Quantifying Grade Crossing Condition as an Input to Modeling Safety

Teng (Alex) Wang & Reginald Souleyrette
University of Kentucky, Lexington, KY

Ahmed Aboubakr & Edward Randerson
University of Illinois at Chicago, Chicago, IL
Introduction

Background:

- highway-rail grade crossing is unique
  - Weak link (suboptimal design)
  - High growth in rail and truck traffic predicted
    - Congestion/delay
    - Tonnage, VMT and damage
    - In general ... conflict
  - Over 216,000 rail highway grade crossings in the US and over 9000 in the state of Kentucky alone (FRA)
Concerns

Safety ...

- 1,963 rail highway crossing incidents in 2012 and over 1,300 incidents in the first eight months of 2013 (FRA)
- High-centered crossing collisions between train and truck (hump)
- Crossing roughness related to highway safety
- Safety models (e.g., WBAPS) do not include hump or roughness

Rail crossing fatalities in the US
Concerns

Infrastructure (system preservation) ...

- Asset management
  - Preventive maintenance
  - Vehicle damage
  - Public (customer) service (rideability)
  - Conventional inventory method
  - No quantitative method currently exists

- Evaluate the physical performance of crossings
  - Design, materials, construction and environment
  - Conventional measurement methods
  - Limitations
Objectives

- Capture terrain economically and quickly
  - For ride/hump
  - For design/materials performance
  - 3D data acquisition system (DAS)

- Quantify roughness
  - Measured accelerations (accelerometer)
  - Estimated accelerations (terrain model + vehicle dynamic model)

- Develop measures for systematic assessment
Technology

Meanwhile ... technology advances

- Developments in computer science
- 3D sensing and imaging technologies
  - LiDAR
  - Photogrammetry
  - Kinect sensor
  - Structured light
Design and Build Data Acquisition System (DAS)
A highway rail crossing surface 3D points cloud
After the all 3D points cloud tiles were merged into one crossing surface, each point had X, Y, Z coordinates recorded (to the nearest millimeter). A color coded rendering of the crossing surface elevation is shown here. Blue indicates lower elevation, while Red shows the higher elevations.
Using the 3D point cloud, crossing roughness may be quantified as depth and area of cracks, area and volume of bumps or pot-holes, or other formulations. An example displaying surface curvature gradient is illustrated below. Blue areas are relatively flat as compared to Red areas in this visualization.
Field Test

Brannon road crossing in Jessamine County, KY (US DOT crossing number 841647U)

- highway traffic 5,900 veh/day
- rail traffic 70 trains/day
- WBAPS 0.042 crashes/year
- projected highway traffic 14,000 veh/day in 2040
Measured accelerations (accelerometer)

Field data collection equipment and device:

• 2009 Chevrolet Impala sedan
• a real time acceleration sensor records and stores 3 axis (XYZ) acceleration data at 100 hertz with the range of +/- 10 g, accuracy +/- 1% and resolution at 0.010 g
• a laptop PC preloaded with recording software
• a smart phone with built-in A-GPS that records and stores the GPS coordinates and vehicle speed at 1 hertz
• a stop watch
Field Data Collection Procedure

• Close to constant speed at crossing (mostly 35mph)
• Passenger records time at fixed locations before and after the crossing
• Acceleration sensor and GPS kept running during the entire test
• Acceleration data were divided into eastbound and westbound groups
• A few tests run at speeds as low as 15 mph and as high as 45 mph.
• Note, accelerations at 15 mph (advisory) were negligible.
Field Data Analysis and Result

• Acceleration recorded in the Z axis (vertical direction)
• Plotted acceleration vs time
• Approximately 10 seconds before and after the crossing
• Average speed obtained via smart phone GPS (using time stamp)
Eastbound Tests with Speed Close to 35 mph

Z Acceleration (m/s²)

Time (sec)
Westbound Tests with Speed Close to 35 mph

Z Acceleration (m/s^2)

Time (sec)
Tests with Speed Close to 35 mph

Z Acceleration (m/s^2)

Time (sec)

EB2 34.9 mph
EB3 35.1 mph
EB 5 34.9 mph
EB9 34.9 mph
EB10 34.9 mph
Tests with Various Speeds

Z Acceleration (m/s^2)

- EB16 23.9 mph
- EB1 26.2 mph
- EB 5 34.9 mph
- EB15 43.6 mph

Time (sec)
Field Data Analysis and Result

when the test speed is held constant (35 mph), both the frequency and amplitude of acceleration from one test are very close. This indicates that the test is highly repeatable and method is reliable for future work.

For tests were performed at various speeds, it can be seen that as expected, acceleration amplitudes and frequencies increase with increasing speeds.
Vehicle Dynamic Model

Vehicle Dynamic Model Simulation:

A highway vehicle dynamic model was developed based on ATTIF (Analysis of Train/Track Interaction Forces) developed at the Dynamic Simulation Laboratory (DSL) of the University of Illinois at Chicago (UIC).
Wheel Path Crossfire Radar
Vehicle Dynamic Model Simulation
Initial Simulation Result vs Field Collection Data @ 34.9 mph

- **Field Collection Data 34.9 mph**
- **Initial Simulation Result 34.9 mph**
Simulation Result vs Field Collection Data @ 34.9 mph

Z Acceleration (m/s^2)

<table>
<thead>
<tr>
<th>Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>0.5</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>3.5</td>
</tr>
</tbody>
</table>

Field Collection Data 34.9 mph

Simulation Result 34.9 mph
Simulation Result vs Field Collection Data @ 43.6 mph

Z Acceleration (m/s^2)

Time (sec)

Field Collection Data 43.6 mph

Simulation Result 43.6 mph
## Simulation Results Compared to Field Collection Data

<table>
<thead>
<tr>
<th>Speed</th>
<th>P(A:B) A=field B=simulated</th>
<th>MSE (normalized to maximum acceleration)</th>
<th>MAX(A):MAX(B) in m/s²</th>
<th>MIN(A):MIN(B) in m/s²</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.9 mph</td>
<td>0.44</td>
<td>0.34</td>
<td>1.96:4.27</td>
<td>-3.29:-3.51</td>
</tr>
<tr>
<td>26.2 mph</td>
<td>0.65</td>
<td>0.20</td>
<td>2.58:4.72</td>
<td>-3.74:-3.68</td>
</tr>
<tr>
<td>34.9 mph</td>
<td>0.93</td>
<td>0.16</td>
<td>5.56:5.84</td>
<td>-7.00:-7.64</td>
</tr>
<tr>
<td>43.6 mph</td>
<td>0.93</td>
<td>0.16</td>
<td>9.92:8.36</td>
<td>-9.32:-12.51</td>
</tr>
</tbody>
</table>

**Cross correlation index** $P(A:B) = \frac{\text{cross correlation } (A:B)}{\text{cross correlation } (A:A)}$

where $A$, $B$ are time series waves with the same number of data. And $P(A:B) = 1$, when wave $A$ and $B$ are the same shape.
Summary & Next Steps

- Low cost 3D sensor
- Accelerometer validation
- Dynamic model calibration
- Calibration of dynamic model for different speeds
- Test/calibration of dynamic model for different vehicles and crossings
- Test of effect of lateral placement
- Development of method to extrapolate acceleration readings to design vehicle
- Use of 3D sensor to quantify hump crossings
Acknowledgements
Questions?
Thank you!