CONNECTICUT DEPARTMENT OF TRANSPORTATION

SPECIFICATIONS AND GUIDELINES FOR PHOTOGRAMMETRY AND LIDAR

July 2025

CONNECTICUT DEPARTMENT OF TRANSPORTATION

SPECIFICATIONS AND GUIDELINES FOR PHOTOGRAMMETRY AND LIDAR

July 2025 Edition

Table of Contents

A. Introduction

The Connecticut Department of Transportation (CTDOT) relies on precise, reliable spatial data to plan, design, construct, and maintain transportation infrastructure. Modern photogrammetry and Light Detection and Ranging (LiDAR) technologies allow CTDOT Surveys and Consultants to acquire high-resolution topographic and three-dimensional information on roadways, bridges, vegetated corridors, infrastructure, and interiors of facilities. Types of collection include, but are not limited to, static terrestrial LiDAR, mobile LiDAR, aerial LiDAR, and aerial photogrammetry (See Section F).

These methods produce dense, three-dimensional point clouds and georeferenced orthophotos that can capture sub-centimeter detail over large areas. They can also locate hard-to-reach features and allow for more safe data collection. The resulting data not only supports traditional mapping tasks but also can integrate directly into engineering and GIS platforms for advanced analysis and design. CTDOT Surveys utilizes photogrammetry and LiDAR to:

- Extract ground survey features such as pavement surfaces, paint striping, curb returns, catch basins, and tops of rail
- Identify and map overhead utilities, signposts, guide rails, and other roadside assets
- Quantify vegetation and encroachments
- Detect pavement deficiencies, potholes, rutting, change detection, and surface anomalies for planning
- Compute earthwork volumes and generate digital Terrain models
- Perform clash detection and clearance verification for bridges, tunnels, and overhead structures

This document establishes specifications and guidelines for control, processing, delivery, and quality assurance of photogrammetric and LiDAR surveys conducted for CTDOT projects.

B. Control Survey for Photogrammetry and LiDAR

Control Survey for Aerial and Mobile Collection

It is CTDOT's intent to generally adopt the standards and procedures outlined by "ASPRS Positional Accuracy Standards for Digital Geospatial Data EDITION 2, VERSION 2.0 (2024)".

Ground Control Target (GCT) is used in this manual to describe any controlling point of a photogrammetry or LiDAR survey, typically a painted target or other cultural feature that is accurately identifiable within the data. These points are otherwise known as aerial control points, target points, photo points, etc. Validation Point (VP) is used to mean any similar point, although not necessarily horizontally identifiable, that is used not to control the survey but instead to validate the survey (vertically, horizontally, or both), typically in areas between control points. Validation Points are expected to be located on hard surfaces, such as concrete or pavement, unless otherwise specified as intended for soft surface validation.

The style of Ground Control Targets shall be determined by the Consultant based on current best-practice and sensor type. The District responsible for the project shall typically be tasked with providing horizontal and vertical control as well as providing values for Ground Control Targets and Validation Points. The party or Consultant charged with providing the mobile LiDAR or photogrammetric survey shall be responsible for reporting registration and validation/control residuals.

The location of the necessary GCTs and VPs shall be determined by the photogrammetrist or LiDAR consultant in collaboration with CTDOT. Generally, CTDOT requires a Ground Control Target be placed a minimum of every 500 feet, typically with a Validation Point staggered equidistantly between two Ground Control Targets (Exhibit A). The 500' placement may be extended as deemed appropriate by the collection consultant and/or the Surveyor.

In general, all projects require a minimum of half the number of VPs (on hard surface) as GCTs, up to a limit of 30, unless otherwise excepted by Central Surveys. On wide, linear corridors, consideration should be made to ensure Ground Control Targets and Validation Points are placed on both sides of the corridor, either through alternating or setting points on either side of a particular station.

An effort should be made for validation on roadway surfaces to be both horizontal and vertical. This can be accomplished through utilizing existing painted features (corners of stripes, tips of arrows, sharp edges of concrete, etc.) or painting targets. At least half of Validation Points on the roadway shall be discernable

horizontally and evenly distributed through project area. Vegetated surfaces, roadway cross-sections, or additional checks at the Surveyor's discretion may be vertical-only.

Mobile LiDAR Validation Point Specifics

Unless otherwise deemed necessary by the Surveyor, CTDOT mobile LiDAR survey projects do not necessarily require the minimum 30 Validation Points that are required for ASPRS certification, provided the Consultant has demonstrated to the Office of Central Surveys the appropriate use of proven technologies and the ability to produce reliable results with fewer check points.

Since the number of Validation Points required is half the number of Ground Control Targets, large projects that contain over 60 GCTs will only require, *at minimum*, 30 VPs. In other words, 30 is the ceiling for the minimum number of required points. For example, a project with 80 GCTs only requires 30 VPs, although more (such as 35 or 40) may be recommended or requested. A project requiring 20 GCTs will need at least 10 VPs. However, no mobile LiDAR project shall be validated by fewer than five Validation Points on the roadway or hard surfaces. Therefore, a project with six (6) GCTs will require five (5) VPs (not 3).

When vertical accuracy validation is required on soft surfaces (vegetated), half the number of Validation Points are required on the soft surface as are required for the hard surface Validation Points in the project. Soft-surface areas where the Surveyor has low confidence in the elevation data should be denoted and labeled with polygons in the mapping.

Care should be made to distribute vegetated Validation Points throughout the project, with at least 50% situated in areas deemed a priority for the designer and at the Surveyor's discretion.

Photogrammetry and Aerial LiDAR Validation Point Specifics

The procedure for validating the accuracy of a traditional aerial Photogrammetric and LiDAR-derived survey generally follows the same guidelines as the mobile LiDAR, with some notable exceptions.

CTDOT will follow guidelines regarding setting Ground Control Targets as per the Consultant recommendations and manufacturer best-practices, but Validation Points shall meet the minimum ASPRS standard of 30 Validation Points on non-vegetated surfaces, at least half of which shall be for horizontal and vertical. When needed, for vegetated or soft surfaces, half the number of Validation Points required for non-vegetated surfaces will also be required, with an emphasis on areas of concern by the Design team. Even the largest CTDOT

project is typically small compared to the 1000 square kilometer minimum area requiring 30 checkpoints for ASPRS certification, however this procedure is intended to replace previous CTDOT methods of elevation and contour checks based on sheet size and scale.

RTK or GNSS methods may be considered for horizontal and/or vertical validation, if the expected accuracy of the Validation is twice that of the requested Photogrammetry accuracy.

For Unmanned Aerial Systems (UAS) derived photogrammetry, the same requirements shall apply as described above for Mobile LiDAR.

Exhibit A

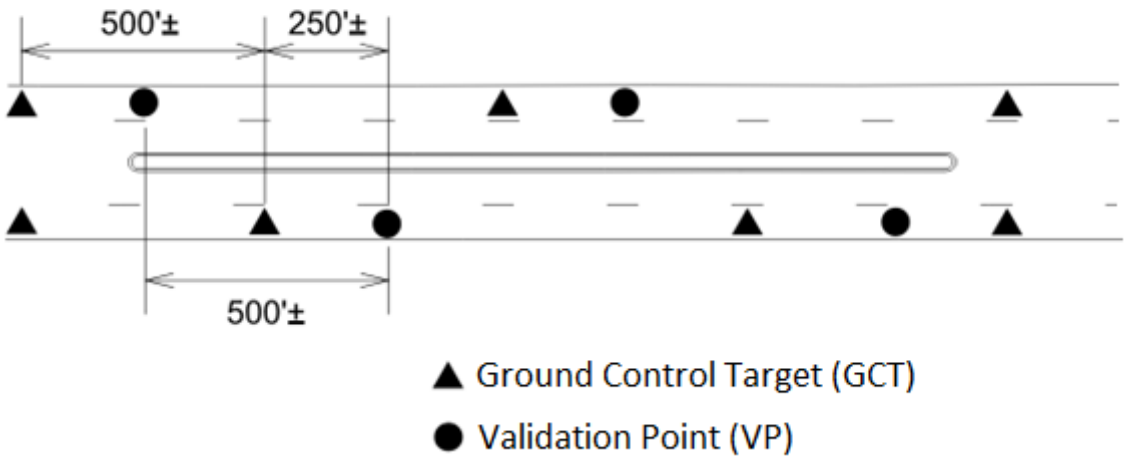

Exhibit A: Example of typical GCT and VP layout for linear highway LiDAR project.

Control Survey for Static Terrestrial LiDAR

Targeting and control for terrestrial scans performed by CTDOT are generally dependent on scanner manufacturer recommendation and best practices. Target type should be according to manufacturer- recommendations.

If utilizing free-scan method, three identifiable targets are recommended for any two overlapping or adjacent scans.

Additionally, supplemental control or boundary points may be measured (tied in) from terrestrial scanning utilizing black and white targets and bi- or tripods,

provided the control is measured from at least two (2) independent scans and registration residual values are half the CTDOT accuracy level desired.

Validation points may be any unmovable, discernable feature in the point cloud. Cloud-to-cloud and cloud-to-target residuals must be reported. Validation Points or additional map checks are encouraged particularly when targets cannot be utilized. Generally, scans are registered and locked, before registering to survey control. CTDOT requires registration to at least three coordinated survey control points and residuals to be reported. Those residuals may indicate low accuracy or scan registration blunders.

Statement on Accuracy

Primary Control Points, Ground Control Targets, and Validations Points shall be measured at twice the accuracy of the desired geospatial produce accuracy desired per ASPRS standards. Generally, this will imply all control to be measured to CTDOT standards for horizontal control, with Ground Control Targets and Validation Points typically measured minimally at a secondary control standard or Level 2 and 3 GNSS accuracy standards. Digital leveling to establish elevation of target points and validation points is almost always required for GCTs and hard-surface VPs depending on desired accuracy of deliverable.

Use of GNSS

Primary control shall be placed on either end of a linear project, intended as Primary Project Control and to be utilized as GNSS base stations for mobile LiDAR calibration. The method of measurement shall be according to CTDOT Level II GNSS specifications. Furthermore, the project may be boxed or surrounded by primary control, especially if RTK or GNSS methods are intended to be utilized to measure the Ground Control Targets and Validation Points or perform additional map checking. A typical network design might include two primary control points set approximately 500’ away from (measured approximately perpendicularly) from the linear corridor in either direction for each 2-mile linear project section (Exhibit B).

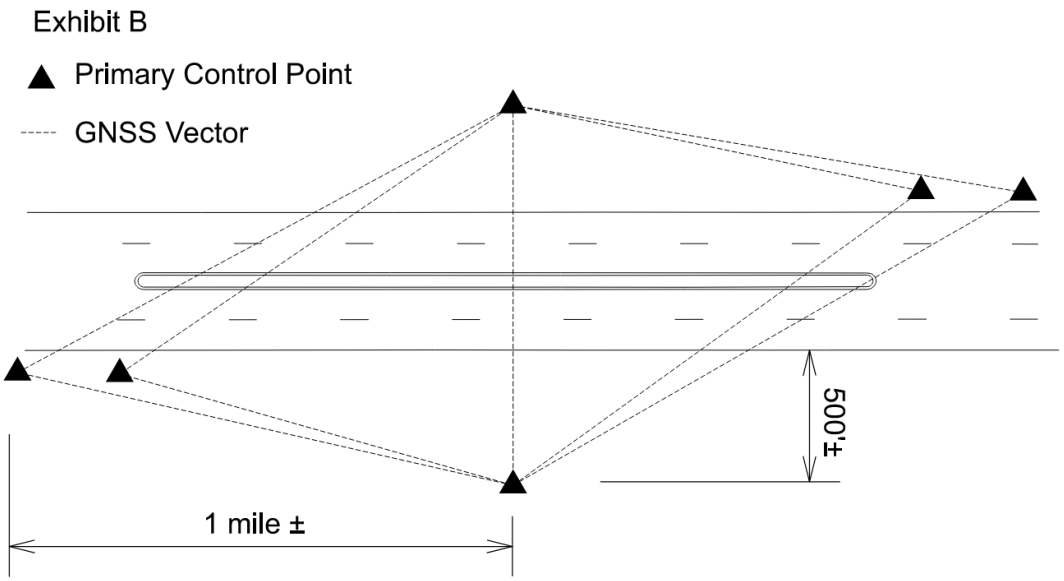

Exhibit B: Example of typical primary control layout when using GNSS.

C. Plan and Accuracy Checks for Photogrammetry, Aerial LiDAR, and Mobile LiDAR Mapping

Accuracy checks for Photogrammetry and LiDAR-based projects for CTDOT surveys are three-fold. Before acceptance by the Department, and depending on the required deliverable, the following elements are to be checked for accuracy: the survey data (i.e. point cloud, orthophoto, Digital Elevation Model), the produced ORD Terrain, and the derived planimetric mapping.

Validation Report

The Consultant or Surveyor shall be required, as necessary based on collection method, to include or retain a validation report denoting:

a. Project narrative with location layout and contact person.
b. A list of equipment used for laser imaging on each collection date(s). Include the brand and serial number of LiDAR, camera, IMU, GNSS unit and vehicle.
c. The type of software and version that was used for processing.
d. Final project Scanner System calibration to CTDOT-provided control and

targets

e. Registration residuals for the Ground Control Targets. The documentation of the type(s) of Local transformation(s) used. An Excel file with control point, X, Y, Z, residual X, residual Y, residual Z to the Point Cloud and Terrain (Exhibit C)
f. Registration residuals for the survey Validation Points. The documentation of the type(s) of Local transformation(s) used. An Excel file with control point, X, Y, Z, residual X, residual Y, residual Z to the Point Cloud and Terrain (Exhibit C).
g. Cloud to cloud registration residuals in an Excel file with point, X, Y, Z, residual X, residual Y, residual Z.
h. Aerotriangulation report and imagery residuals to Ground Control Targets and Validation Points.

Although CTDOT requires the Consultant's validation report, Central Surveys or the District Surveyor will independently assess the validation both to the point cloud or DEM and to the Terrain before acceptance of the survey. Ground Control Targets and Validation points shall be compared to the average depth of the point cloud (and horizontal location) and deviations recorded. Error at the 95% confidence interval shall be noted and must be less than the required accuracy required of project.

Sample Validation Report											
TARGET #	EASTING	NORTHING	ELEVATION	EASTING LIDAR	NORTHING LIDAR	ELEVATION	X DIFFERENCE	Y DIFFERENCE	Z DIFFERENCE		DIRECT
GCT-1	1108636.297	676736.652	34.770	1108636.301	676736.635	34.768	-0.004	0.017	0.002		0.018
GCT-2	1108647.904	676880.645	38.220	1108647.904	676880.642	38.227	0.000	0.004	-0.007		0.008
GCT-3	1109123.980	676826.614	48.730	1109123.980	676826.633	48.736	0.000	-0.019	-0.006		0.020
GCT-4	1109708.562	677083.462	67.640	1109708.564	677083.459	67.646	-0.002	0.003	-0.006		0.007
GCT-5	1110445.801	677092.353	88.540	1110445.796	677092.351	88.545	0.005	0.002	-0.005		0.008
GCT-6	1111156.962	677375.645	93.750	1111156.963	677375.639	93.755	-0.001	0.006	-0.005		0.008
GCT-7	1111754.634	677356.072	82.240	1111754.615	677356.081	82.249	0.019	-0.009	-0.009		0.023
GCT-8	1112168.909	677583.183	69.590	1112168.912	677583.180	69.581	-0.002	0.003	0.009		0.010
GCT-9	1112206.988	677472.590	72.220	1112206.991	677472.587	72.228	-0.003	0.003	-0.008		0.009
GCT-10	1112072.735	677684.812	61.470	1112072.738	677684.800	61.474	-0.003	0.013	-0.004		0.014
							-0.004	-0.019	-0.009		0.007
							0.019	0.017	0.009		0.023
							0.007	0.010	0.006		0.014
							MAGNITUDE				0.015
							DEVIATION				0.023
							DEVIATION				0.023
							Horizontal error @ 95% =	0.020	Vertical error @ 95% =	0.012	

Exhibit C: Sample validation report showing GCT residuals to Point Cloud.

Terrain Check

CTDOT will assess the Validation Points to both the point cloud and to the Terrain (DEM) from the provided Validation Report. If deemed necessary due to deviations of the Validation Points with the Terrain, CTDOT may assess the mapping Terrain to the survey (point cloud, DEM, orthoimage, reality mesh, etc.) through a delta comparison. The survey (point cloud) shall not deviate from the mapping Terrain by more than half the error required of the project. Usually, deviations will occur due to interpolations between breaklines or incorrect breaklines. Areas requiring additional breaklines or data in the Terrain will be identified and sent to the Consultant for reprocessing.

Mapping check

Primarily, CTDOT will assess the integrity of LiDAR or photogrammetry surveys and Terrains utilizing Validation Points (YXZ for targets or Z-only). However, cultural features should be checked for correct symbology according to the CT DDE. In addition, if the Surveyor deems necessary upon analysis of the Validation Report, Terrain Check, and project specifications, cultural features may be field-checked for accuracy of location. Generally, LiDAR-based datasets can be assessed at least partially from the point cloud, whereas some traditional photogrammetry and aerial LiDAR will require field measurement and verification. Cultural features include, but are not limited to, roads, walls, railways, utilities, transmission lines, buildings, signs, drainage structures, sidewalks, etc.

All mapping shall be visually reviewed with the source data (point cloud, imagery) to ensure that all cultural features are shown that are visible on the aerial photographs or LiDAR. Should a question arise as to a cultural feature being visible or not in the data, the reviewer shall petition the Photogrammetrist or Consultant to recheck the cultural features in question.

All cultural features that are missing and can be identified on the aerial photographs or in point clouds, shall be so noted, and the Photogrammetrist or Consultant will be required to plot all missing identifiable cultural features. Cultural features not identifiable on aerial photographs or in the point clouds shall be located by ground surveying methods and plotted on their respective map sheets (See Section C).

Areas obscured in the LiDAR or imagery due to dense vegetation, shadows, or other factors will be labeled as “OBSCURED AREA”. No elevation data will be compiled without additional field survey.

When the Consultant has completed the mapping, including the addition of all miscellaneous field survey data and revisions as ordered, a final visual check will be made to determine the completeness of the maps.

Final Deliverables

In addition to the aforementioned Validation Report, all photogrammetry and LiDAR projects shall include all final registered point cloud files (LAS or e57) and imagery utilized to produce the mapping (See Sec. 2.4 of Location Manual).

At minimum, all point cloud files are to contain a basic classification scheme, including ground, low vegetation, medium vegetation, and high vegetation. It must be understood that “vegetation” at this level may be a misnomer, and these classifications are used to indicate a difference in elevation from the ground surface (so may include objects and features other than vegetation).

CTDOT or the Consultant shall provide thorough and specific point classification by request, including in situations where designers require delivery of specific features in the point cloud.

Data Retention

All remote sensing data, including raw, unedited point cloud files and photographs, shall be retained not less than five (5) years or according to Department retention policies, whichever is greater. Although typical deliverables include adjusted and edited information, raw data should be accessible to CTDOT. All District Survey files, including raw files, should be stored within the current CTDOT storage medium.

D. Field Edit and Final Review of Photogrammetry, Aerial LiDAR, and Mobile LiDAR Mapping

This phase of a photogrammetric or LiDAR mapping project is comparable to the location survey phase of a ground survey mapping project.

Once it has been determined, during the plan and accuracy phase, that the project mapping meets the prescribed standards of accuracy, and mapping as derived from the imagery or point clouds is complete, it is the responsibility of the Surveyor perform a field edit of the mapping. The Surveyor shall locate and

describe any items of topography or culture not discernible in the mapping, not included as part of the remote sensing scope, or in additional areas, as well as other items noted in the Location Survey Manual, Revised August 2025, Section 1 (4.2 and 5.6).

All field location work shall be done with a total station instrument, GNSS receiver, and/or additional terrestrial LiDAR instrument and a data collector storing 3D data, which can then be incorporated with the photogrammetric or LiDAR mapping for the final map compilation in an Open Roads Designer (ORD) file format.

A final field walk will be performed to verify the mapping.

E. Map Notes

All mapping compiled utilizing any of the methods detailed in this section shall contain a note in the title block as to the methods and validation results. An example of said note is as follows:

THIS MAPPING WAS COMPILED FROM A (INSERT MOBILE LIDAR, UAS PHOTOGRAMMETRY, AERIAL LIDAR, OTHER) DATA SET COLLECTED BY (INSERT CONSULTANT) ON (INSERT DATE). IT HAS BEEN TESTED ACCORDING TO ASPRS POSITIONAL ACCURACY STANDARDS FOR DIGITAL GEOSPATIAL DATA, EDITION 2, VERSION 2 (2024). THE STANDARDS CALL FOR A MINIMUM OF THIRTY (30) VALIDATION POINTS, THIS TEST WAS PERFORMED USING __ VALIDATION POINTS. THIS DATA SET WAS PRODUCED TO MEET A ___FT $RMSE_V$ VERTICAL POSITIONAL ACCURACY CLASS (__FT AT 95% CONFIDENCE). THE TESTED VERTICAL POSITIONAL ACCURACY WAS FOUND TO BE $RMSE_V$ = ___FT (__FT AT 95% CONFIDENCE) USING THE NUMBER OF CHECKPOINTS IN THE NVA (NON VEGETATED ACCURACY) TESTED AREA. (INSERT VEGETATED ACCURACIES AND OR HORIZONTAL POSITIONAL ACCURACIES AS NECESSARY). PLANIMETRIC MAPPING FEATURES WERE COMPILED BY (INSERT CONSULTANT) AND MERGED WITH ADDITIONAL SURVEY PROVIDED BY (INSERT DISTRICT) SURVEYS.

F. CTDOT Remote Sensing Guidelines Table

Type	**Mobile LiDAR**	**Static Terrestrial LiDAR**	**Aerial Photogrammetry and LiDAR**	**UAS Photogrammetry and LiDAR**
Application	Pavement, long corridors	Bridge substructure, intersections, difficult terrains, railroad	Long corridors, vegetated areas (LiDAR)	Facilities, large parcels, planning, supplemental survey
Expected Vertical Accuracy (at 95%) (may vary)	0.05’	0.03’	0.05’- 0.25’	0.10’ - 0.25’
Minimum Number of Ground Control Targets	5	3	5	5
Ground Control Target Placement	Maximum every 500 ft.	3 minimum per scan recommended	As required by Consultant	Maximum every 500 ft.
Minimum Number of Validation Points – Pavement	Typically every 500 ft. No fewer than 5, half the number of Ground Control Targets up to 30	As deemed necessary by Surveyor	30	Typically every 500 ft. No fewer than 5 half the number of Ground Control Targets up to 30
Minimum Number of Validation Points – Vegetated	No fewer than 5 if required, focus on areas of concern, half the number of Pavement VPs	As deemed necessary by Surveyor	15 if required, focus on areas of concern	No fewer than 5 if required, focus on areas of concern, half the number of Pavement VPs