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Driver Behavior at Highway-Rail Grade Crossings
With Passive Traffic Controls
- A Driving Simulator Study

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Research Background

- Fatality, Injury and Collision Trends at Highway-rail Grade Crossings

Source: All Highway-Rail Incidents at Public and Private Crossings, 1992-2013, Federal Railroad Administration (FRA)
Research Background

- **140,000** Track Miles & **212,000** Highway-rail Grade Crossings
- **FRA**: Light-Duty Vehicle Crashes at Highway-rail Grade Crossing 2004~2013

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Total Crashes = 15,639
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Source: Highway-Rail Grade Crossing Accident/Incident Report (Form 6180.57)
Research Background

- FRA Data: Spatial distribution of highway-rail crossing crashes-2004-2013

Total Crashes = 15,639

Source: Highway-Rail Grade Crossing Accident/Incident Report (Form 6180.57)
Research Background

- Types of Highway-rail Grade Crossing

**Passive Crossings**
- Crossbucks
- Advance warning signs
- Pavement markings
- STOP signs
- Yield Signs
- Other signs
- No signs or signals

**Active Crossings**
- Gates
- Flashing lights
- Highway signals, wigwags, or bells
- Special*

*Note: “Special” are traffic control systems that are not train activated, such as a crossing being flagged by a member of the train crew.

Source: Railroad-Highway Grade Crossing Handbook, & Cooper et al., 2007
Issues

- High cost + Large # of passive crossings → Not enough funding
- Research on passive controls needed...
- Low frequency of oncoming trains → Hard to capture real crossing behaviors
- Driving simulator: Behaviors at simulated crossings
UT Driving Simulator

- **Apparatus**
  - DriveSafety DS-600c
  - Visual and audio effects
  - Ford Focus sedan
  - 300° horizontal field-of-view
  - Five projectors
  - Three LCD mirror displays.
Driving Simulator

- Participants (convenience sample)
  - 64 subjects
  - 44 males, 20 females
  - Age distribution: min-18, max-59
Driving Simulator

❖ Scenarios

- Two-lane rural roads
- Clear weather
- RR crossings:
  1. Basic settings—advanced warning sign & crossbuck
  2. Basic settings + STOP sign
  3. Basic settings + YIELD sign

- 3 crossings × 64 drivers = 192 Crossing approaches

32 approaches with STOP sign
32 approaches with YIELD sign
128 approaches with CROSSBUCK Only

64 approaches with train coming
128 approaches no train coming

32 approaches with good sight distance
32 approaches with poor sight distance
128 approaches with medium sight

The point of view of a driver as they approach a railroad crossing
Methodology

Observation

- Looking behavior
- Stopping behavior
- Approach speed at different stages

*Speed limit is 45 mph*

Two stages of crossing-approaches, according to Railroad-highway Grade Crossing Handbook (Tustin et al., 1986).

Advance warning & Stages of far-crossing and near-crossing

Note: Since the sign legibility distance was about 50 meters (164 feet) in this simulator test, this study chose 60 meters (197 feet) to signs as the start point of data input.
Results

Looking Behavior

Looking behavior: Clear head movement to look at both sides of the road when approaching a crossing.
Results

❖ Stopping Behavior

Stopping behavior: Complete stop in front of a crossing

Note:
Comparison between cases without train coming
Results

- **Approach Speed**

  *Influence of opposing vehicles on driver’s response*

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**YIELD Sign**

![Graphs showing speed (mph) vs. distance to crossing (m) for different scenarios.]

**NOTE:** 1 m = 3.28 ft;

*Red dots and boxes are for “YIELD sign” crossings;
*Blue dots and boxes are for “CROSSBUCK-only” crossings;

Advanced warning sign is placed straight ahead 95m [312ft] from crossing.
Results

❖ Approach Speed

Influence of sight distance on driver’s response

STOP Sign

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Distance to crossing (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor Sight Distance No Train Present</td>
<td>Clear Sight Distance No Train Present</td>
</tr>
</tbody>
</table>

NOTE: 1 m = 3.28 ft;
* Red dots and boxes are for “STOP sign” crossings;
* Blue dots and boxes are for “CROSSBUCK-only” crossings;
_xor_ Advanced warning sign is placed straight ahead 95m [312ft] from crossing.
Data Analysis

- **Mixed-Effects Model**

  - $Y = \beta X + \gamma Z + \varepsilon$, 
  - $\gamma \sim N(0, G)$, 
  - $\varepsilon \sim N(0, \sigma^2 I_n)$

$Y$ = response for each approach (i.e., looking behavior, stopping behavior, and approach speed) in the data;

$X$ = vector for fixed independent variables (sign, sight distance, traffic, and train presence, driver age and gender);

$\beta$ = vector of estimated fixed effects for matrix $X$; and

$Z$ = vector of a matrix for random independent variables ($Driver$ $ID$);

$\gamma$ = vector of estimated random effects for matrix $Z$;

$\varepsilon$ = vector of unknown random errors;

$G$ = the covariance matrix for the random effects;

$\boldsymbol{0}$ = an $n \times 1$ vector of zeroes; and

$I_n$ = the order-$n$ identity matrix
Path Analysis

\[ Y_1 = \beta_{10} + \beta_{11}X_1 + \beta_{12}X_2 + \ldots + \beta_{1j}X_j + \epsilon_1 \]

\[ Y_2 = \beta_{20} + \beta_{21}X_1 + \beta_{22}X_2 + \ldots + \beta_{2j}X_j + \gamma Y_1 + \epsilon_2 \]

\( Y_1 = \) Looking behavior;

\( Y_2 = \) Responses (i.e., stopping behavior and speed reduction);

\( \beta_{ij} = \) Vector of estimated parameter for each set of variables \( X_j \);

\( \gamma = \) association of looking behavior \( Y_1 \) with responses \( Y_2 \);

\( \epsilon_i = \) Error terms, which are assumed to be uncorrelated.
Descriptive statistics

Descriptive statistics of dependent and independent variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>STD</th>
<th>Min</th>
<th>Max</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Step Speed Reduction (mph)</td>
<td>3.575</td>
<td>5.583</td>
<td>-23.793</td>
<td>27.182</td>
<td>192</td>
</tr>
<tr>
<td>Second Step Speed Reduction (mph)</td>
<td>9.701</td>
<td>12.212</td>
<td>-24.167</td>
<td>40.376</td>
<td>192</td>
</tr>
<tr>
<td>Total Speed Reduction (mph)</td>
<td>13.276</td>
<td>13.604</td>
<td>-33.479</td>
<td>43.559</td>
<td>192</td>
</tr>
<tr>
<td>Looking Behavior (Yes) *</td>
<td>0.776</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>192</td>
</tr>
<tr>
<td>Stopping Behavior (Yes)</td>
<td>0.297</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>192</td>
</tr>
<tr>
<td>Sign (STOP)</td>
<td>0.167</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>192</td>
</tr>
<tr>
<td>Sign (YIELD)</td>
<td>0.167</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>192</td>
</tr>
<tr>
<td>Sight Distance (Clear)</td>
<td>0.167</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>192</td>
</tr>
<tr>
<td>Sight Distance (Poor)</td>
<td>0.167</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>192</td>
</tr>
<tr>
<td>Opp. Vehicle Action (Stop)</td>
<td>0.167</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>192</td>
</tr>
<tr>
<td>Opp. Vehicle Action (Cross)</td>
<td>0.167</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>192</td>
</tr>
<tr>
<td>Train Presence (Yes)</td>
<td>0.333</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>192</td>
</tr>
<tr>
<td>Gender (Male)</td>
<td>0.688</td>
<td>-</td>
<td>0</td>
<td>1</td>
<td>64</td>
</tr>
<tr>
<td>Age</td>
<td>28.688</td>
<td>10.472</td>
<td>18</td>
<td>59</td>
<td>64</td>
</tr>
</tbody>
</table>

NOTE:
1. First Step Speed Reduction = speed reduced from 100 to 60 meters from the Crossing;
2. Second Step Speed Reduction = speed reduced from 60 to 2 meters from the Crossing;
3. Bases for independent variables are Sign (Crossbuck), Sight Distance (Medium), Opp. Vehicle Action (No Opp. Vehicle) and Train Presence (No);
4. 1 meter = 3.28 feet;
5. * Looking behavior is both dependent and independent.

64 approaches with train coming (half with STOP sign and half with YIELD sign)
## Modeling Results

### Looking Behavior and Stopping Behavior

<table>
<thead>
<tr>
<th>Model</th>
<th>Mixed-effects Binomial Logistic Model for Looking and Stopping Behaviors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Y= Looking Behavior</td>
</tr>
<tr>
<td><strong>Dependent Variables</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Independent Variables</strong></td>
<td>β</td>
</tr>
<tr>
<td>Looking (Yes)</td>
<td>-</td>
</tr>
<tr>
<td>Sign (STOP)</td>
<td>4.006**</td>
</tr>
<tr>
<td>Sign (YIELD)</td>
<td>1.480</td>
</tr>
<tr>
<td>Sight Distance (Clear)</td>
<td>-0.819</td>
</tr>
<tr>
<td>Sight Distance (Poor)</td>
<td>-0.592</td>
</tr>
<tr>
<td>Opp. Vehicle Action (Stop)</td>
<td>1.163</td>
</tr>
<tr>
<td>Opp. Vehicle Action (Cross)</td>
<td>0.233</td>
</tr>
<tr>
<td>Train Presence (Yes)</td>
<td>0.032</td>
</tr>
<tr>
<td>Gender (Male)</td>
<td>2.281*</td>
</tr>
<tr>
<td>Age</td>
<td>0.013</td>
</tr>
<tr>
<td>Constant</td>
<td>0.124</td>
</tr>
<tr>
<td><strong>Number of obs.</strong></td>
<td>192</td>
</tr>
<tr>
<td><strong>Number of groups</strong></td>
<td>64</td>
</tr>
<tr>
<td><strong>Wald Chi²</strong></td>
<td>11.52</td>
</tr>
<tr>
<td><strong>Prob &gt; Chi²</strong></td>
<td>0.118</td>
</tr>
<tr>
<td><strong>Log likelihood at convergence</strong></td>
<td>-79.79</td>
</tr>
</tbody>
</table>

** = significant at a 99% confidence level; * = significant at a 95% confidence level; ^ = significant at a 90% confidence level.

Adding STOP sign → \( Pr(\text{looking}) \) increases by 29.1%, \( Pr(\text{full stop}) \) by 69.7%

YIELD sign not significant (5% level)...
## Modeling Results

### Approach Speed

Mixed-effects maximum likelihood models for speed reduction

<table>
<thead>
<tr>
<th>Model</th>
<th>Mixed-effects ML Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dependent Variables</strong></td>
<td>Y = First Step Speed Reduction</td>
</tr>
<tr>
<td><strong>Independent Variables</strong></td>
<td>β</td>
</tr>
<tr>
<td>Looking (Yes)</td>
<td>3.257**</td>
</tr>
<tr>
<td>Sign (STOP)</td>
<td>-0.550</td>
</tr>
<tr>
<td>Sight Distance (Clear)</td>
<td>0.622</td>
</tr>
<tr>
<td>Sight Distance (Poor)</td>
<td>-1.664</td>
</tr>
<tr>
<td>Opp. Vehicle Action (Stop)</td>
<td>-0.457</td>
</tr>
<tr>
<td>Opp. Vehicle Action (Cross)</td>
<td>-1.270</td>
</tr>
<tr>
<td>Train Presence (Yes)</td>
<td>1.806*</td>
</tr>
<tr>
<td>Gender (Male)</td>
<td>0.454</td>
</tr>
<tr>
<td>Age</td>
<td>-0.004</td>
</tr>
<tr>
<td>Constant</td>
<td>1.125</td>
</tr>
<tr>
<td><strong>Number of obs.</strong></td>
<td>192</td>
</tr>
<tr>
<td><strong>Number of groups</strong></td>
<td>64</td>
</tr>
<tr>
<td><strong>Wald Chi²</strong></td>
<td>19.09</td>
</tr>
<tr>
<td><strong>Prob &gt; Chi²</strong></td>
<td>0.039</td>
</tr>
<tr>
<td>Log likelihood at convergence</td>
<td>-590.012</td>
</tr>
</tbody>
</table>

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**Adding STOP sign → Lower speeds**

*Drivers who looked reduced speed further.*
**Path Analysis ➔ Direct, Indirect, and Total effects on Speed Reduction**

STOP signs

YIELD signs

Good Sight Distance

Poor Sight Distance

Opp. Vehicles Action (Stop)

Opp. Vehicles Action (Cross)

Train Presence

Driver Gender (Male)

Driver Age

Looking Behaviors (Yes)

Total Speed Reduction

**STOP Sign- Total Impact:**

11.769 + 8.25 \times 29.1\% = 14.175 \text{ mph speed reduction}

** = significant at a 99\% confidence level; * = significant at a 95\% confidence level; ^ = significant at a 90\% confidence level.
Conclusions

- STOP signs → Hi Pr (Looking for oncoming train)
- STOP signs → Lo Pr (Approach speed)
- YIELD signs → Behavior very similarly to CROSSBUCK signs
- Path analysis → Deeper understanding of driver responses at crossings through looking behaviors
- Mixed-Effects Regression Model → Driving simulator studies which involve human subjects making repeated observations
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