Identifying the Potential of Improved Heavy Truck Crashworthiness

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Project Goals

Identify opportunities to reduce truck driver injury through improved cab structures.

• Crash data analysis to identify and describe driver injury mechanism.

• Some crash types can be most effectively addressed through advanced crash avoidance technologies (ACATs).

• FE models of most harmful remaining crashes to identify opportunities for improved restraint systems, more accommodating interior structures, and possibly air bags.
Scope of truck driver injury in crashes

• NIOSH statistics rank truck driving among the top 7 occupations in injuries per worker.
• Truck driving accounts for the greatest number of work-related fatalities.
Trends in Truck Driver Fatalities and Serious Injuries, 2006-2012

<table>
<thead>
<tr>
<th>Year</th>
<th>Fatalities</th>
<th>A-injury</th>
<th>B-injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>784</td>
<td>3,536</td>
<td>7,111</td>
</tr>
<tr>
<td>2007</td>
<td>796</td>
<td>2,891</td>
<td>6,735</td>
</tr>
<tr>
<td>2008</td>
<td>639</td>
<td>2,966</td>
<td>6,498</td>
</tr>
<tr>
<td>2009</td>
<td>487</td>
<td>1,690</td>
<td>5,066</td>
</tr>
<tr>
<td>2010</td>
<td>540</td>
<td>1,777</td>
<td>6,635</td>
</tr>
<tr>
<td>2011</td>
<td>547</td>
<td>1,833</td>
<td>5,524</td>
</tr>
<tr>
<td>2012</td>
<td>592</td>
<td>1,597</td>
<td>7,139</td>
</tr>
</tbody>
</table>
## Truck Driver Injury by Crash Type

<table>
<thead>
<tr>
<th>Most harmful event</th>
<th>% of Fatals</th>
<th>% of Fatal or A-injury</th>
<th>Prob. Of Fatal</th>
<th>Prob. Of K/A</th>
<th>% of crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll</td>
<td>34.2</td>
<td>44.5</td>
<td>1.9</td>
<td>12.2</td>
<td>4.3</td>
</tr>
<tr>
<td>Fire</td>
<td>16.4</td>
<td>3.6</td>
<td>5.8</td>
<td>6.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Other non-collision</td>
<td>2.8</td>
<td>1.6</td>
<td>0.2</td>
<td>0.6</td>
<td>3.2</td>
</tr>
<tr>
<td>Collision with:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truck/bus</td>
<td>13.0</td>
<td>13.4</td>
<td>0.3</td>
<td>1.7</td>
<td>9.4</td>
</tr>
<tr>
<td>Light vehicle</td>
<td>4.4</td>
<td>9.9</td>
<td>0.0</td>
<td>0.2</td>
<td>62.4</td>
</tr>
<tr>
<td>Unknown vehicle type</td>
<td>6.0</td>
<td>5.4</td>
<td>0.3</td>
<td>1.2</td>
<td>5.2</td>
</tr>
<tr>
<td>Train</td>
<td>1.6</td>
<td>1.5</td>
<td>2.1</td>
<td>9.5</td>
<td>0.2</td>
</tr>
<tr>
<td>Ped/bike/animal</td>
<td>0.5</td>
<td>1.3</td>
<td>0.0</td>
<td>0.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Other non-fixed object</td>
<td>0.7</td>
<td>1.6</td>
<td>0.1</td>
<td>1.3</td>
<td>1.5</td>
</tr>
<tr>
<td>Hard fixed object</td>
<td>18.2</td>
<td>14.8</td>
<td>1.1</td>
<td>4.2</td>
<td>4.1</td>
</tr>
<tr>
<td>Soft/other fixed object</td>
<td>2.3</td>
<td>2.3</td>
<td>0.1</td>
<td>0.4</td>
<td>6.5</td>
</tr>
<tr>
<td>Unknown other/other fixed object</td>
<td>0.1</td>
<td>0.0</td>
<td>0.5</td>
<td>1.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
<td>0.2</td>
<td>1.2</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Rollover Is the Primary Driver Injury Mechanism, Regardless of Belt Use

• All tractor drivers:
  – 40.4% of injuries occurred in rollover.
  – When trucks rolled over, almost half of drivers were injured (49.3%).
  – One of three drivers received K-, A-, or B-injuries.
  – One in eight died or received incapacitating injuries.
  – When trucks did not roll over, 3.8% were injured.
  – When trucks did not roll over, only 1.9% received K-, A-, or B-injuries.
  – When trucks did not roll over, only 0.6% of drivers received fatal or A-injuries.
Driver K/A Injury by Impact Point, All Crashes, Rollovers Excluded

<table>
<thead>
<tr>
<th></th>
<th>Front</th>
<th>Right</th>
<th>Back</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor</td>
<td>53.4</td>
<td>12.9</td>
<td>9.8</td>
<td>14.9</td>
</tr>
<tr>
<td>SUT</td>
<td>59.0</td>
<td>4.9</td>
<td>12.9</td>
<td>13.3</td>
</tr>
</tbody>
</table>
Advanced Collision Avoidance Technologies

• Electronic stability control
  – Rollover, loss of control.

• Forward collision warning/collision mitigation braking.
  – Rear-end truck striking crashes.

• Lane/road departure warning & prevention; side object detection.
  – Lane change/merge crashes; run off road crashes.
ACAT Effectiveness Estimates

- **ESC**
  - Rollover: 0.0% to 75% effective, depending on circumstances.
  - Most effective against 1st event rollovers on curves, dry roads.
  - LOC: 18% to 39.6% effective; most effective on curved, wet roads.
- **FCW**: 24-31% effective in rear-end truck-striking crashes.
- **CMB** alone: 4% to 44% effective. Most effective with sensors that trigger on stopped vehicles.
- **FCW + CMB**: 24% to 57% effective in rear-end, truck striking crashes.
- **LDW**: 31% to 50% effective in unintended lane departures.
- **RDW**: 2% to 45% effective in single-vehicle run-off road crashes.
Estimate residual crash population for ACAT deployment scenarios

• Develop ACAT effectiveness estimates.
• Develop methodologies to apply effectiveness estimates to heavy truck crash population.
  – Account for environmental, driver, and other conditions that may degrade effectiveness.
  – Repeated iterations to develop statistically robust estimates of crashes not prevented.
• Develop crash typology of residual crashes to identify top crash types.
Rollover and Frontal Impact

- Primary crash types to model
- Untripped rollover
- Frontal impact
Finite element modeling of truck occupant kinematics in rollover and frontal impact
FE Truck Interior Modeling
Cloud points of truck interior measured from actual truck
FE Truck Interior Modeling

- FE truck model with cloud points for the main interior components.
Truck Cab Mounts

- Acceleration data from TruckSim will be applied at Cab Mounts in FE Model.
Dummy Accelerometers
Dummy Positioning and Seatbelt Pretensioner
Dummy Accelerometers

- Head Accelerometer
- Chest Accelerometer
- Right Upper Leg (Femur) Accelerometer
- Pelvis Accelerometer
- Left Lower Leg (Tibia) Accelerometer
- Left Upper Leg (Femur) Accelerometer
- Left and Right Tibia Accelerometers
- Left and Right Femur Accelerometers
- Pelvis Accelerometer

UMTRI

Texas A&M Transportation Institute
Rollover Testing

- Previous study at IMMI (Chinni et al., 2007):
  - Purpose: gain insight into vehicle dynamics of rollover & assess occupant protection
  - Tractor-trailer driven by remote control - overturned onto driver’s side during overcorrecting maneuver
  - 40mph
  - TruckSim software used to predict overturning maneuver path
# Rollover Speeds for Simulation from Crash Data

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Untripped rollover</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
<td>Fatal</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>3,143</td>
<td>484</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>39 mph</td>
<td>57 mph</td>
<td></td>
</tr>
<tr>
<td>Median</td>
<td>45 mph</td>
<td>55 mph</td>
<td></td>
</tr>
<tr>
<td>Mode</td>
<td>50 mph</td>
<td>55 mph</td>
<td></td>
</tr>
<tr>
<td>Std deviation</td>
<td>16.50</td>
<td>14.43</td>
<td></td>
</tr>
</tbody>
</table>

Source: TIFA, GES, 2006-2010
Rollover Testing

- TruckSim software used to create rollover crash scenario
  - Truck path as Chinni et al., 2007;
  - Untripped condition;
  - 40 mph;
  - 80,000 lbs truck GVW

- Accelerations at cab mounts will be output for crash pulses in FE Model

- FE model of truck interior run to identify body contact points and accelerations to predict injury.
Head Injury Criteria

\[ HIC = \max \left[ \int_{t_1}^{t_2} a(t) dt \left( t_2 - t_1 \right) \right]^{2.5} \]

\[ p(fracture, AIS \geq 2) = N \left( \frac{\ln(HIC) - 6.96352}{0.84664} \right) \]

\[ N_{ij} = \frac{F_z}{F_{int}} + \frac{M_y}{M_{int}} \]

\[ p(AIS \geq 2) = \frac{1}{1 + e^{2.054 - 1.195N_{ij}}} \]
Chest and Leg Injury Criteria

\[
p(AIS \geq 2) = \frac{1}{1 + e^{4.9795 - 0.326F}}
\]

\[
RTI = \frac{M}{240} + \frac{F}{12}
\]

\[
CTI = \frac{A_{max}}{90} + \frac{D_{max}}{103}
\]

\[
p(AIS \geq 2) = 1 - \exp\left(-e^{\frac{\ln(RTI) - 0.2728}{0.2468}}\right)
\]

\[
p(AIS \geq 2) = \frac{1}{1 + e^{(4.847 - 6.036CTI)}}
\]
Driver Contact Points in Rollover by Belt Use

- Windshield, front header, sunvisor
- Flying glass
- Steering wheel
- Instrument panel
- Windshield + front header, A pillar etc.
- Left roof rail
- Left side, any
- Right roof rail
- Right side, any
- Other roof
- Seat back
- Belt webbing, buckle, etc.
- Other interior

Percent

Belted
Not belted, not ejected
Driver Contact Points in Frontal Impacts by Belt Use

![Graph showing contact points and belt use](image-url)
Planned Simulations and Output

• Untripped rollover
  – Two speeds, 40 mph and 50+
  – Belted and unbelted

• Frontal impacts
  – Speeds to be determined
  – Belted and unbelted

• Identify contact points and accelerations.
• Match to existing driver injury data.
• Identify opportunities to make cab interior more forgiving.
• Optimize restraints
Future Work

• Model additional crash types, e.g., rollover with subsequent impact.
• Explore opportunities for air bags.
• Extend the model to include truck cab crush.
Thank you!
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