



OPTIMIZING CROSS-SLOPE ESTIMATION USING AIRBORNE, MOBILE, AND STATIC LIDAR DATA

ANANNYA GHOSH TUSTI, DR. XIAOHUA LUO, DR. FENG WANG
SMART TRANSPORTATION INFRASTRUCTURE MANAGEMENT LAB, TEXAS STATE UNIVERSITY



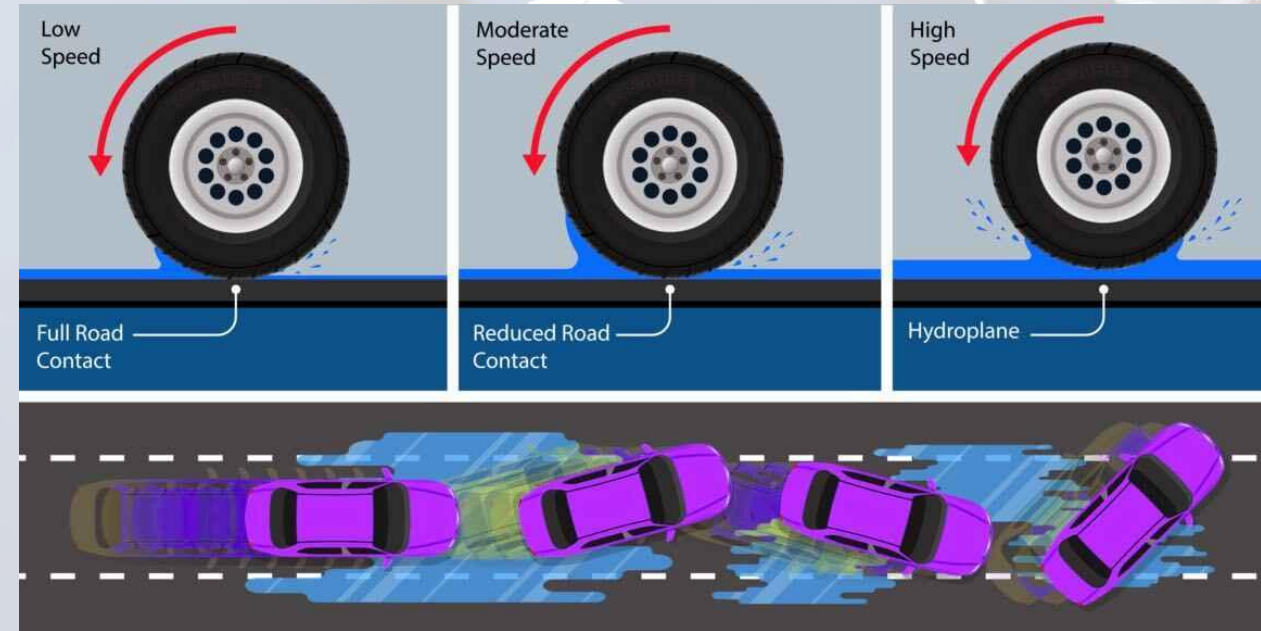
CONTENTS

- Background
- Problem statement and objectives
- Data and methodology
- Experimental observations
- Practical implications
- Conclusion, limitations, and future direction



BACKGROUND

- Nearly 70% of weather-related crashes occur on wet pavement
- Around 1.2 million crashes annually are associated with wet conditions
- Hydroplaning can occur at water depths as low as 0.1 inch
- Inadequate cross-slope reduces drainage and increases risk



Source: <https://www.apollotyres.com>

PROBLEM AND MOTIVATION

- Cross-slope controls how water drains laterally across the pavement surface.
- Poor estimation can distort drainage assessment, ponding interpretation, and hydroplaning-related analysis.
- Agencies need methods that are both accurate enough for engineering decisions and scalable enough for corridor or network use.
- This study focuses on choosing and optimizing lidar-based workflows for that balance.



OBJECTIVE

Estimate roadway cross-slope from multiple LiDAR sources and optimize a patch-based plane fitting workflow for stable, interpretable results.

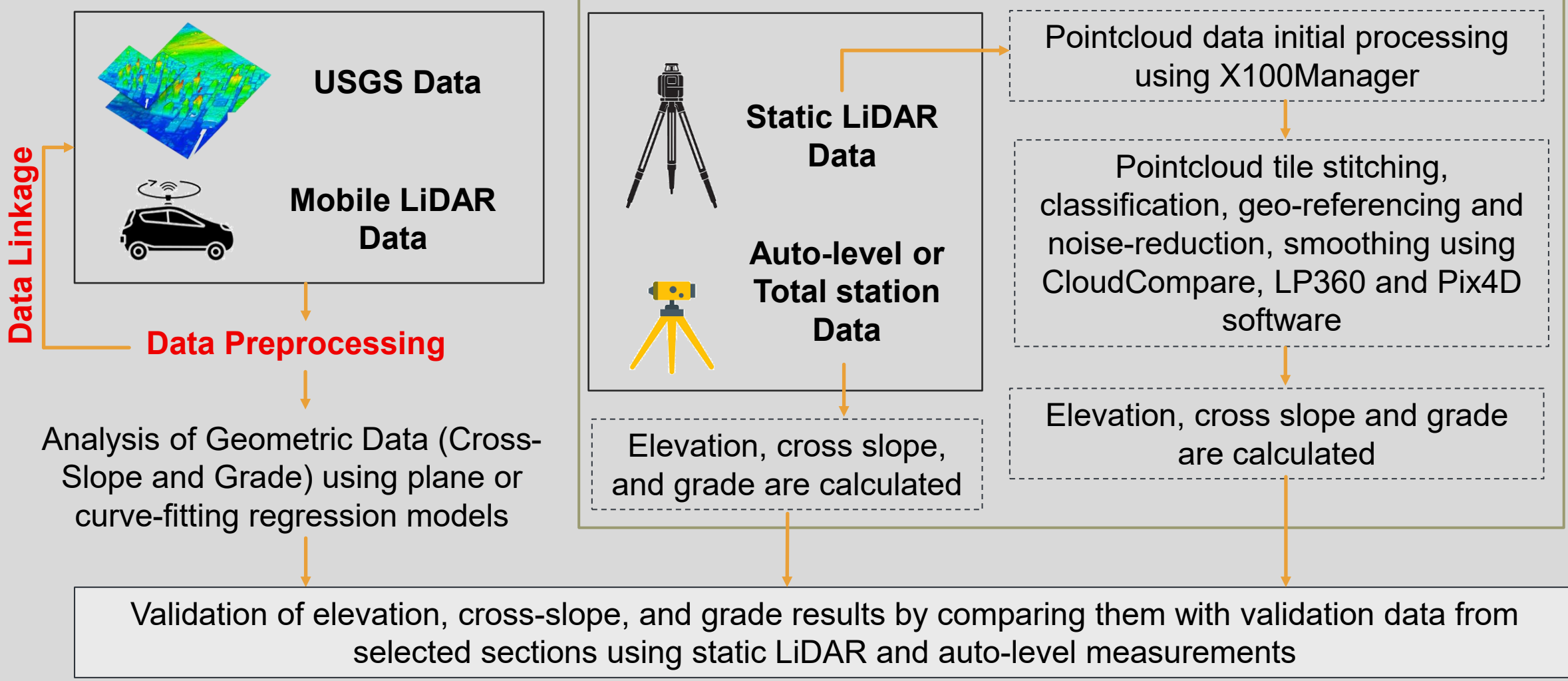
- A clear workflow that links pavement extraction, patch design, orientation control, and slope estimation.
- Validation-oriented and operational multi-source setups for network-level estimation.
- Practical guidance on when to use mobile LiDAR, static LiDAR, airborne LiDAR, and profile data together.



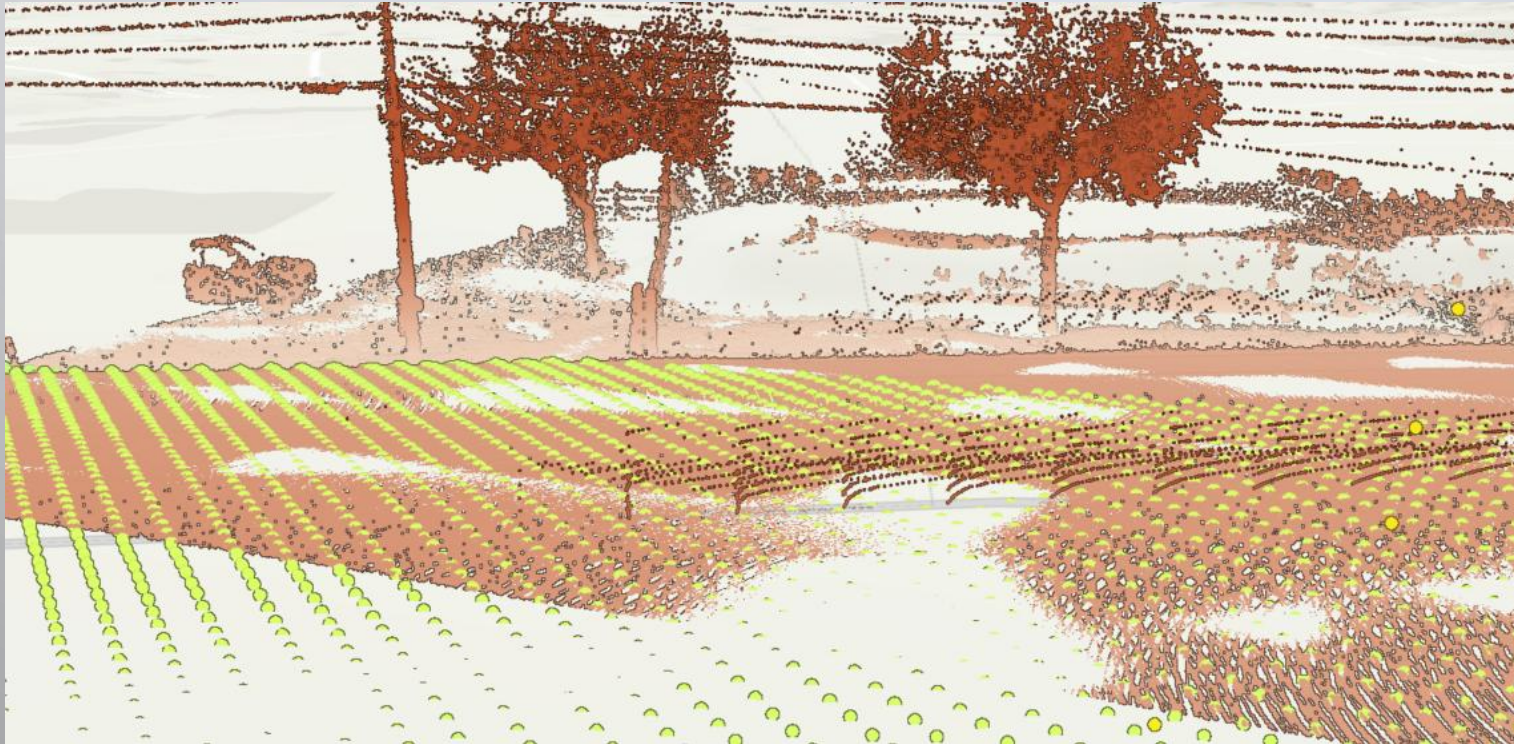
METHOD WORKFLOW

Train Set

Validation Set



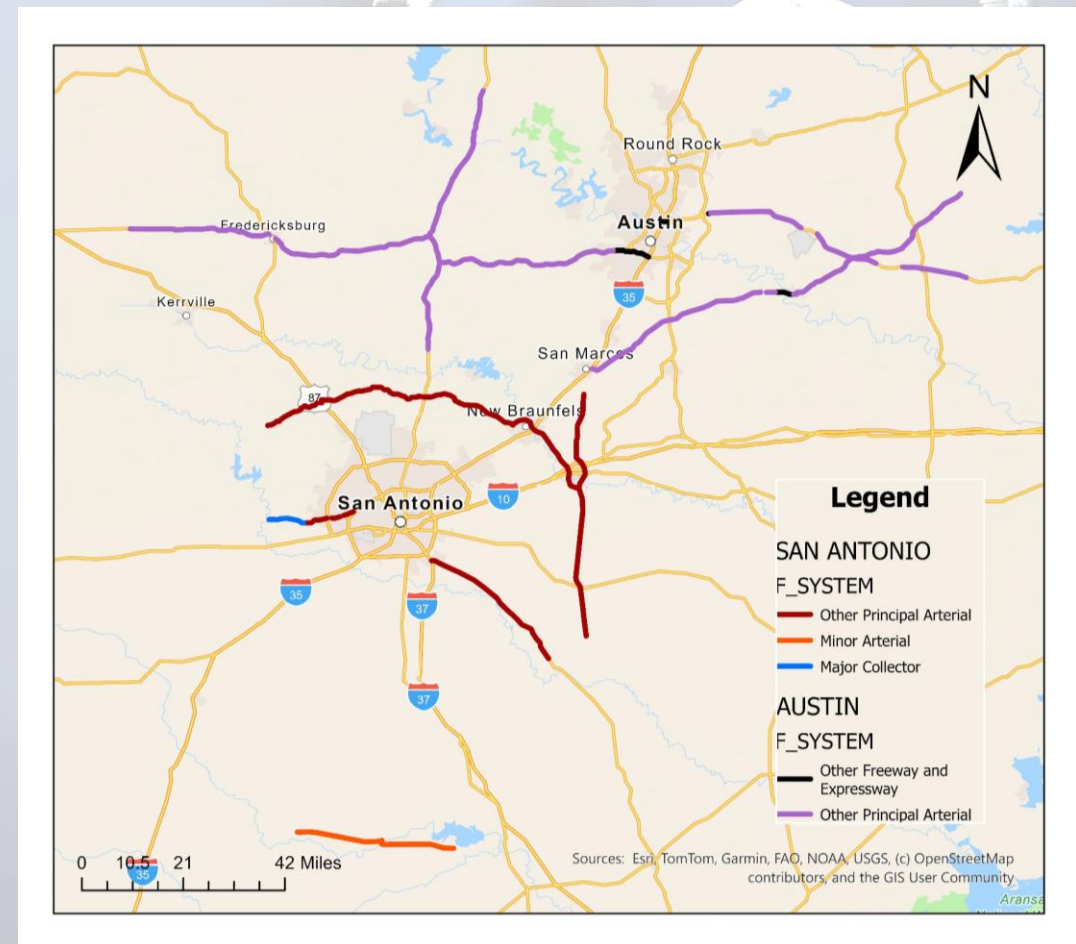
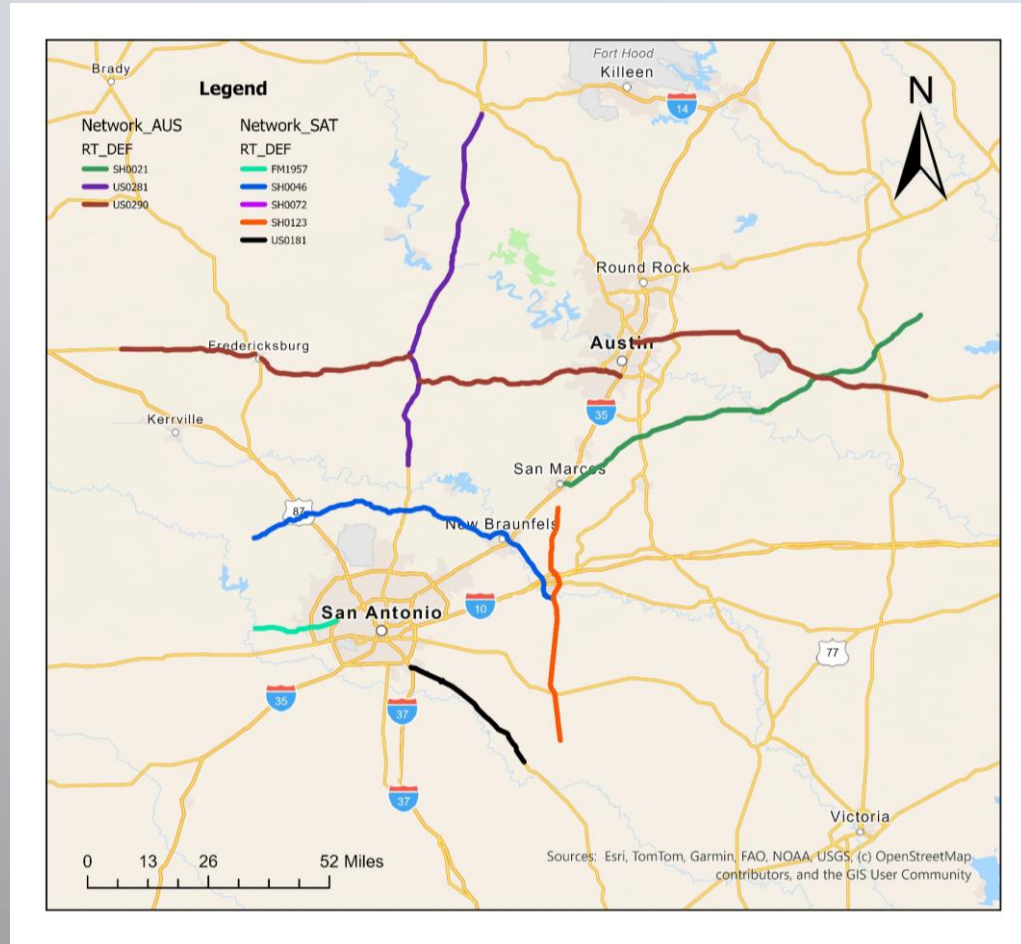
DATA SOURCES AND STUDY DESIGN



Mobile LiDAR derived point clouds (brown) compared to United States Geological Survey (USGS) LiDAR derived point clouds (yellow) for an area along the US290 highway in Austin, Texas.

- USGS Data Density: average 1-10 points/sq m
- Mobile LiDAR Data Density: average > 200 points/sq m
- Static LiDAR Data Density: average 200 points/sq m

DATA SOURCES AND STUDY DESIGN



Austin - 827.74 km roadway

San Antonio - 452.09 km roadway

PLANE FITTING

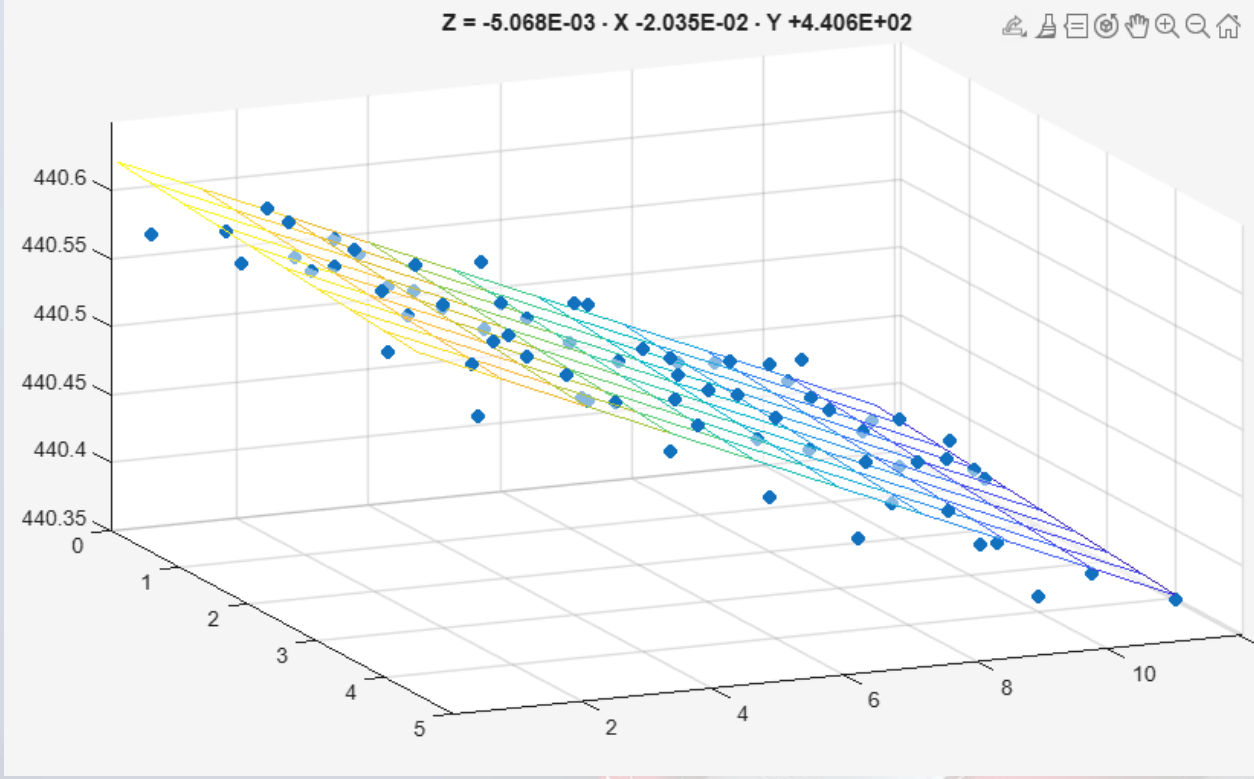
- A local patch of pavement points is selected within each roadway segment.
- A least-squares plane is fitted to the patch to estimate local surface orientation on the processed data.
- Roadway azimuth is used to separate the along-road direction from the transverse direction.
- Cross-slope is then derived from the fitted plane in the transverse direction.



PLANE FITTING



Patch fitting in SH0046 study area



Plane fit to calculate cross slope and elevation from point cloud geometries

$$z = a \cdot x + b \cdot y + c$$

$$a_{\parallel} = a \cdot \sin(\theta) + b \cdot \cos(\theta)$$

$$b_{\perp} = a \cdot \cos(\theta) - b \cdot \sin(\theta)$$

$$\theta = \arctan2(\Delta y, \Delta x)$$

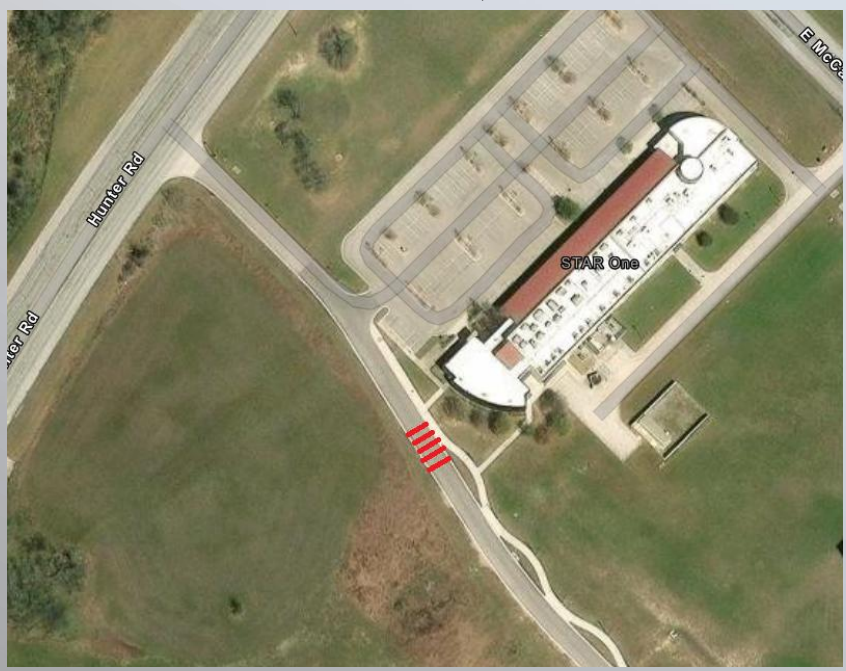
OPTIMIZATION FACTORS

- Patch Size: Too small can be noisy. Too large can smooth away local geometry.
- Orientation Control: Misaligned patches can bias the interpreted transverse slope.
- Noise Filtering and Smoothing: Filtering removes non-pavement points, while smoothing stabilizes the pavement surface. However, excessive smoothing can obscure critical features such as rutting, leading to biased cross-slope estimation.
- Point Density: Dense data improve lane-level detail. Sparse data may need stronger smoothing.

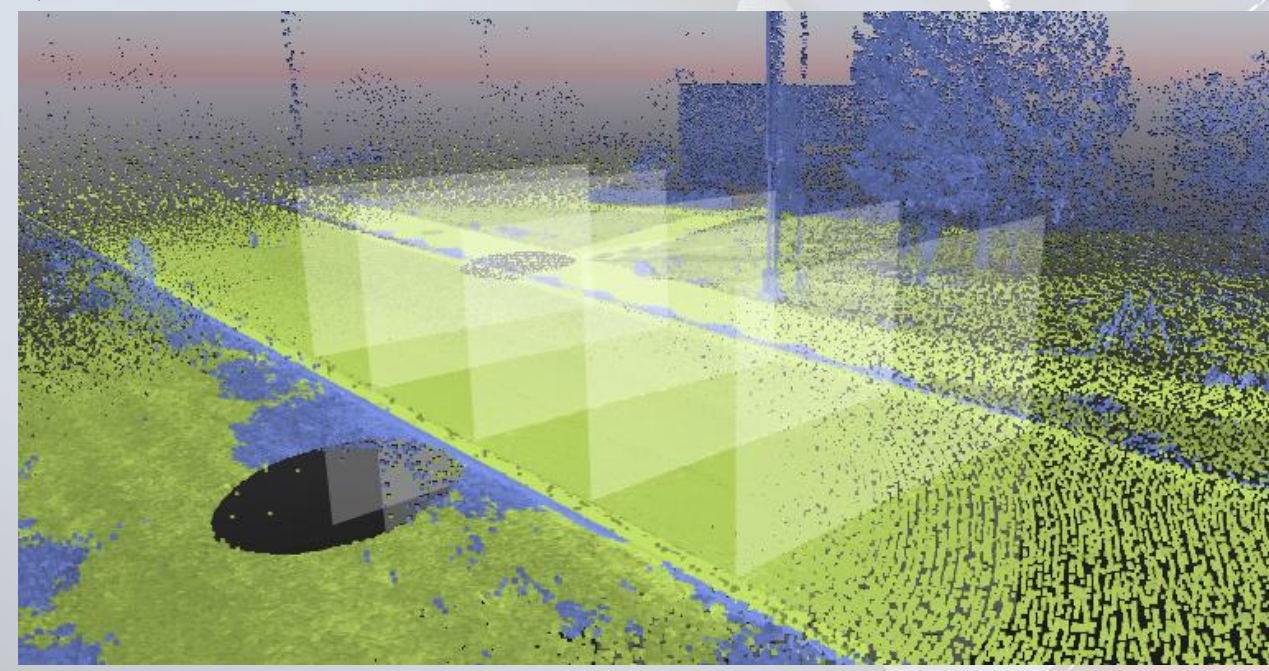


CASE STUDY A: VALIDATION-ORIENTED COMPARISON

USGS LiDAR, Static LiDAR, Auto Level Measurement

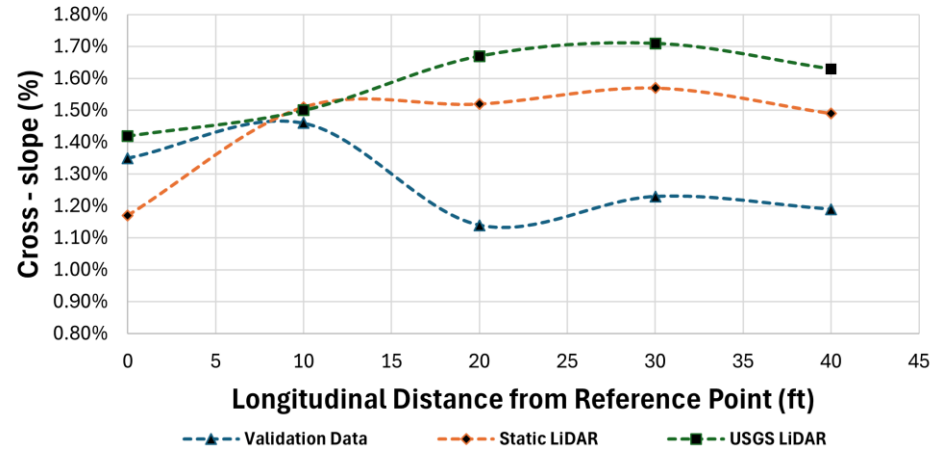


Case study roadway section (3055 Hunter Road). Transverse profiles were collected at 10 ft intervals along the longitudinal direction.

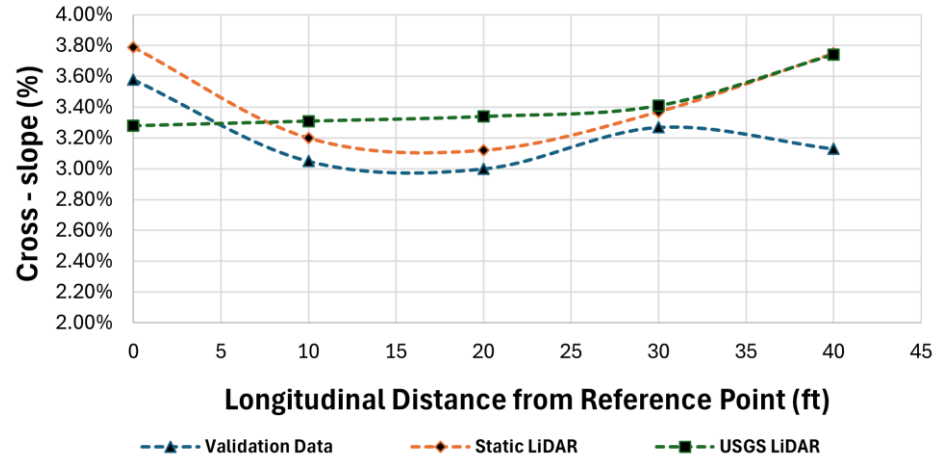


Point clouds acquired using static LiDAR. Green denotes ground points, while blue represents non-ground points. Vertical sections indicate auto level data collection locations.

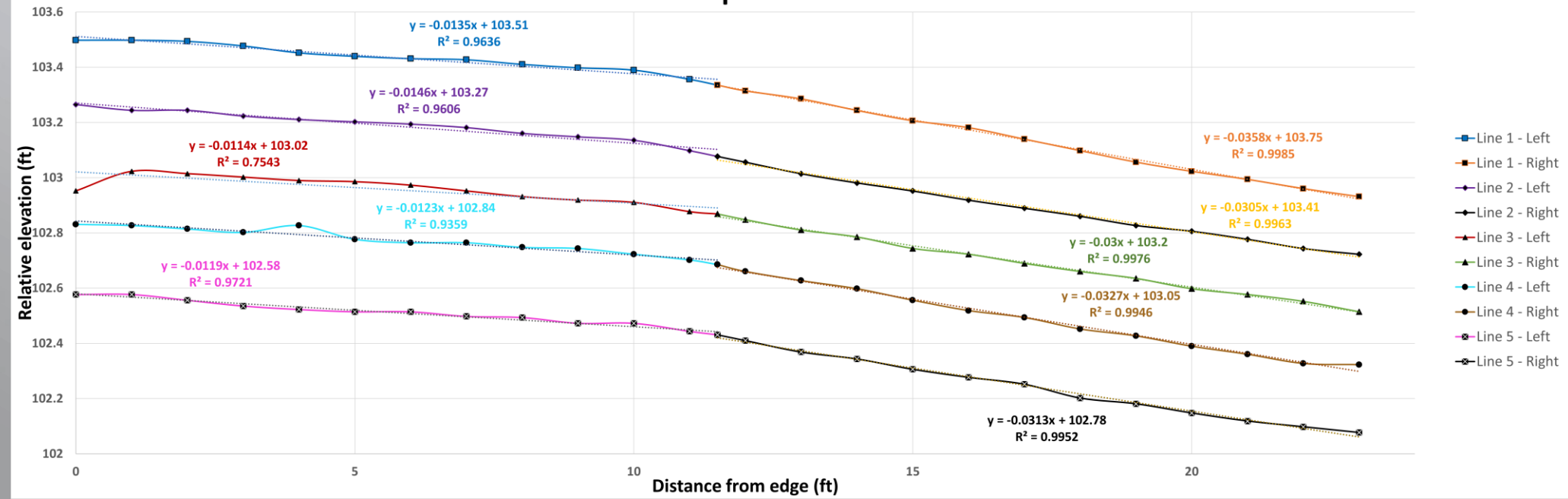
Cross Slope Measurement Comparison (Left)



Cross Slope Measurement Comparison (Right)



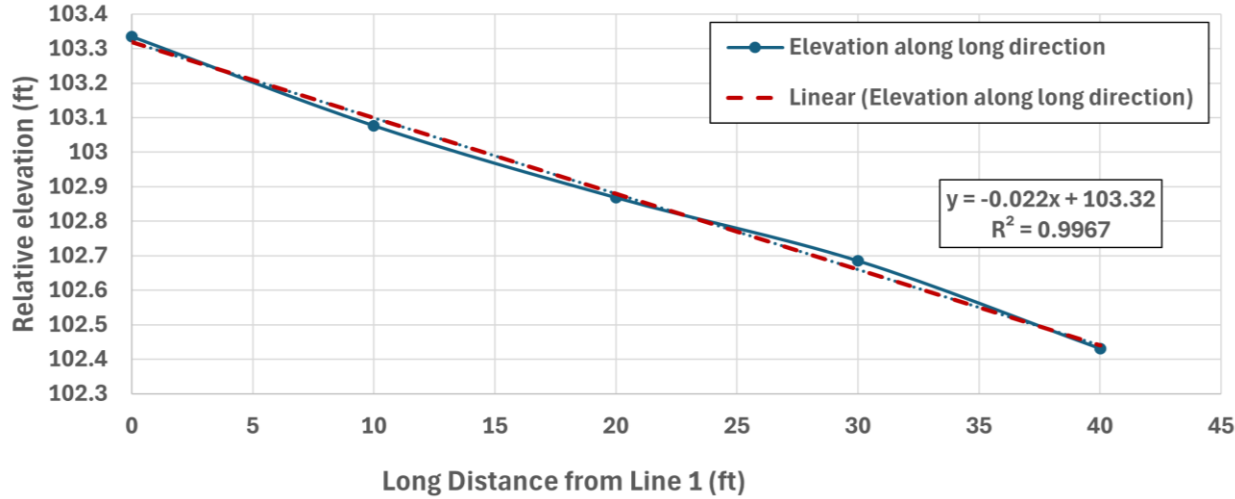
Slope Measurement



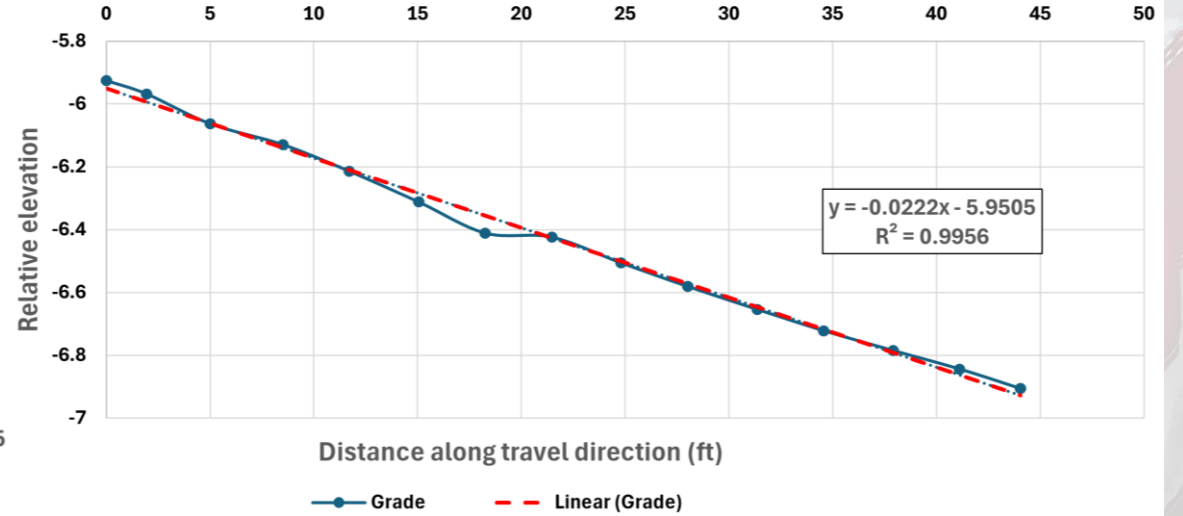
GRADE COMPARISON



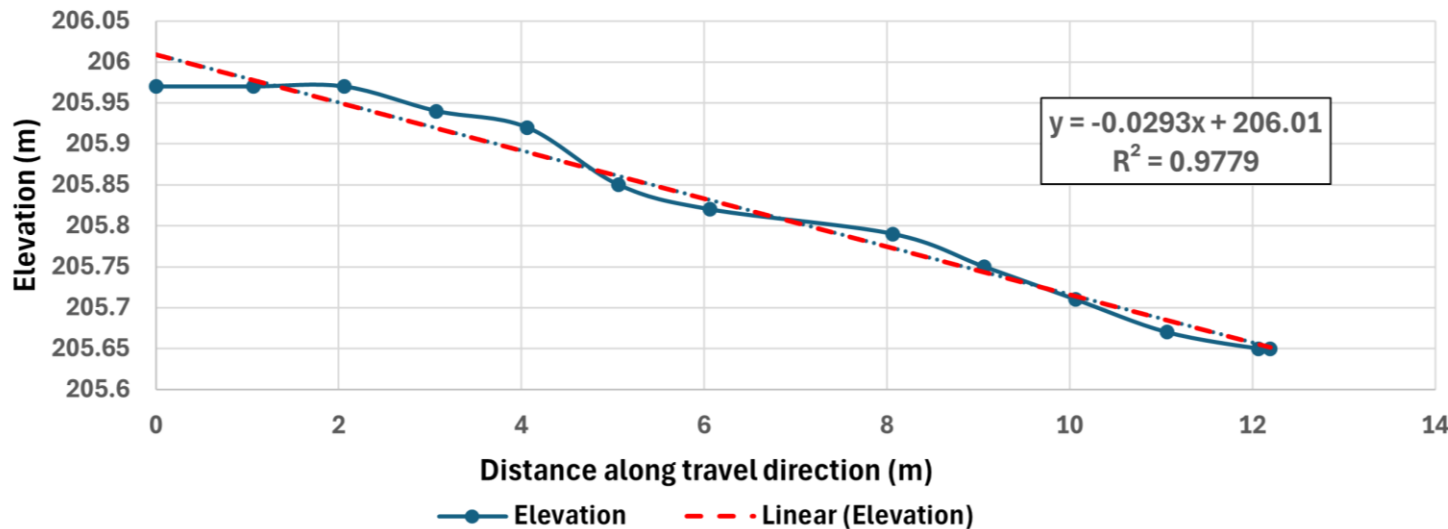
Grade - Auto Level



Grade - Static LiDAR



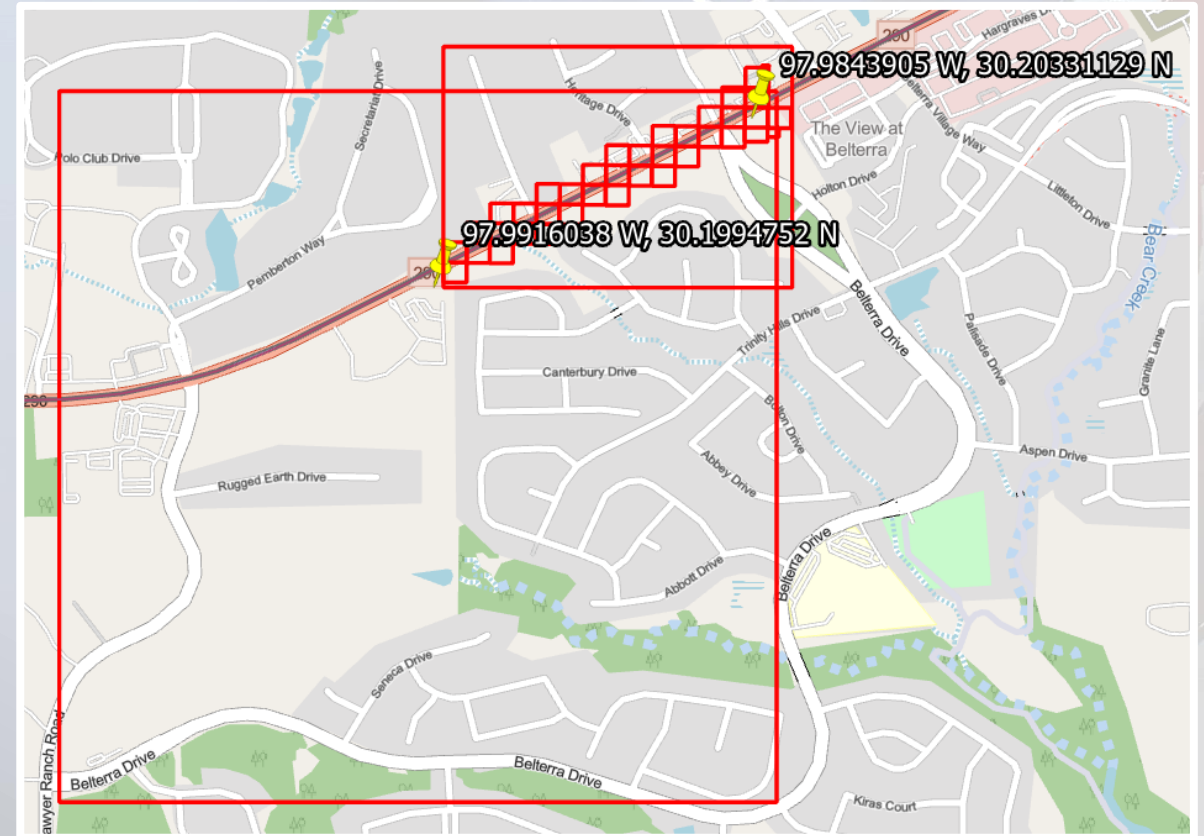
Grade - USGS LiDAR



Grade	
Static LiDAR	2.22%
USGS LiDAR	2.93%
Auto Level	2.20%

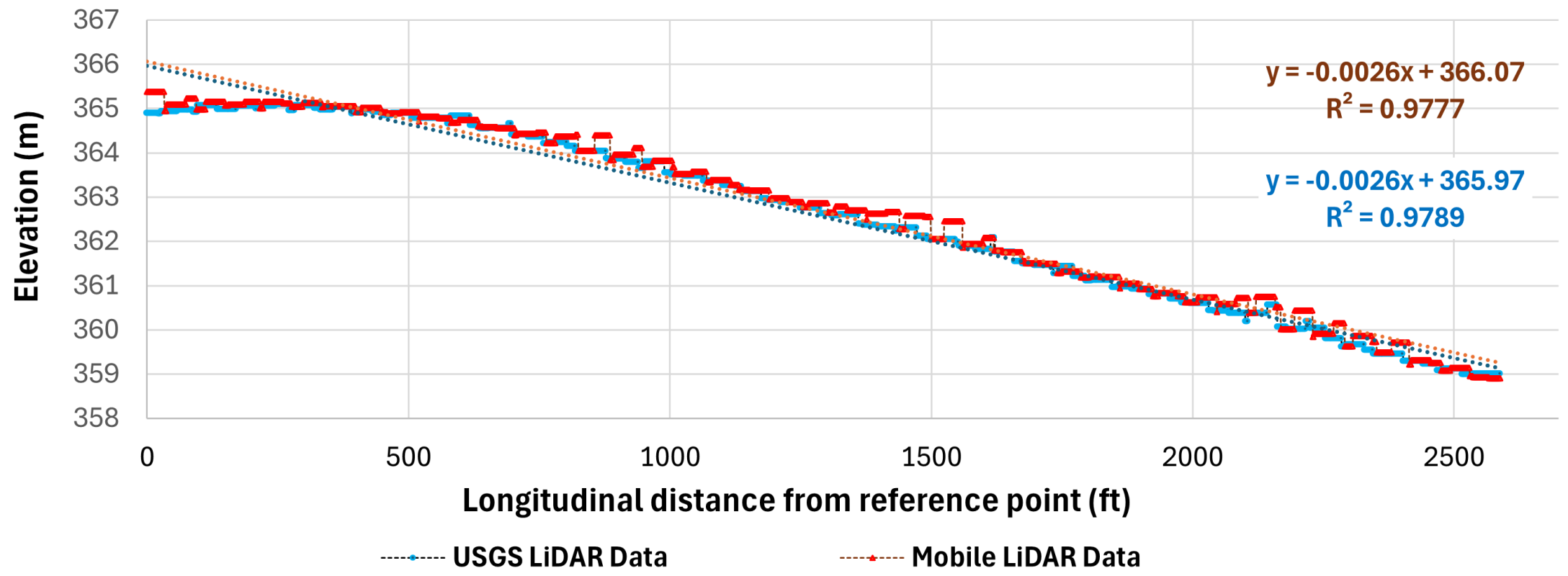
CASE STUDY B

- USGS and Mobile LiDAR Data
- AOI: 2,588 ft roadway, US290
- USGS point cloud density: 7 points per square m, Point spacing 0.358 m
- Mobile LiDAR point cloud density: 69 points per square m, Point Spacing 0.121 m

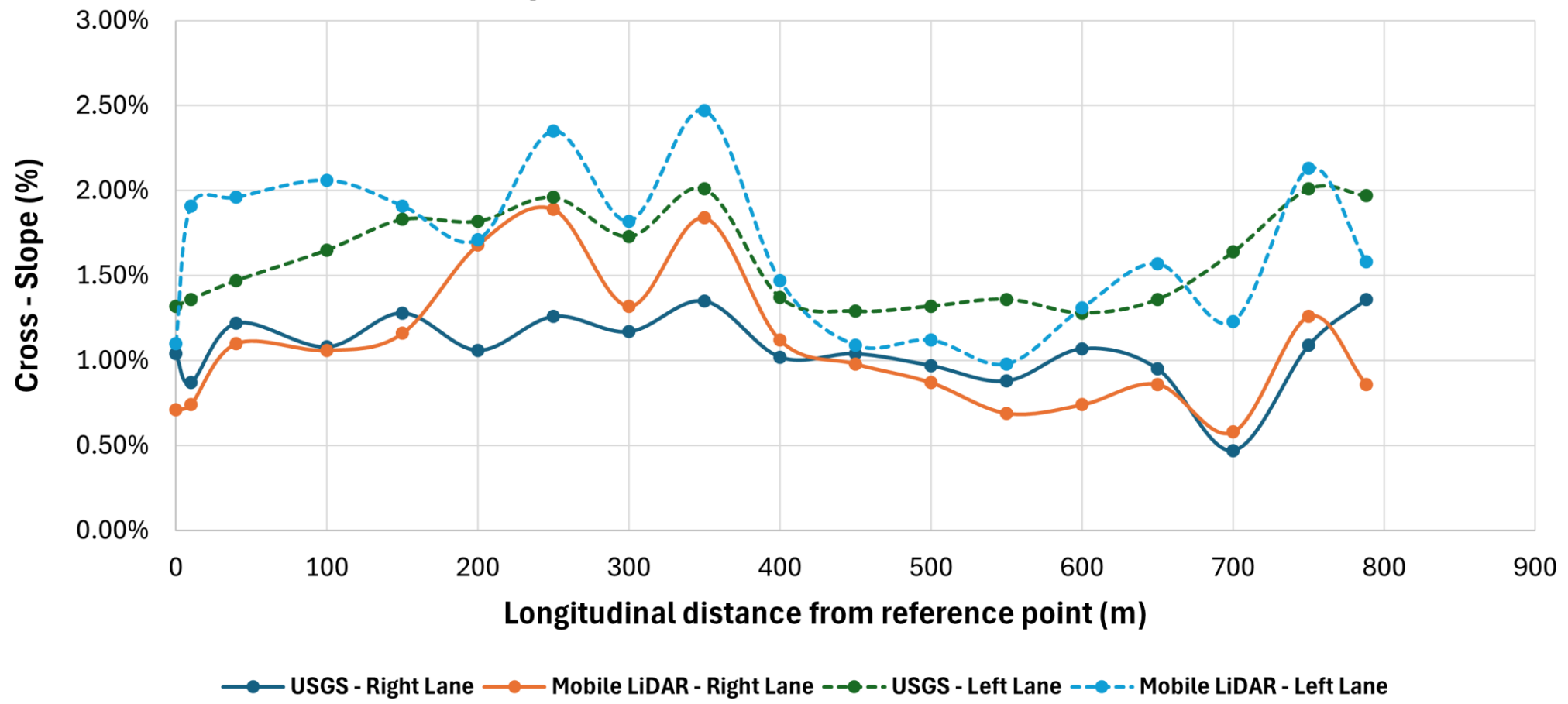


Study area along US 290

Elevation Comparison - USGS vs Mobile LiDAR



Cross- slope estimation - USGS vs Mobile LiDAR



LIMITATIONS AND FUTURE DIRECTION



Limitations

- Complex roadway conditions such as transitions, curves, and grade changes remain difficult
- Lower-density datasets still require stronger guidance for lane-level applications

Future Direction

- Test the workflow across more roadway types and geometric conditions
- Evaluate sensitivity to denoising and smoothing thresholds

CONCLUSIONS

- Patch-based plane fitting was effective for estimating roadway cross-slope from multiple LiDAR sources
- Static and mobile LiDAR produced more detailed and stable lane-level results
- USGS airborne LiDAR supported efficient large-area assessment with acceptable precision
- Optimization of patch size, orientation, and filtering improved slope consistency across datasets



ACKNOWLEDGEMENT

The authors sincerely acknowledge the Texas Department of Transportation (TxDOT) for funding this research under the ***Project 0-7211: Determine Hydroplaning Potential Using Existing Pavement Asset Data***. The authors also acknowledge the support of the CREATE University Transportation Center and thank Cyclomedia for providing the Mobile LiDAR data used in this study.



REFERENCES

- Cassule, L., Sarasua, W., Mahani, M., Burgett, J., Shams, A., Famili, A., 2021. Combined use of LiDAR and photogrammetry for highway cross-slope measurement.
- Ebrahimian, M., Nuruddin, A.A.B., Soom, M.A.B.M., Sood, A.M., others, 2012. Runoff Estimation in Steep Slope Watershed with Standard and Slope-Adjusted Curve Number Methods. Polish journal of environmental studies 21.
- Guo, X., Zhang, C., Cui, B., Wang, D., Tsai, J., 2013. Analysis of Impact of Transverse Slope on Hydroplaning Risk Level. Procedia - Social and Behavioral Sciences, Intelligent and Integrated Sustainable Multimodal Transportation Systems Proceedings from the 13th COTA International Conference of Transportation Professionals (CICTP2013) 96, 2310–2319. <https://doi.org/10.1016/j.sbspro.2013.08.260>



REFERENCES

- Kakara, S., Chowdary, V., 2020. Effect of Pavement Roughness and Transverse Slope on the Magnitude of Wheel Loads. Arab J Sci Eng 45, 4405–4418.
<https://doi.org/10.1007/s13369-020-04492-9>
- Luo, W., Wang, K.C., Li, L., 2016. Hydroplaning on sloping pavements based on inertial measurement Unit (IMU) and 1mm 3D laser imaging data. Periodica Polytechnica Transportation Engineering 44, 42–49. <https://doi.org/10.3311/PPtr.8208>
- Shams Esfandabadi, A., 2018. Highway Cross Slope Measurement Using Airborne and Mobile LiDar (Ph.D.). Clemson University, United States -- South Carolina.
- Tsai, Y., Ai, C., Wang, Z., Pitts, E., 2013. Mobile cross-slope measurement method using lidar technology. Transportation research record 2367, 53–59.
<https://doi.org/10.3141/2367-06>





HONORING THE PAST. PAVING THE FUTURE.

THANK YOU!

Visit our lab website! <https://tilab.wp.txstate.edu/>

