Reducing Service Interruptions in Linear Infrastructure Systems (Transportation and Water/Sewer) by Synchronizing Schedules for Selected Maintenance Activities

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Georgia Institute of Technology

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Introduction

Interdependency of lifeline systems:

• Electric and potable water transmission and distribution, wastewater collection and treatment, highways, railroads, seaports and inland waterway ports.

Interdependent linear infrastructure systems (ILIS)

• In ILIS events are linked by time and dynamics of the interactions between the systems.
Introduction

Interdependent linear infrastructure systems (ILIS)
Introduction

Interdependent linear infrastructure systems (ILIS)
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Interdependent linear infrastructure systems (ILIS)

Compatible conditions
Incompatible conditions
Individual or interactive system failure

Time
No of people affected
Service interruption

New infrastructure
Functional infrastructure with unbalanced stresses
Stress failure

New infrastructure
Functional infrastructure with unbalanced stresses
Stress failure

Individual or interactive system failure

Time

No of people affected
Service interruption

Time

Florida International University
Objectives of this research are to:

- Characterize service interruption profiles in interdependent linear infrastructure systems (ILIS);
- Identify interactively the major events which cause service interruptions;
- Develop a tool to establish checkpoints for service quality.
1. What are the similarities in service interruption profiles in ILIS (transportation, water/sewer)?

2. How do the service failure events relate to one another in ILIS?

3. How can we establish check points?

4. How can we develop coordinated maintenance schedules to reduce service interruptions and increase maintenance cost effectiveness?
Classification hierarchy

Highway Functional Classification Hierarchy

- All U.S. Roads
  - Rural
    - Arterials
      - Principal
      - Minor
    - Collectors
      - Major
      - Minor
  - Local
- Urban
  - Arterials
  - Collectors
  - Local

- Interstate
- Other Principal Arterial

- Interstate
- Other Freeway and Expressway
- Other Principal Arterial

Rural

Urban

Pipelines
Methodology

A. Identification of service interruption hazard modes in linear infrastructure systems (transportation, water & sewer, power)

1. *Causes of service quality decline and interruptions (service specific maintenance factors)*

   *(i.e., design and operational elements such as stresses during operation, aging and wear out, a software coding error, human errors, or operator-and-maintenance-induced factors).*

2. *Service quality and system redundancy*

   *(Identification of mechanisms to detect service interruptions with ease and in a timely manner).*

3. *Service quality metrics*

   *(Potential consequences due to quality decline and interruptions).*
Methodology

B. Service quality and priority assessment

• Interactive analysis to quantify the possible service interruptions due to system specific failure mechanisms.

• ILIS consequence number (ILIS-CN): Being developed using criteria based on frequency and severity of consequences.
C. Profiling, classification and rating of hazard modes

- A rating system (metrics) for different service interruption hazard modes based on:
  - Failure frequency
  - System redundancy for failure
  - Consequence rating
  - Potential impacts on functioning of other co-located linear infrastructures
Methodology
Risk management in lifeline systems

Service Infrastructure
- System/service failure hazard identification
- System/service hazard rating
- System/service failure mode analysis
- Intervention mechanisms

Community characteristics
- Population density
- Public awareness rating
- Information dissemination analysis
- Intervention mechanisms

Service delivery factors
Social factors
Methodology
Risk management in lifeline systems

Hazard driven measures
Technology driven measures
Regulatory driven measures

Economic limitations
Demographic limitations
Environmental limitations

What is desired
What can be achieved
Service Quality
## Methodology - Design factors

<table>
<thead>
<tr>
<th>Origin</th>
<th>Pipeline Service Failure Risk Factors</th>
<th>Transportation Service Failure Risk Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>Age (D2)</td>
<td>Age (D2)</td>
</tr>
<tr>
<td></td>
<td>Pipe Material (D3)</td>
<td>Road Material (D3)</td>
</tr>
<tr>
<td></td>
<td>Pipe Length (D4)</td>
<td>Travel Distance (D4)</td>
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<td></td>
<td>Pipe Capacity (D5)</td>
<td>Road Capacity (D5)</td>
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<td>System Redundancy (D6)</td>
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<td>Pipe Pressure (D8)</td>
<td>Traffic Load (D8)</td>
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<tr>
<td></td>
<td>Material being piped (D9)</td>
<td>Transport needs (people, goods) (D9)</td>
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</table>
# Methodology - Design factors

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<th>Transportation Service Failure Risk Factors</th>
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| **Design**      | Age (D2)  
Pipe Material (D3)  
Pipe Length (D4)  
Pipe Capacity (D5)  
System Redundancy (D6)  
Degree of Automation (D7)  
Pipe Pressure (D8)  
Material being piped (D9) | Age (D2)  
Road Material (D3)  
Distance (D4)  
Capacity (D5)  
System Redundancy (D6)  
Degree of Automation (D7)  
Traffic load (D8)  
Transport needs (people, goods) (D9) |
| **Operational** | No. of People Employed (O1)  
Periodic Training Program (O2)  
Frequency of Inspection (O3)  
Work Hours (O4)  
Morale (O5)  
Work Ethics (O6) | No. of drivers (O1)  
Work Hours (O5)  
Morale (O6)  
Driving Habits (O7) |
| **Environmental** | Geology (E1)  
Geography (E2)  
Weather (E3)  
Vibration (E4)  
Nearby Activities (E5) | Geology (E1)  
Geography (E2)  
Weather (E3)  
Vibration (E4)  
Nearby Activities (E5) |
| **Acts of God** | Earthquake (G1)  
Arson (G2)  
Flood (G3)  
Hurricane (G4) | Earthquake (G1)  
Arson (G2)  
Flood (G3)  
Hurricane (G4) |

### Urban Factors

1. Population density
2. Land use
3. Transportation network structure
4. Pipeline network structure
Numerical Analyses

% Traffic Function

Land Service Function

Traffic Function

Arterials

Local streets

100% access

% Land Services

No access

Clearly serve traffic movement

Intermediate roads having a theoretical balance between traffic and land service

Clearly serve adjacent land

Serves only a network function

No network function

Distributors/Collectors

Road type

(a) Road type and function (access vs network)
Pipeline classification hierarchy

Ground surface
<table>
<thead>
<tr>
<th>Origin</th>
<th>Failure Risk Factor</th>
<th>Risk Factor Score</th>
<th>Detectability Score</th>
<th>Consequence Score</th>
<th>VPN</th>
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<td>24</td>
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<td></td>
<td>Traffic Load</td>
<td>4</td>
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<td>5</td>
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<tr>
<td></td>
<td>Transport Need</td>
<td>4</td>
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## Numerical Analyses (Pipeline)

<table>
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<tr>
<th>Origin</th>
<th>Failure Risk Factor</th>
<th>Risk Factor Score</th>
<th>Detectability Score</th>
<th>Consequence Score</th>
<th>VPN</th>
<th>Overall VPN</th>
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<td>Pipe Material</td>
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<td>Pipe Length</td>
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<td>Pipe Capacity</td>
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<td>576</td>
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<tr>
<td></td>
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<td>2</td>
<td>2</td>
<td>6</td>
<td>24</td>
<td>576</td>
</tr>
<tr>
<td></td>
<td>Degree of Automation</td>
<td>4</td>
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<td>5</td>
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<td></td>
<td>Pipe Pressure</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>32</td>
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</tr>
</tbody>
</table>

- **VPN**: Value at Risk
- **Overall VPN**: Overall Value at Risk
• $V_r = \text{vulnerability due to road closure}$
Road closure = Population impact due to road closure

• $V_p = \text{vulnerability due to pipeline breakage}$
Pipeline breakage =
  Population impact due to road closure $\times$
  Population impact due to pipeline service failure
Benefits for end users

• Developing strategies to minimize service interruptions (i.e., identifying areas where agencies can coordinate maintenance schedules to maximize maintenance efficiencies to improve service quality and reduce cost);

• Improving service quality (technical, environmental, social, economic) factors;

• Improving service quality by smart maintenance planning for transportation and water/sewer infrastructure.
Thank you