Development of a Traffic Incident Management System for Contending with Non-recurrent Highway Congestion

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March 11, 2014

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Overview

- Introduction
- Component 1: Incident response management strategies
- Component 2: Prediction models for clearance times
- Component 3: A detour decision support system
- Contributions, future research, and conclusions
Non-recurrent traffic congestion due to incidents has contributed up to 60 percent of the total freeway corridor delay in the United States (Lindley, 1987).

About 25 percent of congestion in the U.S. is incident-related (FHWA, 2005).

The starting time and duration of non-recurrent congestion, due mainly to incidents, are random in nature.

Thus, it is critical to have an efficient and effective incident management system.
Key Tasks in an Incident Management System

- An optimal deployment strategy for response units
- Estimation of required clearance times for reported incidents
- Detour feasibility analysis
- Detour optimization analysis
- Provide travel time information to roadway users
  - queue, delay and travel time analysis

Introduction
Incident Management System

Incident Detection

Dispatching ERU

Collecting/Updating Incident & Traffic related Data

Predicting Incident Duration

Estimating Clearance Time

Detour feasibility analysis system

1. Incident Response Management Strategies
2. Prediction Models for Clearance Times
3. A Detour Decision Support System

Detour Optimization
Implementing Optimal Detour Plans
Output
Inform to Highway Users

NO

YES

Detour?

Evaluating Traffic & Incident Impact to the Network

Establishing Feasible Detour Plans

Analyzing the Necessity of Detour Operations

Introduction
Introduction

Needs for Each Component

1. Incident Response Management Strategies
   - To maximize contributions of incident response units with limited resources by assigning them to optimal locations.

2. Prediction Models for Clearance Times
   - To contend with stochastic nature of clearance times so as to maximize the system’s operational reliability.

3. A Detour Decision Support System
   - To facilitate responsible agencies to perform efficient traffic management in real time operations.
Research Objectives

1. Incident Response Management Strategies
   - Develop a deployment strategy for incident response units to minimize the total incident-induced delay

2. Prediction Models for Clearance Times
   - Develop a reliable model to estimate the clearance duration of a detected incident, and to identify critical contributing factors as well as their interrelationships

3. A Detour Decision Support System
   - Develop a detour decision support model for control center staff to determine the necessity of detouring traffic
1. Incident Response Management Strategies
Facility location problem

- how many response units are needed?
- where should they be allocated in response to the temporal and spatial distribution of incidents?

1) Covering models (Toregas et al., 1971; Schilling et al., 1979; Hogan and ReVelle, 1986; Nair and Miller-Hooks, 2009)

2) P-median models; and (Hakimi, 1964; Carson and Batta, 1990; Haghani et al., 2003; Yang et al., 2005)

3) P-center models (Sylvester, 1857; Garfinkel et al., 1977; ReVelle and Hogan, 1989; Talwar, 2002)

Minimize the number of service stations, the total operational costs, or to maximize the demand (incidents) covered by the pre-determined number of facilities
1. Incident Response Management Strategies

Data Sources

- Incident management program operated by Maryland state highway administration (MDSHA)
  - **Coordinated Highways Action Response Team (CHART)**
    - Has documented incident-related information over the past two decades
    - Date/time, location, nature, involved vehicles, lane closure...
**Effectiveness of CHART**

CHART responded approximately **81% (22,796/28,345)** of incidents during the last two years.

- **Does the CHART involvement matter?**
  - CHART reduced the avg. clearance time **by 27%**

<table>
<thead>
<tr>
<th></th>
<th>w/o CHART</th>
<th>w/ CHART</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean on CT (mins)</td>
<td>37.91</td>
<td>27.51</td>
</tr>
</tbody>
</table>

- **Does the prompt CHART response matter?**
  - CHART reduced the avg. clearance time **by 45%**

<table>
<thead>
<tr>
<th></th>
<th>CHART</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean on CT (mins)</td>
<td>21.85</td>
</tr>
<tr>
<td>Others</td>
<td>21.85</td>
</tr>
<tr>
<td>First responder</td>
<td>39.49</td>
</tr>
</tbody>
</table>
Needs for Research

- The efficient response of CHART can contribute to the reduction in not only the response time but also the clearance time → reduction in delay

- However, not all incidents can be promptly responded by CHART due to their limited resources

- Therefore, it is critical to develop a strategy to optimally deploy available response units so as to maximize their contributions
1. Incident Response Management Strategies

Model Construction

❖ Inputs
  ▪ Incident distribution, incident duration, lane blockage information, traffic volume, capacity, and available resources

❖ Objective function
  ▪ Minimize the total delay induced by incidents

❖ Constraints
  ▪ Every freeway segment must be served by one unit
  ▪ Response units can only be dispatched from location $i$ if they are stationed there
  ▪ The total number of response units is limited by available resources

❖ Outputs
  ▪ Assigned station and coverage for each unit
1. Incident Response Management Strategies

Relations between Incident Duration and Total Delay

Cumulative Arrivals and Departures

$\mathbf{f} (T_i, rc, c, q)$

Departure rate, $rc_1$ (Reduced capacity 1)

Departure rate, $rc_2$ (Reduced capacity 2)

Arrival rate, $q$

Departure rate, $c$

onset  response  cleared  recovered

time

Reduced delay due to additional lanes open

Reduced delay due to reduced clearance duration
1. Incident Response Management Strategies

Model Formulation

Objective Function: Min total delay for responded incidents

\[
\min_{x,y} \sum_{i} \sum_{j} x_{ij} \cdot f_j \cdot d_j \left( t_{ij} \right)
\]

Total Delay

1. Delay from incidents occurring at node j (Olmstead, 1996)

\[
d_j \left( t_{ij} \right) = \frac{1}{2} \cdot T_{ij} \cdot \left( q_j - r_{c,j} \right) \cdot \left( c_j - r_{c,j} / c_j - q_j \right)
\]

\[T_{ij}: \text{Response Time + Clearance time}\]

2. Response time and clearance time (Olmstead, 1996)

\[
T_{ij} = \begin{cases} (RT_{ij} + CT_{ij}) & \text{if CHART is not involved} \\ (RT_{ij} + CT_{ij} - 1) & \text{if CHART is involved and first responder} \\ (RT_{ij} + CT_{ij} - 2) & \text{if CHART is involved but not the first responder} \end{cases}
\]

\[
T_{ij} = (RT_{ij} + CT_{ij}) + \text{Var} \left( \begin{array}{c} CT_{ij} \\ CT_{ij} - 1 \\ RT_{ij} + CT_{ij} - 2 \end{array} \right)
\]

\[x_{ij} = 1 \text{ if incidents at } j \text{ are responded by a response unit at } i\]

\[y_i = 1 \text{ if a response unit is stationed at } i\]

\[G(N,A): \text{a network of freeways, where } N \text{ and } A \text{ are the sets of nodes and links}\]

\[i, j: \text{index for nodes } i, j \in N\]

\[f_j: \text{probability that an incident occurs at node } j\]

\[t_{ij}: \text{travel time from } i \text{ to } j\]

\[d_j: \text{delay from incidents occurring at node } j \text{ according to } t_{ij}\]

\[T_{ij}: \text{response time + estimated clearance time according to } t_{ij}\]

\[q_j: \text{traffic volume at } j\]

\[c_j: \text{capacity at } j\]

\[r_{c,j}: \text{reduced capacity at } j\]
1. Incident Response Management Strategies

Model Formulation (cont’d)

Constraints:

1. Every freeway segment must be served
   \[ \sum_{i \in N} x_{ij} = 1 \quad \forall \; i \in N \]

2. Response units can only be dispatched from
   location \( i \) if they are stationed there \( (y_i = 1) \)
   \[ x_{ij} \leq y_i \quad \forall \; j \in N \]

3. The total number of available response units is
   limited by available resources \( (R) \)
   \[ \sum_{i \in N} y_i \leq R \]

\[ x_{ij} \in [0,1] \; \forall \; (i,j) \in N \quad y_i \in [0,1] \; \forall \; i \in N \]
Empirical Study

- Segments of I-70, I-270 and US 15 in MD

Site Characteristics
- 63 miles
- Radial shape of roads
- Frederick, Howard, and Carroll Counties

Highway Incident Management
- TOC-7
- 3 units
- Operation Hours: 5AM – 9PM on weekday
  - Study Period: AM peak (7AM – 9:30 AM on weekday)
1. Incident Response Management Strategies

### Incident Frequency Distribution

**Incident frequencies fluctuate over the network!**

<table>
<thead>
<tr>
<th>Incident</th>
<th>I-70</th>
<th>I-270</th>
<th>US 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>35-42</td>
<td>5</td>
<td>26</td>
<td>1</td>
</tr>
<tr>
<td>42-48</td>
<td>20</td>
<td>27</td>
<td>13</td>
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<tr>
<td>49-52</td>
<td>4</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>52-53</td>
<td>10</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>53-54</td>
<td>7</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>54-55</td>
<td>13</td>
<td>13</td>
<td>4</td>
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<td>55-56</td>
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<td>2</td>
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<td>56-57</td>
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<td>1</td>
<td>1</td>
</tr>
<tr>
<td>58-59</td>
<td>10</td>
<td>26</td>
<td>1</td>
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<tr>
<td>59-60</td>
<td>4</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>60-61</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>61-62</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
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<td>62-63</td>
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<td>1</td>
<td>1</td>
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<tr>
<td>63-64</td>
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<td>1</td>
</tr>
<tr>
<td>64-65</td>
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<td>2</td>
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<tr>
<td>65-66</td>
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<td>1</td>
<td>3</td>
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<td>66-67</td>
<td>6</td>
<td>1</td>
<td>3</td>
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<td>67-68</td>
<td>7</td>
<td>1</td>
<td>3</td>
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<tr>
<td>68-69</td>
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<td>2</td>
<td>1</td>
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<tr>
<td>69-70</td>
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<td>70-71</td>
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<tr>
<td>71-72</td>
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<td>72-73</td>
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<td>82-83</td>
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<td>2</td>
<td>1</td>
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<tr>
<td>83-84</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>84-85</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>85-86</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>86-87</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>87-88</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>88-89</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>89-90</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>90-91</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>91-92</td>
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<td>2</td>
<td>1</td>
</tr>
<tr>
<td>92-93</td>
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<td>1</td>
<td>3</td>
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<tr>
<td>93-94</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>94-95</td>
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<td>1</td>
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<tr>
<td>95-96</td>
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<td>3</td>
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<tr>
<td>96-97</td>
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<td>1</td>
</tr>
<tr>
<td>97-98</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>98-99</td>
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<td>1</td>
<td>3</td>
</tr>
<tr>
<td>99-100</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
1. Incident Response Management Strategies

Model output Analysis

1. Assigned station and service coverage for each unit
2. Average travel time (minutes)

<table>
<thead>
<tr>
<th>Fleet Size</th>
<th>Min. Avg. Response Time</th>
<th>Min. Total Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>7.88</td>
<td>8.38</td>
</tr>
<tr>
<td>3</td>
<td>6.90</td>
<td>7.51</td>
</tr>
<tr>
<td>4</td>
<td>6.22</td>
<td>6.22</td>
</tr>
<tr>
<td>5</td>
<td>5.89</td>
<td>5.94</td>
</tr>
<tr>
<td>6</td>
<td>5.60</td>
<td>5.83</td>
</tr>
<tr>
<td>7</td>
<td>5.40</td>
<td>5.56</td>
</tr>
</tbody>
</table>

CHART current practice (7.79 mins)
1. Incident Response Management Strategies

Model output analysis (cont’d)

3. Total delay (veh-hr)

<table>
<thead>
<tr>
<th></th>
<th>fleet size 2</th>
<th>fleet size 3</th>
<th>fleet size 4</th>
<th>fleet size 5</th>
<th>fleet size 6</th>
<th>fleet size 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHART</td>
<td>4,749,141</td>
<td>4,584,707</td>
<td>4,566,630</td>
<td>4,549,114</td>
<td>4,532,457</td>
<td></td>
</tr>
<tr>
<td>Traditional model</td>
<td>4,829,998</td>
<td>4,729,356</td>
<td>4,584,707</td>
<td>4,567,920</td>
<td>4,551,095</td>
<td>4,541,785</td>
</tr>
</tbody>
</table>

- CHART current practice (5,612,805 veh-hr)
- Proposed model
- Traditional model

Vehicle-hour

min. avg. response time

min. total delay
1. Incident Response Management Strategies

2. Prediction Models for Clearance Times

3. A Detour Decision Support System


Detour feasibility analysis system:
- Evaluating Traffic & Incident Impact to the Network
- Establishing Feasible Detour Plans
- Analyzing the Necessity of Detour Operations
- Detour Optimization

Detour? [NO] → Output → Inform to Highway Users
2. Prediction Models for Clearance Times
Why do we need such a model?

- Key input for the incident management system
  - Optimal deployment strategy analysis
  - Detour feasibility analysis
  - Detour optimization analysis
  - Traveler information – queue, delay and travel time analysis

However, the required clearance time for a reported incident is very difficult to reliably predict in advance.
**2. Prediction Models for Clearance Times**

**Challenge to Predict Clearance Times**

- Skewed shape and distributed in a wide range

<table>
<thead>
<tr>
<th>CT (mins)</th>
<th>Frequency</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;=30</td>
<td>3870</td>
<td>65%</td>
</tr>
<tr>
<td>30-60</td>
<td>1176</td>
<td>20%</td>
</tr>
<tr>
<td>60-90</td>
<td>397</td>
<td>7%</td>
</tr>
<tr>
<td>90-120</td>
<td>138</td>
<td>2%</td>
</tr>
<tr>
<td>&gt;120</td>
<td>344</td>
<td>6%</td>
</tr>
<tr>
<td>total</td>
<td>5925</td>
<td>100%</td>
</tr>
</tbody>
</table>

- Difficult to fit with a continuous or discrete distribution
- Most statistical models cannot perform well
  - They tend to focus on the major classes of the data

However, most studies in the literature applied statistical approaches to develop a model
2. Prediction Models for Clearance Times

Literature Review

1) Probabilistic Distributions (Golob et al., 1987; Giuliano, 1989; Garib et al., 1997; Sullivan, 1997; Ozbay and Kachroo, 1999)

In the most literature
- Using limited scale data
- No validation for models

2) Conditional Probability Models (Nam and Mannering, 2000; Boyles et al., 2007)

The proposed Model is
- tackling heterogeneity in most incident data sets
- enhancing prediction accuracies; and
- assessing the prediction model’s robustness for different data sets

3) Regression Models (Khattak et al., 1995; Giuliano, 1989; Garib et al., 1997; Ozbay and Kachroo, 1999)

4) Decision/Classification Tree Models (Ozbay and Kachroo, 1999; Smith et al. in 2001; Ozbay and Noyan in 2006)

5) Discrete Choice or Classification Models (Lin et al., 2004)

6) Time Sequential Models (Khagak et al., 1995; Wei and Lee, 2007)

7) Unconventional Models (Wang et al., 2005; Wu et al., 2011)
2. Prediction Models for Clearance Times

Flowchart to Develop the Proposed Model

**Phase 1:** Filter out outliers

**Phase 2:** Sequential Classifiers with Association Rules (SCAR)

**Phase 3:** Develop Supplemental models

- Non-statistics-based approach
- No assumption for distributions

An integrated system for predicting incident clearance times

Focusing on intermediate CT and incidents that cannot be categorized by SCAR
Phase 1 – Filter Out Outliers

- PAM: Partitioning Around Medoids (Kaufman and Rousseeuw, 1990)
  - Medoids: most centrally located elements
  - Goal: detecting a group of clusters including a small number of elements

36/6000 incidents are selected as outliers
Flowchart to Develop the Proposed Model

**Phase 1**: Filter out outliers

**Phase 2**: Sequential Classifiers with Association Rules (SCAR)

- Short: ≤ 30 mins
- Intermediate: 30-120 mins
- Long: ≥ 120 mins

**Phase 3**: Develop Supplemental models

An integrated system for predicting incident clearance times

2. Prediction Models for Clearance Times
Association Rules (Agrawal et al., 1993)

- Mining explicit relations between clearance time and associated factors in a format of rules.
  - For example,

\[
\{\text{personal injury, rainy}\} \rightarrow \{\text{intermediate CT}\}
\]

- **Support** of an itemset \(X (\text{supp}(X))\): the proportion of data entries in the database which include the itemset \(X\)

- **Confidence** of a rule: \(\text{conf}(X \rightarrow Y) = \frac{\text{supp}(X \cup Y)}{\text{supp}(X)}\)

  \[
  \begin{align*}
  \text{supp}(X) &= 6 \\
  \text{supp}(X \cup Y) &= 3 \\
  \text{conf}(X \rightarrow Y) &= \frac{3}{6} = 0.5
  \end{align*}
  \]
Procedure to Construct the SCAR System

Phase 1

Extract rules using an AR technique

Any significant rules?

Phase 2

Phase 3

Build a classifier using the best set of ARs

Filter out classified cases based on the developed set of classifiers

2. Prediction Models for Clearance Times
2. Prediction Models for Clearance Times

Illustration of the SCAR System

An Incident Is Detected

(TOC3 & Minor lane closure & no info. for pavement condition)

(AOC & 12 lanes on both & on US-50)

(on weekday & disabled veh & CHART detected)

--- AR 1

or

or

--- AR 2

--- AR 3

Classifier 1

Yes

Short (≤ 30 mins)

(2 veh involved & fatality) or

(during daytime & minor road & fatality)

Yes

Short (≤ 30 mins)

No

No

Continued...
Phase 2 - Model Results

- 44 Classifiers
- Each consists of 2 or 3 ARs
- About 72% of samples can be explained with SCAR
- Accuracies for each category of clearance duration

<table>
<thead>
<tr>
<th>Clearance Time</th>
<th>Class ratio</th>
<th># of Classifiers</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td>64.98%</td>
<td>27</td>
<td>87.70%</td>
</tr>
<tr>
<td>Intermediate</td>
<td>28.95%</td>
<td>13</td>
<td>90.50%</td>
</tr>
<tr>
<td>Long</td>
<td>6.07%</td>
<td>4</td>
<td>75.86%</td>
</tr>
</tbody>
</table>

30 - 120 mins
2. Prediction Models for Clearance Times

Flowchart to Develop the Proposed Model

Phase 1: Filter out outliers

Phase 2: Sequential Classifiers with Association Rules (SCAR)

Phase 3: Develop Supplemental models

An integrated system for predicting incident clearance times

To predict CT for incidents that cannot be classified by SCAR

To classify predicted intermediate CT into shorter intervals
2. Prediction Models for Clearance Times

Phase 3 – Developing Supplemental Models

1. A model for data not classified by SCAR
   - <= 30 minutes
   - 30 – 60 minutes
   - 60 – 90 minutes
   - 90 – 120 minutes
   - > 120 minutes

2. A model to classify the predicted intermediate clearance times into smaller intervals
   - Intermediate-sub1: 30 – 60 minutes
   - Intermediate-sub2: 60 – 90 minutes
   - Intermediate-sub3: 90 – 120 minutes

Support Vector Machine and Random Forests are applied
Illustration of the Proposed System

2. Prediction Models for Clearance Times

Start: Input Incident Info.

SCAR

Can be classified by SCAR?

Yes

Is an intermediate incident?

Yes

Supplemental Model 2
30-60 mins
60-90 mins
90-120 mins

No

Supplemental Model 1

No

Output
2. Prediction Models for Clearance Times

MOEs to Evaluate the System’s Performance

Contingency Table ($c_{ij}$)

<table>
<thead>
<tr>
<th>Clearance Duration (minutes)</th>
<th>Observation</th>
<th>≤ 30</th>
<th>30 – 60</th>
<th>60 – 90</th>
<th>90 – 120</th>
<th>&gt; 120</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 30</td>
<td>1068</td>
<td>95</td>
<td>20</td>
<td>3</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>30 – 60</td>
<td>130</td>
<td>146</td>
<td>50</td>
<td>16</td>
<td>23</td>
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</tr>
<tr>
<td>60 – 90</td>
<td>81</td>
<td>96</td>
<td>33</td>
<td>9</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>90 – 120</td>
<td>13</td>
<td>37</td>
<td>23</td>
<td>9</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>&gt; 120</td>
<td>8</td>
<td>12</td>
<td>9</td>
<td>8</td>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>

Weights ($w_{ij}$)

<table>
<thead>
<tr>
<th>Clearance Duration (minutes)</th>
<th>Observation</th>
<th>≤ 30</th>
<th>30 - 60</th>
<th>60 - 90</th>
<th>90 - 120</th>
<th>&gt; 120</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 30</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>30 – 60</td>
<td>0.75</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>60 – 90</td>
<td>0.5</td>
<td>0.75</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>90 – 120</td>
<td>0.25</td>
<td>0.5</td>
<td>0.75</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>&gt; 120</td>
<td>0</td>
<td>0.25</td>
<td>0.5</td>
<td>0.75</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
## 2. Prediction Models for Clearance Times

### MOEs to Evaluate the System’s Performance

#### Contingency Table ($c_{ij}$)

<table>
<thead>
<tr>
<th>Clearance Duration (minutes)</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\leq 30$</td>
</tr>
<tr>
<td>$\leq 30$</td>
<td>1068</td>
</tr>
<tr>
<td>$30 - 60$</td>
<td>130</td>
</tr>
<tr>
<td>$60 - 90$</td>
<td>81</td>
</tr>
<tr>
<td>$90 - 120$</td>
<td>13</td>
</tr>
<tr>
<td>$&gt; 120$</td>
<td>8</td>
</tr>
</tbody>
</table>

#### Weights ($w_{ij}$)

<table>
<thead>
<tr>
<th>Estimation/Prediction</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>$\leq 30$</td>
<td>1</td>
</tr>
<tr>
<td>$30 - 60$</td>
<td>0.75</td>
</tr>
<tr>
<td>$60 - 90$</td>
<td>0.5</td>
</tr>
<tr>
<td>$90 - 120$</td>
<td>0.25</td>
</tr>
<tr>
<td>$&gt; 120$</td>
<td>0</td>
</tr>
</tbody>
</table>

**Acceptability**

$$= \frac{\Sigma_{i} \Sigma_{j} w_{ij} c_{ij}}{\Sigma_{i} \Sigma_{j} c_{ij}}$$

- $w_{ij}$: weights for cells $(i, j)$
- $c_{ij}$: number of cases in a cell $(i, j)$
## Overall System Performance

<table>
<thead>
<tr>
<th>Incident Categories</th>
<th>Clearance Duration (minutes)</th>
<th>Class ratio</th>
<th>Accuracy</th>
<th>Acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Train</td>
<td>Test</td>
</tr>
<tr>
<td>Minor</td>
<td>&lt;= 30</td>
<td>65.0%</td>
<td>80.3%</td>
<td>82.2%</td>
</tr>
<tr>
<td>Intermedi-sub1</td>
<td>30 – 60</td>
<td>20.0%</td>
<td>38.1%</td>
<td>37.8%</td>
</tr>
<tr>
<td>Intermedi-sub2</td>
<td>60 – 90</td>
<td>6.6%</td>
<td>35.9%</td>
<td>24.4%</td>
</tr>
<tr>
<td>Intermedi-sub3</td>
<td>90 – 120</td>
<td>2.4%</td>
<td>46.2%</td>
<td>20.0%</td>
</tr>
<tr>
<td>Major</td>
<td>120 +</td>
<td>6.0%</td>
<td>57.5%</td>
<td>57.7%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>100.0%</td>
<td>66.7%</td>
<td>66.8%</td>
</tr>
</tbody>
</table>

**Better** than five comparable models developed using support vector regression, random forests, and multiple linear regression, in terms of accuracy and acceptability.
Incident Management System

1. Incident Response Management Strategies
2. Prediction Models for Clearance Times
3. A Detour Decision Support System

- Incident Detection
  - Dispatching ERU
    - Collecting/Updating Incident & Traffic related Data
      - Predicting Incident Duration
        - Estimating Clearance Time
          - Evaluating Traffic & Incident Impact to the Network
            - Establishing Feasible Detour Plans
              - Analyzing the Necessity of Detour Operations

- Detour feasibility analysis system
  - Detour Optimization
    - Implementing Optimal Detour Plans
      - Output
        - Inform to Highway Users
3. A Detour Decision Support System
Most states consider only

- Incident duration > 30 minutes
- Complete road closure

The proposed model:

- Account for more critical factors
  - Traffic volumes, benefit, cost, safety, travel times, etc.
- Allow the decision maker to place different weights to different factors, based on the either resource constraints or priority.
3. Detour Decision Support System

The Proposed System Architecture

- **Initial Assessment** to guarantee the detour will be beneficial in the roadway operation.

- **Decision Goal:** Is Detouring Beneficial?
  - **Input Information**
    - Inputs by Users:
      - Incident-related info
      - Traffic volume
      - Detour plan
    - Detour Rate > 0%
      - **Detour**
      - **No Detour**

- **Benefit-Cost Ratio**
- **Safety & Reliability**
- **Accessibility**
- **Acceptability**

- **Detour**
- **No Detour**

- **Analytical Hierarchy**
  - (1) Decision Goal: Is Detouring Beneficial?
  - (2) Input Information
  - (3) Detour Rate > 0%
  - (4) Benefit-Cost Ratio, Safety & Reliability, Accessibility, Acceptability
  - (5) Detour, No Detour
Simulation-based Analysis

- **To estimate the optimal diversion rate** from the freeway mainline to mitigate the congestion at the incident segment
  - Concurrently adjust signal timings at the arterial intersections to best accommodate the detour traffic
  - Multi-objective functions
    - Max total throughput of the freeway corridor
    - Min total time of detour travelers on the detour route
  - Constraints
    - Control for signal timing (**min green time**)
    - Control diverging traffic (**max diverging rate**)

3. Detour Decision Support System
3. Detour Decision Support System

The Proposed System Architecture

(1) Decision Goal: Is Detouring Beneficial?

(2) Input Information

(3) Detour Rate > 0%

- YES
- NO → No Detour

(4) Initial Assessment
to guarantee the detour will be beneficial in the roadway operation

- Benefit-Cost Ratio
- Safety & Reliability
- Accessibility
- Acceptability

(5) Detour or No Detour

Inputs by Users
- Incident-related info
- Traffic volume
- Detour plan

Second Assessment
to ensure the detour will be beneficial in various aspects
3. Detour Decision Support System

Decision Criteria on the Second Assessment

- Benefit-Cost Ratio

Input: Incident & Traffic Info.

Estimate Benefits:
- Saved delay, fuel consumption, emission

Estimate Costs:
- Operation & maintenance

Output: B/C
3. Detour Decision Support System

Decision Criteria on the Second Assessment

- Safety and Reliability
  - Impacted area → reduction in secondary incidents
  - Measured by the max queue length
    - A multiple linear regression model based on numerous variables regarding incident, location, heavy vehicle volumes, and traffic volumes (Kim et al. 2013)
3. Detour Decision Support System

Decision Criteria on the Second Assessment

- **Accessibility**
  - Traffic signals, stop signs and speed limits on the detour route
  - Measured by travel time

- **Acceptability**
  - Depend on the characteristics of driving populations and timely supply of the real-time traffic information
  - Measured by the anticipated compliance rate (user input)
3. Detour Decision Support System

The Proposed System Architecture

**Initial Assessment** to guarantee the detour will be beneficial in the roadway operation

**Second Assessment** to ensure the detour will be beneficial in various aspects

**Inputs by Users**
- Incident-related info
- Traffic volume
- Detour plan

**Decision Goal:** Is Detouring Beneficial?

1. Decision Goal: Is Detouring Beneficial?
2. Input Information
3. Detour Rate > 0%
   - NO: No Detour
   - YES:
     - Benefit-Cost Ratio
     - Safety & Reliability
     - Accessibility
     - Acceptability
     - Detour
     - No Detour
4. Final Decision
3. Detour Decision Support System

Case Study

Weights for Criteria

- Benefit-cost ratio: 0.31
- Safety and reliability: 0.31
- Accessibility: 0.18
- Acceptability: 0.20

Scenario 1
- A Full Road Closure (3/3)
- 60 minute-incident duration
- System Recommendation: Detour operations are beneficial (recommended) with 60% confidence.
  - # of signals on detour route: 2
  - Speed limit on detour route: 50 mph

Scenario 2
- A Full Road Closure (3/3)
- 90 minute-incident duration
- System Recommendation: Detour operations are NOT beneficial (recommended) with 62% confidence.
  - # of signals on detour route: 5
  - Speed limit on detour route: 40 mph
### 3. Detour Decision Support System

#### Comparisons of Decisions by Agency

<table>
<thead>
<tr>
<th>Decision Criteria (used by agencies in the literature)</th>
<th>Scenario No.</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane Blockage (number of closed lane(s)/total number of lanes)</td>
<td>3/3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incident Duration (minutes)</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NC DOT-main office</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NC DOT-Charlotte</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NJ DOT</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oregon DOT</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NY DOT</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL DOT</td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARTIMIS (Ohio/Kentucky)</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Idaho (Ada County)</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wisconsin DOT</td>
<td>Not clear</td>
<td>Not clear</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decisions by Agency</th>
<th>Scenario No.</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC DOT-main office</td>
<td>Y</td>
<td></td>
<td></td>
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<tr>
<td>NC DOT-Charlotte</td>
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<td></td>
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<td>NJ DOT</td>
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<tr>
<td>Wisconsin DOT</td>
<td>Not clear</td>
<td>Not clear</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decision by Proposed System</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>N</td>
<td></td>
</tr>
</tbody>
</table>

- **Scenario No.**: 1
- **Lane Blockage**: 3/3
- **Incident Duration (minutes)**: 60
- **Optimal Detour Flow**: 0.85, 0.54
- **Total Travel Time (hr) with Detour**: 3,232, 10,163
- **Total Travel Time (hr) without Detour**: 3,617, 10,182
- **Saved Travel Time (hr)**: 386, 19
- **B/C with Detour**: 14.74, 0.60
- **B/C without Detour**: 0.07, 1.68
- **Max Queue with Detour (Mile)**: 1.37, 2.24
- **Max Queue without Detour (Mile)**: 1.66, 2.59
- **Travel Time (min) via Freeway**: 2.52, 2.52
- **Travel Time (min) via Detour**: 6.55, 7.52
The System Flexibility with Relative Importance

- **Base scenario**
  - 15 minutes incident duration with full lane blockage (3/3)

<table>
<thead>
<tr>
<th>Case</th>
<th>B/C</th>
<th>S&amp;R</th>
<th>Acces</th>
<th>Accep</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case A</td>
<td>0.31</td>
<td>0.31</td>
<td>0.18</td>
<td>0.20</td>
<td><strong>Higher weights on B/C and safety and reliability</strong>&lt;br&gt;<strong>Detour operations are recommended with 58% confidence.</strong></td>
</tr>
<tr>
<td>Case B</td>
<td>0.18</td>
<td>0.20</td>
<td>0.31</td>
<td>0.31</td>
<td><strong>Higher weights on accessibility and acceptability</strong>&lt;br&gt;<strong>Detour operations are Not recommended with 53% confidence.</strong></td>
</tr>
<tr>
<td>Case C</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td><strong>Equal weights on all factors</strong>&lt;br&gt;<strong>Detour operations are recommended with 53% confidence.</strong></td>
</tr>
</tbody>
</table>
Contributions, Future Research, and Conclusions
Contributions

- Empirically investigated the effectiveness of a well-operated incident response program
  - An efficient response operation can also reduce the incident clearance duration and produce significant benefits.

- Developed an efficient model for optimally allocating the available response units from a new perspective of minimizing the total incident-induced delay
  - The developed model’s performance and robustness have been confirmed from the extensive numerical results and the comparative study with the existing models and the current practice in Maryland
Contributions (cont’d)

- Developed an integrated system to provide a **reliable prediction** of the clearance duration for a detected incident.
  - Incident clearance duration is one of the essential parameters for estimating the resulting traffic impacts and assessing the operational efficiency

- Provided **some insightful information** on the interrelationships between key factors contributed to incident duration and their collective impacts on clearance times
  - Would be useful for traffic agencies to plan and improve their incident management programs.
Provided operational **guidelines and tools** for responsible agencies to conduct their assessment of traffic diversion plans as well as design of control strategies during the incident management period.

Developed an **integrated system** that can assess the necessity of traffic detour/diversion **based on the comprehensive review** of associated factors.
Future Research

- Enhancing **reliability** of the incident response management strategy
  - Considering the **likelihood** of having **multiple incidents** over a short time period
  - Taking into account of the **stochastic nature of incident patterns**
  - Investigating the pros and cons between the **dispatching and patrolling** strategies for different times of a day under various traffic conditions and incident patterns
  - Studying the **optimal fleet size** based on the benefit-cost analysis for a given incident distribution, resource constraints, and operational costs
Future Research (cont’d)

- Enhancing **computational efficiency** for real-time operations of the detour decision support system
  - To supplement or replace simulation- or optimization-based models
  - To generate key traffic control parameters such as **optimal diversion rate** and **reduced total travel time** by detour operations.
Conclusions

- My field experimental analysis has confirmed the need to contend daily non-recurrent congestion with an efficient and effective incident management program.
  - An efficient incident management needs to optimal use available resources, and best coordinate all responsible agencies.
This study enhanced the efficiency and effectiveness of the current traffic incident management system in Maryland by developing more reliable models embedded in the system.

- An incident management system with the proposed key models, incident detection, and detour optimization tools can substantially reduce the delay, fuel consumption, and emission caused by incidents.

- Such a system, if properly integrated with travel time information system, can substantially improve the quality and efficiency of commuters over congested highways.
Thank You
Q & A