TxDOT Mobile Lidar Specifications and Project Workflow for Design-Grade Mapping Applications

Gorrondona & Associates, Inc. – Scott Dunham, CP, CMS Lidar
TxDOT Design Division Remote Sensing Services Section

June 2025

Contents

Manual Use

This manual serves as a comprehensive guide for mobile Lidar specifications and a general mobile Lidar project workflow. It empowers Mobile Lidar consultants to exercise their judgment in the development of drive plans, control layouts, technology selection, and workflow optimizations while ensuring strict adherence to TxDOT accuracy and deliverable standards for transportation infrasructure design.

Mobile Mapping Systems


Figure 1: Mobile Lidar Point Cloud, colorized by elevation

Mobile Lidar is a technology used to map the environment by measuring distances of objects with laser light. It is an efficient solution for surveying large areas that are impractical with terrestrial scanners but require an accuracy and resolution that exceed airborne technologies.

Mobile Lidar systems typically consist of one or more Lidar sensors, GPS receivers, an inertial measurement unit (IMUs), and multiple cameras mounted on a vehicle. As the vehicle moves through an area, the Lidar sensor emits laser pulses in multiple directions, measuring the time it takes for the laser to reflect off surfaces and return to the sensor. By combining these distance measurements with navigaitonal information, mobile Lidar systems can create highly detailed design-grade mapping of the surrounding environment for TxDOT projects. It is important to note that Mobile Lidar is a line-of-sight technology and requires conventional survey to supplement any obscured areas, or voids in the data.

Aerial photogrammetry and airborne Lidar are often integrated with mobile Lidar data for a blended geospatial solution for TxDOT. Mobile Lidar is utilized to capture highly accurate information on roadway surfaces and beyond the edge of pavement, aerial mapping provides a wider swath of data for engineering design.

Mobile Lidar Components

- Lidar Sensor - OSHA Regulation 1926.54 and manufacturers' recommendations when using any laser equipment. Never stare into the laser beam or view laser beams through magnifying optics, such as telescopes or binoculars. Additionally, the eye safety of the traveling public and other people should always be considered, and the equipment operated in a way to ensure the eye safety of all.
- An IMU typically consists of an electronic gyro within a sealed unit mounted securely on or near the primary sensor.

- One or more onboard (roving) GNSS dual frequency receiver(s) capable of RTK data and kinematic data that can be post processed.
- One or more static GNSS dual frequency receiver(s) at base station(s) capable of simultaneous collection and storage of RTK data and kinematic data that can be post processed.
- A DMI typically mounted near vehicle wheel housing. It is used primarily as a supporting measurement that allows for sensor collection at relative distance intervals and can suspend measurements while the vehicle is motionless due to vehicle traffic stops during collection.
- The collection rate (epoch) of the mobile Lidar system sensors must be adequate to meet project accuracy and point density requirements.

Mobile Lidar Project Requirements

- RPLS or ASPRS CMS-Lidar (Precertified for TxDOT work category 15.3.4 Mobile Lidar) is required for overseeing Mobile Lidar mapping projects.
- Prior to data acquisition, the control layout must be provided to the TxDOT PM and included with the final deliverables for each project.
- The Mobile Lidar crew, at a minimum, should consist of a driver and a Lidar operator.
- TxDOT Level 3 ground control points, as specified in the "TxDOT Survey Levels of Accuracy for GPS," should be set prior to Mobile Lidar acquisition to ensure visibility within the point cloud. Lidar ground control points may be surveyed concurrently or following Mobile Lidar data acquisition.
- The base station must be set up on a known control point (TxDOT Level 3), typically in the center of the project area, not exceeding 15 km (9.32 miles). Longer projects that are 10 miles and above may necessitate multiple base stations.
- Mobile Lidar accuracy must be a minimum of +/- 0.05-ft vertical RMSE relative to control targets. Ground control points for Mobile Lidar will be surveyed using digital leveling or base and rover methods, determined during project scoping.
- Sufficient scan overlap with adjacent drive lines.
- For all Mobile Lidar missions, a 5-minute static session before and after data acquisition is mandatory. The static session allows for the alignment of the inertial measurement unit (IMU and the GNSS for improved processing.
- A Lidar ground-truthing report must be provided as part of the final deliverables.

Mobile Lidar System Technology Requirements

- Mobile Lidar System Minimum Technology Specifications:
  A dedicated Mobile Lidar System (MLS) is recommended by TxDOT. If a non-dedicated mobile Lidar sensor is mounted to a vehicle, it must achieve the same data quality as a dedicated mobile Lidar mapping system. The following factors must be considered when producing design-grade mapping for critical infrastructure:

    - Lidar point density.
    - Final RMSEV and RMSEH accuracy.
    - Angular accuracy.
    - Laser range.
    - Reflectivity capabilities on hard surfaces (dedicated mobile Lidar sensors are designed for this).
    - Lidar sensor must be able to collect at highway speeds or posted speed limits for safety.
    - Fixed position on collection platform (dedicated mobile Lidar system) - this stability helps maintain consistent sensor orientation and reduces positional errors, contributing to repeatable higher accuracy in data acquisition.
    - A minimum 1,000 points/m^2 Lidar point density.
    - The system must include a 360° imagery solution equipped with multiple on-board high-definition cameras. Georeferenced images provide supporting information from multiple perspectives to the Lidar dataset of the entire roadway environment. Image references of above ground utilities and other key planimetric features (including bridge substructure elements) provide Lidar Mapping Technicians to effectively cross-reference features between two datasets. This is critical when a particular feature is not clearly discernable in the Lidar pointcloud, impacting completeness of the final mapping products.
- It is recommended to mount the sensor on a truck or sprinter van for a higher angular vantage point, at least 9' above the ground.
- The Mobile Lidar system must have onboard GNSS, collecting 1-second epoch intervals.
- An onboard IMU with multiple readings per second.
- Mobile Lidar sensors must undergo an annual Lidar sensor calibration performed by the manufacturer. The annual calibration is performed in a laboratory where all Lidar system components are thoroughly tested for measurement quality. The updated calibration values of the Lidar and camera sensor orientation are input into the Lidar processing software for improved processing accuracy. This is essential for TxDOT design-grade mapping.

Mobile Lidar Data Requirements

- Point cloud data should be provided in LAS format accompanied by metadata.
- Images must be georeferenced to the point cloud and supplied in JPEG format.
- All Lidar data must be classified to ASPRS 1.2 (or above) specifications.
- The point cloud must be appropriately tiled to facilitate end-user computing efficiency.
- For optimal data quality, the point cloud must contain a minimum of 1,000 points per square meter (approximately 140 points per square foot) for a single pass at 60 mph, within 10 feet of the vehicle trajectory, as illustrated below. Slower speeds will yield greater point density, however data collection operations below the posted speed limits would require a lane closure and would impact the traveling public.

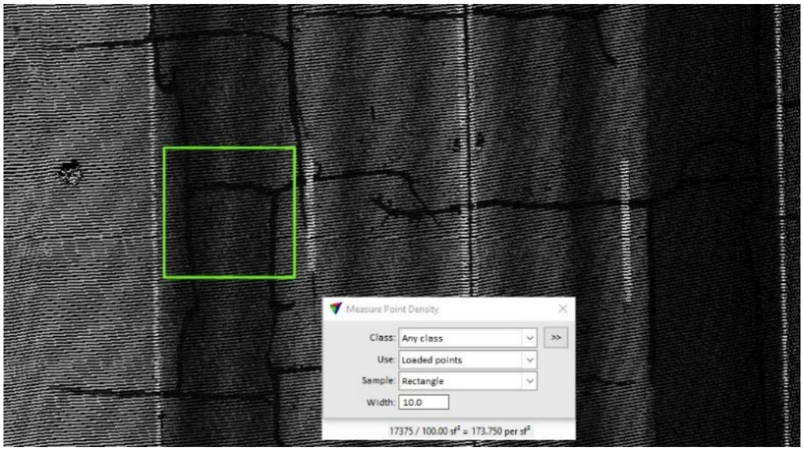


Figure 2: Mobile Lidar Density of approximately 1,000 points per meter², 140 points per sq. ft.

Mobile Lidar Accuracy Requirements

Mobile Lidar accuracies are as follows:

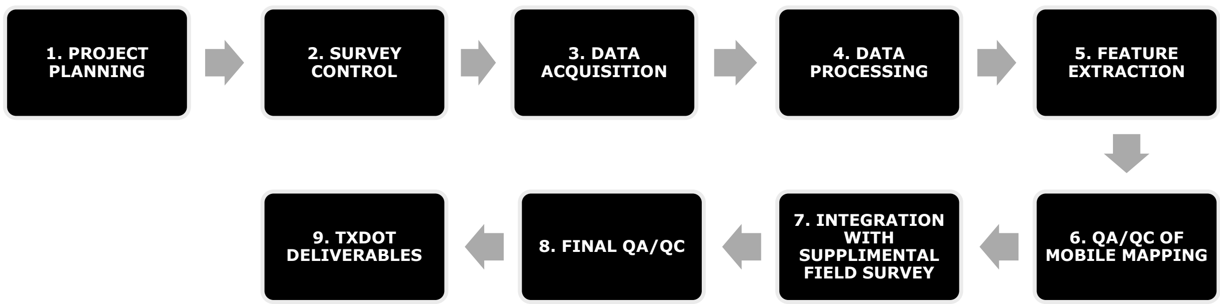
- Absolute Accuracy: +/-0.05-ft. RMSE vertical accuracy on hard surfaces, constrained to a control network.
  - Hard Surfaces (survey control methodology to be discussed in scoping):
    - Digital leveling methods: 0.05-ft. accuracy.
    - Base and Rover methods: 0.05-ft. accuracy.
  - Soft Surfaces:
    - 0.33-ft. vertical accuracy on soft surfaces with short grass. Results on soft surfaces are similar with the (American Society of Photogrammetry and Remote Sensing) ASPRS Class I Photogrammetry Specifications.
    - Coordination with TxDOT to mow the corridor prior to data acquisition is recommended if tall grass is present near roadway.
  - Extraction distances:
    - Dependent on the height of the sensor and the angle of incident, the mobile Lidar consultant may use caution in extracting 2D/3D planimetrics and 3D DTM data beyond 50 feet from edge of pavement (EOP) because of point cloud disbursement in the signature return at that distance.

Lidar Ground-Truthing Requirements

Mobile Lidar projects are expected to include a minimum of 30 Lidar ground-truthing checkshots for projects under two miles. For projects greater than 2 miles, a minimum of 10 Lidar ground-truthing checkshots per mile is required (with no less than 30 checkshots for Lidar accuracy assessment).

- The determination of the ground-truthing check shot count for a project will be undertaken by an RPLS or ASPRS CMS in Lidar, considering factors such as urban and rural environments, tree cover/ground vegetation, GPS quality, and other relevant considerations.

Mobile Lidar Workflow



1. PROJECT PLANNING

Drive Plan

Mobile Lidar necessitates meticulous planning to establish a comprehensive drive plan capable of covering the entire project area. The drive plan must be formulated in a KMZ format and should be included with the control layout.

Control Network Layout

An appropriate number of Lidar ground control points will be strategically positioned in flat (no slopes) and open areas, and a base station will be established on a primary (preferably) control point along the corridor. Lidar chevrons will adhere to TxDOT Level 3 accuracy specifications.

Environmental Factors

Environmental considerations play a pivotal role in the planning phase of Mobile Lidar projects. The following is a list of common environmental factors that can significantly impact Lidar quality:

- Temperature: The Lidar sensor operates within a temperature range of 14°F to 104°F. Data collection outside this range may result in poor-quality data.
- Precipitation: All scanning activities must occur in dry conditions. Standing water on the ground or morning dew can create void areas within the Lidar point cloud. Water or frozen precipitation has limited reflectivity, making it crucial to ensure dry ground at the time of data collection through thorough planning and forecasting.
- Sun Angle: Rising or setting sun angles can lead to lens flare, degrading the quality of images captured by the Mobile Lidar system.

- Dust: Airborne dust or debris, whether caused by wind or traffic, can introduce noise within the Lidar point cloud.
- Electromagnetic Interference: Railroad crossings, toll booths, and powerlines are potential sources of signal interference with ground-based Lidar collection. Careful consideration and planning are required to mitigate these interferences and ensure data accuracy.

2. SURVEY CONTROL

Mobile LIDAR Chevron

Mobile Lidar targets are established prior to data acquisition to ensure visibility within the Lidar point cloud.

- Each Mobile Lidar project will be meticulously planned, considering specific control layouts tailored to terrain type, urban/rural environments, vertical changes along the corridor, bridges, and intersections of minor and major roads.
- Mobile Lidar control points will be strategically set at 1,000-ft. intervals on non-divided highways. For divided highways with a median or jersey barrier, control points must be positioned in each direction of the corridor.
- In rural areas with low relief, such as West Texas, control points can be spaced at intervals greater than 1,000 ft., if Mobile Lidar vertical accuracy of 0.05-ft. is met or exceeded. However, if interval spacing exceeds 1,000 ft., additional vertical checkshots will be required. The number of additional checkshots will be determined by the Mobile Lidar consultant.

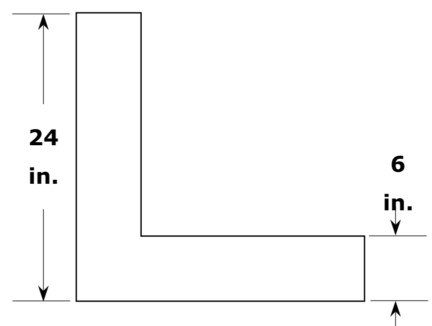


Figure 3 : Mobile Lidar Chevron Dimensions, red dot is PK nail location

- The dimensions of the Mobile Lidar chevron are illustrated on the right. The red dot on the Mobile Lidar Chevron diagram indicates the placement of a Mag (or similar) nail when setting a control point.
- Mobile Lidar ground control points must have reflective paint (glass beads) for optimal visibility within the point cloud. Mobile LIDAR consultants often use black base paint and then paint a white topcoat of reflective paint (with a control point shape template), leaving a black outline against the white reflective paint for high-contrast ground control points. Reflective adhesive tape has also been successfully used in the field, but field crews must be cautious of cold or hot temperatures affecting the bonding properties with the pavement surface.

Mobile Lidar ground control points can be set in a variety of shapes and dimensions. It is up to the mobile Lidar consultant to choose what works best within their Lidar processing software recognition tools for ground control point identification for trajectory alignment.

3. DATA ACQUISITION

Pre-Acquisition Checks:

Prior to Mobile Lidar data acquisition, the Mobile Lidar Acquisition Team must perform the following:

- Driving the Mobile Lidar vehicle in a safe environment (such as an empty parking lot) in a figure-eight pattern to excite the IMU.
- Static sessions before and after each Mobile Lidar mission are mandatory for each collection day. If the GPS base station needs to be reestablished, static sessions for the mobile Lidar system must be performed again.

Once pre-acquisition checks are completed, the mobile Lidar mission can continue. The Mobile Lidar acquisition team will implement the drive plan developed by the RPLS or ASPRS CMS-Lidar. Throughout the acquisition process, the Lidar operator will monitor IMU measurements, GPS satellite constellation lock, laser performance, and camera settings. Any potential obstructions leading to shadowing, which may create voids in the data, will be noted, and the acquisition team will conduct an additional pass if necessary to minimize voided areas. Notes detailing obscured area boundaries will be provided to the Mobile Lidar Manager for the identification of area requiring supplemental survey.

As a best practice, the Mobile Lidar Manager, serving as an additional set of eyes beyond the field acquisition team, will utilize a GIS Web Map to observe Mobile Lidar acquisition in real-time. This ensures the complete coverage of the project limits before demobilization from the project site.

4. DATA PROCESSING

Processing

With processing, images are georeferenced to the point cloud, individual trajectories are aligned to each other and the total point cloud is constrained to the control network. Lidar data will be transferred from the Mobile Lidar system and converted to .LAS files and JPEG images. Mobile Lidar data (including navigational info and vehicle trajectories) will go through a pre-processing regiment to create the .LAS files for each Lidar strip and align images to the point cloud. During post-processing, trajectories are split, aligned to each other, and the entire point cloud is registered to the control network.

<u>Image calibration:</u>

- Establish image alignment to point cloud.
- Visually inspect image alignment to point cloud.

<u>Lidar processing (trajectory alignment)</u>, Lidar consultants will:

- Extract .LAS files.

- Review IMU and GPS quality reports.
- Review .LAS files for completeness.
- Translate all data to the required coordinate system.
- Scan to scan matching.
- Evaluate vertical alignment of overlapping scan position data.
- Evaluate horizontal alignment of overlapping scan position data.
- Tile data (data management) < 300mb per tile for end user consumption.
- Perform QA/QC of the processed Lidar data compared against the control network and run an RMSE report to be reviewed by RPLS. Figure 4 illustrates a sample RMSE report.

250	3129545.432	13824454.818	35.913	35.908	-0.005
251	3130189.243	13824572.796	37.498	37.515	+0.017
252	3130508.143	13824464.975	35.567	35.560	-0.007
253	3131033.561	13824979.713	37.116	37.115	-0.001
254	3131819.364	13825068.526	36.505	36.504	-0.001
255	3131572.619	13825266.297	37.151	37.143	-0.008
256	3131565.651	13825586.812	35.519	35.518	-0.001
258	3131896.670	13825125.355	35.790	35.779	-0.011
259	3131877.281	13825386.410	36.882	36.878	-0.004
260	3131648.710	13825633.915	34.703	34.697	-0.006
261	3132805.891	13825689.106	29.224	29.224	+0.000
262	3132534.723	13826378.273	34.515	34.516	+0.001
263	3133072.501	13825762.102	20.616	20.613	-0.003
264	3132890.175	13826030.664	23.820	23.823	+0.003
265	3133442.086	13825854.212	18.581	18.574	-0.007
266	3133421.342	13825895.370	18.683	18.685	+0.002

Average dz	-0.003
Minimum dz	-0.020
Maximum dz	+0.017
Average magnitude	0.005
Root mean square	0.007
Std deviation	0.006

Figure 4: RMSE report

Lidar Ground Truthing

Ground truthing checkshots collected by Survey/Mobile Lidar consultants will be used for comparative analysis against the final TIN. A minimum of 30 check points for projects under two miles, evenly distributed throughout the project area, are required for any field check task. Each Lidar consultant will determine check point locations throughout the project to provide quality statistics for the entire project area. For larger corridor projects above two miles in length, at least 10 checkshots per mile in well-defined, flat, and open areas on both hard and soft surfaces are necessary. This requirement does not include any points withheld from the final quality statistics. Urban areas with dense planimetric features may require more checkshots, due to more line-of-sight obstructions, parked cars, walls, etc.

Classification

Classification software must be utilized for classifying Mobile Lidar data for feature extraction purposes. The Mobile Lidar data will be classified according to the standard ASPRS 1.2 (or above) specifications:

Classification Value	Classification Type
0	Never Classified
1	Unassigned
2	Ground
3	Low Vegetation
4	Medium Vegetation
5	High Vegetation
6	Building

Figure 5: ASPRS LAS 1.4 Classifications

Point Cloud Noise

Mobile Lidar captures points on all surfaces within the distance, surface reflectivity, and/or angle of incidence limits for the Lidar system. Points on surfaces such as vehicles or false points caused by the distortion of the laser signal return are considered noise and must be classified to "0 – Never Classified".

5. FEATURE EXTRACTION

The first step in the feature extraction phase is to identify obscured areas so that survey field crews can collect supplemental data concurrently with the Mobile Lidar mapping.

Next, 2D/3D planimetric/3D DTM feature extraction is performed using a point cloud data management, data quality assessment, and extraction software (similar to TopoDOT and Terrasolid). Feature extraction is carried out by utilizing both the Lidar and calibrated, georeferenced images. All Mobile Lidar feature extraction will adhere to the TxDOT Photogrammetry Feature Collection Standards, outlined in the TxDOT Surveyors' Toolkit. It is important to speak with the TxDOT Project Manager to determine feature collection requirements for each project.

- Lidar technicians will collect all 2D/3D planimetric and 3D DTM features typically shown at a 1" = 50' map scale, as standard in MicroStation Open Roads Designer (ORD) and will comply with TxDOT CADD Standards.

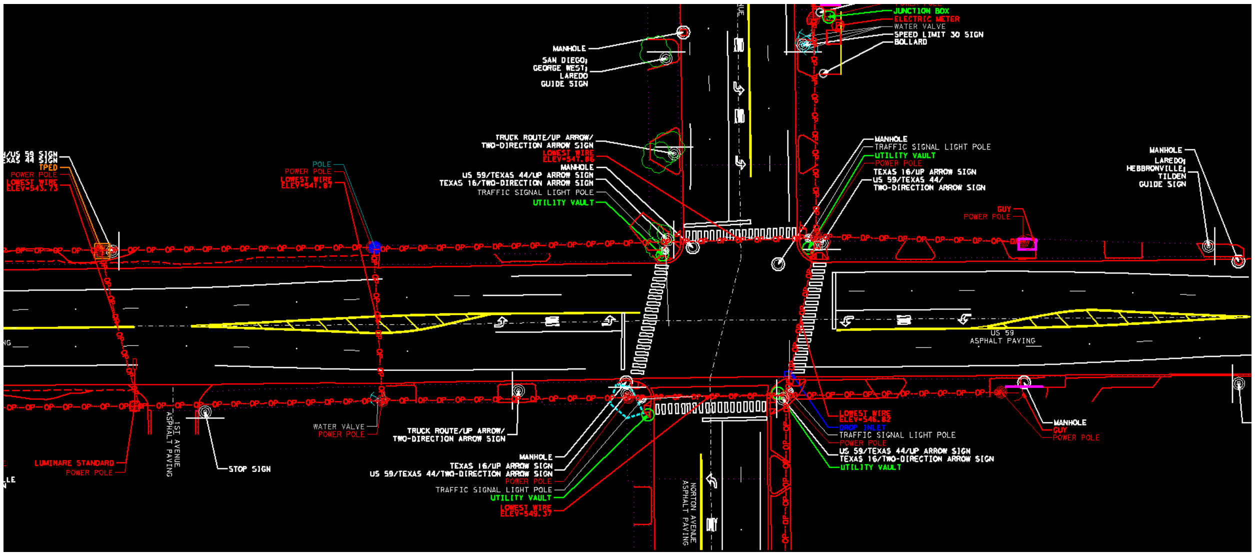


Figure 6: TxDOT Mobile Lidar 2D Planimetrics Extraction

6. QA/QC OF MOBILE MAPPING:

All feature-extracted 2D/3D planimetrics/3D DTM information will be initially edited by the Mobile Lidar Manager. Lidar ground-truthing checkshots will be compared with TIN. A preliminary TIN will be created and used as part of the initial review process before sending the final Lidar data to the RPLS for integration with conventional survey data.

7. INTEGRATION WITH SUPPLEMENTAL SURVEY:

Any obscured areas within the mobile Lidar mapping will require a supplemental field survey. Integration of Mobile Lidar Mapping with the supplemental survey will be performed and reviewed by an RPLS. Any QC markups will be sent back to the Mobile Lidar Manager and the extraction team to perform any revisions and fixes. Any changes in the final data will require a TIN file to be re-generated and reviewed.

8. FINAL QA/QC:

Final QA/QC of merged Mobile Lidar and Conventional Survey data will be performed by an RPLS, and all mapping data will be prepared for final deliverables to the State.

9. TXDOT MOBILE LIDAR DELIVERABLES:

- KMZ containing drive plan and control layout.
- Mobile Lidar acquisition certification containing date, time, and weather conditions observed during data collection.
- Processed and classified point cloud in LAS format with metadata.

- Georeferenced images in JPEG format.
- 2D/3D Planimetrics, 3D DTM, and TIN in MicroStation Open Roads Designer (ORD).
- ASCII point file containing Mobile Lidar ground control point locations.
- Completed Aerial Ground Control Submission (Form ROW-S-GrndCntrl).
- RMSE report with statement of accuracy from Lidar ground-truthing check shots.

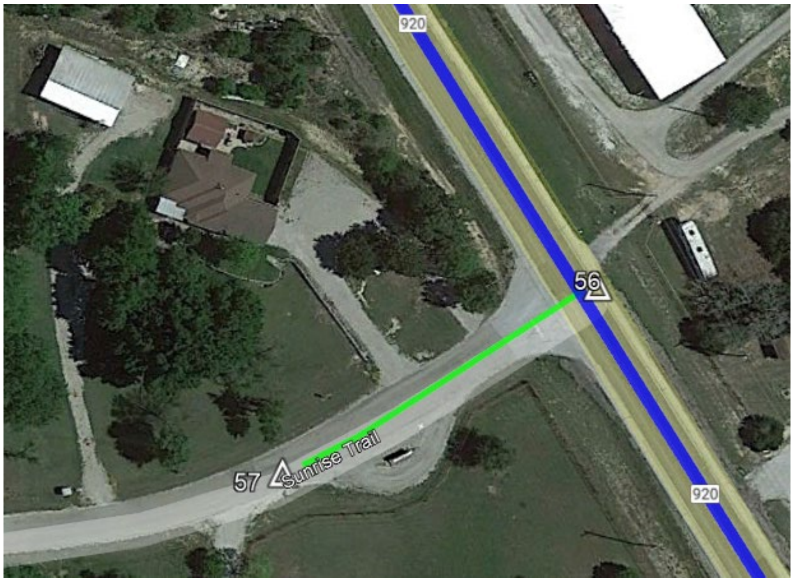
ATTACHMENT A: Typical Mobile Lidar Control Layout Planning

Mobile Lidar control layouts are to be submitted to the TxDOT Project Manager for review prior to data acquisition. Careful ground control planning must be executed to ensure the most efficient layout, placing control points in safe locations to keep field survey crews out of harm's way.

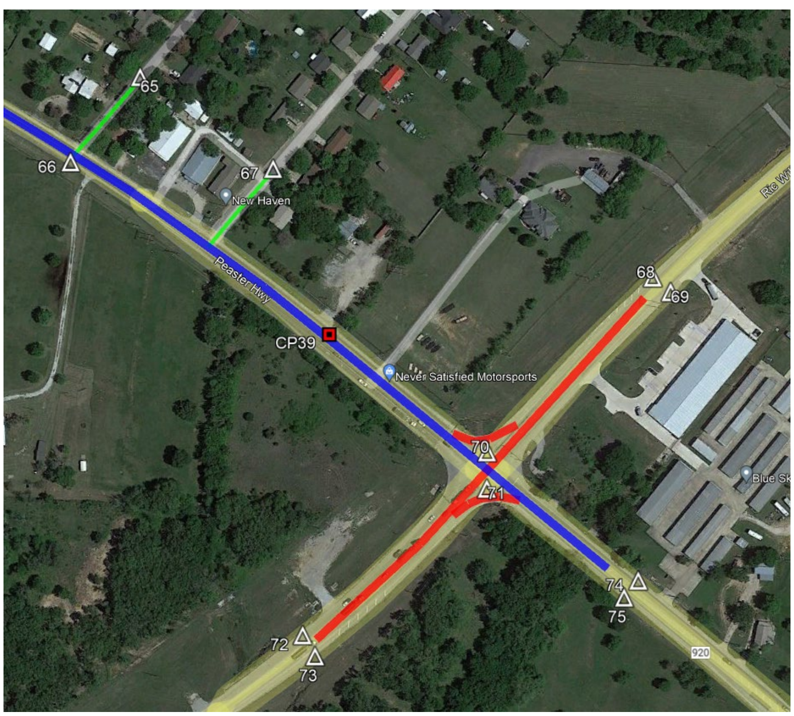
1. Lidar ground control point pairs at the beginning and end of project limits and any crossing/intersecting major roads.

2. Control before and after bridges to pin down Lidar where GPS signal is lost under the bridge or any other overhead obstructions.

3. Reduce 1,000-ft. spacing interval with extreme roadway curves, to maintain line of sight for levels.
4. Control is project specific in urban areas and may have reduced interval spacing for GPS urban canyon and other line of sight factors.
5. Single Lidar ground control points placed on side minor side roads.

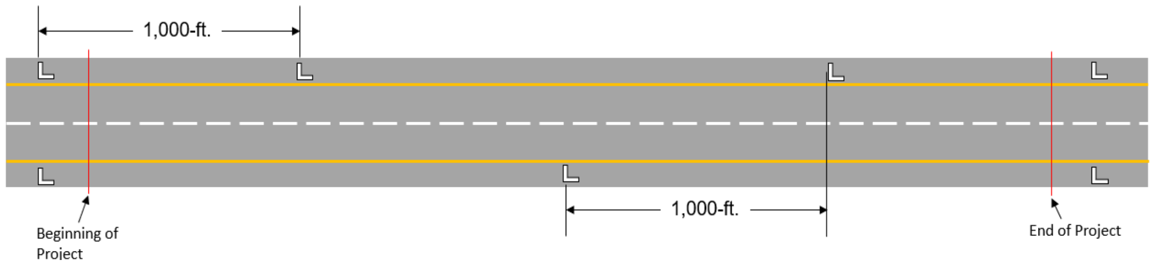


6. Control pairs at the ends of crossing major roads.

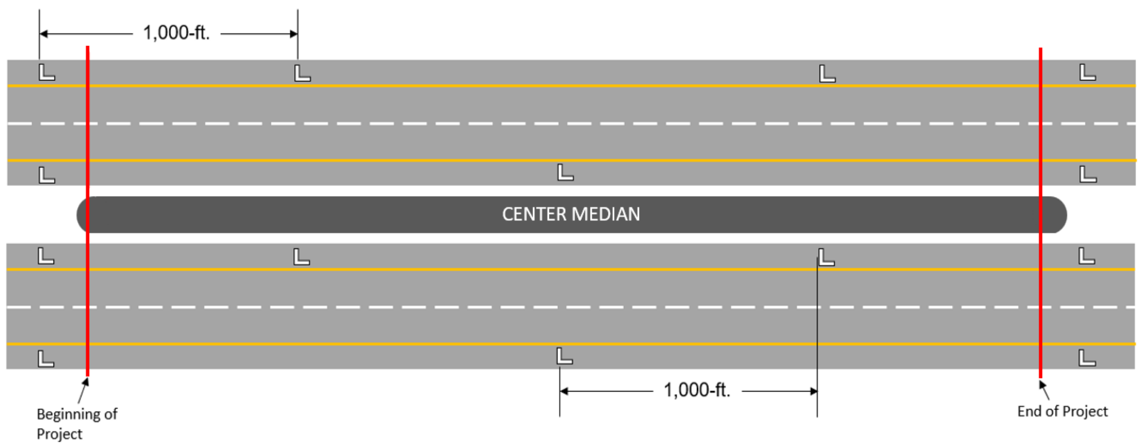


CONTROL INTERVAL DIAGRAMS

2-Lane Undivided Highway – control pairs at least 100 feet beyond the beginning and end of project limits and staggered control set every 1,000 feet within the project limits.



2-Lane Divided Highway - control pairs at least 100 feet beyond the beginning and end of project limits and staggered control set every 1,000 feet within the project limits, on each direction of divided highway.



Curved Road - staggered control at reduced intervals, dependent on the severity of curve. grade mapping.