Safety Benefits of Forward Collision Warning, Brake Assist, and Autonomous Braking Systems in Rear-End Collisions

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Introduction

• Precollision system – PCS
• The three PCS algorithms:
  • Forward collision warning (FCW)
  • Forward collision warning + Precrash brake assist (FCW + PBA)
  • Forward collision warning + Precrash brake assist + Autonomous precrash brake (FCW + PBA + PB)
• FCW warn the driver through visual, audio, and/or tactile means of an impending collision
• PBA amplifies driver braking input
• PB autonomously add to the vehicle’s braking deceleration, even without driver input
• The study only involves rear-end collisions
Previous Work

• Significant work has been done on individual proposed systems, but they do not attempt to predict fleetwide benefits.

• The effectiveness of the integrated PCS components is not the linear combination of each component.

• Simulators are also commonly used but often only examine a small set of collision scenarios.

• The objective of this paper is to estimate the safety benefits for the striking vehicle in rear-end collisions that are equipped with PCS.
Case Selection and PCS Modeling

- National Automotive Sampling Systems / Crashworthiness Data Systems (NASS/CDS)
- A sample of 1396 collisions, corresponding to 1.1 million crashes, were computationally simulated
- Time to collision (TTC) is directly related to driver’s threat recognition in frontal collisions and is measured by radar sensors:

\[ \text{TTC} = \frac{x}{V_{12}}. \]

Fig. 1. Activation timing of PCS components leading to a crash.
ΔV Estimation and Prediction

• ΔV is change in velocity of a vehicle during a crash event
• ΔV is reconstructed from the recorded crush depth
• Adding in the effects of PCS, ΔV is calculated to determine the severity of the collision if PCS was onboard
Modeling Driver Input and Vehicle Dynamics in Response to PCSs

- The four kinds of reaction time:
  - Fast reaction
  - Medium reaction
  - Slow reaction
  - No reaction

- The four precrash maneuvers:
  - Not braking
  - Hard braking
  - Weak braking
  - Accelerating

Fig. 4. Schematic of PCS component activation based on reaction time for (1) fast, (2) normal, (3) slow, and (4) no response. Filled circles indicate the time of driver brake application.

Fig. 5. Probability density function of driver reaction times and characteristic reaction times used for PCS simulations. Of the drivers, 17% have no response prior to the collision. The median response (1.07 s) is characteristic of 43% of the drivers. A fast response of 0.57 s and a slow response of 1.48 s are characteristic of 20% of the drivers, respectively.
PCS Braking Pulses for Precrash Maneuver and Response Time

Fig. 6. Schematic of PCS braking pulses for precrash maneuver and response time for the FCW + PBA + PB algorithm. The dashed line shows the estimated braking pulse without PCS activation, and the solid line shows the brake pulse after PCS activation, with the magnitudes $g$ and delay times $s$ labeled.
Overall Algorithm Effectiveness and Injury Risk After PCS Activation

• To determine the overall system performance, the distribution of reaction times was combined with the distribution of precrash maneuvers observed in the known population.

• Injury reduction benefits only computed for belted occupants.

• Only a maximum abbreviated injury score of 2 or greater is considered (On a scale of 0 to 6)

<table>
<thead>
<tr>
<th>Maneuver</th>
<th>NB</th>
<th>HLB</th>
<th>WEB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response Time$^a$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NR</td>
<td>17%</td>
<td>5%</td>
<td>6%</td>
</tr>
<tr>
<td>FR</td>
<td>20%</td>
<td>6%</td>
<td>7%</td>
</tr>
<tr>
<td>MR</td>
<td>43%</td>
<td>13%</td>
<td>15%</td>
</tr>
<tr>
<td>SR</td>
<td>20%</td>
<td>6%</td>
<td>7%</td>
</tr>
</tbody>
</table>


$^b$NB – no braking, HLB – hard, late braking, WED – weak, early braking.
System Limitations

- Maximum vehicle braking deceleration is restricted by the road surface type and conditions
- Most PCSs do not activate at low vehicle speeds

<table>
<thead>
<tr>
<th>Surface Condition</th>
<th>Braking (no lockup)</th>
<th>Sliding (all wheels locked)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Pavement / Asphalt / Concrete</td>
<td>0.8</td>
<td>0.65</td>
</tr>
<tr>
<td>Wet Pavement / Asphalt / Concrete</td>
<td>0.7</td>
<td>0.55</td>
</tr>
<tr>
<td>Snow</td>
<td>0.4</td>
<td>0.25</td>
</tr>
<tr>
<td>Ice</td>
<td>0.15</td>
<td>0.075</td>
</tr>
<tr>
<td>Dry Gravel/Dirt</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Wet Gravel/Dirt</td>
<td>0.6</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Results

Fig. 8. Cumulative distribution of crashes after PCS algorithm implementation.

TABLE VI
MEDIAN REDUCTION IN ΔV AND PREVENTED COLLISIONS FOR EACH PCS ALGORITHM

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Percentage of Crashes Prevented</th>
<th>Median ΔV (kmph)</th>
<th>Percent Reduction of Median ΔV</th>
</tr>
</thead>
<tbody>
<tr>
<td>No PCS</td>
<td>-</td>
<td>17.0</td>
<td>-</td>
</tr>
<tr>
<td>FCW</td>
<td>3.2%</td>
<td>14.7</td>
<td>14%</td>
</tr>
<tr>
<td>FCW + PBA</td>
<td>3.6%</td>
<td>13.0</td>
<td>24%</td>
</tr>
<tr>
<td>FCW + PBA + PB</td>
<td>7.7%</td>
<td>11.3</td>
<td>34%</td>
</tr>
</tbody>
</table>

Fig. 9. Effectiveness of pcs algorithms in reducing the number of seriously to fatally injured drivers (MAIS2+).

TABLE VII
PREDICTED NUMBER OF MODERATELY TO FATALLY INJURED DRIVERS FOR PCS ALGORITHMS (NASS/CDS 1993–2008)

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Predicted Number of Injured Drivers</th>
<th>Percent Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>No PCS</td>
<td>12,338</td>
<td>-</td>
</tr>
<tr>
<td>FCW</td>
<td>8,755</td>
<td>29%</td>
</tr>
<tr>
<td>FCW + PBA</td>
<td>7,487</td>
<td>39%</td>
</tr>
<tr>
<td>FCW + PBA + PB</td>
<td>6,123</td>
<td>50%</td>
</tr>
</tbody>
</table>
Conclusion and Discussion

• Additional PCS components increased effectiveness in mitigating collisions
• Benefits in collision severity ($\Delta V$) and number of injured drivers are summarized on previous slide
• FCW-only and FCW + PBA prevented 3.2% and 3.6% of crashes respectively
• PB is thought of as a collision-mitigating countermeasure. The FCW + PBA + PB prevented 7.7% of crashes
• Limitations: PCS assumed to engage properly; Diver model was greatly simplified; $\Delta V$ reconstruction techniques were limited by available information, etc
Citation

Questions

• What are the three PCS algorithms that was examined in the paper?
• How does each of the three active safety systems help reduce crash-related injuries and property damage?
• What was the metric that used to judge collision threat by the PCSs?
• What was the four kinds of precrash maneuvers and the four reaction times investigated?
• What were the percentages of serious to fatal injuries prevented by each algorithm?