Level Crossing Research at NURail Universities

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The National University Rail (NURail) Center is a consortium of seven partner colleges and universities offering an unparalleled combination of strengths in railway transportation engineering research and education in North America.
Highway-Rail Grade Crossings

• Over 200,000 level crossings in the US alone

• Hundreds of fatal accidents

• Rough crossings result in delays, vehicle damage, discomfort

• Huge maintenance issue for RR and DOT alike
Outline of This Presentation

- Work of 4 NURail universities (9 projects)
- Common goal of improving safety
- Three general themes
  - human factors
  - risk analysis
  - infrastructure assessment
Papers are available for all projects

Contact the speaker at Souleyrette@uky.edu
#1 In-Vehicle Alerts; How Best to Warn Drivers?

**Stimuli**

- 31 novel auditory cues
  - 9 Earcons (Beeps)
  - Varied in pitch, pulse rate, wave shape, etc.
  - 6 Auditory Icons (train sounds)
  - Train horns, “track” sounds, warning bells, etc.
  - 16 Verbal messages
  - 2 Genders (M, F)
  - 2 Voice types (Human, TTS)
  - 4 words (Alert, Caution, Danger, Warning)

**Subjective Measurements**

- 7 psychological dimensions
  - Likert scale 1-7
  - Overall Appropriateness
  - Urgency
  - Meaning
  - Discriminability
  - Annoyance
  - Startle effect
  - Natural-In-Car

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Baldwin & Lewis, 2014
Experimental Design

22 minute loop, train present at 23rd crossing (gate)
Evaluation Auditory Warnings using Driver Simulator

Compliance coding scheme

- + 1 for each direction looked (max 2)
- + 1 for coasting (releasing accelerator pedal)
- + 1 for slowing down (press on brake pedal)
- - 1 for not coming to a complete stop (if STOP sign)

“ding ding, Railroad Crossing ahead, look left and right”
Principal Component Analysis suggested two main factors (95% of variance explained across all 7 dimensions):

“Utility” – meaning & natural & urgency
“Impulsivity” – annoying & startle
Significance of Results

Compliance by sign type

- Signs only
- With Alerts

- Gate
- Xbuck
- Yield
- Stop
#2 Integration of Driver Simulator and NDS Data

- SHRP2-NDS (Naturalistic Driving Study)
  - Data were live recorded in-vehicle
  - Behavior very similar to the natural environment
  - Expensive and difficult to set up
  - Data collected between 2011 and 2013
  - 3,500 Vehicles in 6 Regions: FL, IN, NY, NC, PA, WA
  - More than five million trips and over 1,000 crossings involved
  - Data used to analyze driver behavior at grade crossings, primarily in non-accident situations
Data analysis

No significant speed decrease (0)
No Rotation outside 8 degrees
Pitch within 8 degrees
No scanning behavior (0)

Significant speed decrease (+1)
Scan in 1 direction (+1)
Head pitch within "range" (not looking to their feet)
Scores - Crossing Type

• Clusters are based on:
  – Traffic control devices (passive, active w/ lights, active w/ lights & gates)
  – Angle of the crossing
  – Total trains per day
  – Highway maximum speed

• Scanning vs. speed reduction behavior offers similar trending with all main TCDs
Correlation analysis

Compliance score vs Total Trains Per Day

- Initial results show drivers display more compliant behaviors as the number of trains per day increases
- More data are needed in some of the clusters to reach a 90% confidence with 5% standard error
Next Steps

- Simulate a variety of observed sites
- Calibrate driver simulator with NDS data
- Provide warnings in similar circumstances to test improvement
Auditory warning of approaching crossing...

• Requires GPS + crossing location database
• No vehicle-train communication necessary (not “Active” from the RR perspective)
• Increases saliency, especially at passive crossings
• Reminds drivers to comply (and *how to comply*)
#3 Grade Crossing
Pedestrian Safety

- Interviews with experts
  - Lower priority unless adjacent to highway crossing
  - Lack of tools, cost data, uniformity
  - Distraction the big problem

- Survey of users
  - Younger users notice active, old notice passive
  - Regular users & females more safety conscious

- Video
  - Larger groups more likely to violate
Quantitative Analysis of Train Derailments Due to Highway-Rail Grade Crossing Incidents
Probabilistic Risk Assessment

- **Incident Probability**
  - Train encounters highway rail grade crossing
  - Incident does not occur
  - Incident occurs

- **p(D|I) Calculator**
  - Passenger train
    - No derailment
    - Derailment
  - Freight train
    - No derailment
    - Derailment

- **Consequences**
  - No casualties
  - Casualties
  - Carrying hazardous materials
    - Release
    - Other Consequences
  - No Release

Derailment Likelihood Calculator – p(D|I) curve

- Now recall our function $p(D|I) = \frac{1}{e^{-\gamma} + 1}$ which is a function of VS, TS, TL, EC, IT, LV.
Key Findings

- Speed and weight of highway and rail vehicles important
- **Regression models** calculate probability of derailment based on physical factors
- **Easy-to-use calculator** for use by practitioners (ranking tool)
### Key Findings (cont)

- **Case study** on how results can be used with existing metrics
- Combining consequence data, incident likelihood, derailment likelihood helps decide **which crossings to upgrade**

| Crossing | Warning Device | Highway Class | Pax | Trans | All Trans | Timetable Speed | Track Class | Expected Value | 95th Percentile WBAPS Prediction | p(D|I)_exp * Rank | f(I) | Rank | p(D|I)_95 * Rank | f(D)_exp Rank | f(D)_95 Rank |
|----------|----------------|---------------|-----|-------|-----------|-----------------|-------------|----------------|-------------------------------|-----------------|------|------|----------------|----------------|-------------|
| 4U O. Active | UA | 0 | 2 | 30 | 3 | 0.03689 | 1 | 0.03689 | 1 | 0.02110 | 4 | 0.00078 | 3 | 0.000473 | 3 |
| 4V Passive | UL | 0 | 2 | 30 | 3 | 0.03373 | 2 | 0.19140 | 4 | 0.00252 | 22 | 0.00099 | 23 | 0.000538 | 23 |
| 4W Passive | UL | 0 | 2 | 30 | 3 | 0.03373 | 2 | 0.19140 | 4 | 0.04836 | 2 | 0.0163 | 1 | 0.000926 | 2 |
| 4T O. Active | UC | 0 | 2 | 30 | 3 | 0.03348 | 3 | 0.19146 | 3 | 0.00877 | 16 | 0.00029 | 9 | 0.00170 | 12 |
| 4K O. Active | UA | 0 | 4 | 10 | 1 | 0.02570 | 4 | 0.19882 | 2 | 0.01293 | 9 | 0.00033 | 6 | 0.00227 | 7 |
| 4N O. Active | UA | 0 | 4 | 10 | 1 | 0.02570 | 4 | 0.19882 | 2 | 0.02149 | 3 | 0.00055 | 4 | 0.00427 | 4 |
| 4R O. Active | UC | 0 | 4 | 10 | 1 | 0.02570 | 4 | 0.19882 | 2 | 0.02092 | 5 | 0.00054 | 5 | 0.00416 | 5 |
| 4S O. Active | UA | 0 | 4 | 10 | 1 | 0.02570 | 4 | 0.19882 | 2 | 0.05827 | 1 | 0.00015 | 2 | 0.1159 | 1 |
| 4C O. Active | UC | 0 | 4 | 10 | 1 | 0.02390 | 5 | 0.16090 | 5 | 0.06719 | 19 | 0.00015 | 20 | 0.00108 | 19 |
| 4E O. Active | UC | 0 | 6 | 10 | 1 | 0.02390 | 5 | 0.16090 | 5 | 0.01311 | 8 | 0.00029 | 9 | 0.00211 | 9 |
| 4F O. Active | UC | 0 | 4 | 10 | 1 | 0.02390 | 5 | 0.16090 | 5 | 0.05898 | 15 | 0.00020 | 17 | 0.00144 | 17 |
| 4H O. Active | UC | 0 | 4 | 10 | 1 | 0.02390 | 5 | 0.16090 | 5 | 0.01011 | 12 | 0.00023 | 13 | 0.00163 | 13 |
| 4I O. Active | UC | 0 | 4 | 10 | 1 | 0.02390 | 5 | 0.16090 | 5 | 0.00982 | 14 | 0.00021 | 15 | 0.00155 | 15 |
| 4O O. Active | UC | 0 | 4 | 10 | 1 | 0.02390 | 5 | 0.16090 | 5 | 0.01270 | 10 | 0.00028 | 11 | 0.00204 | 10 |
| 4P O. Active | UC | 0 | 4 | 10 | 1 | 0.02390 | 5 | 0.16090 | 5 | 0.01201 | 11 | 0.00027 | 12 | 0.00193 | 11 |
| 4A O. Active | UL | 0 | 4 | 10 | 1 | 0.02154 | 6 | 0.15518 | 6 | 0.01003 | 13 | 0.00022 | 14 | 0.00156 | 14 |
| 4B O. Active | UL | 0 | 4 | 10 | 1 | 0.02154 | 6 | 0.15518 | 6 | 0.01440 | 7 | 0.00031 | 8 | 0.00223 | 8 |
| 4G O. Active | UL | 0 | 4 | 10 | 1 | 0.02154 | 6 | 0.15518 | 6 | 0.00773 | 18 | 0.00017 | 19 | 0.00120 | 19 |
| 4J O. Active | UL | 0 | 4 | 10 | 1 | 0.02154 | 6 | 0.15518 | 6 | 0.00589 | 21 | 0.00013 | 22 | 0.00091 | 22 |
| 4L O. Active | UL | 0 | 4 | 10 | 1 | 0.02154 | 6 | 0.15518 | 6 | 0.00823 | 17 | 0.00018 | 18 | 0.00128 | 18 |
| 4M O. Active | UL | 0 | 4 | 10 | 1 | 0.02154 | 6 | 0.15518 | 6 | 0.00962 | 14 | 0.00021 | 16 | 0.00149 | 16 |
| 4Q O. Active | UL | 0 | 4 | 10 | 1 | 0.02154 | 6 | 0.15518 | 6 | 0.00962 | 14 | 0.00021 | 16 | 0.00149 | 16 |
| 4D Gates | UA | 0 | 4 | 10 | 1 | 0.01666 | 7 | 0.14098 | 7 | 0.01883 | 6 | 0.0033 | 7 | 0.0328 | 6 |

Corridor 4 Incident Total: f(I) = 0.34961 f(D)_exp = 0.00901 f(D)_95 = 0.06299
Combination of Micro and Macro Models for Risk Assessment

- **Macroscopic** models derived from entire state or country
  - Correlation between *crossing characteristics* and past accident frequency
  - E.g., **US DOT** Accident Prediction Formula.
- Microscopic perspective: *individual characteristics* of accidents and crossings
  - Discover **local trends**
- **Combined** micro and macro model development
  - Compared results to US DOT APF
Quantifying Condition

**GOOD**
- Surface Width is ≤ 22 ft (6.7 m)
- Drainage Adequacy: CSO-N (1041 cm, difference in elevation between ditch flow line/vegetation and top edge of shoulder)
- Structural Adequacy: Limited rating (≤ 3) (≤ 8 (3 m) requiring minor maintenance during wet periods)

**FAIR**
- Surface Width is 16 - 21 ft (4.9-6.4 m)
- Drainage Adequacy: CSO-N (1041 cm, difference in elevation between ditch flow line/vegetation and top edge of shoulder)
- Structural Adequacy: Limited rating (≤ 3) (≤ 8 (3 m) requiring minor maintenance during wet periods)

**POOR**
- Surface Width is ≤ 15 ft (4.6 m)
- Drainage Adequacy: CSO-N (1041 cm, difference in elevation between ditch flow line/vegetation and top edge of shoulder)
- Structural Adequacy: Limited rating (≤ 3) (≤ 8 (3 m) requiring minor maintenance during wet periods)

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**Graphs and Diagrams**

- **Railroad Crossing Rating**
- **LiDAR**
- **Vehicle Dynamic Model**
- **Predicted Acceleration**
- **Comparison**
- **Accelaration**
- **Raw Acceleration Data**
- **Compare with RMS**
- **Chapter 3**
- **Chapter 4**
- **Chapter 5**
- **Chapter 6**
- **Chapter 7**
Structured-light Sensor

Physical model
Accelerometer Application

Tests with Speed Close to 35 mph

Z Acceleration (m/s²)

Time (sec)

JEEP Predict IMPALA Before Calibration

\[ y = 1.0009x \]

R² = 0.9507

Use this equation to convert "Jeep" readings to "Impala" readings

R² much better!

Sensitivity of Crossing Ranking using RMS of Various Vehicles

<table>
<thead>
<tr>
<th>Crossing</th>
<th>Post Speed</th>
<th>Ave. RMS</th>
<th>Rank based on Ave. RMS</th>
<th>Rank based on F150</th>
<th>Rank based on IMPALA</th>
<th>Rank based on JEEP</th>
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Performance
A Vehicle Dynamic Model

Do we need to go to the field?

Physical model ⇔ Performance
Rail Crossing Condition Index

**Crossing Roughness Index Rank**

\[ S_a = \frac{1}{MN} \sum_{j=1}^{N} \sum_{i=1}^{M} |z(x_i, y_j)| \]

\[ S_q = \sqrt{\frac{1}{MN} \sum_{j=1}^{N} \sum_{i=1}^{M} z^2(x_i, y_j)} \]
Can we separate the effects of original design from effects of poor surface condition?
Can we separate the effects of original design from effects of poor surface condition?

- **current surface**
- **As-built surface**
Two components of crossing rideability

Components are calculated

Total is field measured

CCI

Acceleration (m/s²)

- Acceleration estimated from profile (m/s²)
- Condition index (m/s²)

Sites:
- Bryan Station
- Briar Hill
- Hatton
- Bridgeport-Benson
Hump Crossings
Hump? ... More that just a “yes or no” question

Figure 9 Car Carrier Trailer pass KY-57 Briar Hill Army Depot
## Validation

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- **Level 1**: $\delta_{\text{min}} > 2$ inch
- **Level 2**: $2$ inch $\geq \delta_{\text{min}} > 0$ inch
- **Level 3**: $0$ inch $\geq \delta_{\text{min}} > -1$ inch
- **Level 4**: $-1$ inch $\geq \delta_{\text{min}} > -2$ inch
- **Level 5**: $\delta_{\text{min}} \leq -2$ inch
3D Rail-highway hump crossing automatic evaluation software GUI

Software Demo Video: https://youtu.be/EwEpXB4Zq2U
3D Rail-highway hump crossing automatic evaluation software result output
2D Rail-highway hump crossing automatic evaluation software GUI

Software Demo Video: https://youtu.be/EwEpXB4Zq2U
2D Rail-highway hump crossing automatic evaluation software result output
Questions?
- Souleyrette@uky.edu

Reports and more information:
- http://www.nurailcenter.org/

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