Train Braking Simulation Study

Conventional Pneumatic, Trailing Distributed Power Pneumatic, and Electronically-Controlled Pneumatic Brake System Performance

Kevin J. Renze, Ph.D.
Methods to Improve Tank Car Safety

• Operational speed constraints (lower energy)
• Build a better product wrapper
  – Increase tank car shell thickness
  – Full height head shields
  – Protect inflow/outflow valves
  – Improve pressure release valves
  – Add thermal insulation and jacket
• Improve track and car inspection and maintenance
• Advanced brake systems
Advanced Brake Systems

Goal: Dissipate train kinetic energy (as heat)

Method 1: Improve brake signal propagation rate
   – Increase the number of paths
   – Change the type of path (pneumatic or electronic)

Method 2: Increase car wheel brake force

\[
\text{Car } NBR = \frac{\text{car net brake shoe force}}{\text{car gross rail load}}
\]
### Emergency Brake Signal Propagation

<table>
<thead>
<tr>
<th>Brake System</th>
<th>Brake Signal Path</th>
<th>Brake Signal Speed</th>
<th>Car Brake Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Pneumatic (CONV)</td>
<td>Train Brake Pipe</td>
<td>~950 ft/sec (from head-end)</td>
<td>Sequential; Front-to-rear</td>
</tr>
<tr>
<td>Distributed Power Pneumatic (Trailing DP)</td>
<td>Train Brake Pipe</td>
<td>~950 ft/sec (from each end)</td>
<td>Sequential; Front-to-rear; Rear-to-front</td>
</tr>
<tr>
<td>Electronically-Controlled Pneumatic (ECP)</td>
<td>Train Electrical Cable</td>
<td>Nearly Instantaneous</td>
<td>Parallel; Nearly Simultaneous</td>
</tr>
</tbody>
</table>
Increase Car Wheel Brake Force

Methods

- Change brake shoe mechanical lever ratio
- Increase target brake cylinder pressure
- Shorten time to fully pressurize the brake cylinder

Yields higher brake shoe force and increased car NBR

- Brake shoe and wheel thermal loads increase
- Loads on track structure change
Air Brake Schematic (Apply Brake)

Air Brake Schematic (Release Brake)

Study Goals

1. Quantify train stopping performance capability for each brake system
2. Assess quality of the stop by comparing in-train force profiles
3. Evaluate kinetic energy dissipation benefits
   - Reduced stopping distance
   - Increased engineer/conductor response time margin
Simulation Study Scope

- Train/track properties
  - Mass/length (52, 78, 104, 130, 156 tank cars)
  - Track grade (-2 to +2 percent)
  - Initial speed (20 to 70 mph)
- Brake configuration (CONV, DP, ECP)
- Net braking ratio (10, 12.8, 14 percent)
- Emergency or full service braking
- Locomotive brakes applied or bailed off
- 3,790 simulation scenarios
Assumptions

• Clean, dry rail
• No inoperative brakes
• Head-end, engineer-induced brake application
• No derailment, collisions among cars, or collisions with other obstacles
• No loss of communications
Simulation Tool

- Train Energy and Dynamics Simulator (TEDS)
- Longitudinal train handling and performance applications
- Funded by Federal Railroad Administration
- Developed by Sharma & Associates, Inc.
- Validated against publicly available laboratory, field, and train empirical data
### Faster Brake Signal Propagation Results

<table>
<thead>
<tr>
<th>Relative to CONV 10% NBR baseline, bailed off</th>
<th>Stopping Distance Reduction, Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Braking Configuration</td>
<td>Speed, mph</td>
</tr>
<tr>
<td>Emergency</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>50</td>
</tr>
<tr>
<td>Full Service</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>50</td>
</tr>
</tbody>
</table>
Emergency Braking, Increased Car NBR

For a given speed and NBR, each brake system provides comparable emergency stopping distance benefits

<table>
<thead>
<tr>
<th>Braking Configuration</th>
<th>Speed, mph</th>
<th>CONV</th>
<th>DP</th>
<th>ECP</th>
<th>CONV</th>
<th>DP</th>
<th>ECP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency</td>
<td>20</td>
<td>12</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>15</td>
<td>17</td>
<td>17</td>
<td>20</td>
<td>22</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>22</td>
<td>24</td>
<td>24</td>
</tr>
</tbody>
</table>

Relative to respective 10% NBR baseline, bailed off, level grade

Stopping Distance Reduction, Percent

- **12.8% NBR**
- **14% NBR**
## Combined Effects, ECP and Increased NBR

<table>
<thead>
<tr>
<th>Braking Configuration</th>
<th>Speed, mph</th>
<th>ECP 10% NBR</th>
<th>ECP 12.8% NBR</th>
<th>ECP 14% NBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency</td>
<td>20</td>
<td>5 to 26</td>
<td>13 to 39</td>
<td>16 to 43</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>5 to 19</td>
<td>17 to 33</td>
<td>21 to 38</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>4 to 15</td>
<td>19 to 31</td>
<td>22 to 36</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>4 to 13</td>
<td>19 to 30</td>
<td>24 to 36</td>
</tr>
</tbody>
</table>

- **10% NBR** – representative of legacy tank car fleet
- **12.8% NBR** – default ECP target, subject to car rigging and HEU setting
- **14% NBR** – maximum acceptable loaded car NBR
## Combined Effects, ECP and Increased NBR

<table>
<thead>
<tr>
<th>Braking Configuration</th>
<th>Speed, mph</th>
<th>Stopping Distance Reduction, Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ECP 10% NBR</td>
</tr>
<tr>
<td><strong>Emergency</strong></td>
<td>20</td>
<td>5 to 26</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>5 to 19</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>4 to 15</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>4 to 13</td>
</tr>
<tr>
<td><strong>Full Service</strong></td>
<td>20</td>
<td>37 to 75</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>37 to 68</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>30 to 64</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>25 to 60</td>
</tr>
</tbody>
</table>
In-Train Forces and Energy Dissipation

- Lower car-to-car buff forces (75 to 250 thousand lb.) for trailing DP and ECP emergency brake application
- ECP 12.8% NBR, full stop, level grade from speed of 50 mph, relative to CONV 10% NBR baseline
  - Stopping distance reduced 500 – 550 feet (about 8 to 9 tank cars)
  - Time margin for engineer/conductor corrective or mitigating action increased about 13 seconds
  - Vehicle kinetic energy decrease of 50% or more equates to distance reduction of 850 feet (14 tank cars) and time margin of 27 seconds
Summary

- Due to faster brake signal propagation rates, ECP out-performed DP, which in turn out-performed CONV
- Increasing the NBR for a given brake system yields substantial and comparable emergency stopping benefits
- Stopping distance reduction, ECP 12.8% NBR, 50 mph
  - About 22 to 28% for emergency braking
  - About 43 to 66% for full service braking
Additional Work

• Follow-on NTSB study quantified advanced brake system performance for in-train derailment scenarios
  – Number of cars that stop short of point of derailment
  – Energy dissipated by the brake system for each car
• Train energy dissipation study was peer-reviewed
• Lower and more uniform in-train force benefits of DP and ECP braking remain to be quantified