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

UNIVERSITY OF KENTUCKY

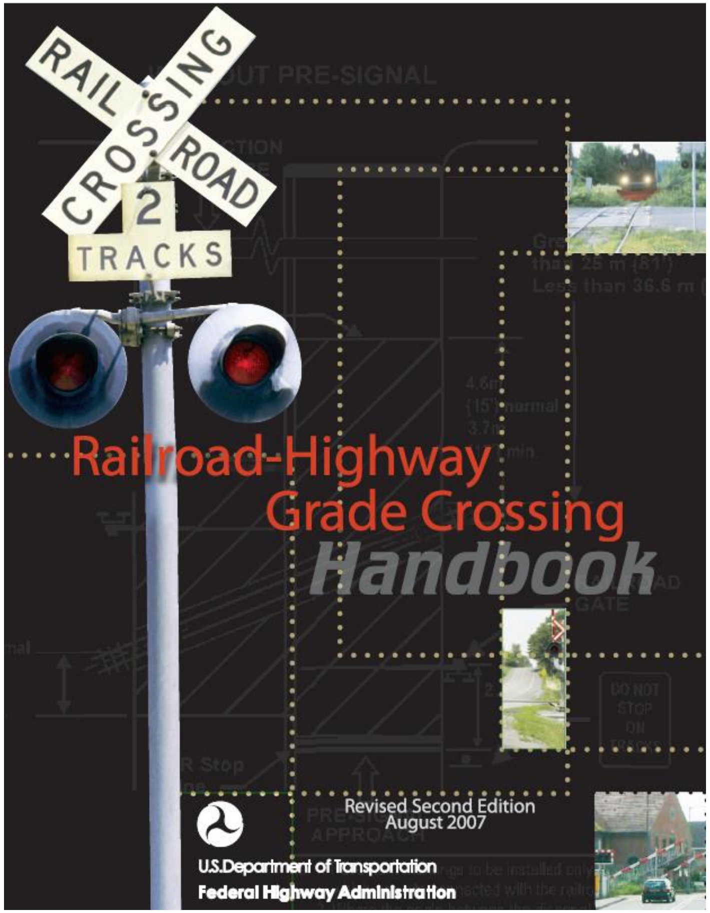
2014 Global Level Crossing Safety and Trespass Prevention Symposium
University of Illinois at Urbana-Champaign

UIC UNIVERSITY OF ILLINOIS AT CHICAGO

Introduction

Background:

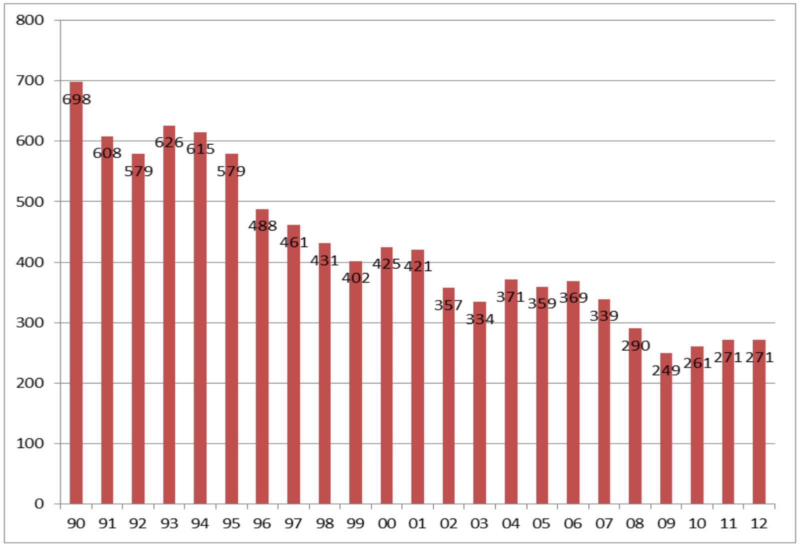
- highway-rail grade crossing is unique
  - Weak link (suboptimal design)
  - High growth in rail and truck traffic predicted
    - Congestion/delay
    - Tonnage, VMT and damage
    - In general … conflict
  - Over 216,000 rail highway grade crossings in the US and over 9000 in the state of Kentucky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



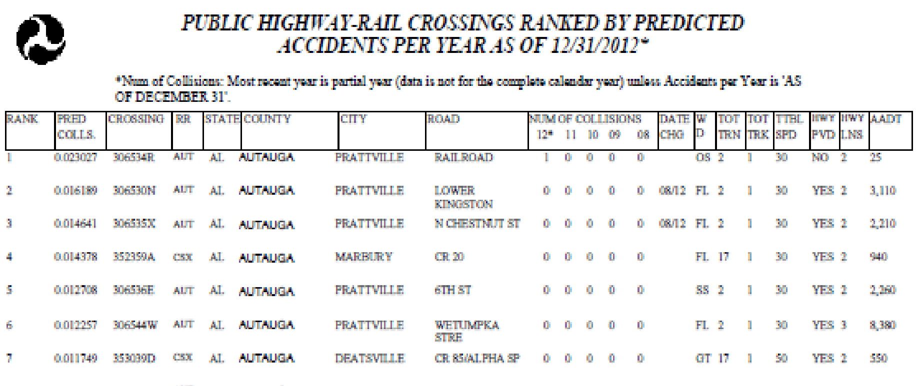
Concerns

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



*PUBLIC HIGHWAY-RAIL CROSSINGS RANKED BY PREDICTED ACCIDENTS PER YEAR AS OF 12/31/2012**

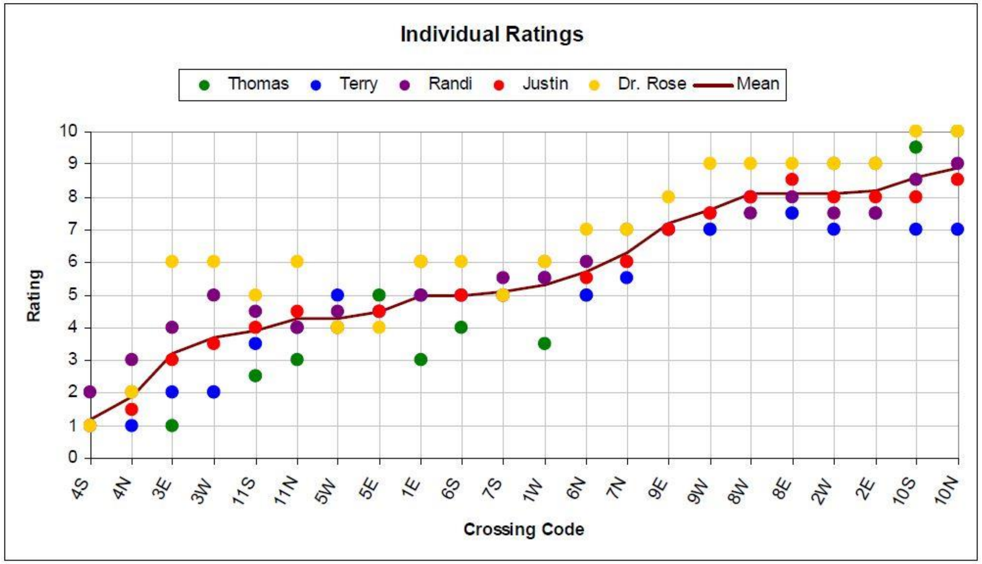
*Num of Collisions: Most recent year is partial year (data is not for the complete calendar year) unless Accidents per Year is 'AS OF DECEMBER 31'.

RANK	PRED COLLS.	CROSSING	RR	STATE	COUNTY	CITY	ROAD	NUM OF COLLISIONS					DATE CHG	WD	TOT TRN	TOT TRK	TTBL SPD	HWY PVD	HWY LNS	AADT
								12*	11	10	09	08								
1	0.023027	306534R	AUT	AL	AUTAUGA	PRATTVILLE	RAILROAD	1	0	0	0	0		OS	2	1	30	NO	2	25
2	0.016189	306530N	AUT	AL	AUTAUGA	PRATTVILLE	LOWER KINGSTON	0	0	0	0	0	08/12	FL	2	1	30	YES	2	3,110
3	0.014641	306535X	AUT	AL	AUTAUGA	PRATTVILLE	N CHESTNUT ST	0	0	0	0	0	08/12	FL	2	1	30	YES	2	2,210
4	0.014378	352359A	CSX	AL	AUTAUGA	MARBURY	CR 20	0	0	0	0	0		FL	17	1	30	YES	2	940
5	0.012708	306536E	AUT	AL	AUTAUGA	PRATTVILLE	6TH ST	0	0	0	0	0		SS	2	1	30	YES	2	2,260
6	0.012257	306544W	AUT	AL	AUTAUGA	PRATTVILLE	WETUMPKA STRE	0	0	0	0	0		FL	2	1	30	YES	3	8,380
7	0.011749	353039D	CSX	AL	AUTAUGA	DEATSVILLE	CR 85/ALPHA SP	0	0	0	0	0		GT	17	1	50	YES	2	550

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



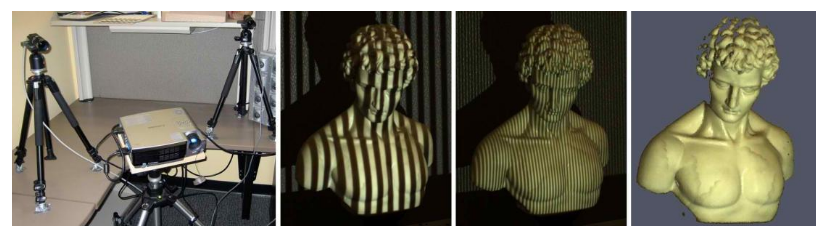
Objectives

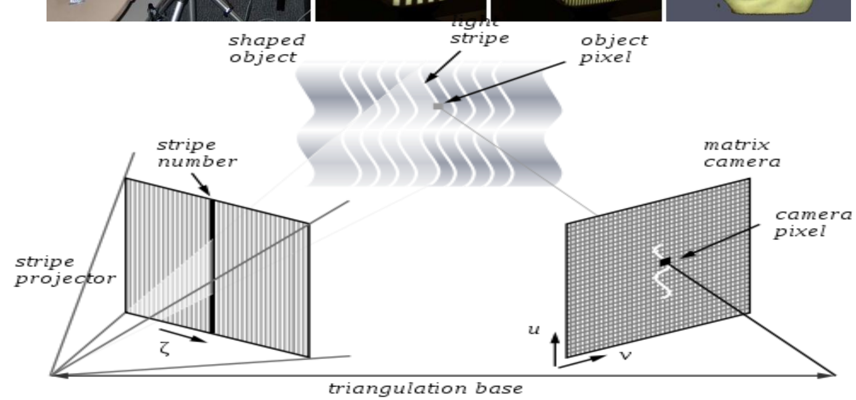
- Capture terrain economically and quickly
  - For ride/hump
  - For design/materials performance
  - 3D data acquisition system (DAS)
- Quantify roughness
  - Measured accelerations (accelerometer)
  - Estimated accelerations (terrain model + vehicle dynamic model)
- Develop measures for systematic assessment

Technology

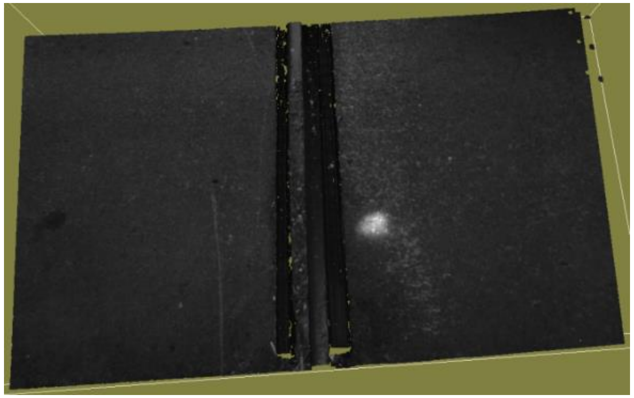
Meanwhile … technology advances

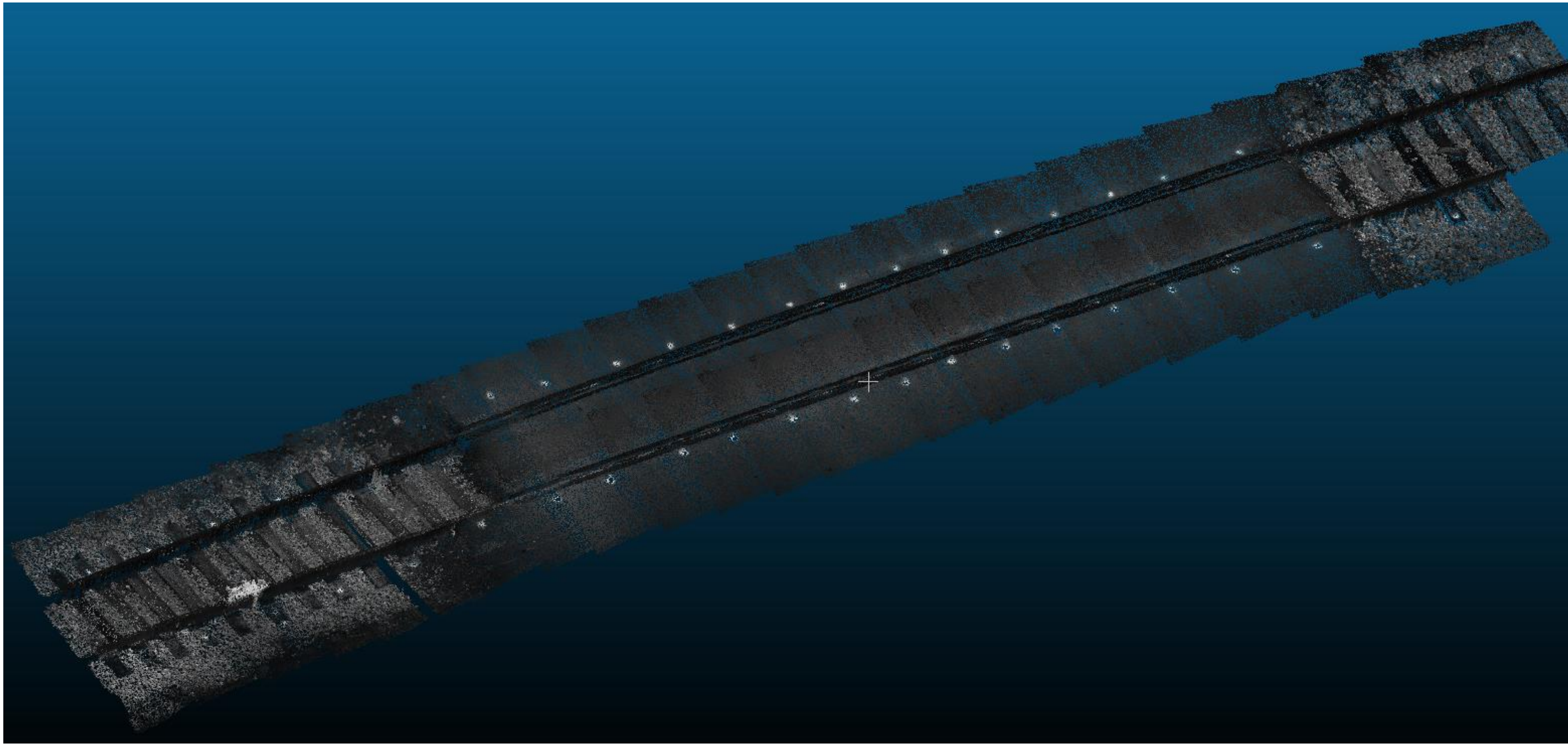
- Developments in computer science
- 3D sensing and imaging technologies
  - LiDAR
  - Photogrammetry
  - Kinect sensor
  - Structured light





Design and Build Data Acquisition System (DAS)

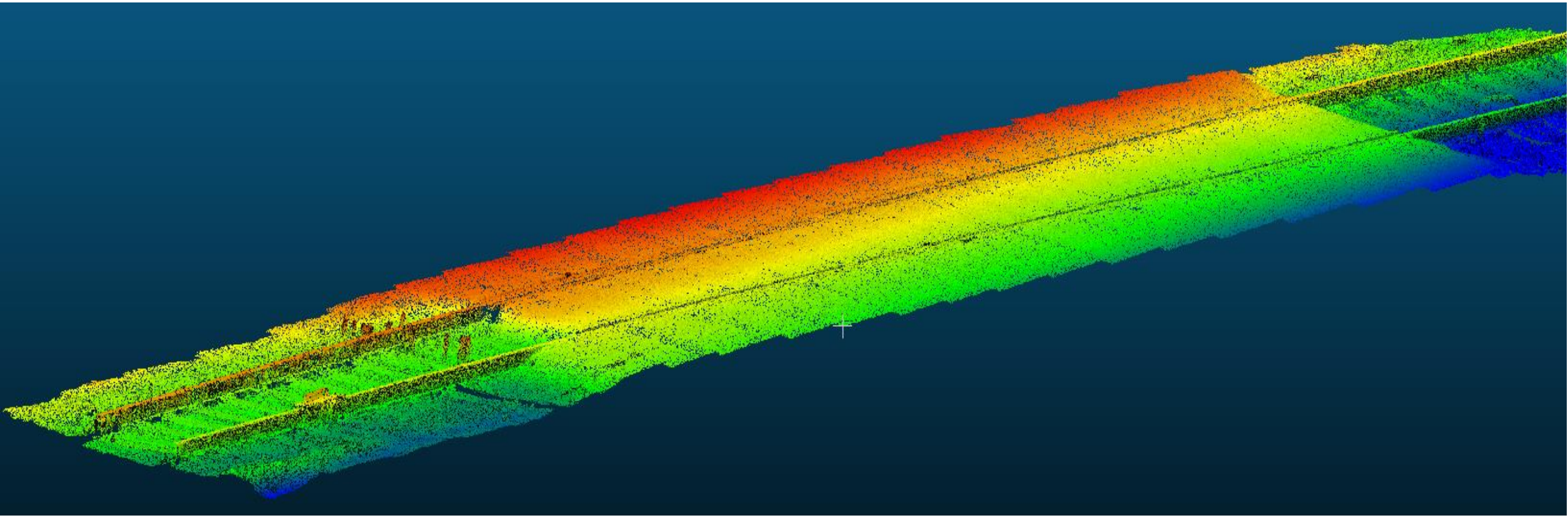




A highway rail crossing surface 3D points cloud

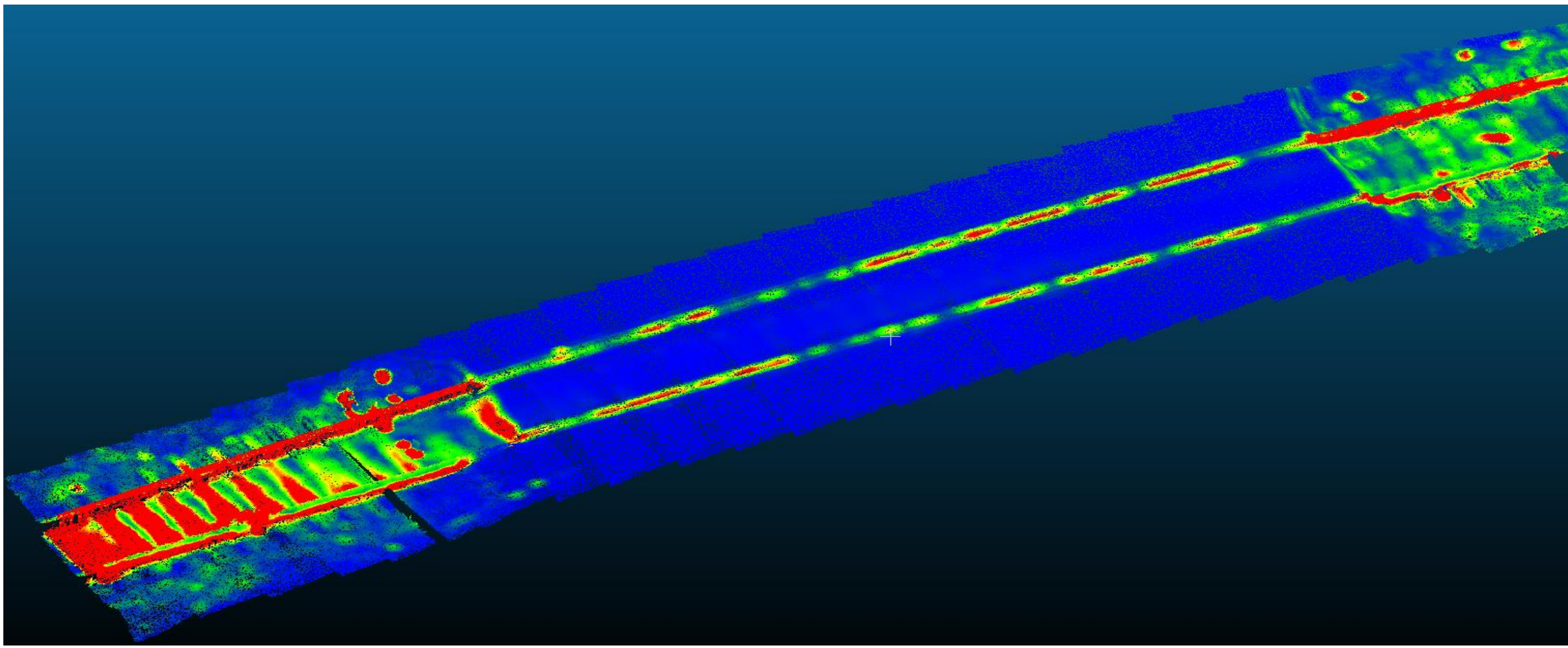
After the all 3D points cloud tiles were merged into one crossing surface, each point had X, Y, Z coordinates recorded (to the nearest millimeter).

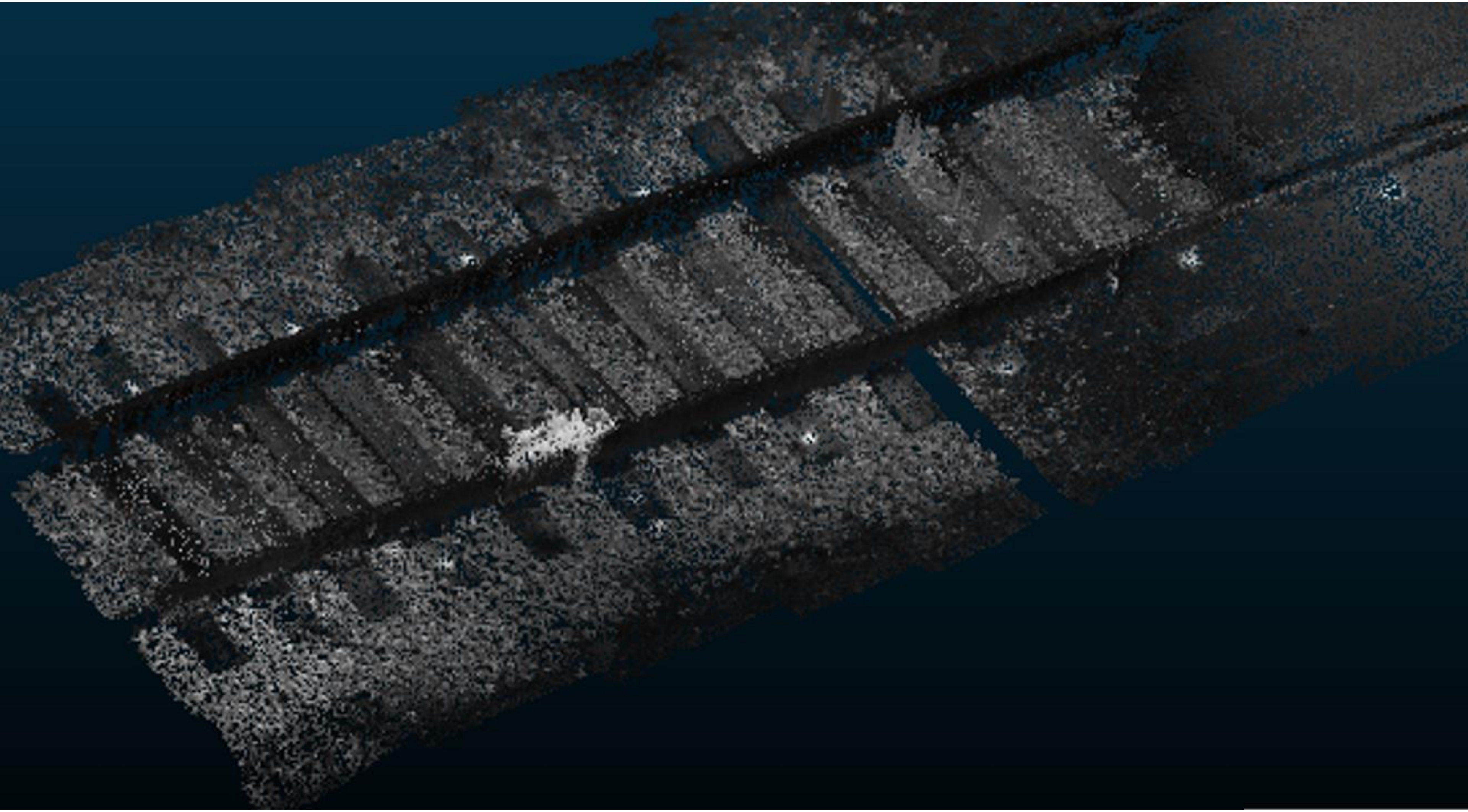
A color coded rendering of the crossing surface elevation is shown here. Blue indicates lower elevation, while Red shows the higher elevations.



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.

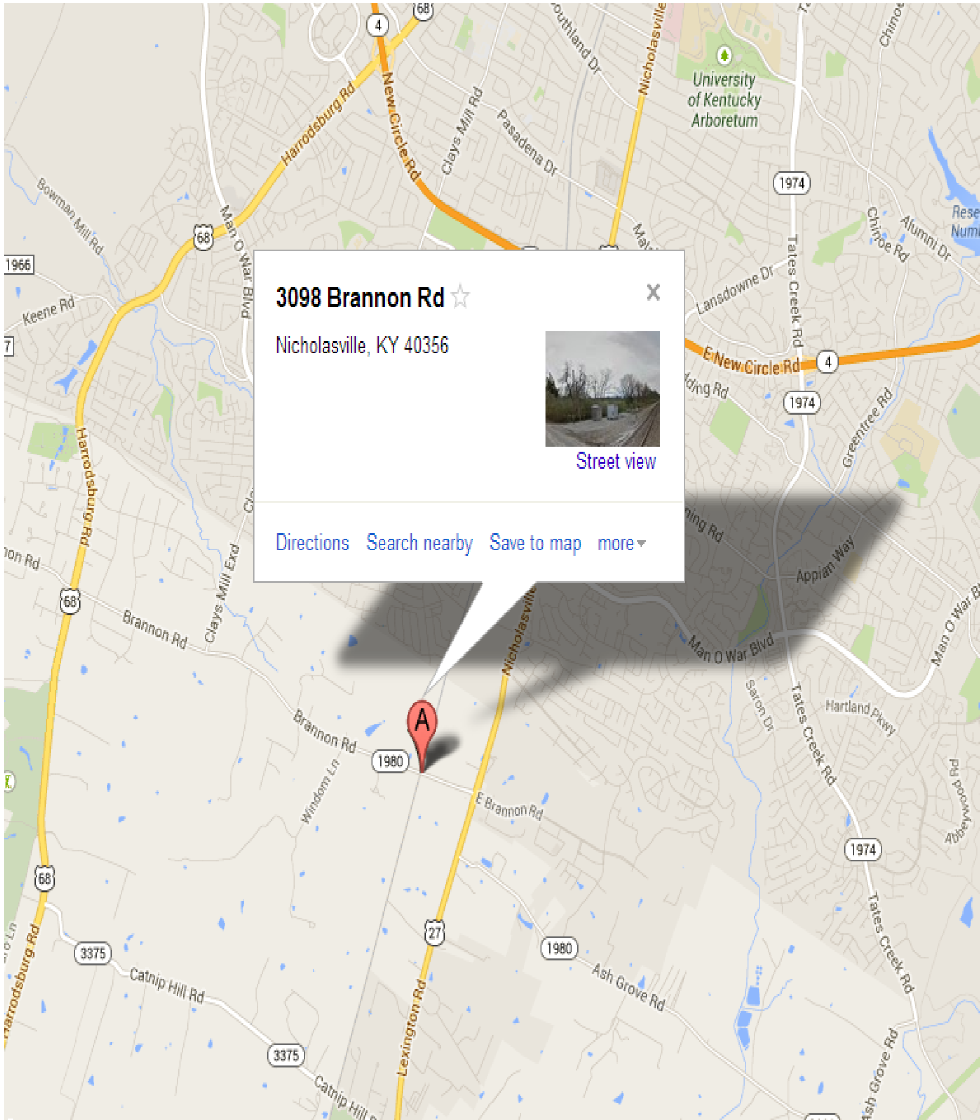




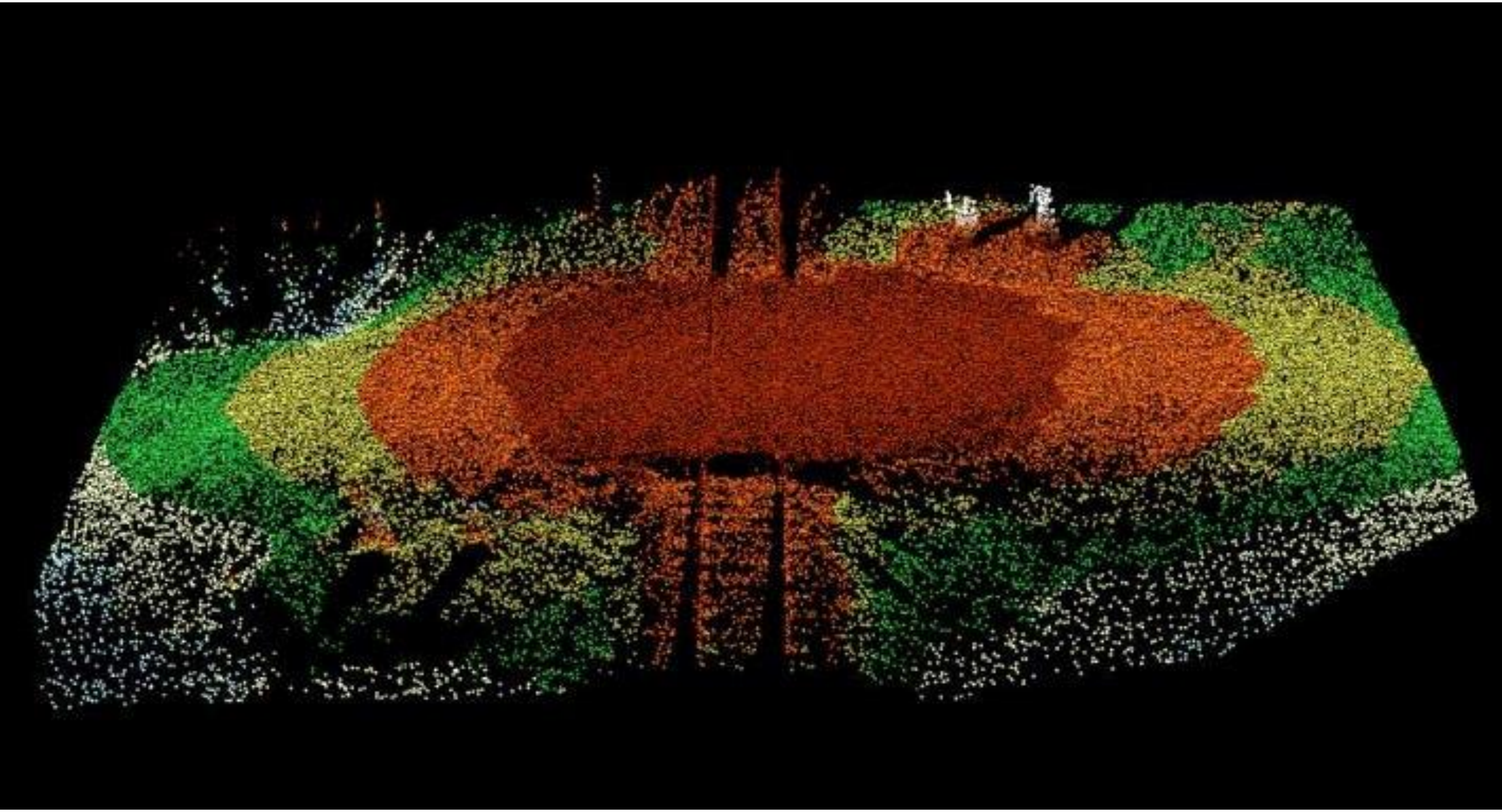
Field Test

Brannon road crossing in Jessamine County, KY (USDOT 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




ROUGH
CROSSING
15
M.P.H.



Measured accelerations (accelerometer)

Field data collection equipment and device:

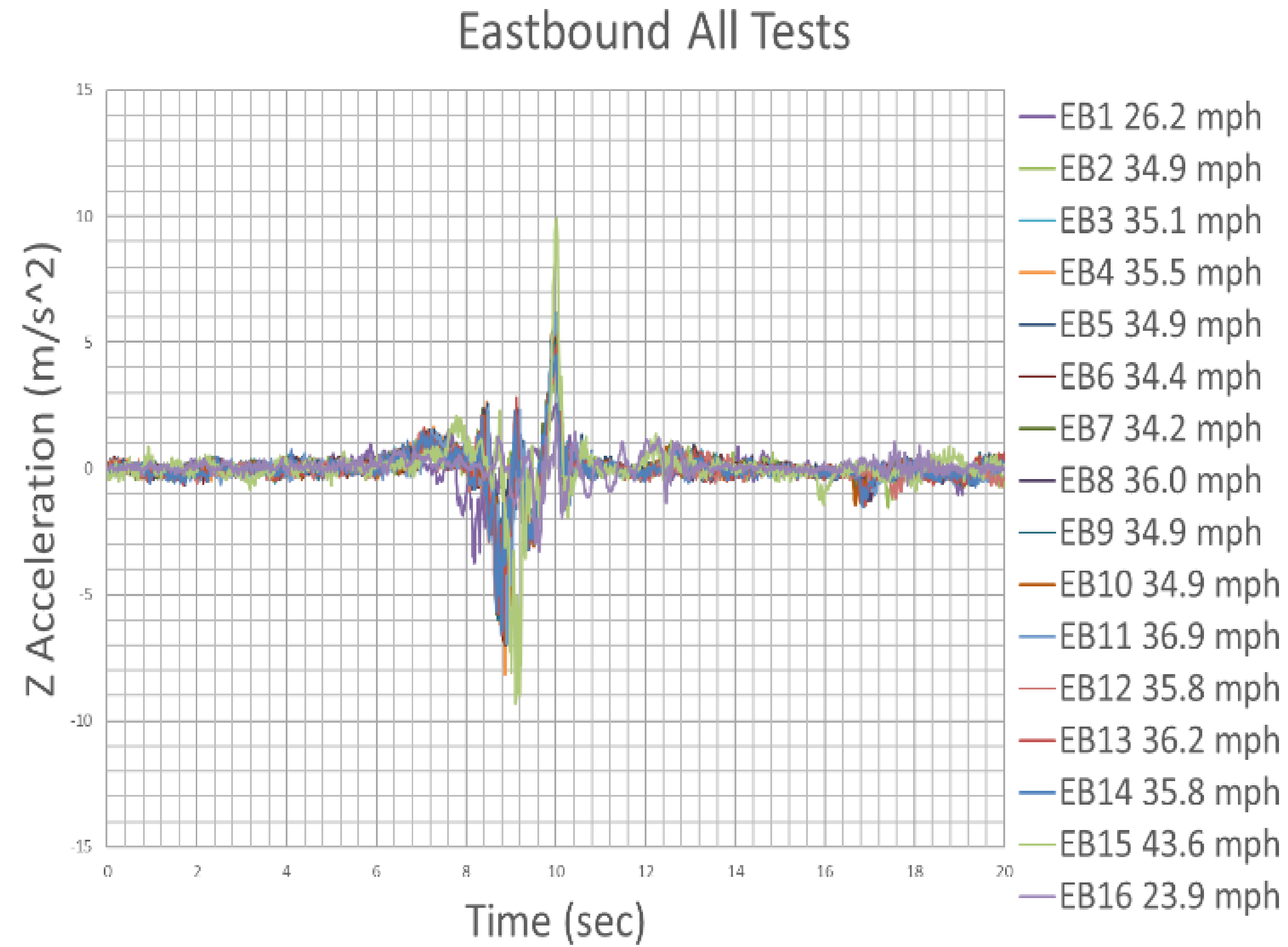
- 2009 Chevrolet Impala sedan
- a real time acceleration sensor records and stores 3 axis (XYZ) acceleration data at 100 hertz with the range of +/- 10 g, accuracy +/- 1% and resolution at 0.010 g
- a laptop PC preloaded with recording software
- a smart phone with built-in A-GPS that records and stores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

Field Data Collection Procedure

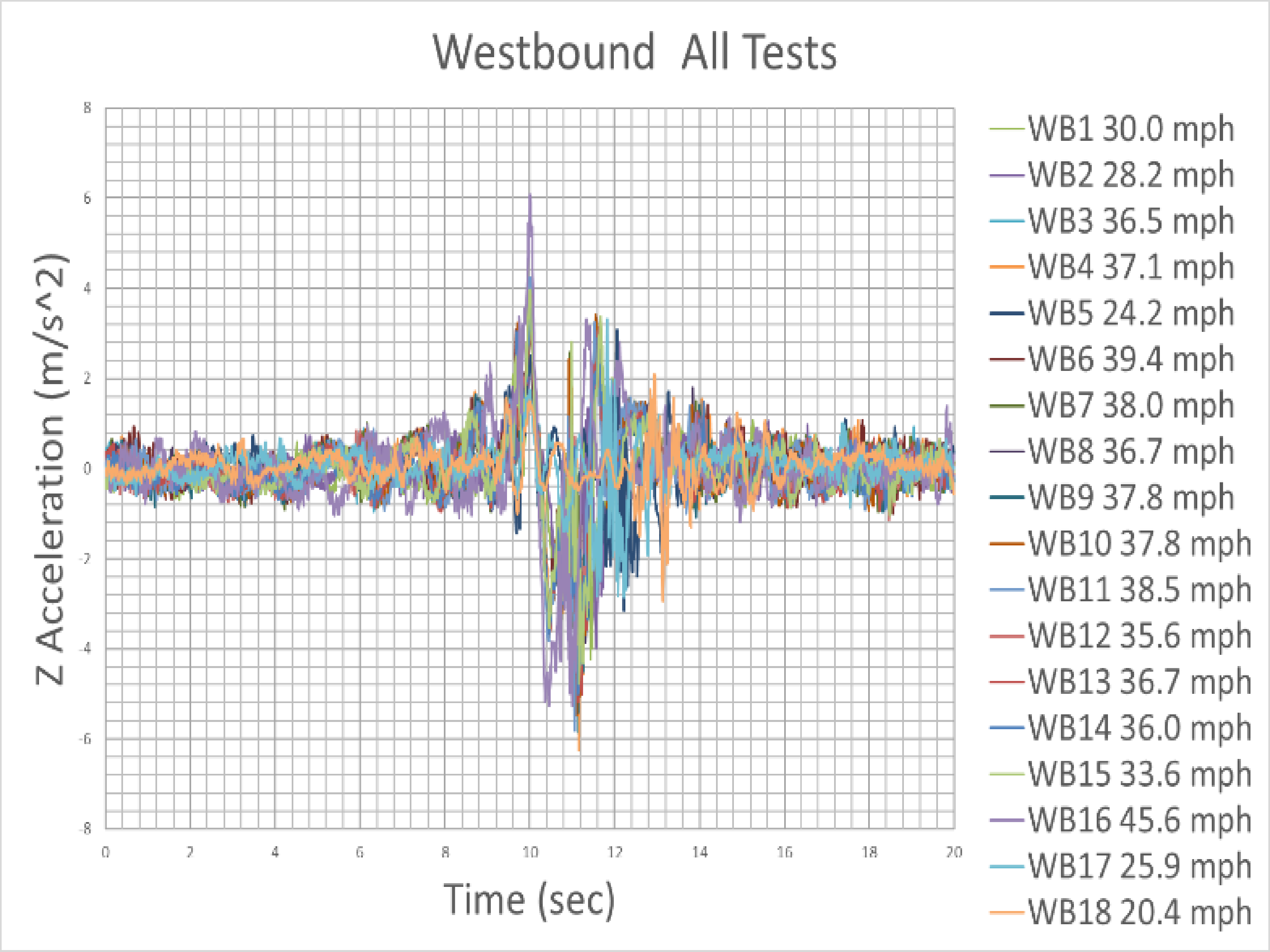
- Close to constant speed at crossing (mostly 35mph)
- Passenger records time at fixed locations before and after the crossing
- Acceleration sensor and GPS kept running during the entire test
- Acceleration data were divided into eastbound and westbound groups
- A few tests run at speeds as low as 15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

Field Data Analysis and Result

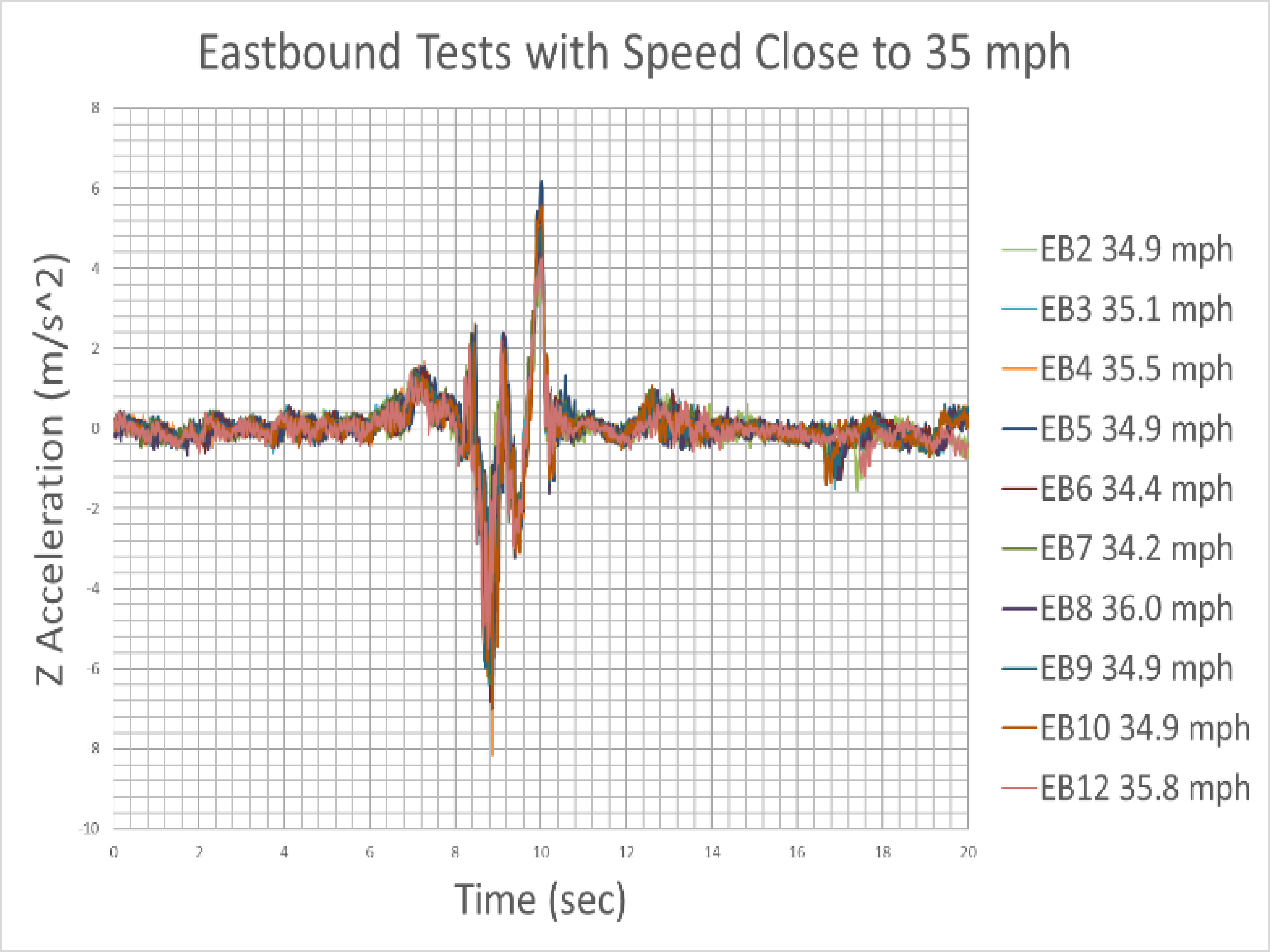
- Acceleration recorded in the Z axis (vertical direction)
- Plotted acceleration vs time
- Approximately 10 seconds before and after the crossing
- Average speed obtained via smart phone GPS (using time stamp)

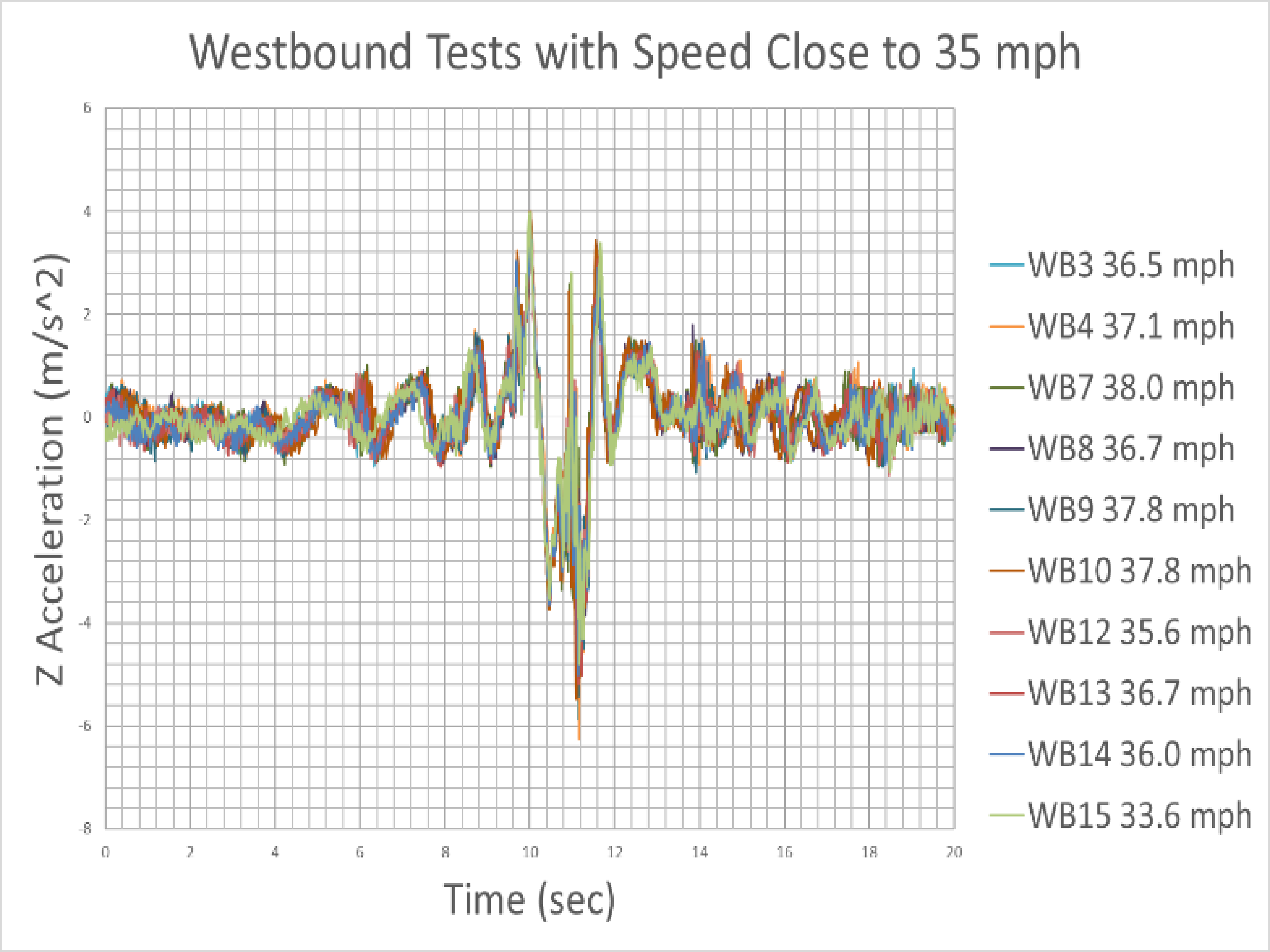


Eastbound All Tests
Z Acceleration (m/s^2)
15
10
5
0
-5
-10
-15
0
2
4
6
8
10
12
14
16
18
20
Time (sec)
EB1 26.2 mph
EB2 34.9 mph
EB3 35.1 mph
EB4 35.5 mph
EB5 34.9 mph
EB6 34.4 mph
EB7 34.2 mph
EB8 36.0 mph
EB9 34.9 mph
EB10 34.9 mph
EB11 36.9 mph
EB12 35.8 mph
EB13 36.2 mph
EB14 35.8 mph
EB15 43.6 mph
EB16 23.9 mph



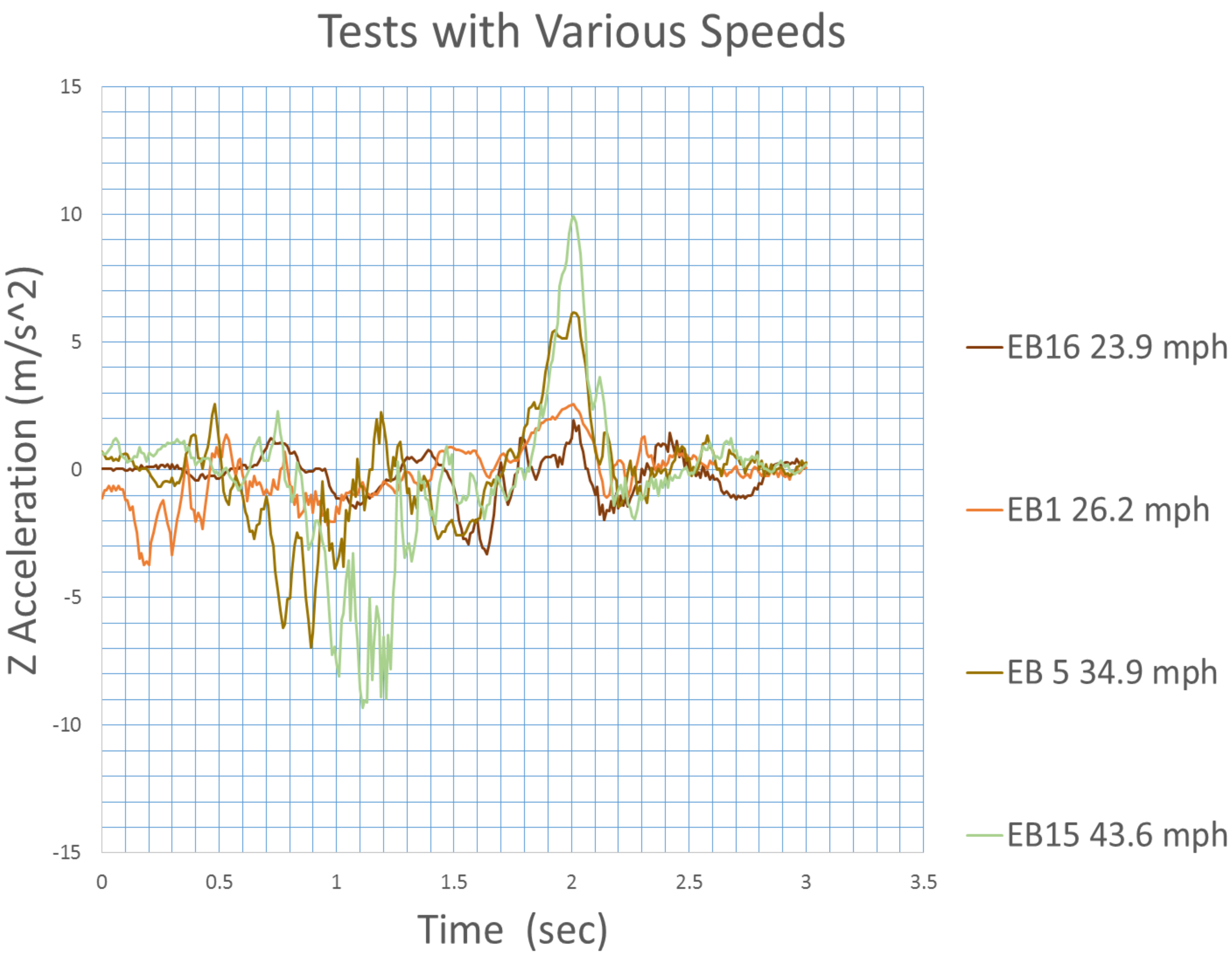
Westbound All Tests
Z Acceleration (m/s^2)
8
6
4
2
0
-2
-4
-6
-8
0
2
4
6
8
10
12
14
16
18
20
Time (sec)
WB1 30.0 mph
WB2 28.2 mph
WB3 36.5 mph
WB4 37.1 mph
WB5 24.2 mph
WB6 39.4 mph
WB7 38.0 mph
WB8 36.7 mph
WB9 37.8 mph
WB10 37.8 mph
WB11 38.5 mph
WB12 35.6 mph
WB13 36.7 mph
WB14 36.0 mph
WB15 33.6 mph
WB16 45.6 mph
WB17 25.9 mph
WB18 20.4 mph


Eastbound Tests with Speed Close to 35 mph
Z Acceleration (m/s^2)
Time (sec)
8
6
4
2
0
-2
-4
-6
-8
-10
0
2
4
6
8
10
12
14
16
18
20
EB2 34.9 mph
EB3 35.1 mph
EB4 35.5 mph
EB5 34.9 mph
EB6 34.4 mph
EB7 34.2 mph
EB8 36.0 mph
EB9 34.9 mph
EB10 34.9 mph
EB12 35.8 mph



Westbound Tests with Speed Close to 35 mph
Z Acceleration (m/s^2)
6
4
2
0
-2
-4
-6
-8
0
2
4
6
8
10
12
14
16
18
20
Time (sec)
WB3 36.5 mph
WB4 37.1 mph
WB7 38.0 mph
WB8 36.7 mph
WB9 37.8 mph
WB10 37.8 mph
WB12 35.6 mph
WB13 36.7 mph
WB14 36.0 mph
WB15 33.6 mph

Tests with Speed Close to 35 mph
Z Acceleration (m/s^2)
8
6
4
2
0
-2
-4
-6
-8
0
0.5
1
1.5
2
2.5
3
3.5
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
15
10
5
0
-5
-10
-15
Z Acceleration (m/s^2)
0
0.5
1
1.5
2
2.5
3
3.5
Time (sec)
EB16 23.9 mph
EB1 26.2 mph
EB 5 34.9 mph
EB15 43.6 mph

Field Data Analysis and Result

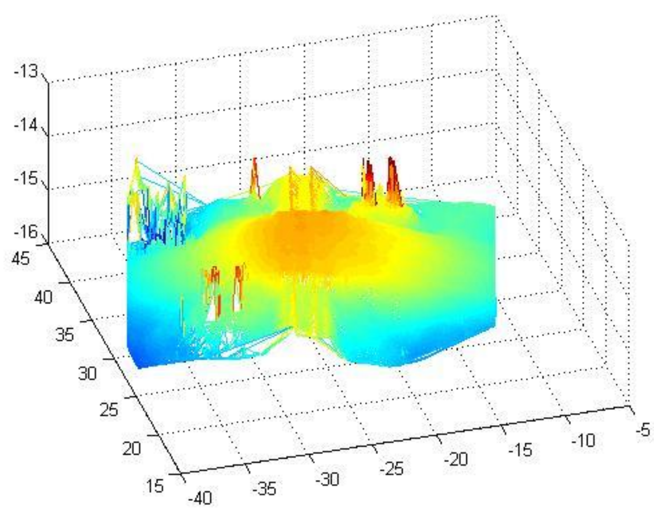
when the test speed is held constant (35 mph), both the frequency and amplitude of acceleration from one test are very close. This indicates that the test is highly repeatable and method is reliable for future work.

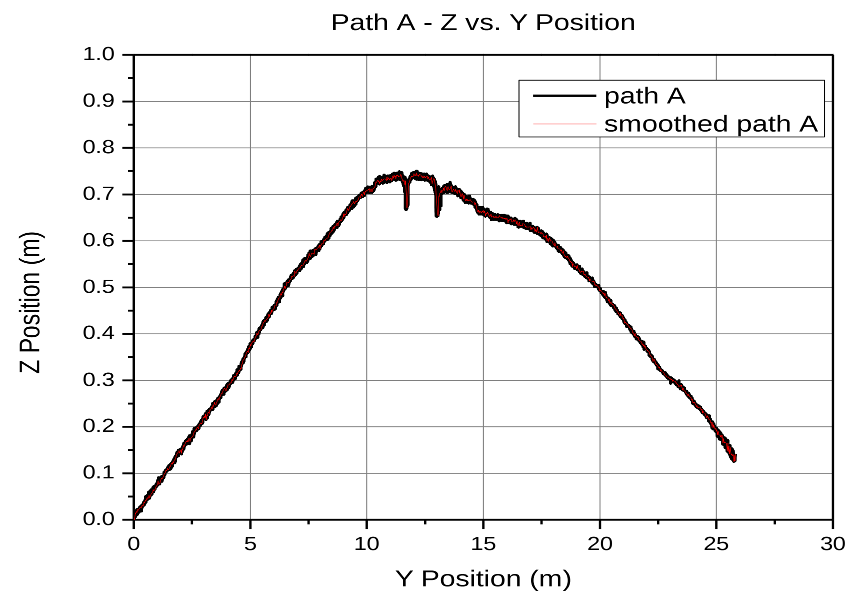
For tests were performed at various speeds, it can be seen that as expected, acceleration amplitudes and frequencies increase with increasing speeds.

Vehicle Dynamic Model

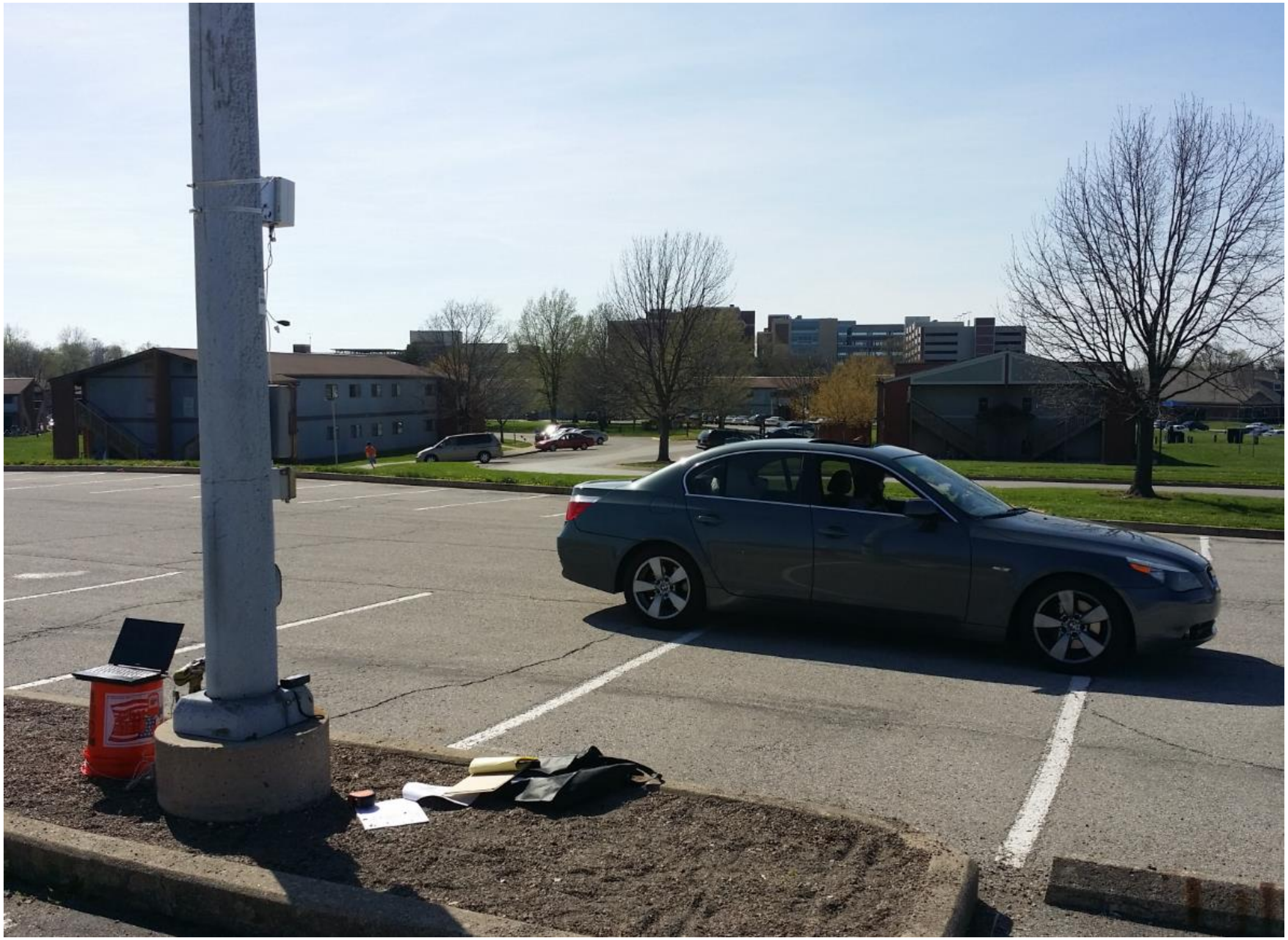
Vehicle Dynamic Model Simulation:

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).

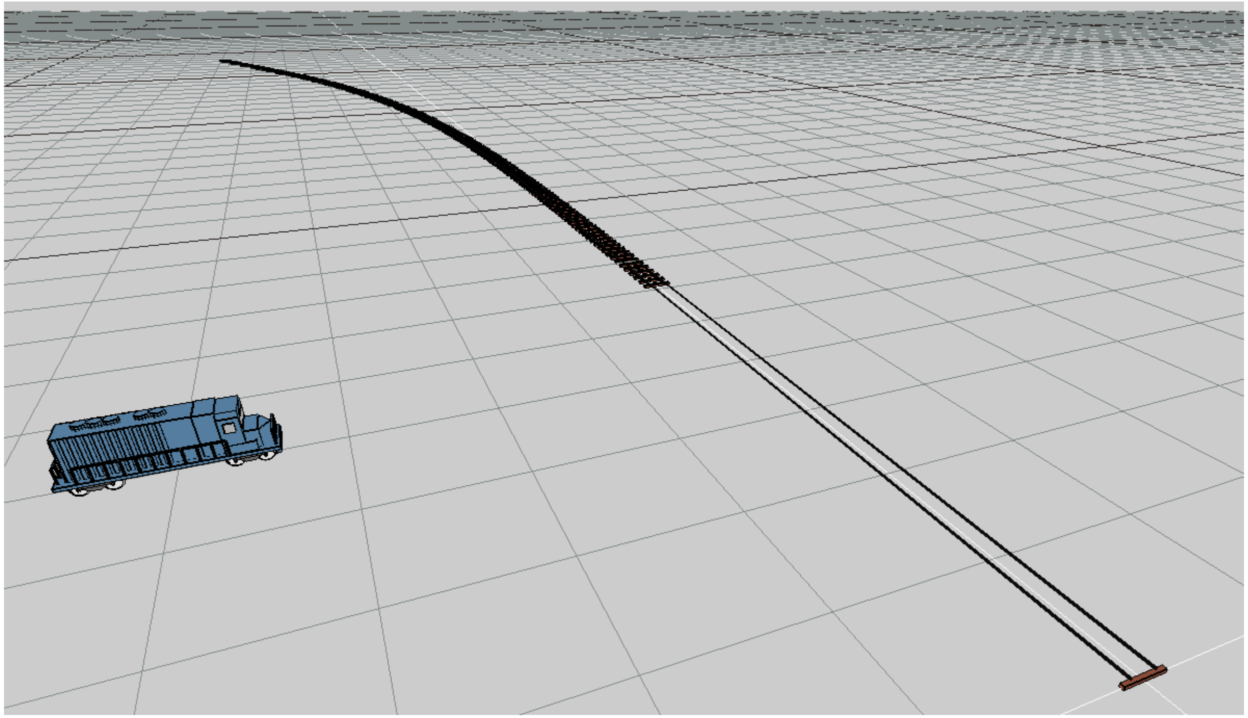


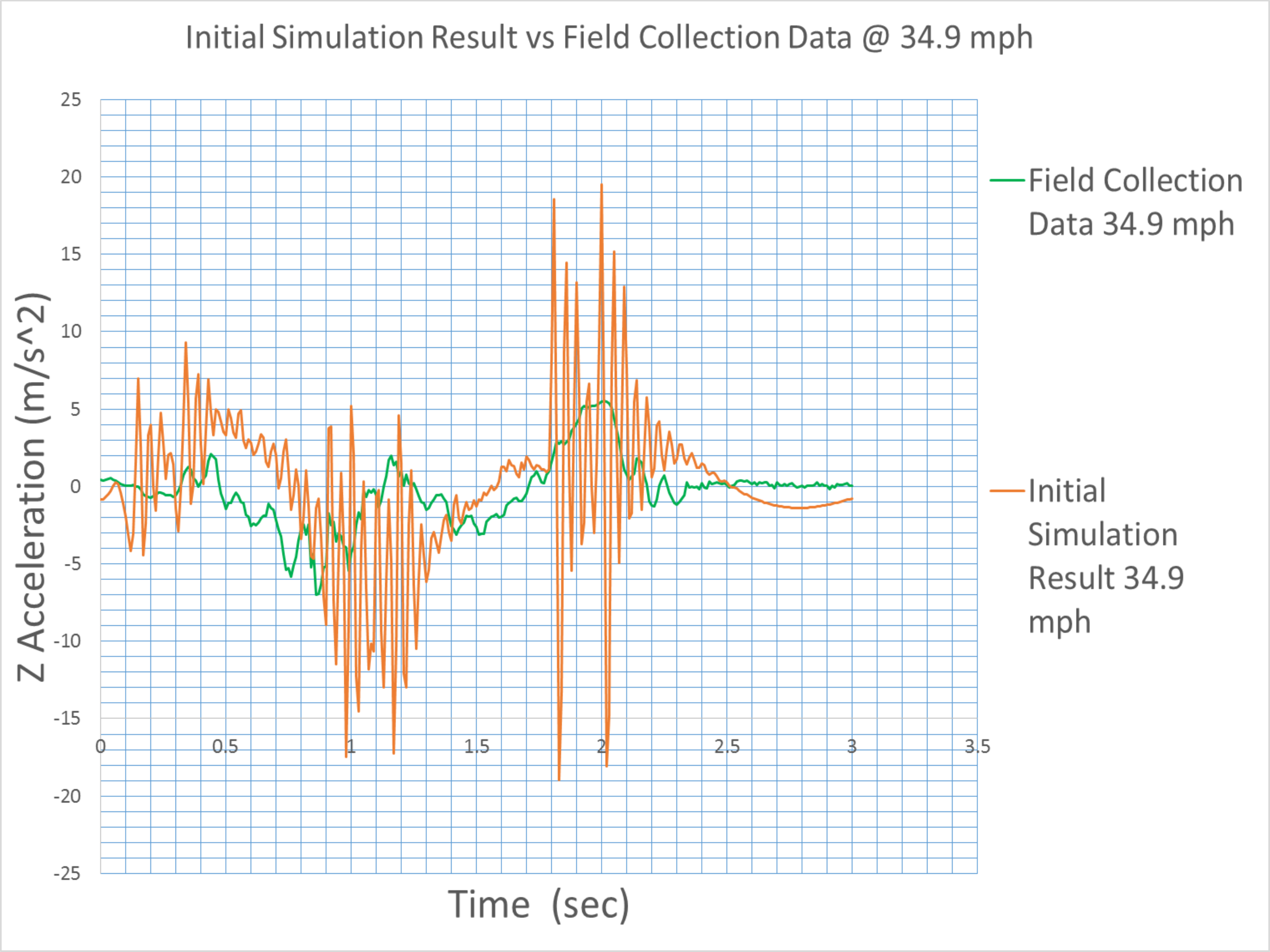


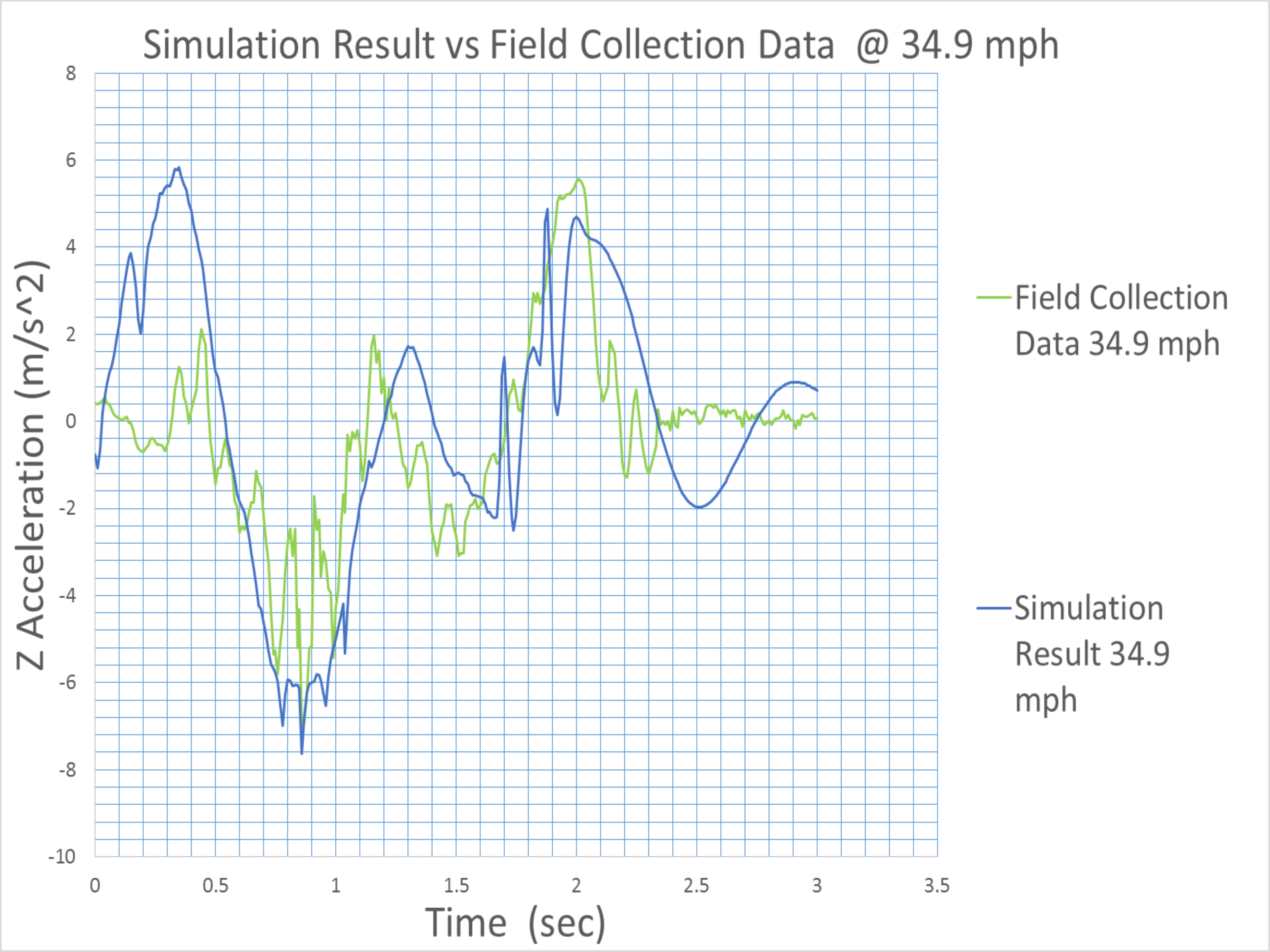
Wheel Path Crossfire Radar



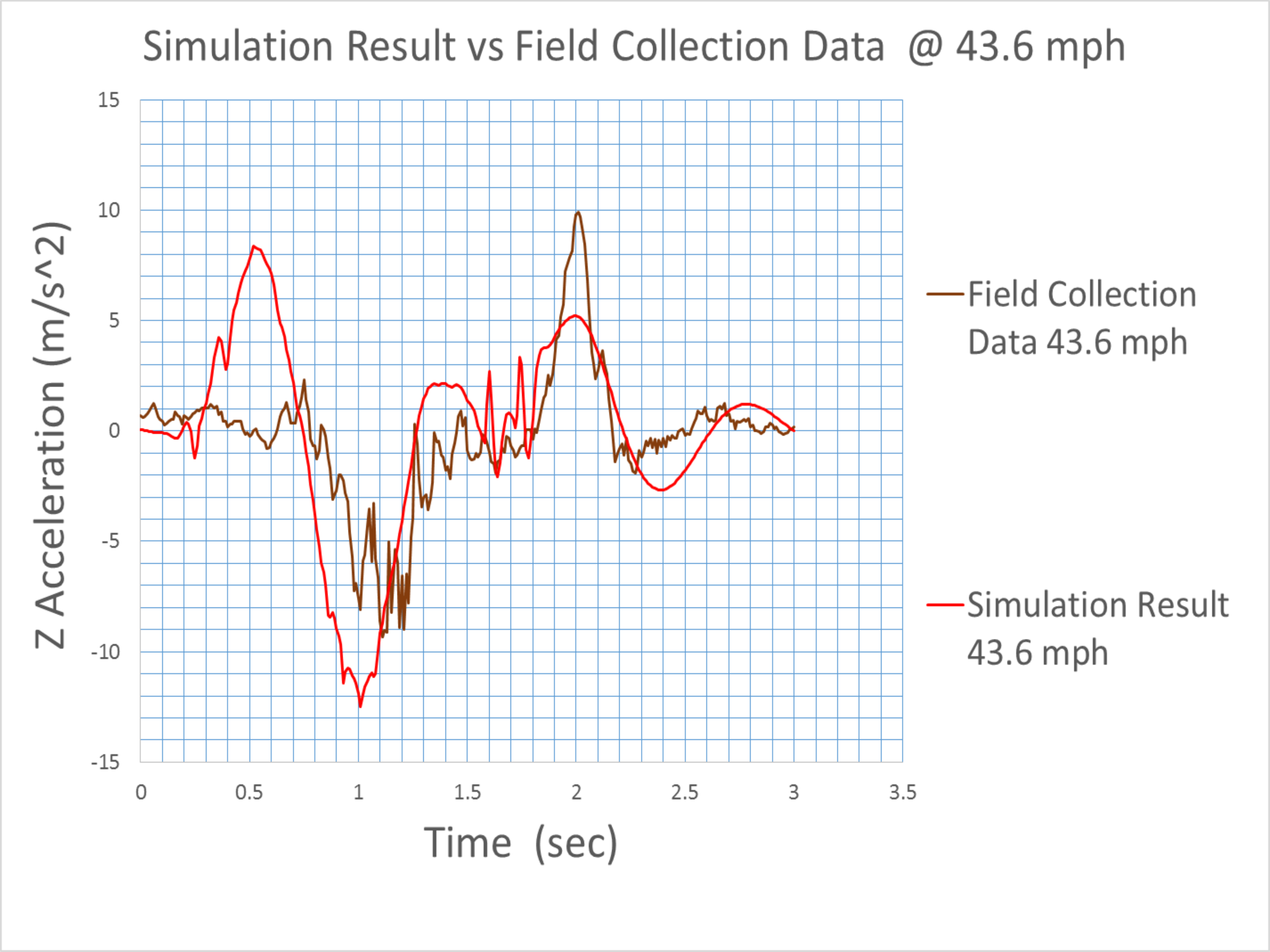
Vehicle Dynamic Model Simulation




Initial Simulation Result vs Field Collection Data @ 34.9 mph
25
20
15
10
5
0
-5
-10
-15
-20
-25
Z Acceleration (m/s^2)
0
0.5
1
1.5
2
2.5
3
3.5
Time (sec)
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)
Time (sec)
8
6
4
2
0
-2
-4
-6
-8
-10
0
0.5
1
1.5
2
2.5
3
3.5
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)
15
10
5
0
-5
-10
-15
0
0.5
1
1.5
2
2.5
3
3.5
Time (sec)
Field Collection Data 43.6 mph
Simulation Result 43.6 mph

Simulation Results Compared to Field Collection Data

Speed	P(A:B) A=field B=simulated	MSE (normalized to maximum acceleration)	MAX(A):MAX(B) in m/s^2	MIN(A):MIN(B) in m/s^2
23.9 mph	0.44	0.34	1.96:4.27	-3.29:-3.51
26.2 mph	0.65	0.20	2.58:4.72	-3.74:-3.68
34.9 mph	0.93	0.16	5.56:5.84	-7.00:-7.64
43.6 mph	0.93	0.16	9.92:8.36	-9.32:-12.51

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

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!