Reliable Planning and Coordination of Emergency Responses to Railroad Incidents

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Agenda

- Background
  - Project motivation, scope and objective
  - Strategic emergency response planning

- Planning for Railroad Incidents
  - Probabilistic crossing blockage
  - Reliable design model

- Numerical Examples

- Ongoing Efforts
  - Correlated crossing blockage
  - Modelling approach
Motivation

- Railroad incidents (esp. those involving hazardous material) pose significant threats to safety, public health, the environment, and economy
  - May 12, 2015 – Eight killed in Amtrak train crash near Philadelphia; over 200 treated at hospitals
  - February 3, 2015 – Seven killed when Metro-North train hits S.U.V. in Railroad’s deadliest accident
  - July 6, 2013 – Lac-Mégantic rail disaster, Quebec, killing 47 and forcing 2000 to evacuate
  - January 13, 2014 – 400,000 gallons of crude oil spilled in North Dakota train wreck forced 1,400 residents of Casselton to evacuate
  - June 20, 2009 - One person died and six were injured due to ethanol train derailment in northern Illinois, forcing 600 homes to be evacuated

- Huge safety issue in Midwestern states such as Minnesota, Illinois, Wisconsin
  - Increasing traffic with Bakken formation crude oil, ethanol, and other hazardous material
The 4E Approach

Increasing vehicle and road traffic safety through a rigorous, science-based approach to the following factors:

<table>
<thead>
<tr>
<th>Engineering</th>
<th>Education</th>
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<tbody>
<tr>
<td>Develop science-based, data-driven regulations designed to increase vehicle and traffic safety for all road-users.</td>
<td>Raise awareness of vehicle and traffic safety problems. Teach people about measures being taken to address the issues.</td>
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<tr>
<th>Enforcement</th>
<th>Emergency Response</th>
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<td>Ensure regulations are evenly and effectively applied across all populations and areas.</td>
<td>Ensure efficient and effective response to incidents so as to minimize loss and injury</td>
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The Challenge

- Emergency response systems (and rail safety) require holistic approaches
  - Emergency response vulnerable to incidents and induced disruptions – **must be reliable against uncertainties, and be smart & “informed”**
  - Catastrophic consequences directly impact multiple entities and/or jurisdictions – **must be coordinated across multiple stakeholders**

**Component 1**
Accident Prediction Models using Macro and Micro Scale Analysis
- Risk quantification & prioritization of crossings

**Component 2**
Prediction of Train Arrival Times for Emergency Response Management & Driver Decision Support
- Real-time train position and systems information

**Component 3**
Positioning, Planning and Operation of Emergency Response Resources, and Coordination between Jurisdictions
Component 3 – Research Scope

- Developing tools & guidelines for strategically positioning, allocating, and operating emergency resources in anticipation of rail incidents
  - Capturing probability and correlation of spatially distributed incidents in multi-modal networks
  - Addressing vulnerability of the emergency response system itself, such as the risk of disruptions to first-responders (e.g., blockage of crossings)
  - Optimizing coordination of emergency responders from multiple jurisdictions (e.g., those from different states and private sector)
- Case studies with real-world context and data
  - Outreach to Illinois and Minnesota government agencies
- Packaging model and algorithm into practical decision-support tools for policy makers

Year 1
- Year 2
Related Work

- Evacuation or rescue planning
- Staging area location
  - Transit terminus
  - Landmarks
  - Population centroids
  - Other open areas

Model Concept

Input
- Evacuee groups
- Candidate locations for staging areas
- Cost for setting up staging areas
- Point-to-point travel costs
determine:
- Facility number
- Facility locations
- Customer assignment plan
Railroad Emergency Response

• What is different?

  – Most areas of incident impact occur within about 0.5 mile from the track, and a few miles along the track

  – Involving multiple stakeholders (public and private)

  – Involving multi-modal networks (highway and railroad) and crossings

  – Emergency response may itself be vulnerable; e.g., travel path of first responders may be blocked at rail crossings
Railroad safety talks headed on the right track

By Karen Zamora (Http://...

DECEMBER 22, 2014 — 9:25AM

When Bill Peterson moved to St. Paul, the line had passed through the city.

Now, he said, it’s more

At a roundtable discussion on Tuesday, Piper said the figure is minutes at a time.

That’s not just an inconvenience that long, it can affect
the train to clear or delay.

The system is broken, Piper said, the way it should be.

The forum, which included representatives, looked at the face of dramatically increased

Minnesota Department of Transportation
395 John Ireland Boulevard
Saint Paul, MN 55155

News Release

March 19, 2015

Contact: Kevin Gutknecht
651-366-4266

Oil-carrying trains travel near many Minnesotans

Numbers point to need for strong rail safety program

ST. PAUL, Minn. - The Minnesota Department of Transportation today released an estimate of how many people live near rail routes that carry crude oil from North Dakota.

Currently, an estimated 326,170 persons live within one-half mile of rail routes that carry the oil from North Dakota across Minnesota, according to MnDOT. One-half mile is considered the evacuation zone if a train derails and evacuation becomes necessary.

“This data provides a greater emphasis on the need for a strong rail safety program,” said MnDOT Commissioner Charlie Zelle. “If trains derail and an emergency occurs, many lives could be in danger.”

Crude oil trains travel on 700 miles of railroad from the North Dakota border through the Twin Cities and other areas of the state for delivery to the east and Gulf coasts. Canadian railroads also carry limited quantities of Alberta heavy crude oil through International Falls and Duluth. Five to seven trains of crude oil pass through the state daily. Each train carries about 3.3 million gallons of oil.

Governor Dayton has recommended improvements at 75 highway-rail grade crossings so trains carrying crude oil and other hazardous materials travel more safely across the state and to ensure that first responders are not stopped at blocked crossings. His proposal would spend $330 million over the next 10 years to provide safer rail crossings. In addition, the governor is recommending
Facility Disruptions

• When a rail crossing is blocked, the first responders have to
  – Seek more distant routes (excessive transportation costs), or
  – Give up service (high penalty)

• Reliable planning against possible blockage
  – Not only minimize facility and transportation costs in the normal scenario
  – But also hedge against costs under random blockages
Probabilistic Crossing Blockage

- Probability = long-term fraction of time for a railroad crossing to be blocked

The number of scenarios increases exponentially with the number of crossings.

The Reliable Design Problem

- Assumptions
  - Each built fire station can reach neighboring potential incident/staging areas via a number of railroad crossings
  - Each crossing is subject to probabilistic blockage
  - Crossing blockage probabilities are site-dependent and known *a priori*
  - Crossing blockages are independent
  - Each incident/staging area may be accessed by a number of fire stations
  - If all assigned fire stations/path have failed, there is a (huge) penalty cost (i.e., the first responders could not reach the incident/staging area in time)

The Reliable Design Problem

Input:
- Candidate location for fire station
  - Facility cost
- High risk / staging area
  - Maximum number of backup levels
  - Service loss penalty
- Railroad/highway network and crossings
  - Blockage probability
  - Point-to-point distance

Decision:
- Fire station number and location
- First-responder travel plan, including back-ups
  (1st, 2nd choice ... crossing-path ...)
The Reliable Design Problem

Parameters:

$I$ Set of all staging areas
$J$ Set of all firestations
$K$ Set of all crossings
$f_j$ Fixed setup cost of firestation $j$
$\mu_i$ Expected accident risk of staging area $i$
$l_{kj}$ Indication variable of whether firestation $j$ can be accessed through crossing $k$
$d_{ijk}$ Distance from firestation $j$ to staging area $i$ through crossing $k$
$R$ Maximum backup level for one staging area to be served

Variables:

$$X_j = \begin{cases} 
1 & \text{if a firestation is build at } j \\
0 & \text{otherwise}
\end{cases}$$

$$Y_{ikjr} = \begin{cases} 
1 & \text{if firestation } j \text{ is assigned to serve staging area } i \text{ through crossing } k \text{ at level } r \\
0 & \text{otherwise}
\end{cases}$$

$$Z_{ikjr} = \text{probability if firestation } j \text{ is assigned to serve staging area } i \text{ through crossing } k \text{ at level } r \text{ given assignment at level } r - 1$$

$$W_{ikjr} = \text{probability that firestation } j \text{ is assigned to serve staging area } i \text{ through crossing } k \text{ at level } r$$

$$W_{ikjr} = Z_{ikjr} \cdot Y_{ikjr}$$
Mixed-Integer Optimization Model

\[
\min \quad R+1 \\
\text{s.t.} \quad \begin{align*}
\text{Construction cost + expected transportation/penalty cost} \\
\text{A fire station must be built, and accessible via a crossing, before it can be used to cover a staging area} \\
\text{A crossing can be used to serve a staging area at no more than one level} \\
\text{Each staging area either gets served at some level, or receives penalty if all assigned fire stations have failed} \\
\text{Define probability for a fire station to reach a staging area under general crossing connectivity} \\
\text{Linearization of quadratic terms} \\
\text{Most decision variables are binary}
\end{align*}
\]
Hypothetical Case Study

- Twelve railroad segments, nine staging areas
- Each railroad segment has a specific incident probability
- Nine candidate fire station locations
- Twelve railroad crossings
- A staging area can be reached by up to three fire stations, only through its adjacent railroad crossings
Hypothetical Case Study
Illinois Case Study

- Implementation for railroad network in Illinois
  - $|I|=16$ customer points
  - $|J|=16$ candidate locations
  - $|K|=21$ access points
  - $R=4$, rail segment-dependent incident probability
  - Distance matrix by shortest path along the highway network

- Result
  - Best result: build 3 fire stations
  - Computation: Solver (CPLEX) reaches 1% gap on a PC within 8 minutes
Illinois Case Study
Recall...

Assumptions

- Each built fire station can reach neighboring potential staging areas via a number of railroad crossings
- Each crossing is subject to probabilistic blockage
- Crossing blockage probabilities are site-dependent and known a priori
- Crossing blockages are independent

- Each staging area may be accessed by a number of fire stations
- If all assigned fire stations have failed, there is a (huge) penalty cost (i.e., the first responders could not reach the staging area in time)

In reality, blockages are likely to be correlated

- Positive; e.g., region-wide shutdown
- Negative; e.g., due to a finite number/length of trains in region
Correlation Representations

- Equivalence (Xie et al., 2015)
  - Scenario probability representation
  - Conditional probability representation
  - Marginal probability representation

Augment the original network by adding blockage “generators” (Li et al., 2013)

- Disruption of generators are independent
- A crossing is functioning if and only if at least one of its connected generators is functioning

Correlation among crossings → Independence across generators

Can general crossing blockage mechanisms (e.g., site-dependency and correlation) be represented by properly selected generators/connections?

Can we optimize fire station location, generator structure, and staging area assignments?
**Proposition.** (Li et al. 2013) *Site-dependent* crossing blockage probabilities can be represented arbitrarily accurately by a properly constructed supporting generator structure.

**Proposition.** (Xie et al., 2015a) *Any correlated* crossing blockage can be represented by a properly constructed generator structure. The number of needed generators is *comparable* to the number of input scenarios.
Summary & Outlook

- Developing tools & guidelines for strategically positioning, allocating, and operating emergency resources in anticipation of rail incidents
  - Emphasizing vulnerability of the emergency response system itself, such as the risk of disruptions to first-responders (e.g., blockage of crossings)
  - Capturing probability and correlation of spatially distributed incidents in multi-modal networks
  - Optimizing coordination of emergency responders from multiple jurisdictions (e.g., those from different states and private sector)

- Case studies with real-world context and data
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Year 1

Year 2
Thank you!

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