions allow access to additional portions of the network, creating the possibility for additional inspection with the new information it brings, and restoration of more of the networks.

Results from the numerical experiments on a case study in Arlington, Virginia, involving roadway and power distribution networks show that coordinating restoration actions across roadway and power networks will benefit the overall recovery process for the community, helping in repairing more elements in a fixed horizon. In fact, repair actions on the roadways can be ordered to support faster return of power services with little loss for the roadway network.

For More Information Principal Investigator: Elise Miller-Hooks Technical reports when published are available at **http://________________________________**	Department of Civil, Environmental, & Infrastructure Engineering George Mason University Phone: 703-993-1685 E-mail: miller@gmu.edu