Cross Slope Collection using Mobile Lidar

ACEC/SCDOT Annual Meeting

December 2, 2015

SCDOT
South Carolina Department of Transportation

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Introduction

Adequate cross slopes on South Carolina Interstates result in:

- Proper drainage
- Enhance driver safety by reducing the potential for hydroplaning.

SCDOT is seeking to have an ***efficient*** method for collecting interstate cross slope data so that an accurate and comprehensive cross slope database can be maintained.

Mobile Scanning to collect accurate cross slope data on South Carolina interstates.

- ✓ *save over 90% of the cost* on cross-slope verification
- ✓ *reduce four to six months of contract time* for each interstate rehabilitation project.

Research Approach

- Comprehensive technical and economic evaluation of multiple mobile scanning systems in terms of the accuracy and precision of collected cross slope data

- Procedures to calibrate, collect, and process this data.

Project team

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Objectives

1. Perform technical and economic comparisons of the alternative mobile scanning technologies and conventional survey methods for cross slope verification

2. Establish a validation site that contains tangent and curve sections using traditional survey methods that may then be used to qualify mobile scanning vendors;

3. Establish SCDOT guidelines for testing procedures and data delivery for the vendor rodeo and ultimately statewide data collection; and

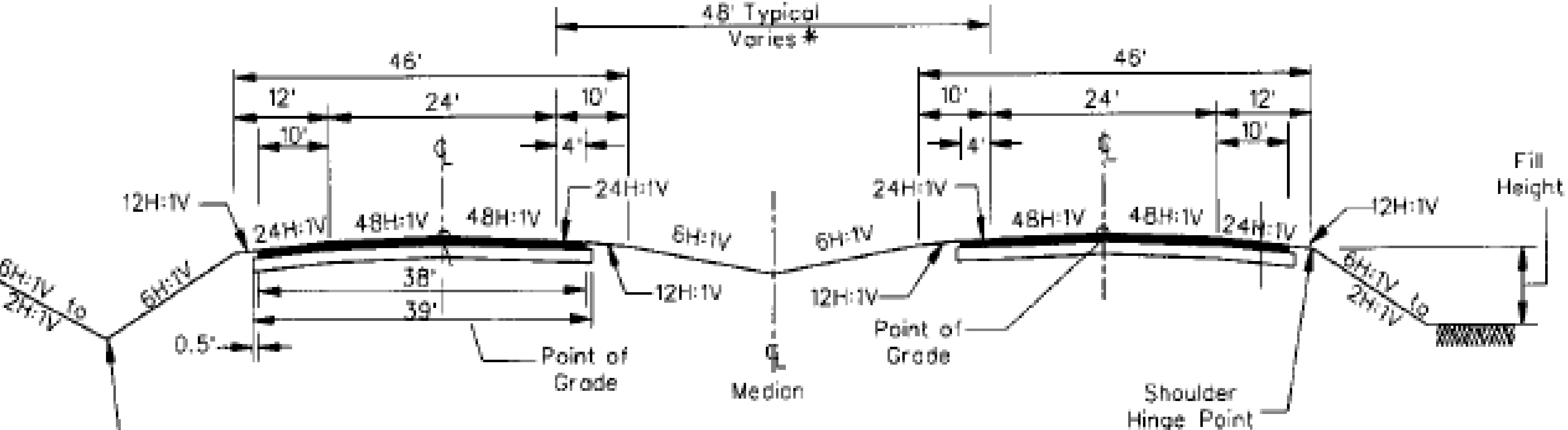
4. Provide a survey of the cross slope and other related geometric properties for the entire interstate system in South Carolina with the selected technology which is suitable for future reference on projects.

Typical Cross-slope

Relatively flat pavement cross-slopes of less than one percent (1%) are prone to creating unacceptable water depths

Cross slopes that are too steep can cause vehicles to drift and become unstable when crossing over the crown to change lanes.

a normal cross slope in South Carolina is 2.08 percent with some exceptions depending on the number of lanes



Hydroplaning

- Hydroplaning is a phenomenon that occurs when a vehicle traveling at high speed basically floats on a film of water covering the roadway.

- When the tires lose contact with the road surface, the vehicle may not be controlled by the driver.

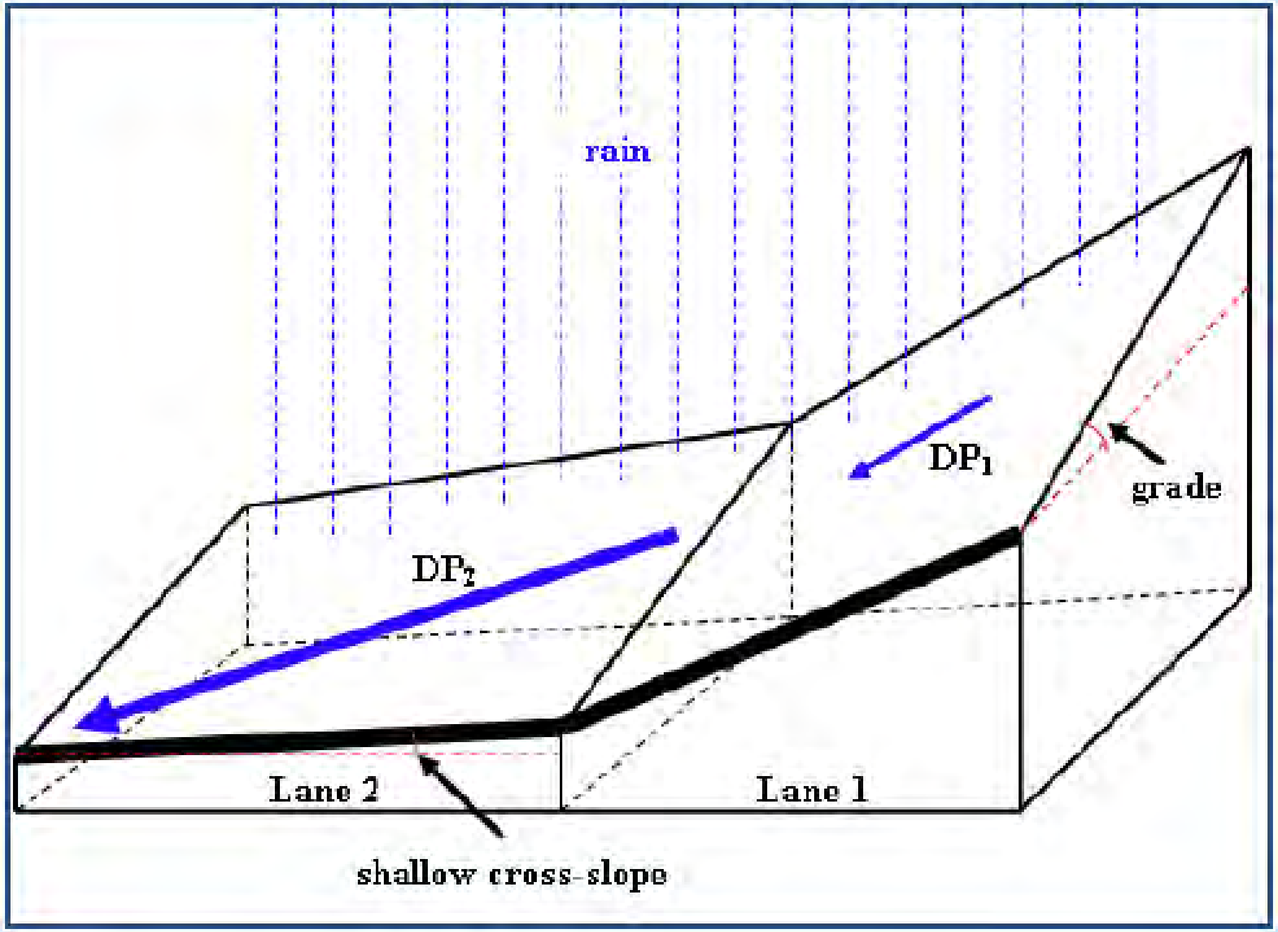
A water depth of 0.15 inches can lead to hydroplaning for a passenger vehicle.

Factors that contribute to hydroplaning:

- Driver
- Vehicle
- Environment
- *Pavement Surface (geometry, condition, drainage)*

- Roadway factors affecting water depth accumulation on the road surface include
  - depth of compacted wheel tracks
  - pavement micro texture
  - pavement macro texture
  - pavement cross-slope
  - Grade
  - width of pavement
  - roadway curvature and longitudinal depressions.

- **Cross Slope**
  Facilitates / hampers drainage
- **Grade**
  Affects drainage path (DP)
- **Rutting**
  Increases water retention



Data Collection Methods

Traditional Survey Methods for Collecting Cross slope

- ✗ Slow and labor intensive
- ✗ Expose crew to hazardous conditions
- ✗ Require traffic control
- ✗ Cause inconvenience to traveling public
- ✗ Costly

Automated Survey Methods

- ✓ Fast (highway speed)
- ✓ Safe (no traffic control required)
- ✓ Efficient (simultaneous data collection)
- ✓ Cost-Effective

SCDOT's cross slope verification specification

The SCDOT's cross slope verification specification is included in the Supplemental Specification updated on November 16, 2009

Contractor is responsible for obtaining the existing cross slope data

- collecting elevation data for the edge of each travel lane
  - Even 100-ft stations in tangents
  - Even 50-ft stations in curves.

Elevation data shall be recorded in accordance with the *SCDOT Preconstruction Survey Manual* (2012) to the nearest **0.01 ft**.

SCDOT's cross slope verification specification

The elevation data shall be collected at the edge of each travel lane at

1. minimum of one random location every 300 ft. in tangent sections

2. beginning and end of super elevation, flat cross slopes within the super elevation transition, and beginning and end of maximum super elevation

3. cross slopes at beginning and end of bridges.

SCDOT's cross slope verification specification

The SCDOT has two acceptable tolerance levels for cross slopes:

- ✓ **Tolerance Level 1**: ± 0.00174 ft/ft (± ¼ in over 12 ft or ± 0.174%) of the design cross slope
- ✓ **Tolerance Level 2**: ± 0.00348 ft/ft (± ½ in over 12 ft or ± 0.348%) of the design cross slope

When final measurements is :

- Within Tolerance Level1: no pay adjustments for the work.
- Outside of Tolerance Level 1: either corrective measures may be required at the contractor's expense or a pay reduction will be assessed to the work.
- outside of Tolerance Level 2: the work will either be corrected at the contractor's expense or work will be subject to a pay reduction

These guide specifications provide a template that can be adopted by state DOTs when developing or modifying their pavement performance specification documents.

the SHRP2 guide specification includes a target value of ***± 0.2% of the design value*** for the final measurement after project completion.

AASHTO Transverse Profile Measurement Standard of Practice

AASHTO PP70-10 recommend the following minimums:

- Interval between transverse profiles
    - <10-ft for network-level collection
    - <1.5-ft for project-level collection.

- The transverse profile width
    - >13-ft for distress detection
    - >14-ft if edge drop-off is desired.

- The data points in the transverse profile are to be no more than 0.4-in apart.
- The resolution of the vertical measurements is to be no greater than 0.04-in

Other states cross slope verification specification

The cross slope specifications in many states are similar to those of the SCDOT with most having a single tolerance level of approximately 0.2% from the design cross slope. While the specifications may be similar, the methods used to measure the cross slope do vary.

State	Method	Frequency	Tolerance
Florida	Electronic level with a length of 4-ft and accuracy of 0.1°	Tangents: 100-ft Superelevation: 100-ft	± 0.2% (average deviation) and ± 0.4% (individual deviation) for tangent and superelevation
Alabama	Straight edge 10-ft long	Not specified	± 0.3% for tangents and superelevations

Automated Survey Methods

Typical Components

Position and Orientation System (POS)

- Differential Global Positioning System (DGPS)
- Inertial Measurement Unit (IMU)
- Distance Measurement Indicator (DMI)
- POS Computer

Inertial Measurement Unit (IMU)

- Generates tilt, roll and yaw data
- 3 accelerometers
- 3 gyroscopes

Distance Measuring Indicator (DMI)

- Linear distance referencing

POS Computer

- **Data storage and processing**

Stand Alone Gyroscope System

Vehicle mounted subsystem that utilizes a combination of gyroscopes that record vehicle pitch, roll, and heading at traffic speeds. The data collected from the gyroscopes can be interpreted by accompanying software to determine pavement cross slope at approximately 13-ft intervals.

Other systems combine sensitive gyroscopes and accelerometers to collect precise vehicle roll data. When this data is coupled with GPS and a supplemental distance measurement system, the transverse profile data can be used to determine the pavement cross slope at rod and level accuracy.

Benefits

1. SCDOT saves millions of dollars on interstate rehabilitation projects by adopting the mobile scanning technology instead of conventional surveying

2. ***Preconstruction*** – could accurately estimate material quantities for potential interstate rehabilitation

3. ***Construction*** – reduces potential disagreement between contractors and the Department

4. ***Finance*** – better cash flow projection with more accurate material quantities and project duration

5. ***Surveyor*** – no longer needs to step into interstate traffic

6. ***Legal/Contracts*** - reduce the risk of tort liabilities of SCDOT arising from non-standard cross-slopes

7. ***All*** - Provides data for other uses such as safety analysis, drainage modeling, pavement design

Additional Literature

Multi-Purpose Survey Vehicle (MPSV)

- Inertial Profiling System
- Position and Orientation System (POS)

Inertial Profiling System

- Three height laser sensors
- Two accelerometers
- Distance Measurement Indicator (DMI)
- Automatic Trigger System

http://aii.transportation.org/Documents/PaveSuite/acdp-presentation.pdf

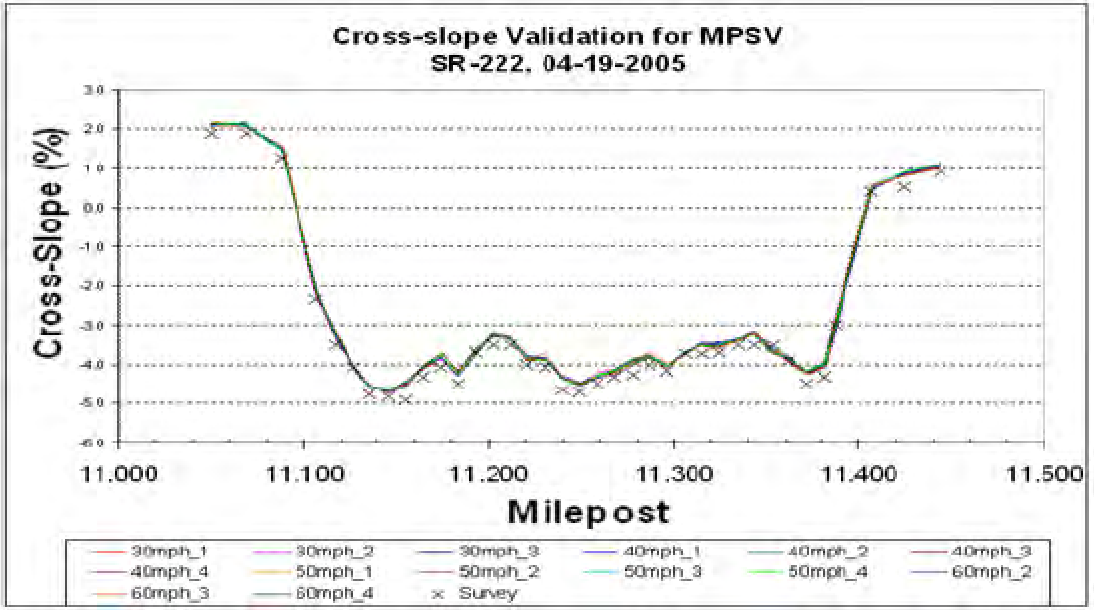
Automated Cross-Slope Analysis Program (ACAP)

- Imports MPSV data
- Calculates cross-slope, grade, rutting, distance)
- Calculates drainage path length
- Generates outputs (tabular and graphical)

http://aii.transportation.org/Documents/PaveSuite/acdp-presentation.pdf

MPSV Cross-Slope Precision

- Repeatability: 0.06%
- Accuracy: ± 0.13 %



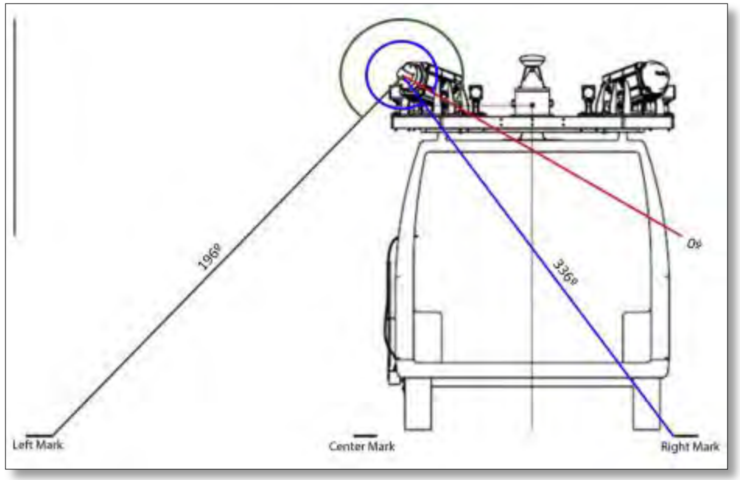
Short-Term Preventive Action

Short-Term Preventive Action

Short-Term Solution

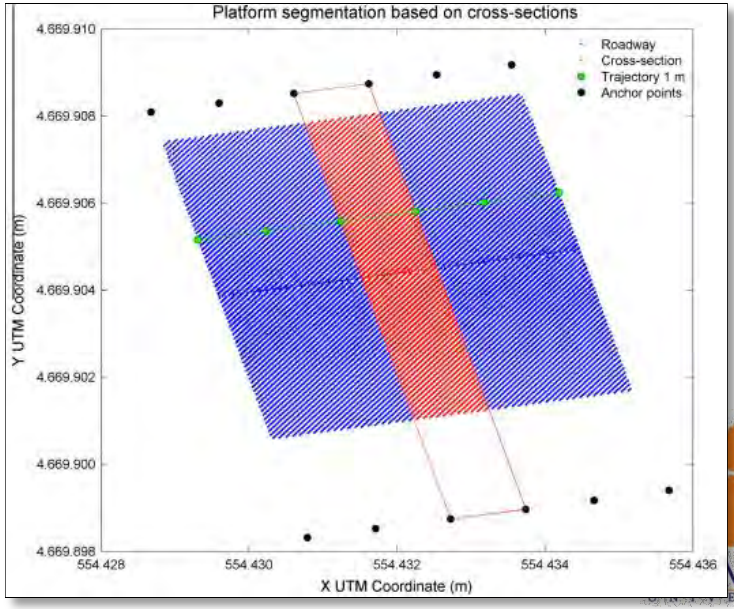
Holgado-Barco et.al. (2014)

Holgado-Barco et.al. (2014) extracted road geometric parameter through the automatic processing of mobile LIDAR system (MLS) point cloud.



Their methodology was carried out in different steps.

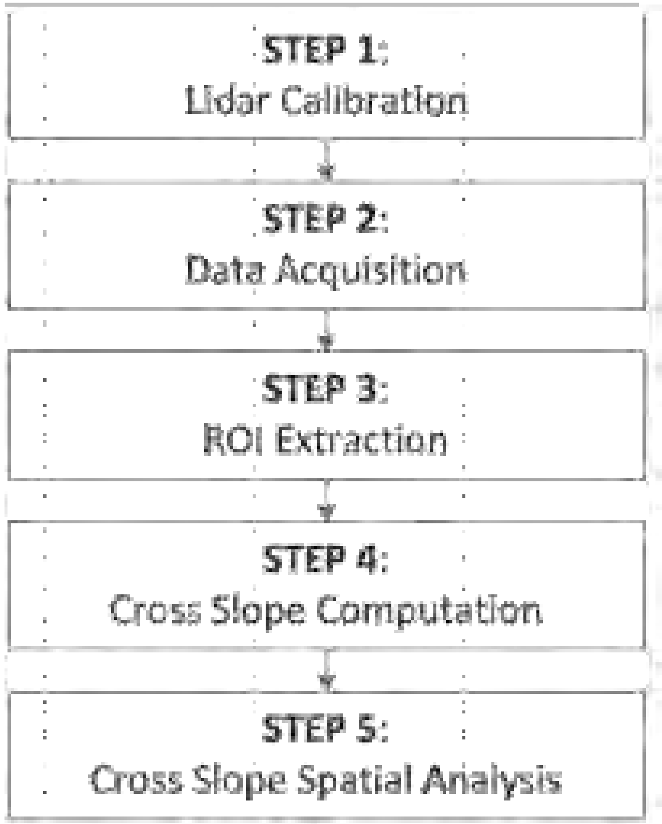
1. data capturing.
2. segmentation, which is to simplify the point cloud to extract the road platform.
3. Applying principal component analysis (PCA)-based on orthogonal regression to fit the best plane on points.
4. extracting vertical and cross section geometric parameter and analysis.



The experiment results validate the method within relative accuracies under 3.5%

Tsai et.al. (2013)

Tsai et.al. (2013) proposed mobile cross slope measurement method, which used emerging mobile LIDAR technology.



The proposed method instruments :

✓ Emerging mobile LIDAR system

- (Reigl LMS-Q 120i)

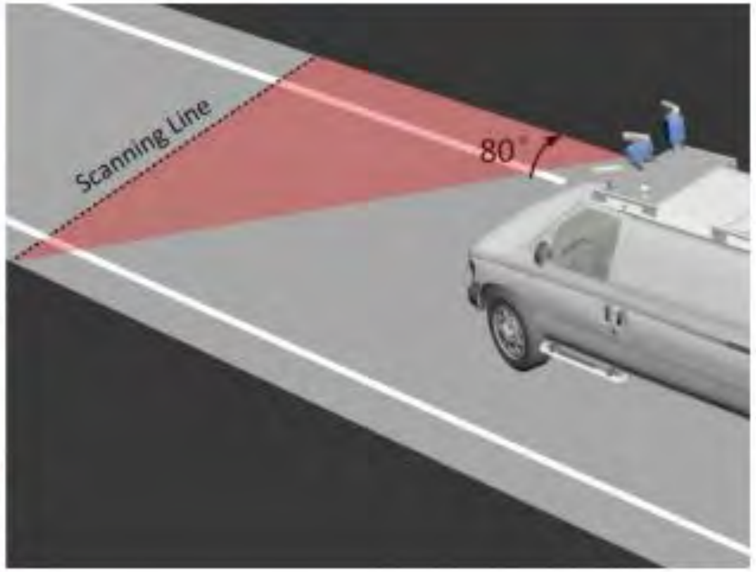
✓ High resolution video camera

- (Point Grey Gras-50S5C)

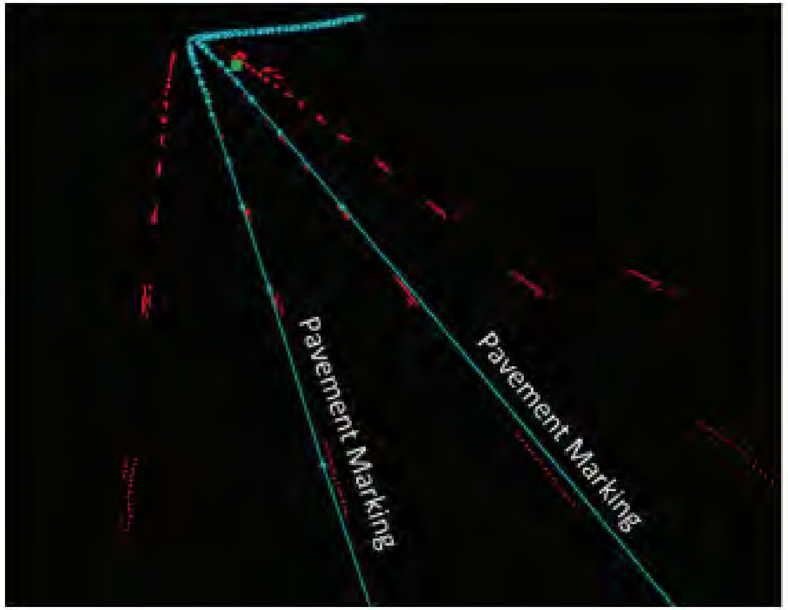
✓ Accurate positioning system

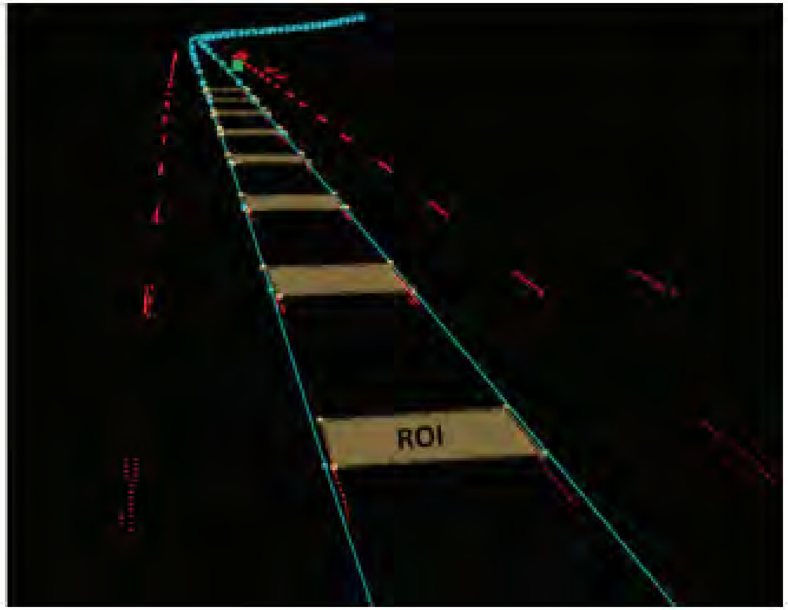
- (Applanix LV 210PP) composed of Global Positioning System (GPS), an inertial measurement unit, and distance measurement instrument.

Tsai et.al. (2013)



Data Acquisition with LIDAR





Region of Interest Extraction

Tsai et.al. (2013)

The results showed the proposed method achieved desirable accuracy

- ✓ Maximum difference of ***0.28% cross slope (0.17°)***
- ✓ Average difference of ***less than 0.13% cross slope (0.08°)*** from the digital auto level measurement.
- ✓ Standard deviations within ***0.05% (0.03°)*** at 15 benchmarked locations in three runs.

The acceptable accuracy is typically 0.2% (or 0.1°) during construction quality control.

The case study on **I-285** demonstrated that the proposed method can efficiently conduct network-level analysis. The GIS-based cross slope measurement map of the **3-miles section** of studied roadway ***can be derived in fewer than 2 person hours*** with use of the collected raw LIDAR data

Front pointing laser is multi-purpose

Sourleyrette et al. (2003)

Sourleyrette et al. (2003) attempted to collect grade and cross slope from LIDAR data on tangent highway sections.

The measurements were compared against autolevel data collection for ***10 test sections along Iowa Highway 1***.

The physical boundaries of shoulders and lanes were determined by visual inspection from

(a) 6-in resolution ortho-photos

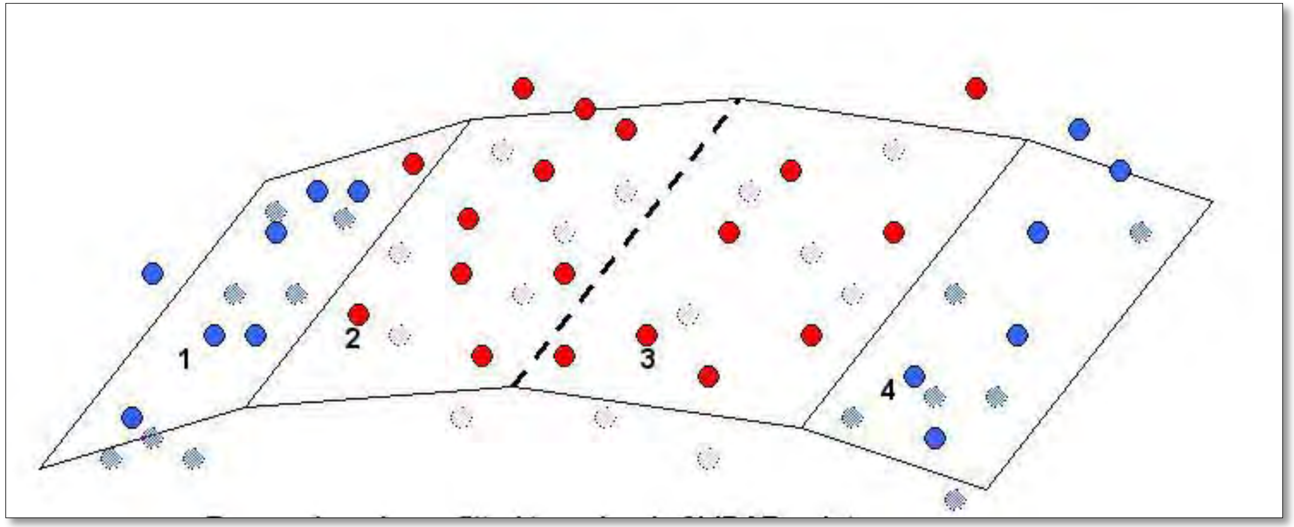
(b) 12-in ortho-photo by Iowa DOT

(c) triangular irregular network (TIN) from LIDAR.

Sourleyrette et al. (2003)

Multi linear regression analysis was taken to fit the plane to the LIDAR data corresponded to each analysis section.

- Grade on pavement surface was calculated to within 0.5% for most sections, and within 0.87% for all sections.



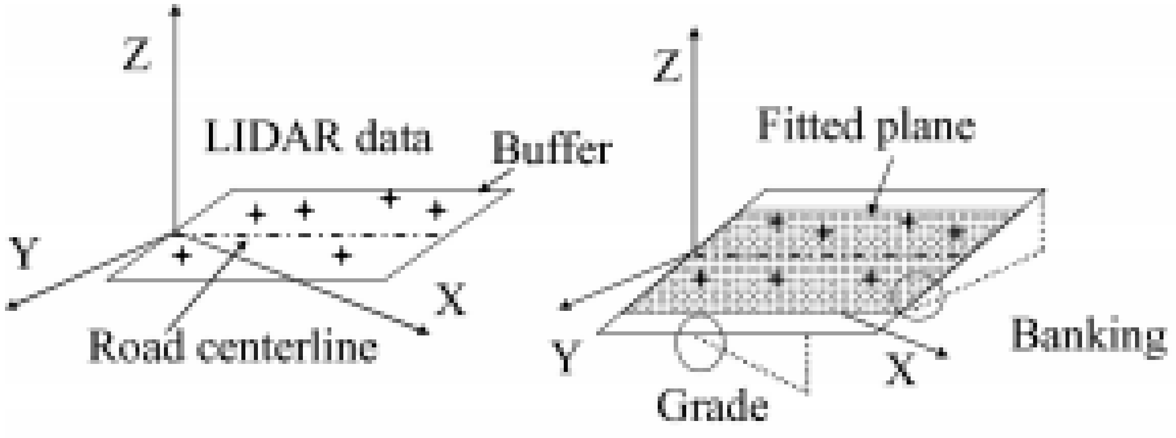
Regression planes fit to the LIDAR point cloud for each of the four analysis sections defined for each test segment

- On shoulder sections, grade was calculated within 1% of the surveyed value.
- Cross slope estimation from LIDAR was deviated from field measurement by 0.72% to 1.65%. model.

Zhang and Frey (2012)

Zhang and Frey (2012) tried to model the road grade using LIDAR to estimate the vehicles emissions.

- The LIDAR data have been used to fit a plane using regression techniques.
- The pilot case study was divided in different segments, which slope is constant.
- A plane fit to the roadway surface on each roadway section using bivariate linear regression.

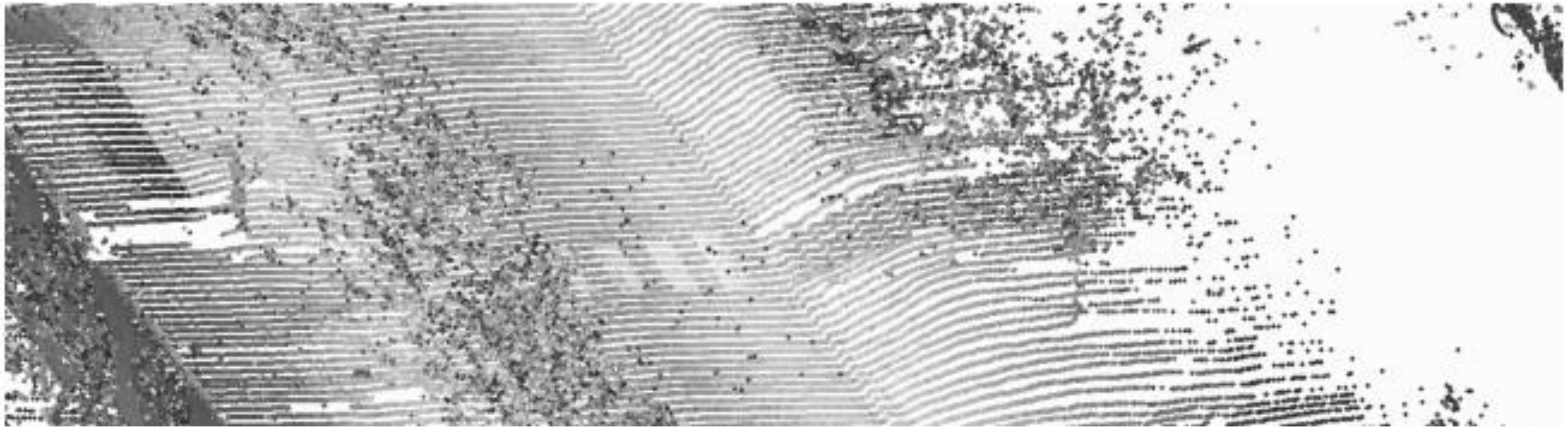


(a) Selection of LIDAR Data for Analysis (b) Estimation of road grade and banking

Jaakkola et al. (2008)

Jaakkola et al. (2008) discussed that laser-based mobile mapping is necessary for transportation study due to the huge amount of data produced.

- The data was collected with the Finnish Geodetic Institute (FGI) Roamer mobile mapping system (MMS).



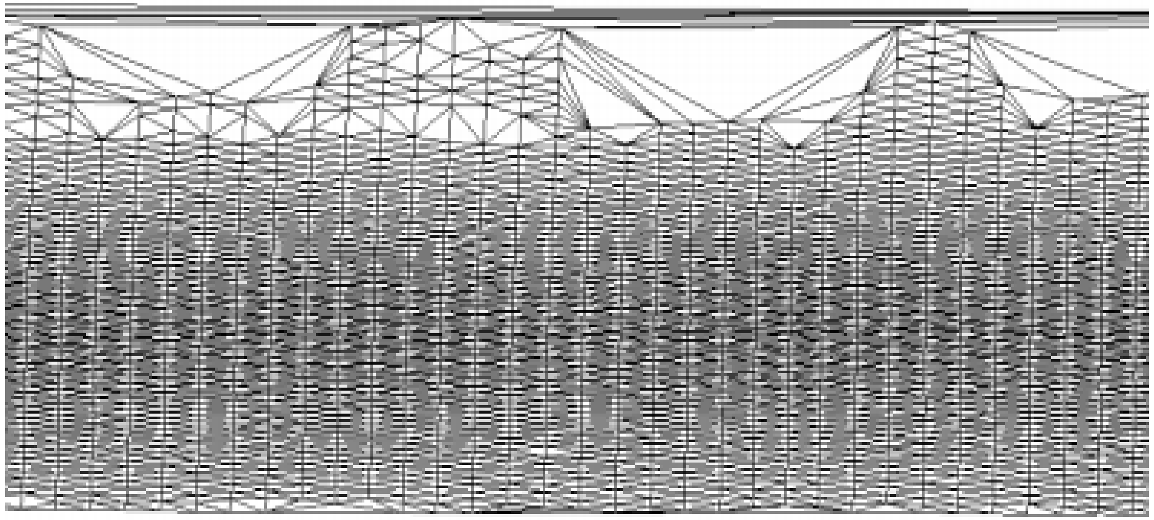
Part of the point cloud

Jaakkola et al. (2008)

The authors classified the points belonging to the painted marking on the road, then they found the curbstones from the height of the image.

Finally, they modeled the pavement as a TIN.

The proposed method was able to find most curbstones, parking spaces, and zebra crossing.



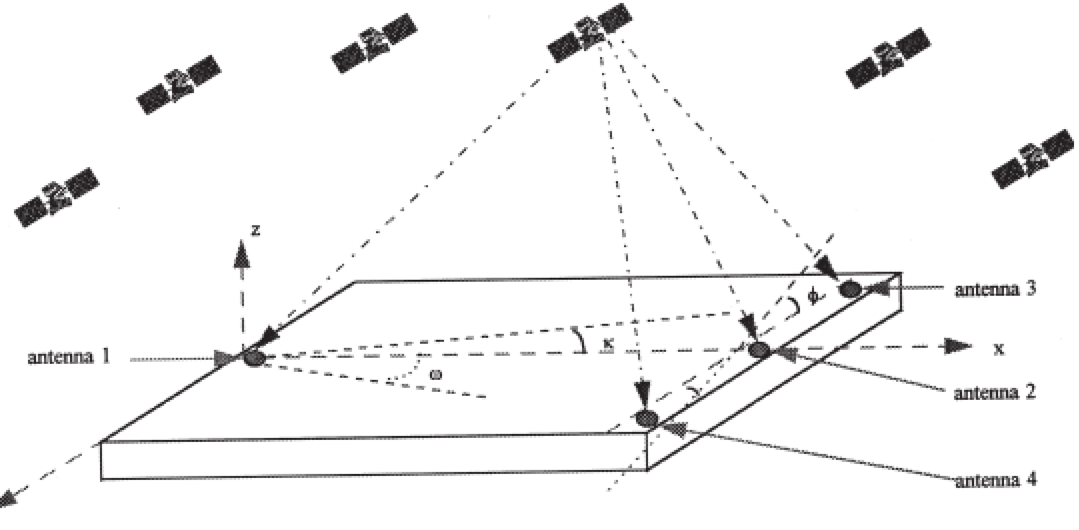
Part of the final road surface triangulation

Due to intensity image, it was often unclear where the edge should be, therefore part of the error could be caused by the ambiguousness of the line edges in the reference data.

Awuah-Baffour et al. (1997)

Awuah-Baffour et al. (1997) applied GPS to conduct high-speed surveys of roadway alignment, grade, and cross slope. Predecessor to LIDAR.

- Only a single lane of data can be collected at a time.
- Sensitive to roadway imperfections because of the high center of gravity.
- Problems with bridges.
- Data collected at 1 second intervals.



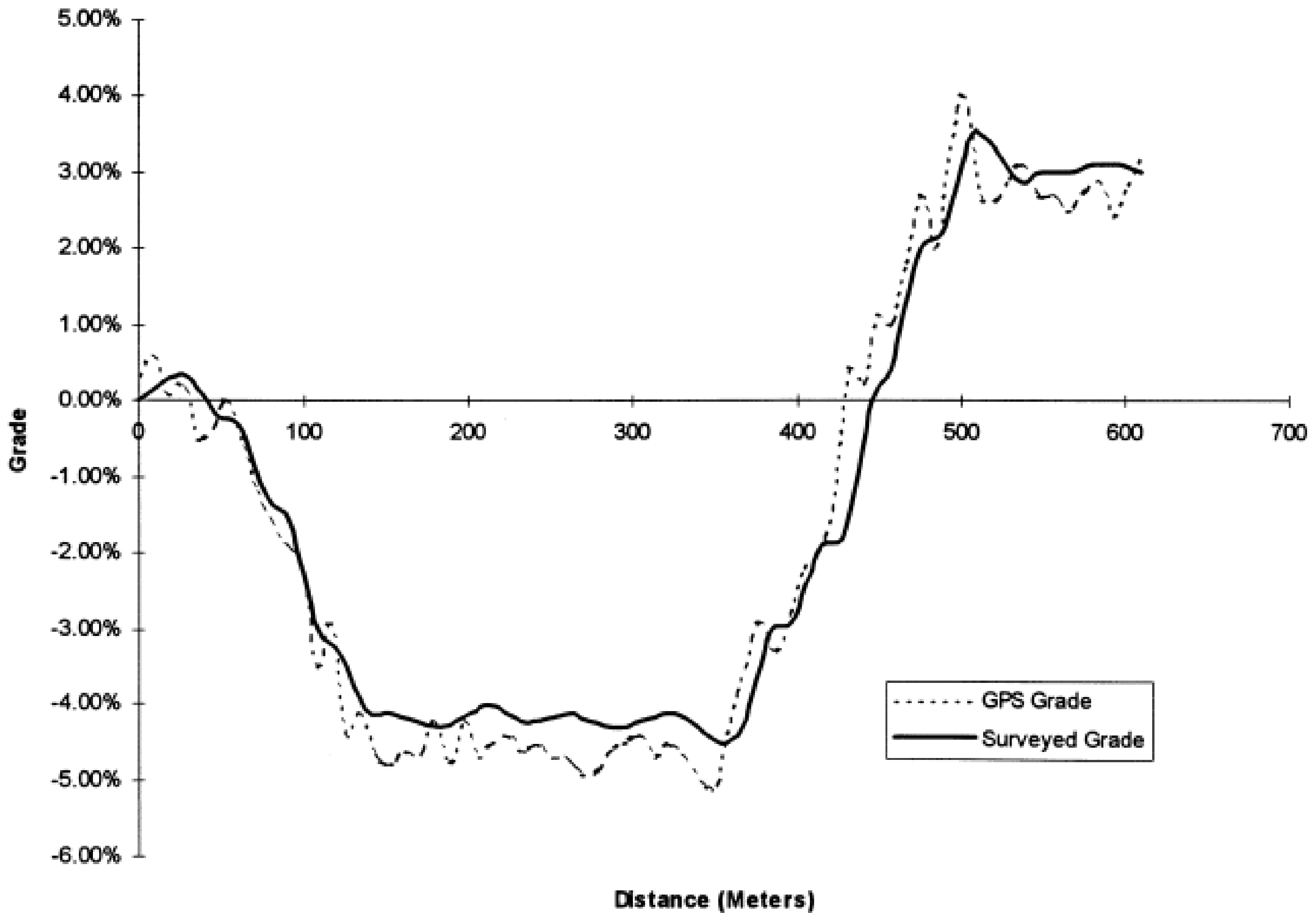
Euler attitude angles.

Awuah-Baffour et al. (1997)

Gathering precise positional data is corresponded to

- roadway measurement
- differential correction with GPS base station at fixed points.

Large volume data can be collected in a **short period of time** while a data collection vehicle travel in the highways

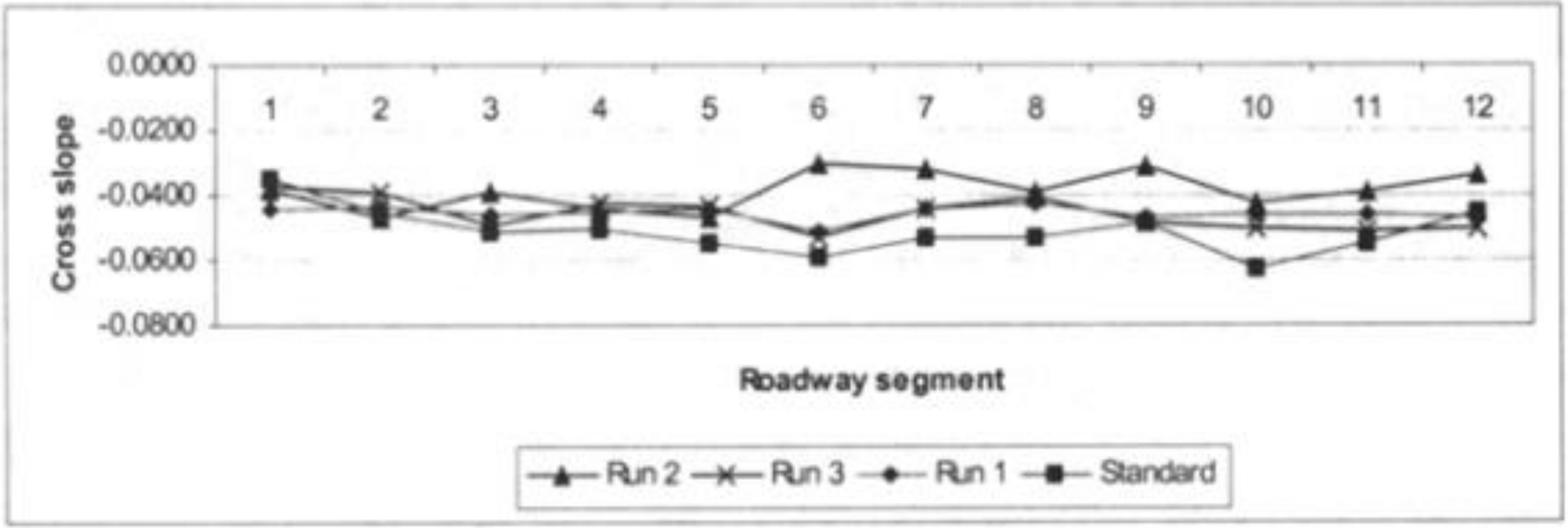


Comparison of GPS and surveying grade data collection

Baffour (2002)

All of the data collected were compared with a standard data set collected using conventional surveying.

The cross slopes were collected in 50’ intervals, and the accuracy was at +/-1%.



Potential Benefit Over LIDAR is that extensive post-processing is not required to acquire cross slope data.

Problem with using a dual RTK GPS system is loss of lock when traveling under bridges.

An inertial device doesn't have this problem.

LIDAR can collect data over multiple lanes with a single pass.

Clemson's Mobile Laboratory

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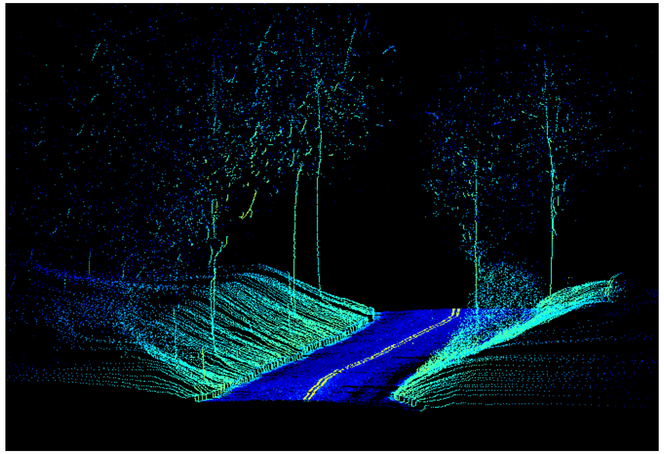

Before there was Street View

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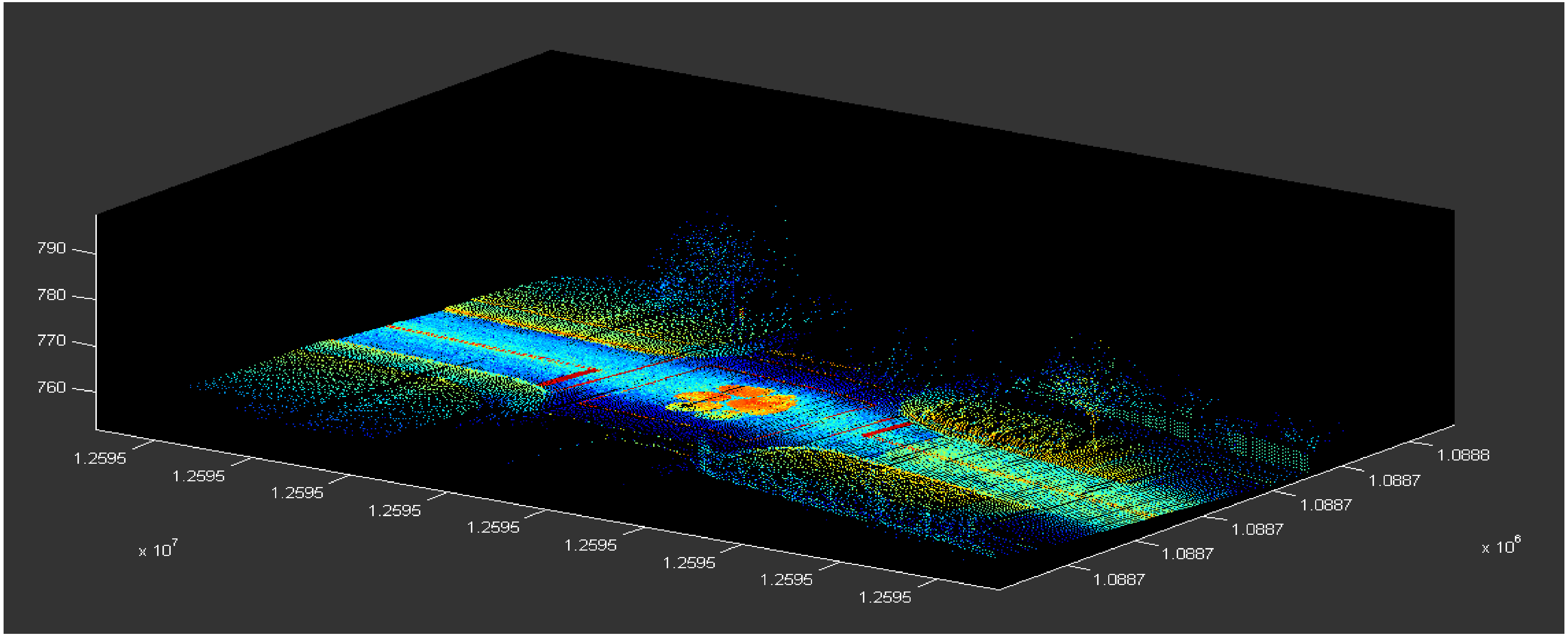
Where are we?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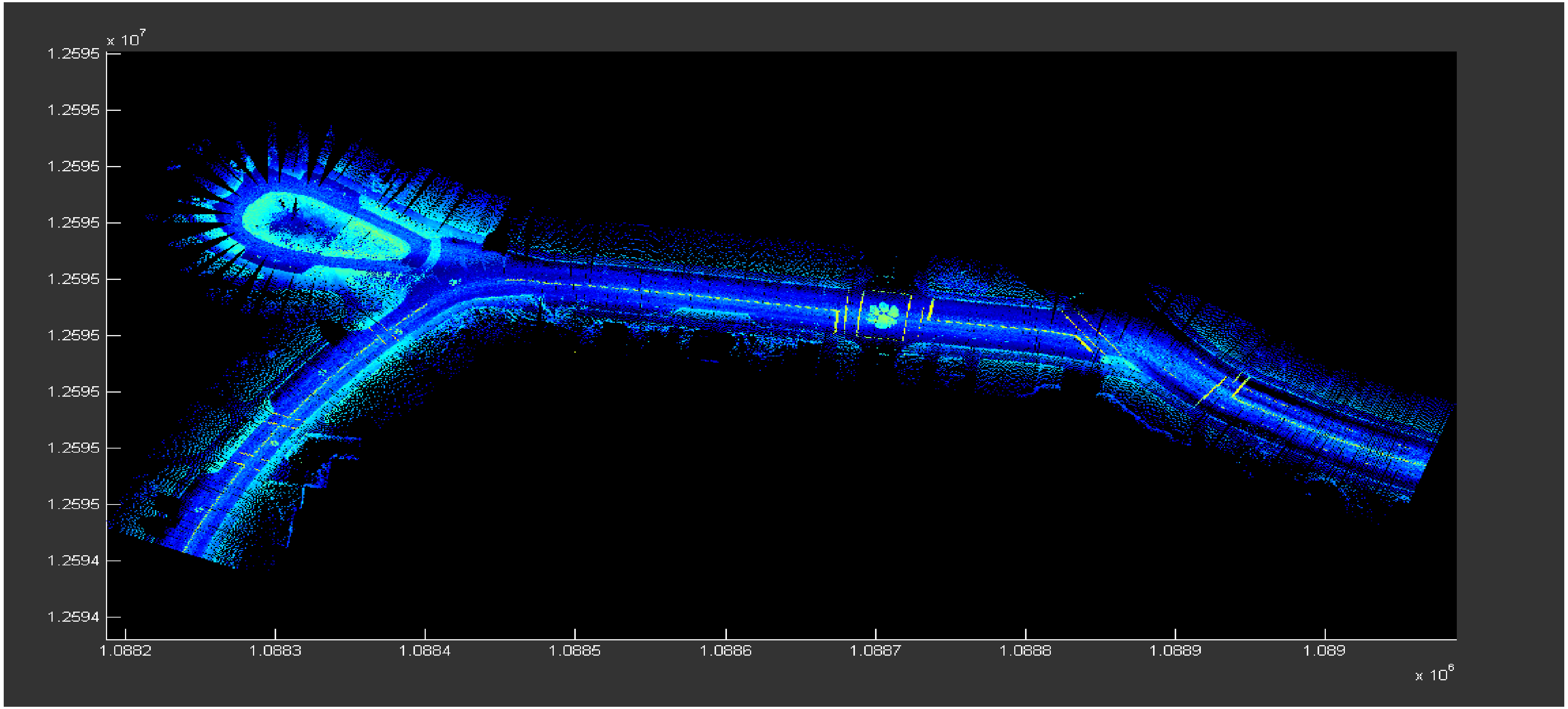
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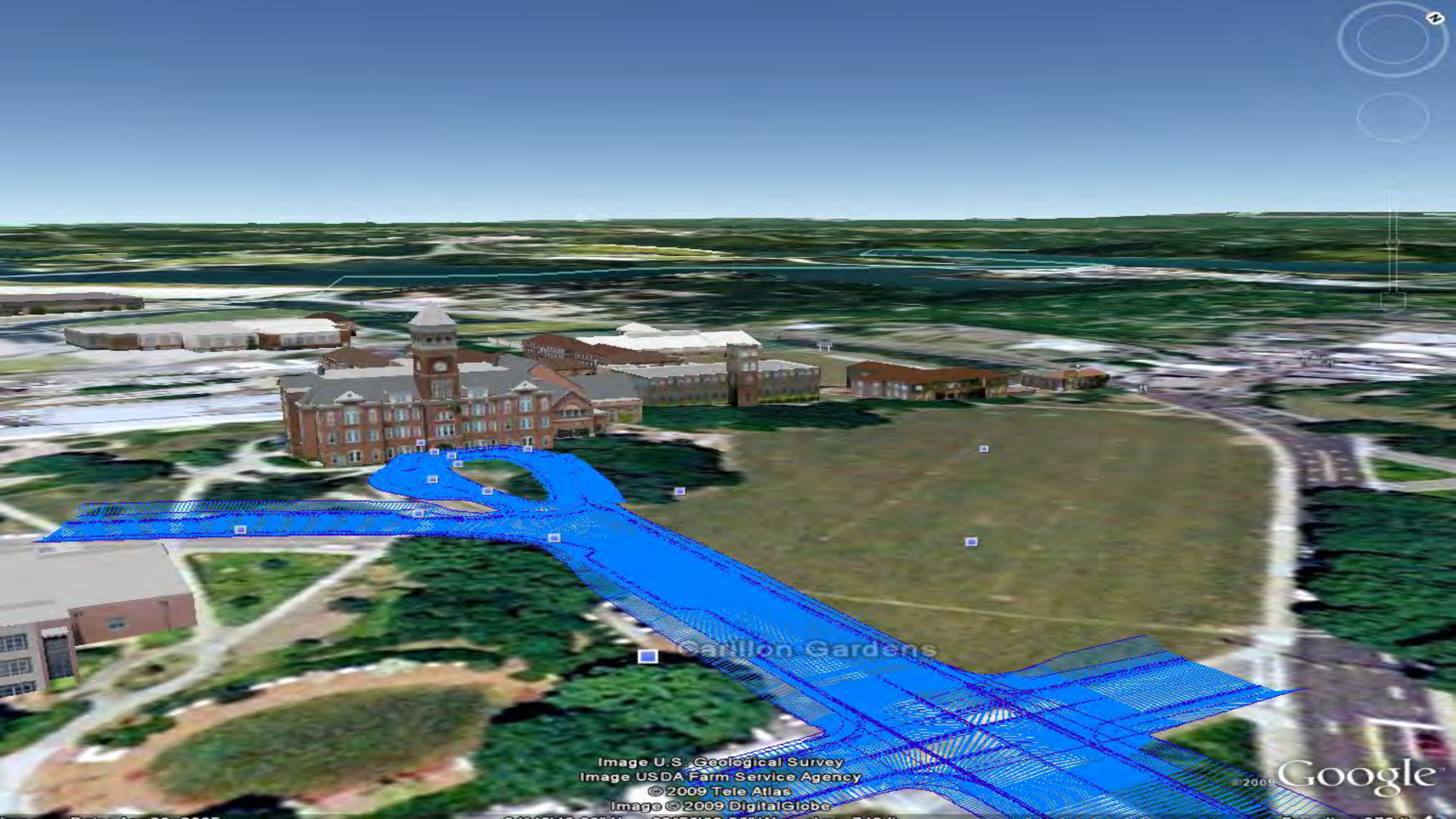

Carillon Gardens
Image U.S. Geological Survey
Image USDA Farm Service Agency
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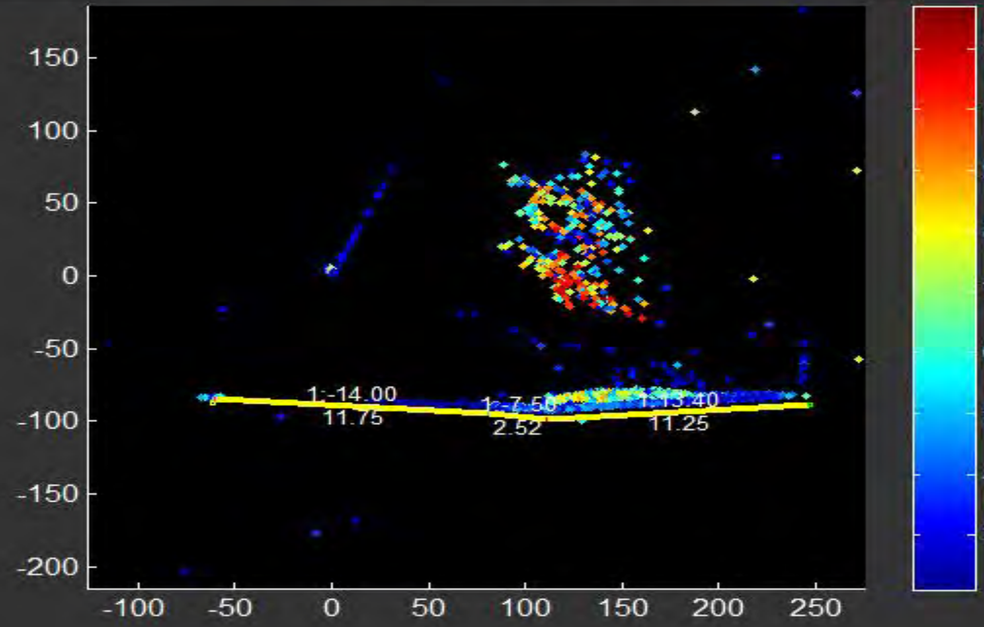
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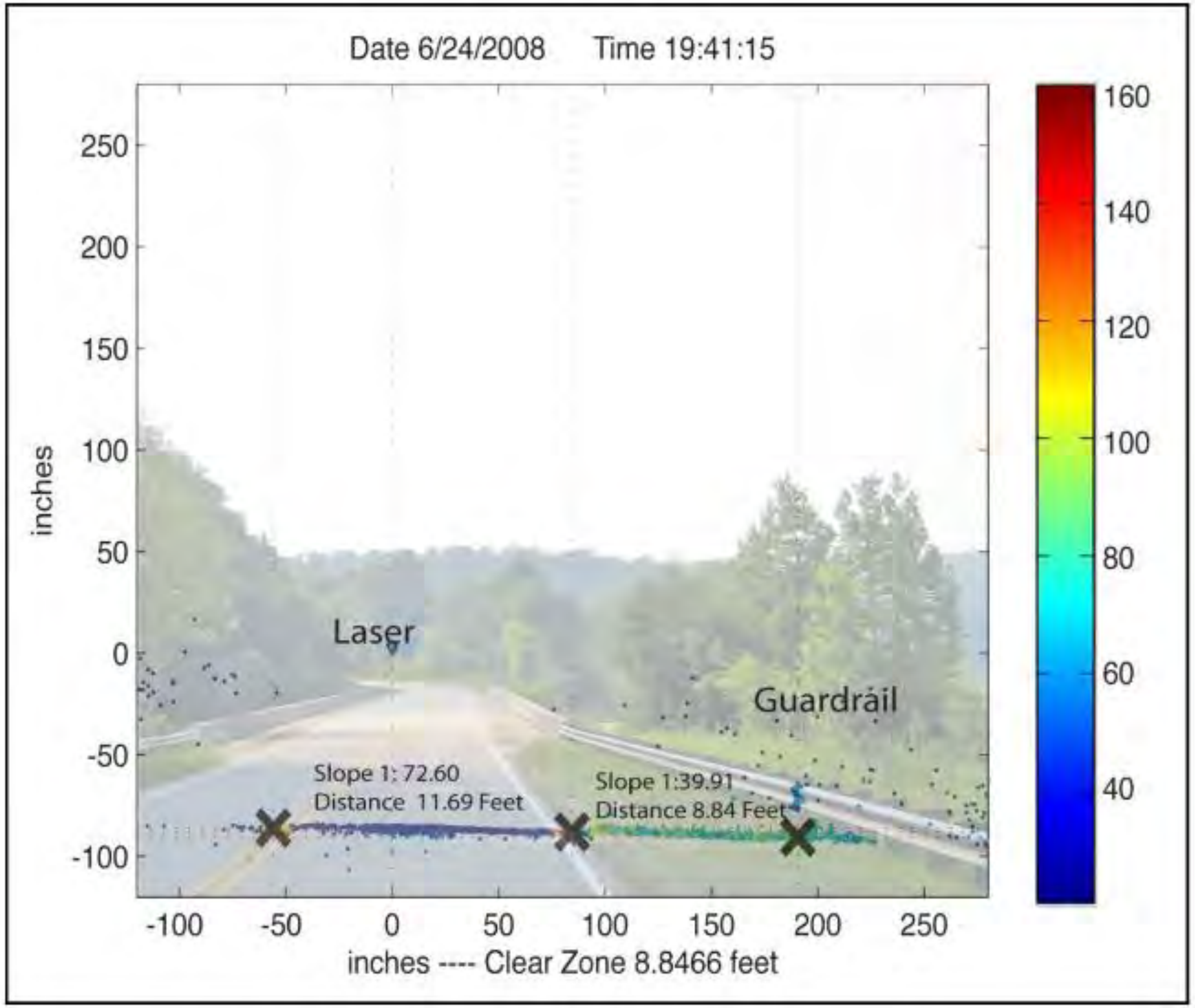

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LIDAR vs. Field Survey

GeoDigital LIDAR data on all restricted access roads around the state.

GeoDigital

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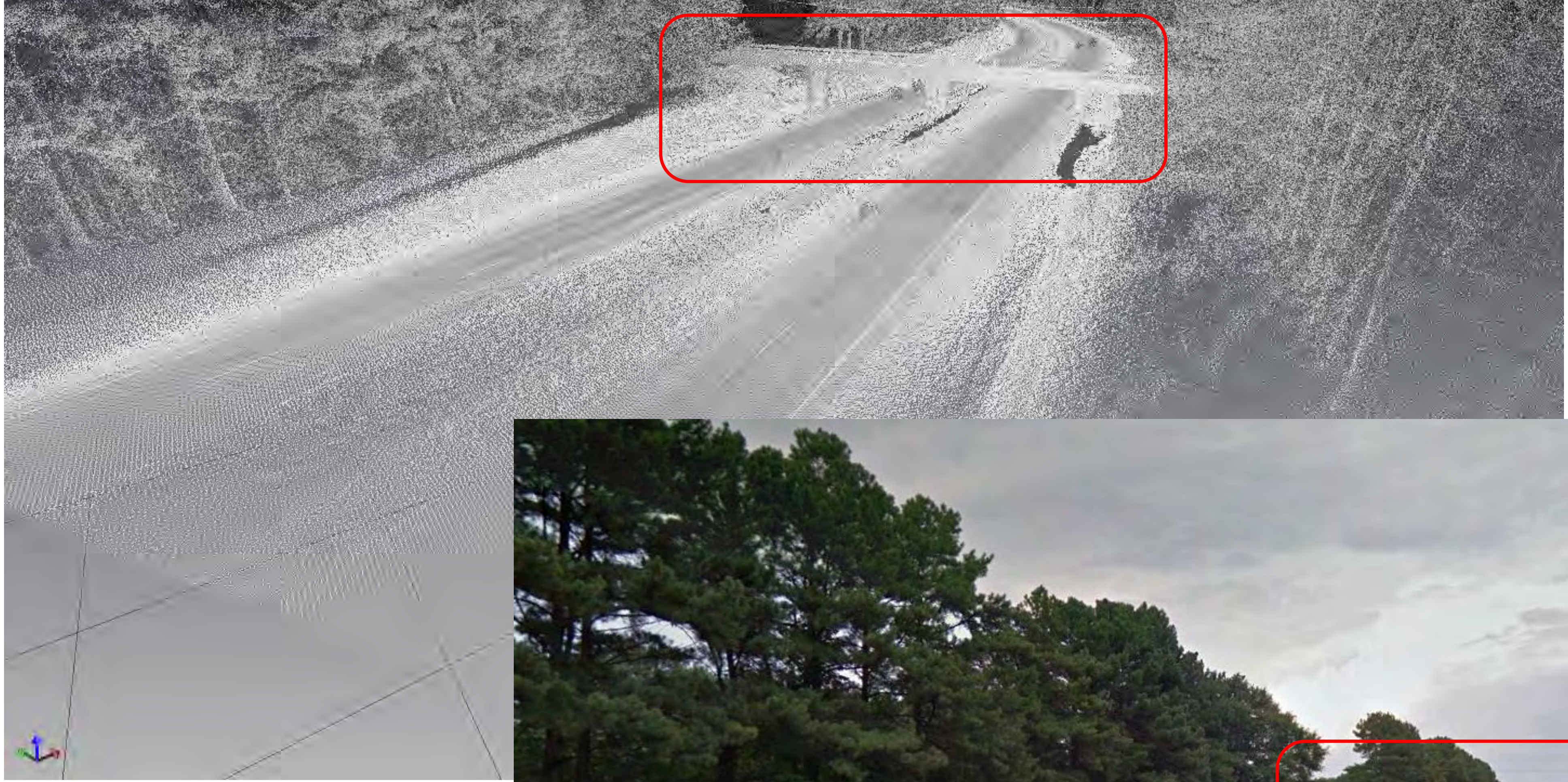
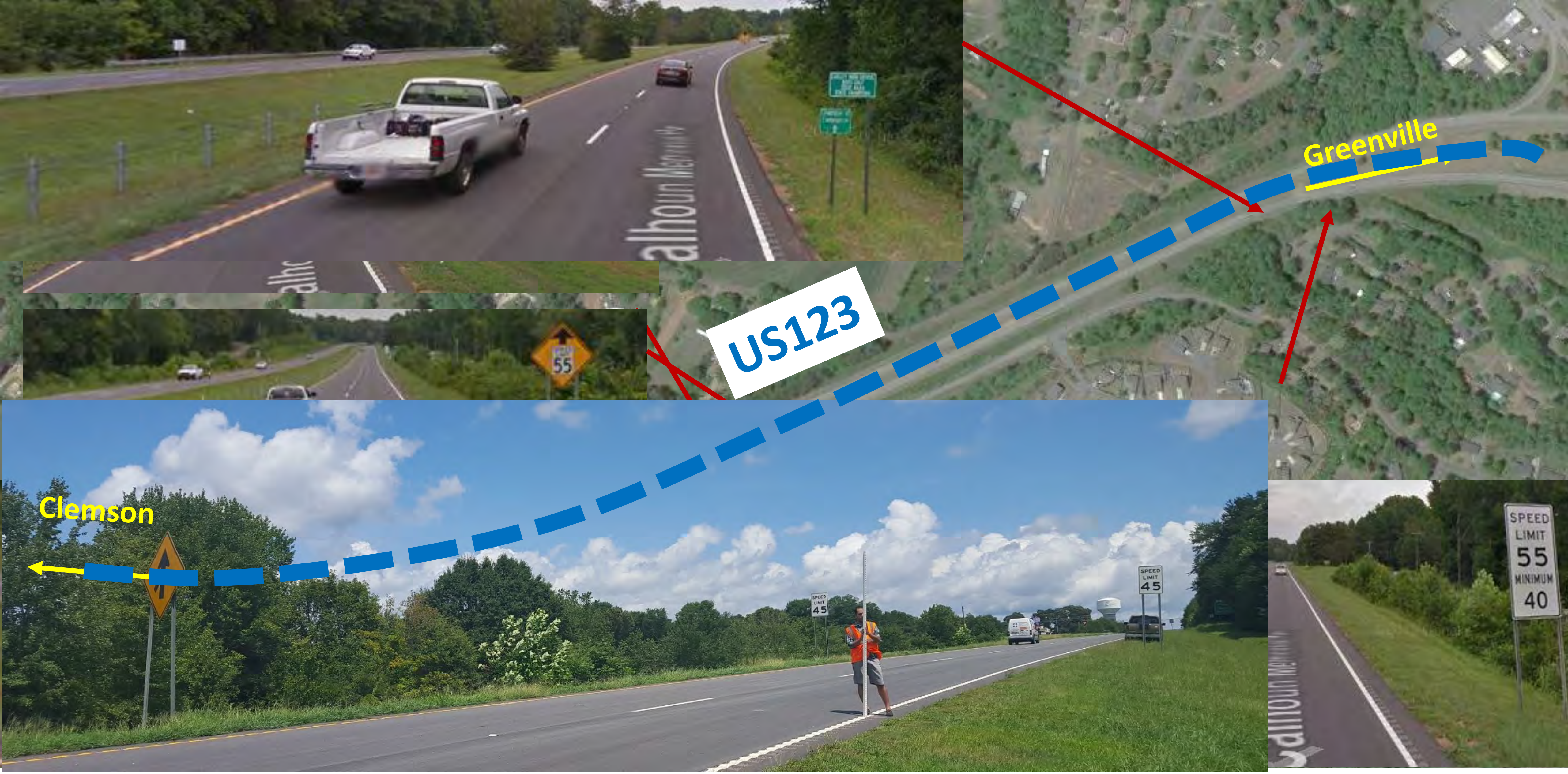


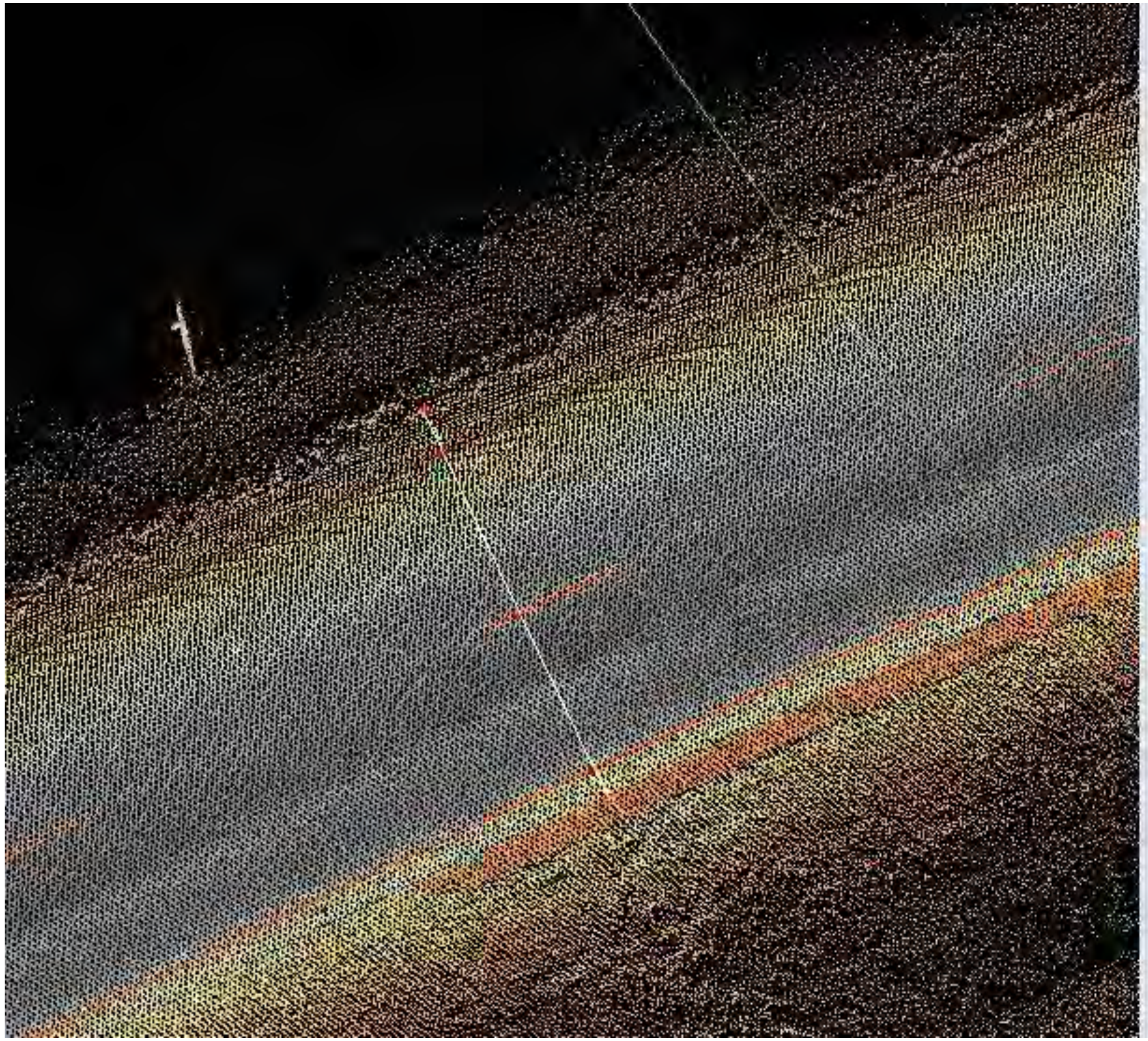

Greenville
US123
Clemson
SPEED LIMIT 45
SPEED LIMIT 45
SPEED LIMIT 55 MINIMUM 40

LIDAR

GeoDigital LIDAR data collection on US 123

GeoDigital

LIDAR



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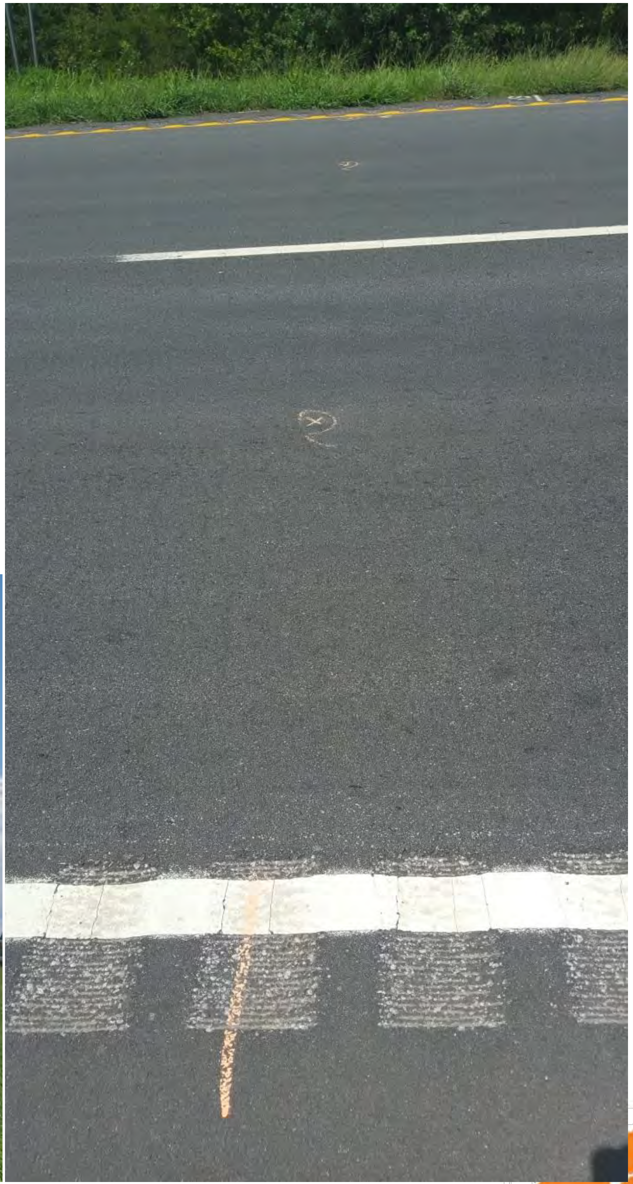
LIDAR vs. Field Survey

Field surveying cross slope data collection



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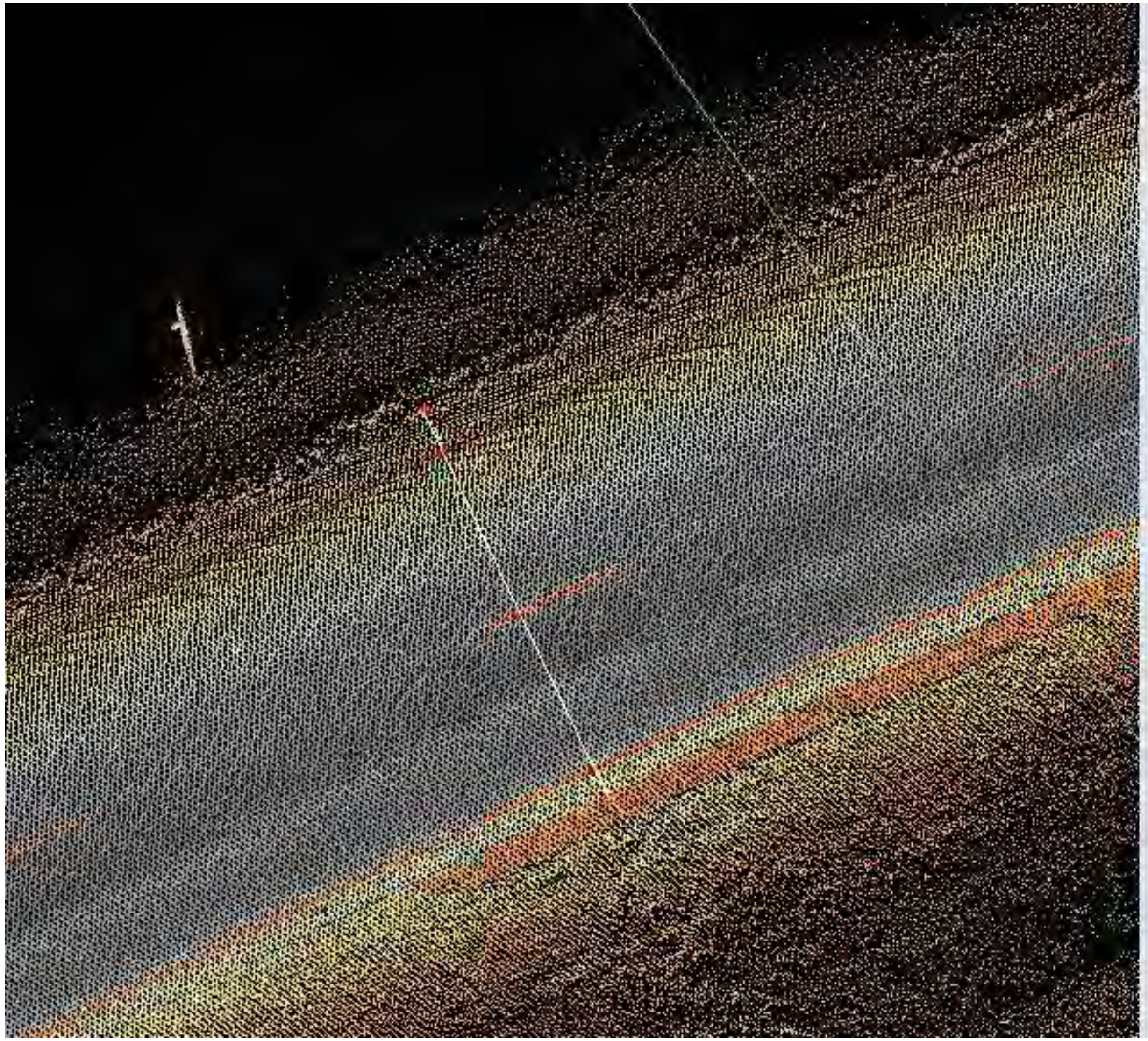
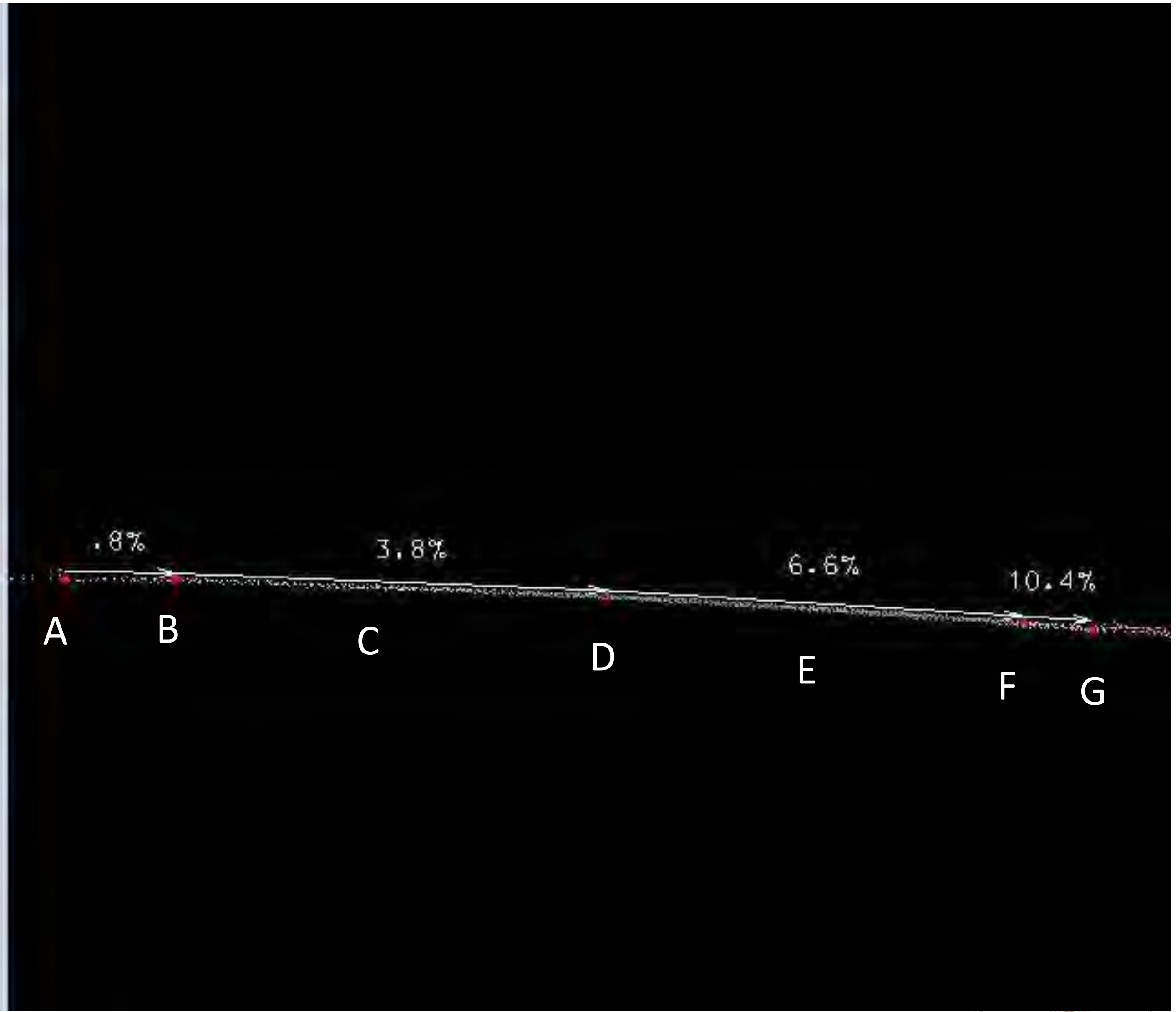
LIDAR vs. Field Survey

LIDAR





LIDAR vs. Field Survey

Point ID	BS	Height of Instrument	FS	Height (Vertical Distance)	Slope Distance	Horizontal Distance	Grade	Grade
BM	6.55			100				
A		106.55	2.03	104.52	-	-	-	
B		106.55	2.08	104.47	2	2	-2.5%	
C		106.55	2.30	104.25	6	6	-3.67%	-3.92%
D		106.55	2.55	104.00	6	5.99	-4.17%	
E		106.55	2.93	103.62	6	5.99	-6.34%	-6.77%
F		106.55	3.36	103.19	6	5.98	-7.19%	
G		106.55	3.55	103.00	2.5	2.49	-7.63%	

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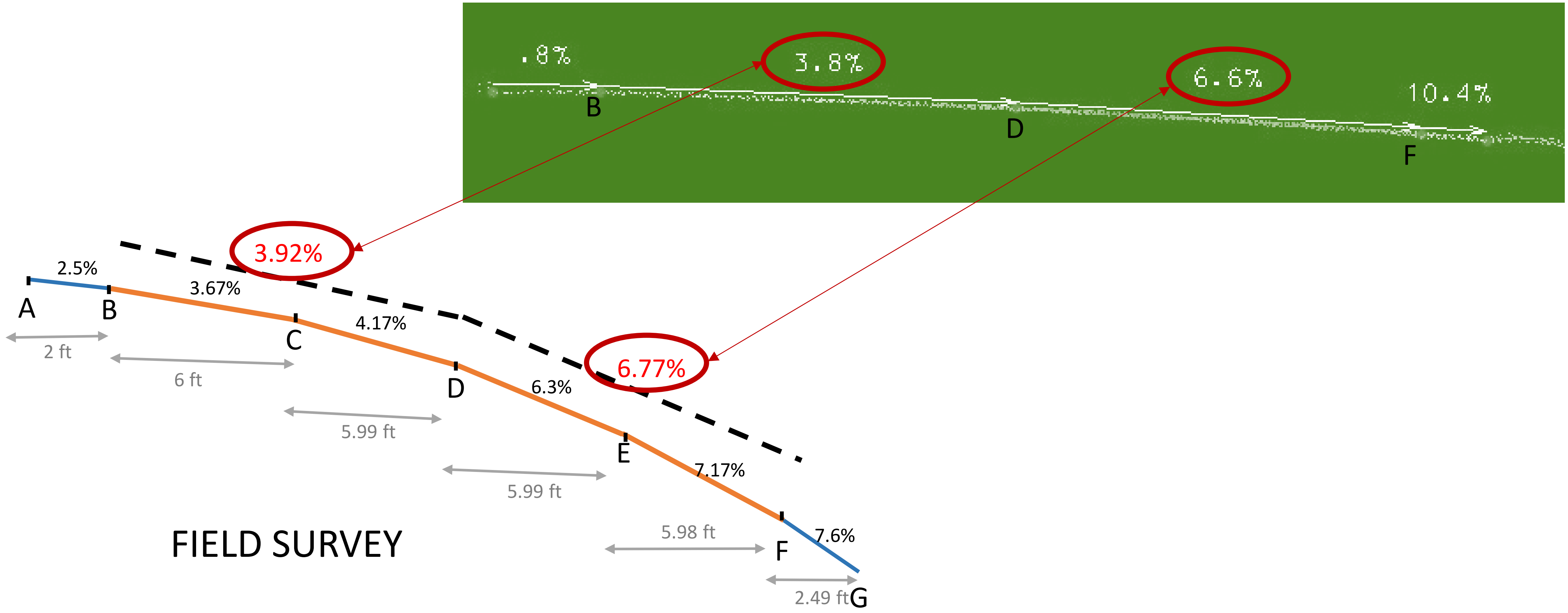
LIDAR vs. Field Survey

LIDAR DATA



LIDAR vs. Field Survey

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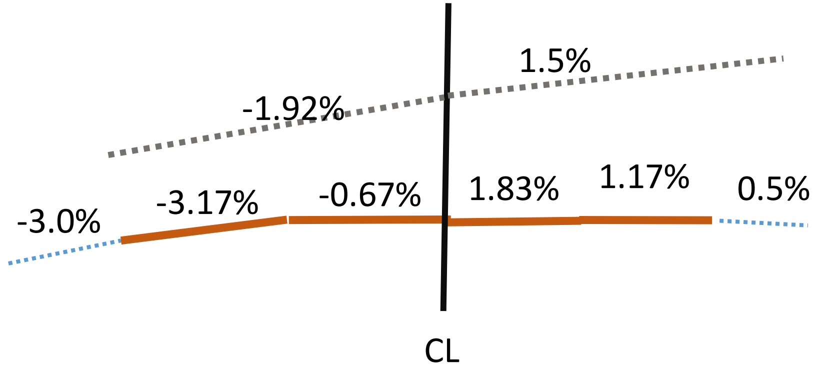
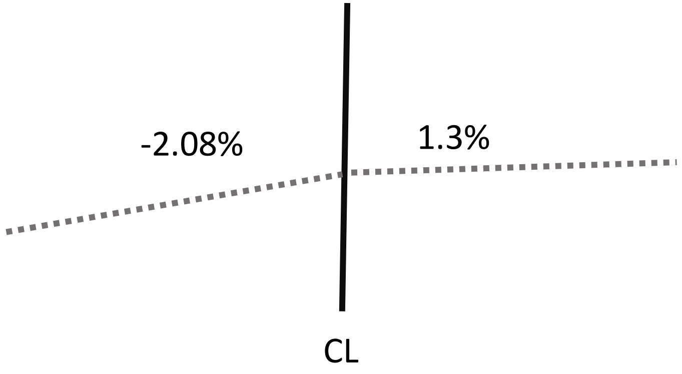
LIDAR vs. Field Survey

Clemson - Easely							
Sign 1 - Guide Sign - Station 34+31							
		TAPE	ROD	HEIGHT	SLOPE (6 FT)		SLOPE(12FT)
SIGN	sign	0	8.02	100	-11.18		-11.18
SHOULDER	A	34	4.22	103.8		0.50	
RIGHT SIDE	B	36	4.23	103.79	1.17		**1.50**
MIDDLE	C	42	4.3	103.72		1.83	
CENTERLINE	D	48	4.41	103.61	0.67		
MIDDLE	E	54	4.45	103.57		3.17	**1.92**
LEFT SIDE	F	60	4.64	103.38	3.00		
SHOULDER	G	62	4.7	103.32		9.80	9.80
	H	72	5.68	102.34			

LIDAR		
	HEIGHT	SLOPE(12FT)
RIGHT SIDE	971.82	**1.3**
CENTERLINE	971.67	
LEFT SIDE	971.42	**2.08**



Field Survey

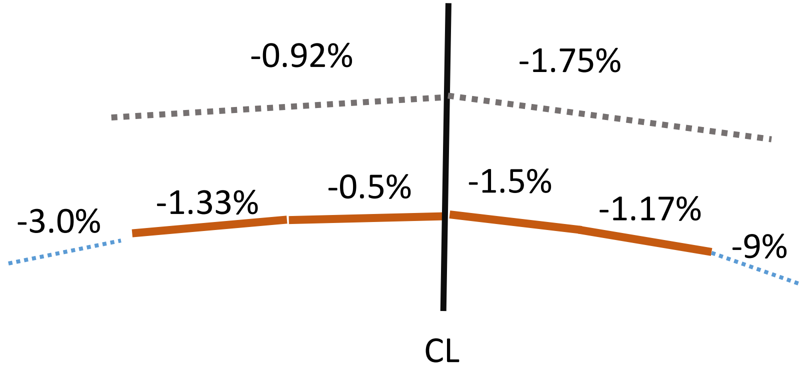


LIDAR

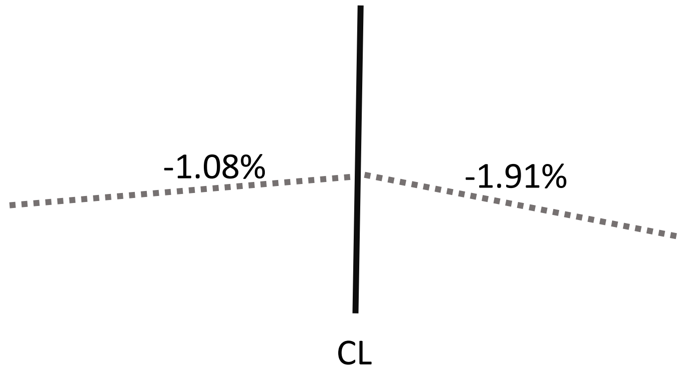
LIDAR vs. Field Survey

Clemson - Easely							
Sign 2 - SPEED LIMIT - Station 38+51.71							
		TAPE	ROD	HEIGHT	SLOPE (6 FT)		SLOPE(12FT)
SIGN	SIGN 1	0	5.81	100			
	SIGN 2	3	5.2	100.61	-9.00		-9.00
SHOULDER	A	9	4.66	101.15		-3.50	
RIGHT	B	11	4.59	101.22	-2.00		**-1.75**
MIDDLE	C	17	4.47	101.34		-1.50	
CENTERLINE	D	23	4.38	101.43	0.50		
MIDDLE	E	29	4.41	101.4		1.33	**0.92**
LEFT SIDE	F	35	4.49	101.32	3.00		
SHOULDER	G	37	4.55	101.26		10.71	10.71
	H	44	5.3	100.51			

LIDAR		
	HEIGHT	SLOPE(12FT)
RIGHT SIDE	969.36	**-1.91**
CENTERLINE	969.59	
LEFT SIDE	969.46	**-1.08**



Field Survey

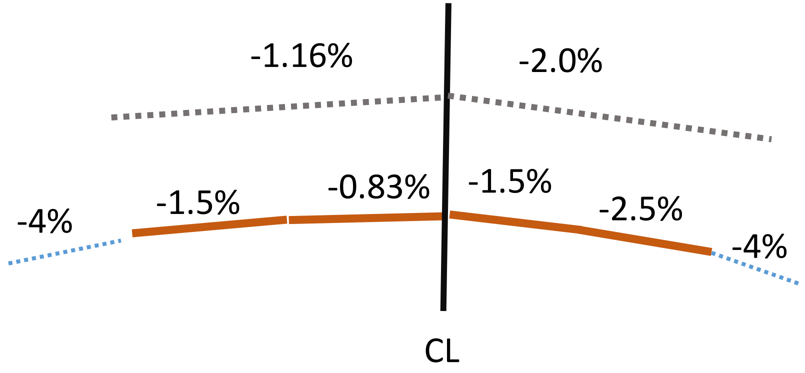


LIDAR

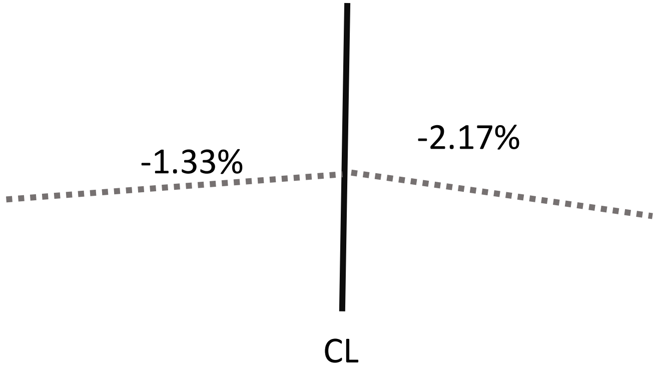
LIDAR vs. Field Survey

Clemson - Easely							
Sign 3 - MILE POST - Station 44+19.98							
		TAPE	ROD	HEIGHT	SLOPE (6 FT)		SLOPE(12FT)
SIGN	sign	0	5.23	100	-9.00		-9.00
SHOULDER	A	5	4.78	100.45		-4.00	
RIGHT	B	7	4.7	100.53	-2.50		**-2.0**
MIDDLE	C	13	4.55	100.68		-1.5	
CENTERLINE	D	19	4.46	100.77	0.83		
MIDDLE	E	25	4.51	100.72		1.50	**1.16**
LEFT SIDE	F	31	4.6	100.63	4.00		
SHOULDER	G	33	4.68	100.55		10.86	10.86
	H	40	5.44	99.79			

LIDAR		
	HEIGHT	SLOPE(12FT)
RIGHT SIDE	962.17	**2.17**
CENTERLINE	962.43	
LEFT SIDE	962.27	**1.33**



Field Survey

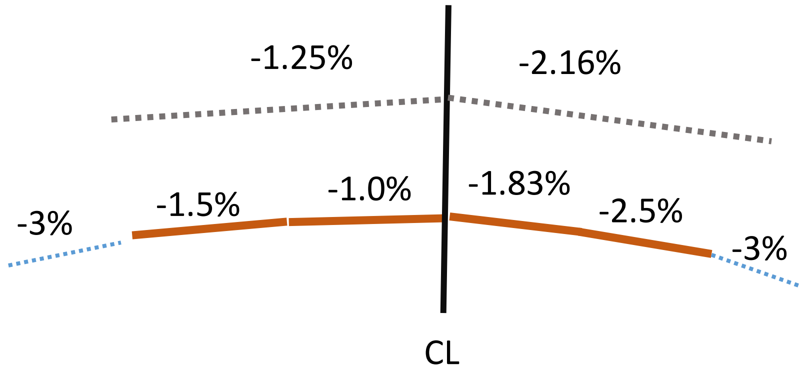


LIDAR

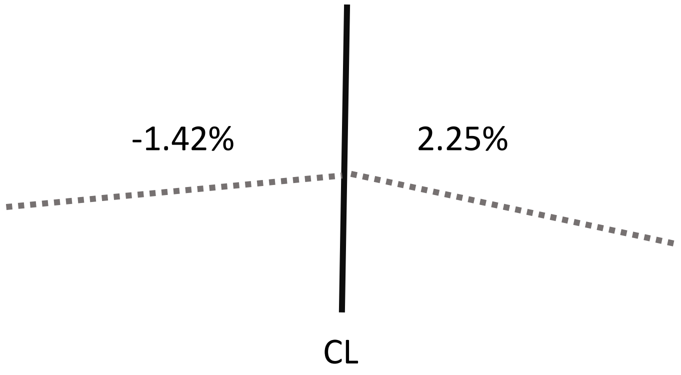
LIDAR vs. Field Survey

Clemson - Easely							
Sign 4 - Guide Sign - Station 44+68.43							
		TAPE	ROD	HEIGHT	SLOPE (6 FT)		SLOPE(12FT)
SIGN	sign	0	5.71	100	-10.67		-10.67
SHOULDER	I	9	4.75	100.96		-3.00	
RIGHT	J	11	4.69	101.02	-2.50		**-2.16**
MIDDLE	K	17	4.54	101.17		-1.83	
CENTERLINE	L	23	4.43	101.28	1.0		
MIDDLE	M	29	4.49	101.22		1.50	**1.25**
LEFT SIDE	N	35	4.58	101.13	3.00		
SHOULDER	O	37	4.64	101.07		10.14	10.14
	P	44	5.35	100.36			

LIDAR		
	HEIGHT	SLOPE(12FT)
RIGHT SIDE	962.20	**-2.25**
CENTERLINE	962.47	
LEFT SIDE	962.30	**1.42**



Field Survey

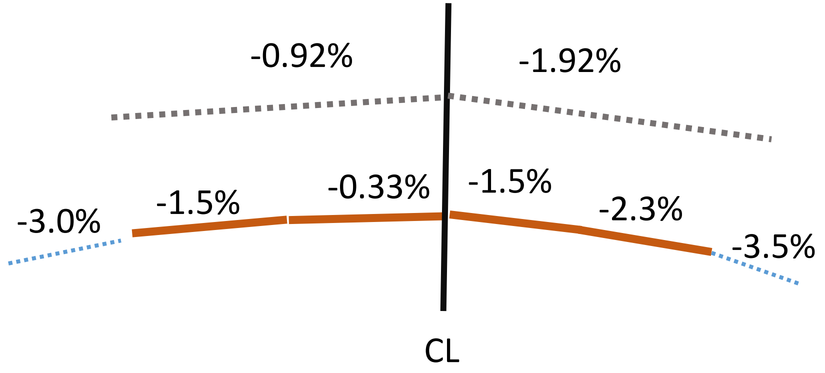


LIDAR

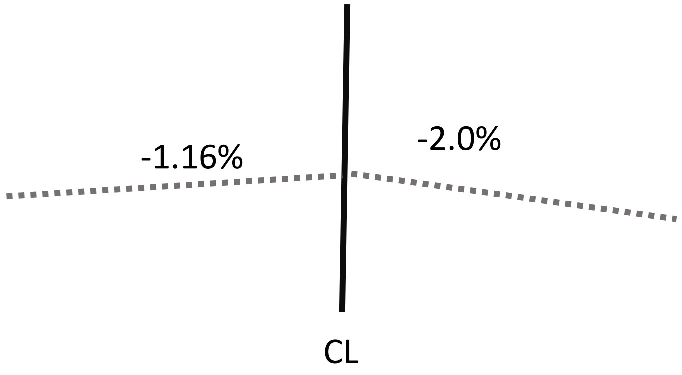
LIDAR vs. Field Survey

Clemson - Easely							
Sign 5 - SPEED LIMIT - Station 45+92.41							
.		TAPE	ROD	HEIGHT	SLOPE (6 FT)		SLOPE(12FT)
SIGN	sign	0	4.91	100	-8.75		-8.75
SHOULDER	Q	8	4.21	100.7		-3.50	
RIGHT	R	10	4.14	100.77	-2.33		**-1.92**
MIDDLE	S	16	4	100.91		-1.50	
CENTERLINE	T	22	3.91	101	0.33		
MIDDLE	U	28	3.93	100.98		1.5	**0.92**
LEFT SIDE	V	34	4.02	100.89	3.00		
SHOULDER	W	36	4.08	100.83		7.71	7.71
	X	43	4.62	100.29			

LIDAR		
	HEIGHT	SLOPE(12FT)
RIGHT SIDE	962.76	**2.0**
CENTERLINE	963.00	
LEFT SIDE	962.86	**1.16**



Field Survey

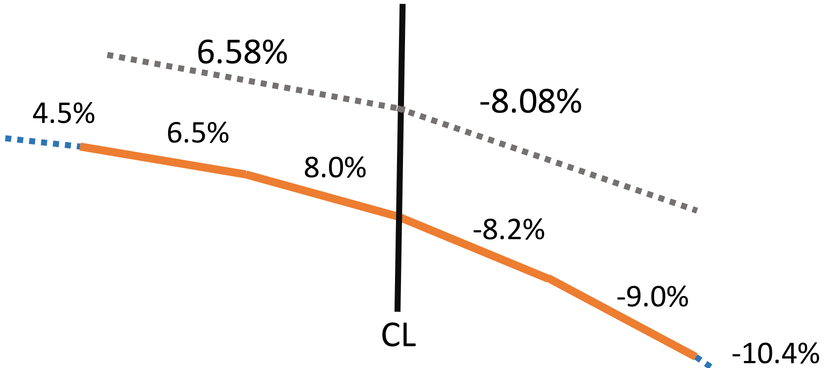


LIDAR

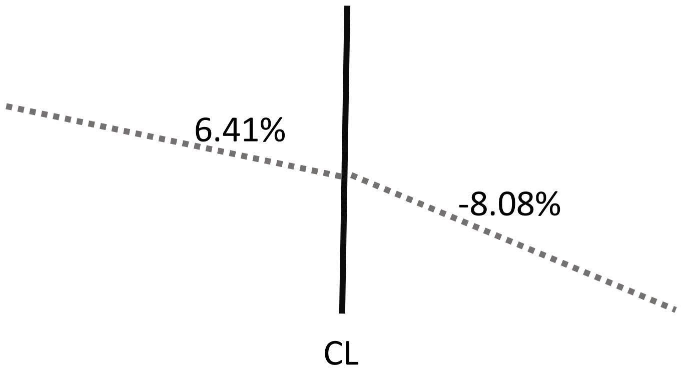
LIDAR vs. Field Survey

Clemson - Easely							
Sign 6A - GUIDE SIGN - Station 57+39.43							
		TAPE	ROD	HEIGHT	SLOPE (6 FT)		SLOPE(12FT)
SIGN	SIGN 1	0	8.45	100			
	SIGN 2	2.2	7.92	100.53	-10.43		-10.43
SHOULDER	A	4.5	7.68	100.77		-9.00	
RIGHT	B	6.5	7.5	100.95	-8.17		**-8.08**
MIDDLE	C	12.5	7.01	101.44		-8.00	
CENTERLINE	D	18.5	6.53	101.92	-6.67		
MIDDLE	E	24.5	6.13	102.32		-6.50	**-6.58**
LEFT SIDE	F	30.5	5.74	102.71	-4.50		
SHOULDER	G	32.5	5.65	102.8		1.86	1.86
	H	39.5	5.78	102.67			

LIDAR		
	HEIGHT	SLOPE(12FT)
RIGHT SIDE	971.59	**-8.08**
CENTERLINE	972.56	
LEFT SIDE	973.33	**6.4**

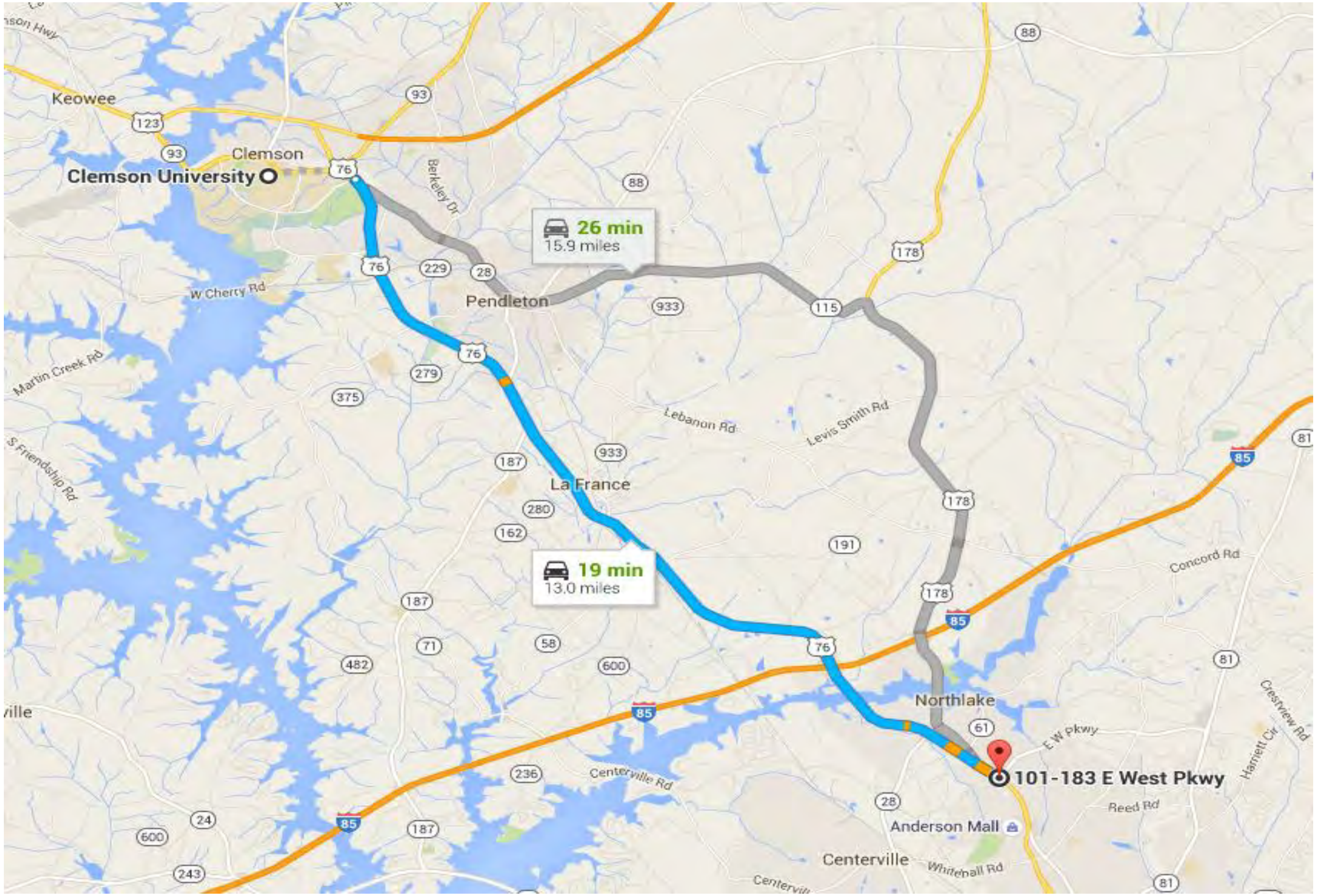


Field Survey



LIDAR

Potential Rodeo Site



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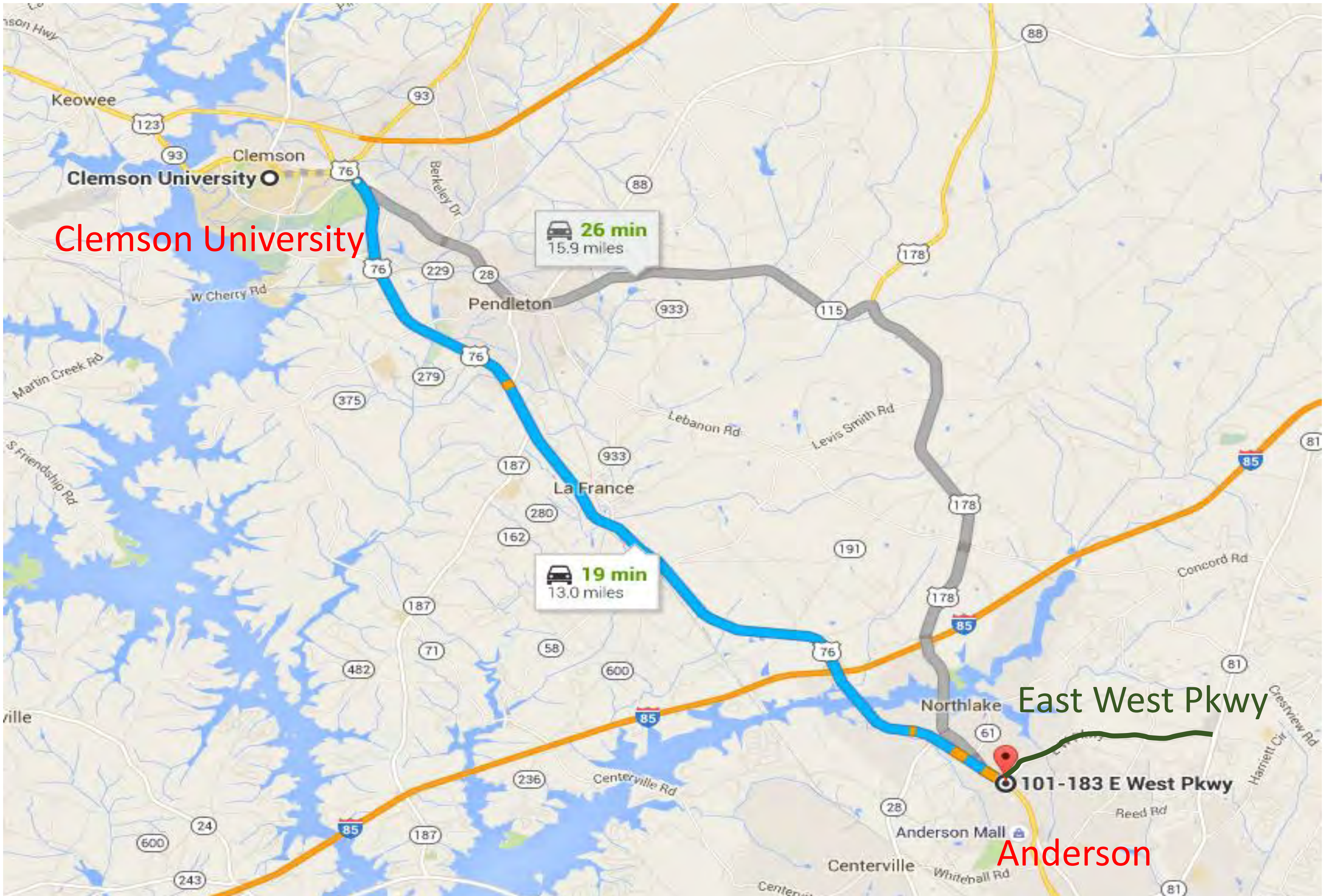
CLEMSON
UNIVERSITY



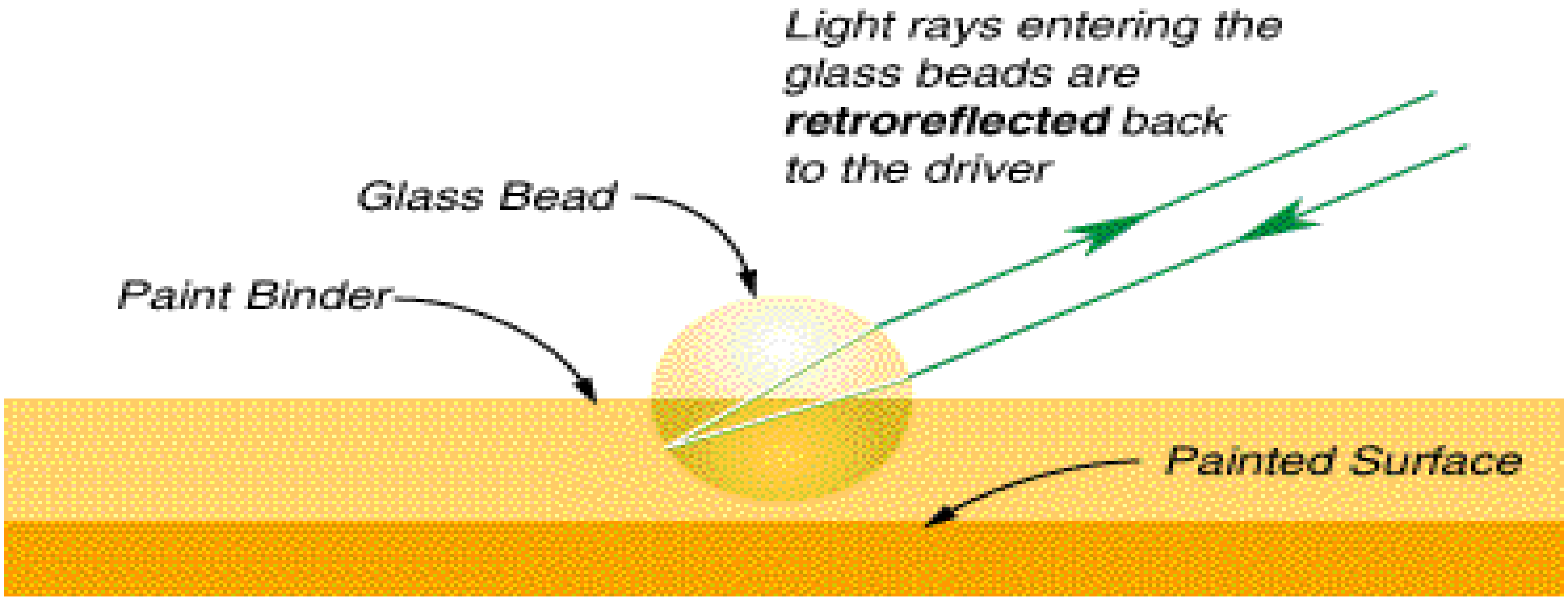
Clemson University
Clemson
Keowee
Pendleton
26 min
15.9 miles
19 min
13.0 miles
La France
Lebanon Rd
Levis Smith Rd
W Cherry Rd
Martin Creek Rd
S Friendship Rd
Berkeley Dr
Northlake
East West Pkwy
101-183 E West Pkwy
Reed Rd
Concord Rd
Centerville Rd
Anderson Mall
Centerville
Whitehall Rd
Anderson


E W Pkwy
E W Pkwy
E W Pkwy
E W Pkwy
E W Pkwy
Hobson Rd
Sam's Club
Towne Creek Trail
736
34
81
Oak
E W Pkwy
E W Pkwy

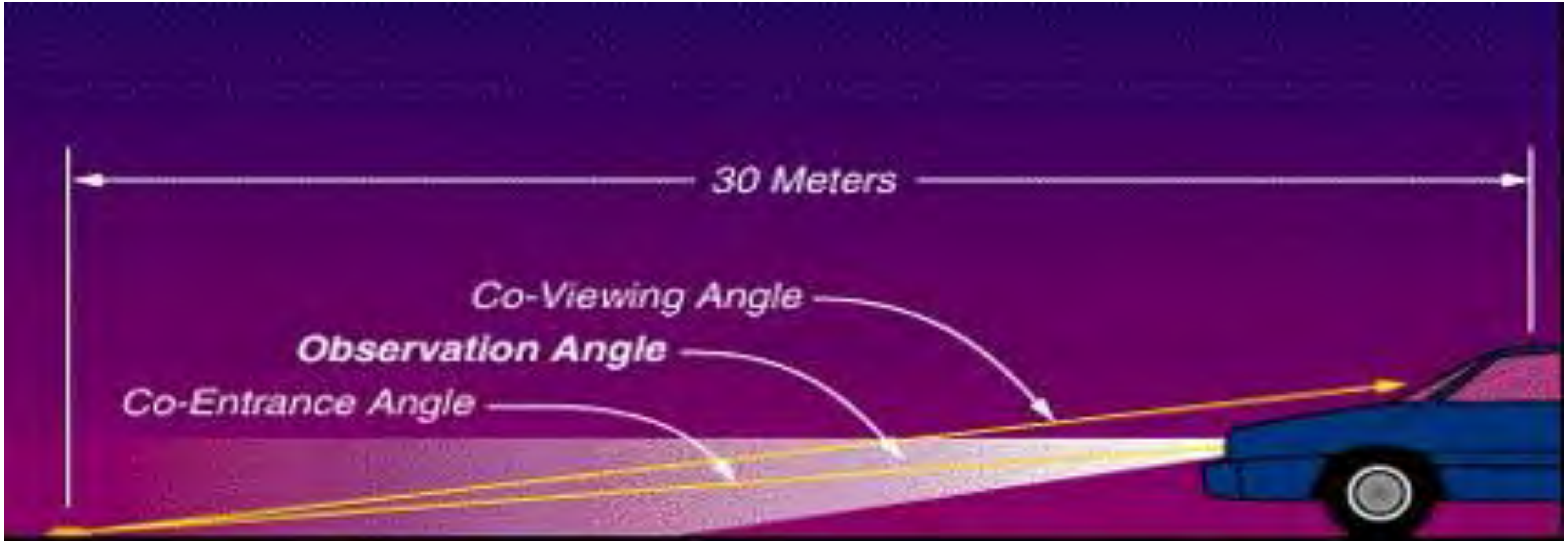
LIDAR has great potential for Asset Management activities.

- Horizontal and vertical alignment of highways
- Cross section details (besides cross slope)
- Guard rail, cable rail, barrier, clear zone and other safety aspects.
- Bridge characteristics
- Curb and gutter
- Signs
- *Pavement marking retroreflectivity*

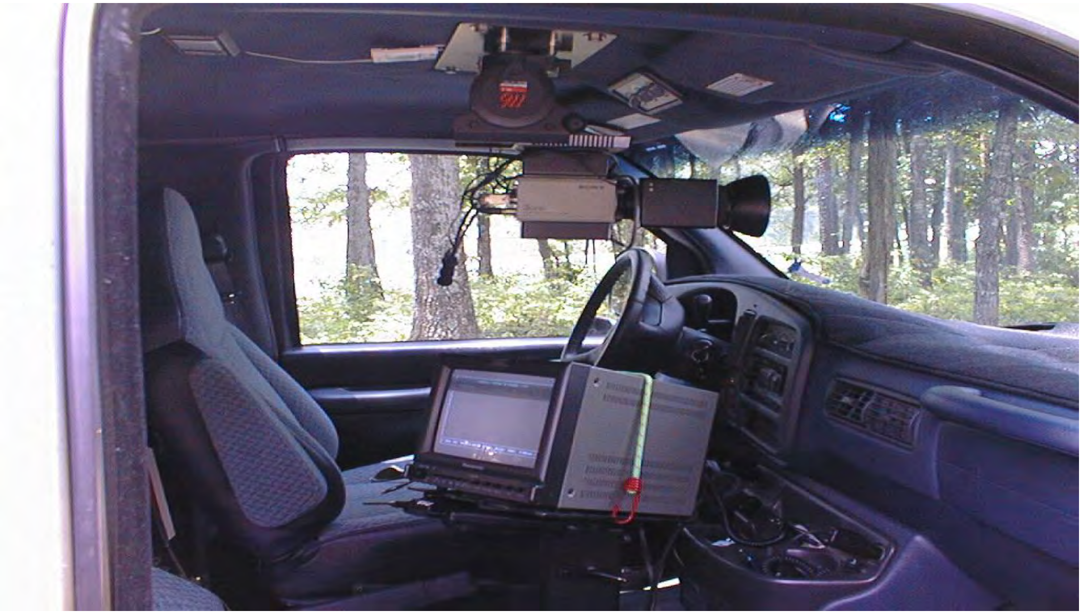
How does it work?



- Influencing factors – size, shape, embedment, wearing, etc.



30 Meter Observation Distance Geometry



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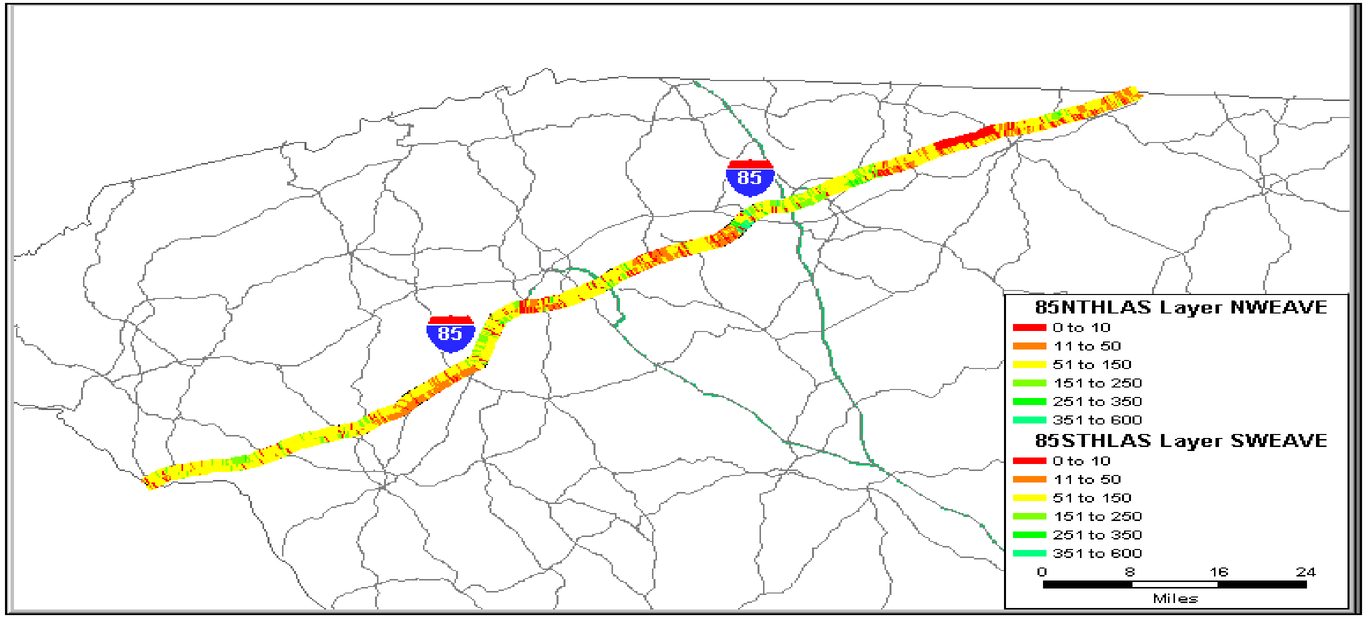
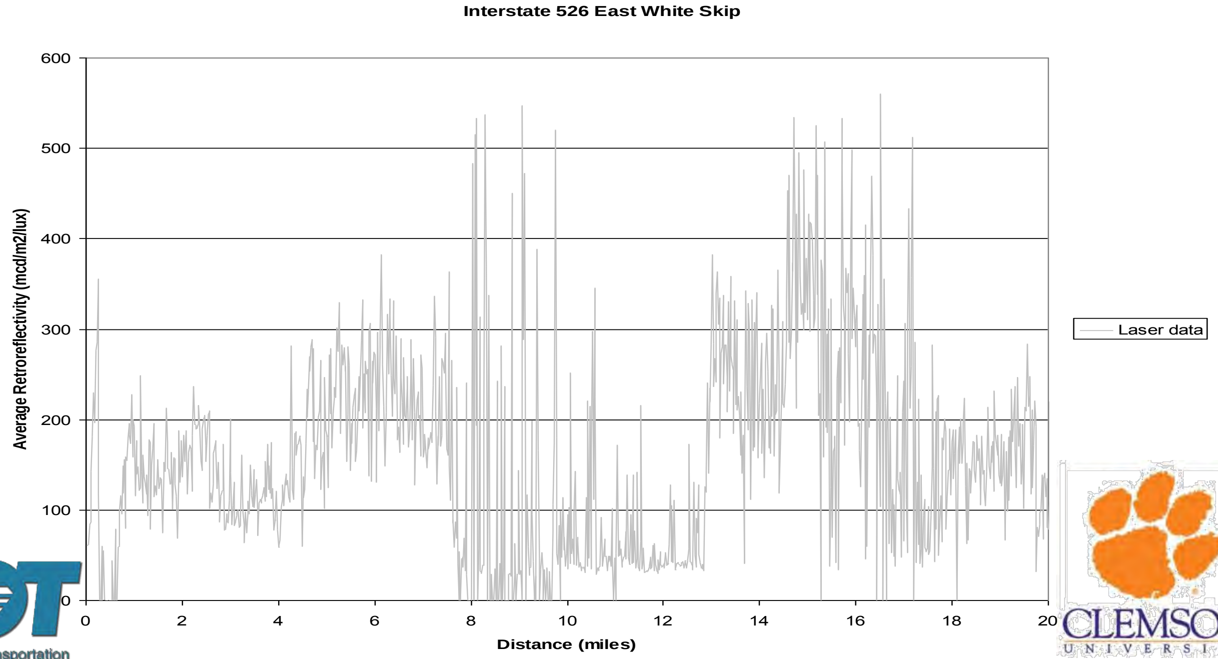

85
85
85NTHLAS Layer NWEAVE
0 to 10
11 to 50
51 to 150
151 to 250
251 to 350
351 to 600
85STHLAS Layer SWEAVE
0 to 10
11 to 50
51 to 150
151 to 250
251 to 350
351 to 600
0 8 16 24
Miles


Interstate 526 East White Skip
Average Retroreflectivity (mcd/m2/lux)
0
100
200
300
400
500
600
0 2 4 6 8 10 12 14 16 18 20
Distance (miles)
Laser data

Final Comments

LIDAR has great potential
Is it too much of a good thing?

- Processing point clouds is tedious and time consuming
- Intensity/amplitude attribute information is critical for extracting useful information in an efficient (and possibly automated manner
- Breaklines are needed for preconstruction and major rehab projects

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Thank you