MASSDOT INNOVATION WEBINAR SERIES

UNCOVERING THE ROOT CAUSES OF TRUCK ROLLOVER CRASHES ON HIGHWAY RAMPS

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MARCH 23, 2023
OUTLINE

• Background and Objectives
• Site Identification and Data Collection
• Model Development and Data Analysis
  – Crash Data Analysis
  – Model for Extracting Trajectories
  – Trajectory Data Modeling
  – Site Specific Analysis
• Summary and Conclusions
BACKGROUND AND OBJECTIVES

• Heavy truck related crashes in the U.S.
  – 4% of total crashes vs. 8% of total fatal crashes [1]
  – 11% on highway ramps [2]
  – 44~52% involved rollovers [2]

• In 2016 alone, truck related crashes in Massachusetts costed nearly $24M due to delay, emissions, and wasted fuel consumption. [3]

This research aims to

- Analyze Massachusetts ramp truck rollover crash records;
- Review literature and best practices on reducing highway ramp truck rollovers;
- Utilize drone and artificial intelligence (AI) tools to uncover the causes of ramp truck rollovers; and
- Identify correlations between truck rollovers and ITS devices, signage and markings, and roadway geometric design.
**CRASH DATA ANALYSIS**

**LOCATION**

<table>
<thead>
<tr>
<th></th>
<th>Beginning of Ramp</th>
<th>Middle of Ramp</th>
<th>End of Ramp</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside</td>
<td>20</td>
<td>8</td>
<td>25</td>
<td>53</td>
</tr>
<tr>
<td>Inside</td>
<td>9</td>
<td>14</td>
<td>17</td>
<td>40</td>
</tr>
<tr>
<td>Total</td>
<td>29</td>
<td>22</td>
<td>42</td>
<td>93</td>
</tr>
</tbody>
</table>
CRASH DATA ANALYSIS (CONT.)

SPATIAL DISTRIBUTION

105 Truck Rollovers from 1/2015 to 2/2022

<table>
<thead>
<tr>
<th>Route Number</th>
<th>Number of Truck Rollovers</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT 24</td>
<td>14</td>
</tr>
<tr>
<td>I-84</td>
<td>5</td>
</tr>
<tr>
<td>I-90</td>
<td>21</td>
</tr>
<tr>
<td>I-91</td>
<td>4</td>
</tr>
<tr>
<td>I-495</td>
<td>32</td>
</tr>
<tr>
<td>I-95</td>
<td>22</td>
</tr>
</tbody>
</table>
CRASH DATA ANALYSIS (CONT.)

TEMPORAL DISTRIBUTION

Distribution of Ramp Truck Rollovers by Time of Day

Crash Frequency

Time of Day (Hours)
CRASH DATA ANALYSIS (CONT.)

MAIN CAUSES

- Speeding: 8
- Load Shift: 4
- Mechanical Issue: 3
- Driver Fatigue: 2
- Other Vehicles: 2
- Other: 1
- Unknown: 1

# of Ramp Truck Rollover Crashes
LITERATURE REVIEW AND BEST PRACTICES

STATIC SIGNS

• Dual-advisory speed signs were tested at five curves in Texas.

• They were able to increase the percentages of driver speed compliance for both passenger cars and heavy trucks measured at the middle of a curve.

LITERATURE REVIEW AND BEST PRACTICES (CONT.)

DYNAMIC SIGNS


LITERATURE REVIEW AND BEST PRACTICES (CONT.)

PAVEMENT MARKINGS


LITERATURE REVIEW AND BEST PRACTICES (CONT.)

DYNAMIC SIGNS VS. PAVEMENT MARKINGS

SUMMARY OF LITERATURE REVIEW

- Evaluation of pavement markings mostly based on driving simulator
- Speeds measured at single point or limited locations
- Lack of before and after studies utilizing advanced new sensors such as high-definition radar in the field
DRONE DATA COLLECTION SITES

<table>
<thead>
<tr>
<th>Location</th>
<th>View angle</th>
<th>Time and date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andover</td>
<td></td>
<td>6/3/2021</td>
</tr>
<tr>
<td>Auburn/Worcester</td>
<td></td>
<td>10/12/2021</td>
</tr>
<tr>
<td>Springfield</td>
<td>Top down</td>
<td>6/6/2022</td>
</tr>
<tr>
<td>Freetown North</td>
<td></td>
<td>6/13/2022</td>
</tr>
<tr>
<td>Freetown South</td>
<td></td>
<td>6/13/2022</td>
</tr>
<tr>
<td>New Bedford</td>
<td>Slanted</td>
<td>6/14/2022</td>
</tr>
<tr>
<td>Sturbridge</td>
<td></td>
<td>6/21/2022</td>
</tr>
</tbody>
</table>

Legend

☆ Drone Data Collection Sites
SAMPLE DATA FROM ANDOVER SITE

300 ft slanted view

300 ft top-down view

400 ft slanted view

400 ft top-down view
SAMPLE DATA FROM ANDOVER SITE (CONT.)

THERMAL VS. RGB

400 ft top-down thermal view

400 ft top-down RGB view
AI ALGORITHMS FOR VIDEO PROCESSING

Input frames from drone video → Deep-learning Vehicle Detection module → OBB for detected vehicles recorded

Real-time risk assessment
Road Safety Analysis

Vehicle Tracking & Motion Analysis
In drone videos, vehicles can appear in any orientations

**Horizontal Bounding Box (HBB)**
- Large amount of non-object space enclosed
- Not suitable for densely packed objects and arranged in tilted fashions

**Oriented Bounding Box (OBB)**
- Enclose vehicles (particularly heavy trucks and buses) with minimal inclusion of the background
AI ALGORITHMS FOR VIDEO PROCESSING (CONT.)
AI ALGORITHMS FOR VIDEO PROCESSING (CONT.)
HIGH-RISK EVENTS DETECTION

• Speeding
• Stalled vehicles
• Stalled/Slow vehicle on exit pavement markings
• Travelling too close to other vehicles
• Vehicles running off the road
• Late lane change
AUBURN/WORCESTER
− 2.5%

+ 1.0%

AUBURN/WORCESTER (CONT.)
AUBURN/WORCESTER (CONT.)

<table>
<thead>
<tr>
<th></th>
<th>Number of observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approaching too fast</td>
<td>9.8</td>
</tr>
<tr>
<td>Unsafe lane changes</td>
<td>22.2</td>
</tr>
<tr>
<td>Traveling between lanes</td>
<td>9.8</td>
</tr>
<tr>
<td>Hourly heavy truck volume</td>
<td>202</td>
</tr>
</tbody>
</table>

(a) traveling between lanes and approaching too fast
(b) following too closely
(c) unsafe lane change
• Prohibit lane changes

• Restrict heavy trucks to one lane (e.g., left lane)

• Convert one of the three warning signs into a dynamic warning sign with continuously flashing beacons or speed triggered beacons
FREETOWN NORTH & SOUTH

<table>
<thead>
<tr>
<th>Location</th>
<th>Truck rollovers</th>
<th>Hourly Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small</td>
<td>Medium</td>
</tr>
<tr>
<td>Andover</td>
<td>0</td>
<td>232</td>
</tr>
<tr>
<td>Worcester</td>
<td>4</td>
<td>801</td>
</tr>
<tr>
<td>Springfield</td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td>4</td>
<td>709</td>
</tr>
<tr>
<td>South</td>
<td>0</td>
<td>662</td>
</tr>
<tr>
<td>Old toll</td>
<td>0</td>
<td>1041</td>
</tr>
<tr>
<td>Freetown North</td>
<td>2</td>
<td>33</td>
</tr>
<tr>
<td>Freetown South</td>
<td>1</td>
<td>163</td>
</tr>
<tr>
<td>New Bedford</td>
<td>2</td>
<td>405</td>
</tr>
<tr>
<td>Sturbridge</td>
<td>3</td>
<td>32</td>
</tr>
</tbody>
</table>
FREETOWN NORTH & SOUTH (CONT.)

<table>
<thead>
<tr>
<th></th>
<th>Number of observations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North</td>
</tr>
<tr>
<td>Approaching too fast</td>
<td>1.5</td>
</tr>
<tr>
<td>Unsafe lane changes</td>
<td>8.2</td>
</tr>
<tr>
<td>Hourly heavy truck volume</td>
<td>16</td>
</tr>
</tbody>
</table>

(a) unsafe lane change 1
(b) unsafe lane change 2
(c) unsafe lane change 3
(d) unsafe lane change 4

(a) last-minute unsafe lane change
(b) approaching too fast

Freetown South

Freetown North
SPRINGFIELD

<table>
<thead>
<tr>
<th>Number of observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approaching too fast</td>
</tr>
<tr>
<td>Last-minute lane change</td>
</tr>
<tr>
<td>Waiting in traffic for lane change</td>
</tr>
<tr>
<td>Hourly heavy truck volume</td>
</tr>
</tbody>
</table>

Sign A
The existing 25 mph advisory speed seems to be reasonable. However, apparently speed compliance among truck drivers is a major issue.

No truck rollovers on this ramp between 1/1/2008 and 12/31/2014 and 4 rollovers (crash numbers #4333162, #4840839, #4844305, and #4917505 all due to speeding) after 2016.

Consider dynamic warning signs and pavement markings at this site.
VEHICLE TRAJECTORY ANALYSIS
DATA SOURCES FOR SAFETY ANALYSIS

Crash Reports
- Widely available
- Detailed crash narratives
- Do not cover near-crash events

Connected Vehicles (CV)/Trajectories
- USDOT CV pilot
- Wejo, Otonomo
- Trajectories revealing individual driver behavior
- Only cover a small percentage of the vehicles on the road

Advanced Sensors
- Trajectories of all vehicles in the detection zone
- Interactions among vehicles
- Sensors can be mounted on a drone
VEHICLE TRAJECTORIES FROM DRONE VIDEOS

Motivations
• Detailed trajectories for understanding highway ramp truck rollover crashes
• Identify risky driving behavior
• Complement existing safety data

Advantages
• Drones can be deployed quickly
• Top-down view avoids occlusion
• Can carry different sensors
• Tethered drone or drone in a box
SAFETY IS COMPLICATED!

- Fatigue
- Distraction
- Lack of Experience
- Speeding
- ......

- Blind Spot Detection
- Other Advanced Driver Assistance Systems
- ......

- Snow
- Fog
- Heavy Traffic
- ......

- Narrow Street
- Sharp Curve
- Poor Signal Timing
- ......

Driver

Vehicle

Traffic & Environment

Roadway
SUMMARY AND RECOMMENDATIONS

• Over 95% of ramp truck rollovers are single-vehicle crashes. Speeding is the predominant reason.

• Various dynamic warning signs and pavement markings appear to be the two most popular strategies for reducing vehicle speeds and improving horizontal curve (including ramp) safety. State DOTs are encouraged to field test such relatively low-cost solutions and conduct before and after studies.

• A new approach is tested to investigate safety issues (Network screening → crash hotspots → detailed trajectory data collection and analysis → integration of traffic sign, pavement markings, roadway geometry, etc.).

• AI plays a critical role in data reduction (e.g., turning videos into information) and identifying factors not available in crash reports. The results can lead to specific safety countermeasures.
THANK YOU!