STATE OF NEW JERSEY
DEPARTMENT OF TRANSPORTATION

SURVEY MANUAL

2014

Prepared by Survey Services

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Preface

Purpose

Many State Departments of Transportation have developed a survey manual. The purpose of the manual is to provide uniform guidelines for implementing survey decisions, and to assure quality and continuity in collection of survey data. The use of the survey manual is to assure appropriate execution of projects in conformity with the operational needs of the Department of Transportation, and to assure compliance with State and Federal criteria. The objective of this manual is not to serve as a general purpose text on the practice of surveying but rather as a guide to fit the special needs of the New Jersey Department of Transportation. Basic education and training in surveying require appropriate schooling, seminars and field exercises with appropriate textbook and learning kits. At the end of this manual there is a suggested reference list, including some helpful Web sites.

This manual deals with technical surveying issues. Other issues such as professional conduct and safety procedures should be in accordance with appropriate Federal and State manuals. For example, all the procedures at NJDOT with respect to safety, traffic protection, operation of tools and equipment, vehicle operation and usage, and first aid must be in accordance with the latest edition of NJDOT "safety manual". To avoid duplications and potential conflicts with existing regulations, this survey manual does not include these procedures.

Content and Format

Survey manuals of other State Department of Transportations follow one of two general conceptual models. Some manuals provide detailed instructions for surveyors, while others take the form of a more general reference guide used by DOT employees and Consultants, who are not necessarily surveyors. The purpose of the first approach is to produce a prescriptive manual to train people in surveying. The danger in such a detailed manual is that it could become easily outdated due to rapid technological developments. Such a manual may require frequent maintenance and revisions to keep it current. The second approach is more technology independent and used to educate its readers about surveying. This education provides proper understanding of surveying and improves the communication among various DOT employees. This manual follows the latter approach. The model used in developing this manual was the Ohio DOT (ODOT) survey manual.

The criteria included in this manual have been developed along the lines of various State's survey manuals, as well as in conformance with applicable Department directives, policies and procedures. The manual assures uniform guidelines for implementing survey decisions, assure quality and continuity in collection of survey data and execution of project support of operations in New Jersey, and assures compliance with Federal criteria. Consideration must also be given to submission standards adopted by city, county, or other local governments when submitting documentation under their jurisdiction.

The manual consists of eleven chapters and an appendix. The first chapter deals with general terms and definitions of surveying and surveying related terms. Chapter two describes the various survey systems. Survey systems are, to some extent, technology free concepts that serve as a foundation for different types of surveys. Chapter three deals with survey measurements and the errors associated with them. Chapter four is a continuation of chapter three and focuses on Global Positioning Systems (GPS). GPS is the current state-of-the-art surveying technique served better with its own chapter. Chapter five discusses surveying equipment, its characteristics, and proper usage. Chapter six discusses location surveys and some field procedures. Photogrammetry is discussed in chapter seven. Photogrammetry is another surveying technique that is somewhat different compared with the traditional surveying. The special chapter serves as a means for emphasizing the applicability and the recommended utilization of photogrammetry as an integral part of the surveying tool box.

Survey Reference Documents

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Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques (Federal Geodetic Control Committee, Version 5.0, May 11, 1989).

Input Formats and Specifications of the National Geodetic Survey Data Base, Volume 1, Horizontal Control Data (Federal Geodetic Control Committee, Rockville, MD, January 1989)

Input Formats and Specifications of the National Geodetic Survey Data Base, Volume 2, Vertical Control Data (Federal Geodetic Control Committee, Rockville, MD, 1980, reprinted 1982, Prepared by the National Oceanic and Atmospheric Administration as NOAA Manual NOS NGS 2).

Kissam, Philip, *Surveying for Civil Engineers*, New York: McGraw-Hill, 1956.

Standards and Specifications for Geodetic Control Networks (Federal Geodetic Control Committee, Rockville, Maryland, September 1984).

Stem James E, State Plane Coordinate System of 1983, *NOAA Manual* NOS NGS 5, 1989.

Survey Manual (State of Ohio Department of Transportation), 1995.

Specifications for GPS Surveys (State of Illinois Department of Transportation), 1996.

Location Survey Manual (State of Florida Department of Transportation), 1994.

Work Zone Safety Set-Up Guide 2005, New Jersey Department of Transportation.

User Guidelines For Single Base Real Time GNSS Positioning (National Geodetic Survey), 2014

National Geodetic Survey Guidelines for Real Time GNSS Surveys (National Geodetic Survey), 2011

RTN Field Procedures and Best Practices (National Geodetic Survey, Presentations Library), 2016

Chapter 7 - Aerial Photogrammetry

7.1 Purpose of this Chapter

The purpose of this chapter is to identify and define the specifications that shall be followed while performing Aerial Photogrammetry for NJDOT.

NJDOT contracts out all aerial surveys as the aerial photography and mapping equipment is not available in the Department. As such, NJDOT relies upon the expertise and experience of the aerial mapping consultant to provide guidance and products that will meet the needs of the project. The survey fieldwork is most often performed by the aerial consultant or survey subconsultant.

The guidelines and specifications described in this chapter are geared towards development of design scale mapping that has been historically referred to as 1”=30’ scale mapping with 1’ contours. The vast majority of aerial mapping contracted by NJDOT calls for mapping standards associated with this scale. Where requirements differ from this scale, the necessary equipment, ground control, flight planning and other key components of the project design may need to be modified. This may be accomplished either to ensure a higher standard is met or to realize efficiencies that may be offered to meet a lower standard. Any variation from the specifications in this chapter shall have the prior approval of the NJDOT Survey SME and Project Manager.

While it is recognized that technical developments, particularly in airborne LiDAR, are making wider application of aerial data possible for design scale mapping, this chapter provides specifications and guidelines for Aerial Photogrammetry. Airborne LiDAR is addressed in a subsequent chapter. Where accessibility, safety, economics, or other concerns call for such consideration it should be done in consultation between a professional aerial surveyor, such as an ASPRS Certified Photogrammetrist, map scientist or state licensed aerial survey professional and the NJDOT Survey SME. This will facilitate development of a custom project design, specifications, and deliverables that meet unique NJDOT project requirements.

Any variation from the specifications in this chapter shall have the prior approval of the NJDOT Survey SME and Project Manager.

7.2 Aerial Surveys

Aerial Photogrammetric surveys utilize photographic, digital, or other data obtained from an airborne platform (e.g. airplane, helicopter, drone). Photographic data processed by means of photogrammetry is combined with field survey data to produce high precision mapping and meet the accuracy standards described in this Chapter.

7.3 Aerial Photogrammetry

Aerial photogrammetry is the science of deducing the physical dimensions of objects on or above the surface of the Earth from measurements on aerial photographs of the objects. The end result produces the coordinate (X, Y, and Z) position of a particular point, a planimetric feature, and a graphic representation of the terrain from a DTM.

Aerial photogrammetry is often used for the following:

1. Highway reconnaissance
2. Environmental plans
3. Preliminary design
4. Geographic Information System (GIS)

The information produced from aerial imagery of the existing terrain allows both designers, planners, and environmental personnel to explore alternate routes without having to collect additional field information. The imagery can be used to layout possible alignments for a more detailed study.

Photogrammetry can relieve survey crews of the most tedious time-consuming tasks required to produce topographic maps and DTMs. However, ground surveys will always remain an indispensable part of aerial surveys as a basis for accuracy refinement, quality control and a source of supplemental information unavailable to aerial data acquisition (i.e. obscured areas).

7.4 Project Location and Limits

The location and limits of the aerial survey project is indicated in the initial request for mapping (usually as beginning and ending MP). The NJDOT Survey SME or designee is responsible for determining the aerial survey location and limits. The aerial mapping consultant shall work closely with the NJDOT Survey SME when determining the aerial survey location and limits.

Location and limits of the aerial survey project need to be clearly defined to ensure complete coverage is acquired. There are several alternative methods to define the location and limits such as on hard copy maps or electronic maps such as GoogleEarth or Bing Maps. (Please note that web-based maps should only be used for planning and general illustration purposes since their spatial accuracy is limited and inconsistent.) Further clarification of the aerial survey location and limits may be provided with some text descriptions. The location and limits of the aerial survey should specify the following:

1. Beginning and end mileposts
2. Required width
3. Minimum distance on either side of the existing transportation corridor

The aerial survey location and limits shall include the following in addition to the project provisions:

1. For crossroad interchanges with grade separations, the aerial survey shall also include a minimum of 1000 feet of the crossroad on each side of the existing transportation corridor centerline and shall usually include any ramps within the interchange limits and 300 feet beyond the end of the ramp on the crossroad.
2. For at-grade intersections (signalized or unsignalized), the aerial survey shall also include 750 feet of the crossroad on each side of the existing transportation corridor centerline and shall include all turning movements such as jughandles, turning lanes, etc.
3. When requested the aerial survey shall also include the area necessary for a complete hydraulic design and/or wetland mitigation site as required in the project specifications.
4. Aerial Photography and Aerial LiDAR shall extend ½ mile beyond the end of the aerial survey location and limits of the highway corridor.

7.5 General

The aerial mapping consultant shall provide specifications meeting the project needs for the following:

1. Camera/Sensor(s)
2. Film or digital imaging requirements, for example: 3-band (RGB), 4-band (RGB&NIR)
3. Scanner type and resolution if film is used.

The aerial mapping consultant shall work closely with the NJDOT Survey SME when determining the aerial mapping specifications.

7.6 Aircraft and Crews

All aerial surveys will be conducted in full compliance with Federal Aviation Administration and Civil Aeronautics Board rules and regulations. It is the aerial mapping consultant’s responsibility to obtain necessary FAA or military authorizations to fly in Special Use Airspace as defined by the FAA’s aeronautical charts.

Crews having a minimum of 200 hours experience in flying precise photographic missions for aerial surveys shall be used. In addition, each crew shall have prior experience (50 hours minimum) with the same type of aircraft to which the crew is assigned.

The use of any UAV shall be discussed with the Survey SME and be in accordance with Chapter 10, Section 10 of the NJDOT Survey Manual.

7.7 Aerial Survey

Prior to beginning any aerial survey activities, the surveyor shall contact NJDOT Geodetic Survey Unit to determine if any new control has been established in the area. The NJDOT Survey SME or designee shall work closely with the aerial mapping consultant to review the scope of work and ensure the project needs are being met. This close working relationship shall continue through the duration of the project to ensure that NJDOT receives an accurate, quality, and useable product. Any known error or oversight on the plans or specifications shall be discussed prior to commencing any work. The NJDOT Project Manager will communicate any modifications to the scope of work to all affected parties. If determined by the NJDOT Survey SME a meeting shall be held to discuss the project and the desired results as soon as possible. The following individuals should attend the meeting:

1. NJDOT Survey SME or designee
2. NJDOT Project Manager
3. Aerial Survey Consultant/Photogrammetrist
4. Any appropriate subcontractor personnel

Any project specific information should be provided by the NJDOT at the meeting.

It is the responsibility of the NJDOT PM to ensure that the scope of work for the project is provided to the aerial mapping consultant and surveyor so that they can ensure that the project needs are being met. If there are any questions or concerns, they should be addressed prior to the commencement of any survey work.

7.8 Ground Control for Aerial Surveys

7.8.1 General

Aerial survey data must be referenced to ground control points in order to maximize the absolute accuracy achievable for the aerial data. This is achieved by survey crews establishing photo ground control within the project area. Targets are placed over ground control so that the location of the point is easily identified on the imagery. The field measurements of the horizontal and vertical elevation (X, Y and Z) of the control points will be used to process the final mapping product. Elevations, (Z), must be provided at ground elevations (modified NJSPCS). If a target is laid over a monument that is below grade, the offset elevation must be applied to the elevation since the aerial control target will be measured at surface grade. The use of commercial RTK and RTNs based on the latest realizations of NAD83 and NAVD88 using the proper techniques can also be utilized.

7.8.2 Ground Control Targeting Requirements

Ground control requirements for aerial mapping will be predicated upon flying height, terrain, equipment, accuracy requirements and technology applied for data acquisition. To meet the design scale accuracy requirements of 1”=30’ plans a photo control point should be established at a maximum approximately every 300’ apart staggered along the edge of the pavement (i.e. shoulder) for the length of the project. A control point targeting plan at this density would satisfy ground control requirements for a photogrammetric approach. The wing targets shall be established in accordance with the flight diagram established by the aerial consultant. In addition, the surveyor shall also establish control pairs at each end of the project and every 1.5 - 2 miles along the project length.

By applying AGPS/IMU, INS technologies and modern digital sensors it is possible to reduce the density of targeted ground control significantly. However, multiple variables must be considered. These include specific sensor capabilities and specifications, flying height, frequency, and quality of AGPS signal and distance to GPS base stations.

The aerial mapping consultant is responsible for determining and specifying all aerial control point locations, material, spacing, and configurations for the survey. The NJDOT Survey SME or designee shall work closely with the aerial mapping consultant when determining what monumentation shall be used for control points. All project control will be established on the ground (modified NJSPCS) by applying the appropriate combined grid scale factor.

Final coordinate values for control points shall be produced and tabulated in four formats to satisfy NJDOT requirements. All coordinates are based on the latest realization of NAD83 adjustment datum. Currently: NAD83 (2011).

https://www.ngs.noaa.gov/datums/horizontal/north-american-datum-1983.shtml

- GEOGRAPHIC POSITIONS *(Latitude, Longitude and Ellipsoidal Heights in meters).*
- NJSPC (METRIC) *(State Plane Coordinates in meters).*
- NJSPC (U.S. SURVEY FEET) *(State Plane Coordinates in U.S. Survey Feet).*
- GROUND/MODIFIED *(Ground Coordinates in U.S. Survey Feet)*.

All orthometric heights will be based on the NAVD88 adjustment datum using the latest geoid model, currently GEOID18.

https://www.ngs.noaa.gov/GEOID/

7.8.3 Photogrammetry

The control points must be visible from a minimum of two overlapping photographs. To apply the basic principle of photogrammetry, at least three photo ground control points are needed for any single stereo model, (one overlapping pair of photographs) or block of adjoining stereo models. This establishes the spatial relationship between the ground and the model coordinates. One or more additional points are required to determine the accuracy of the model based residual error and to identify any data entry errors.

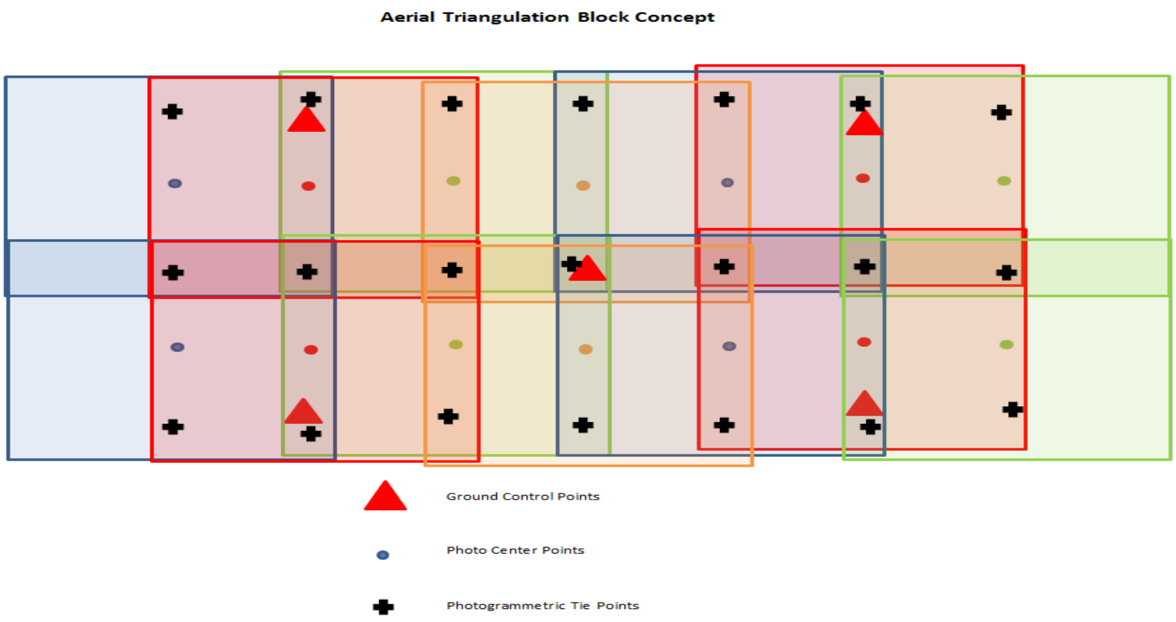


Image Courtesy of Colorado Department of Transportation

When controlling multiple models or blocks of photography, aerial triangulation is applied serving to bridge control across multiple stereo models by combining their relative orientations with the ground control measurements. The following diagram illustrates the aerial triangulation concept for a small block of photographs.

The photo coordinates of identifiable points on the ground (i.e. photo ground control points) are measured on multiple photographs, (at least two), along with other image locations, or tie points, common to multiple photographs to begin the aerial triangulation process. From these measurements and the camera calibration data, a trigonometric calculation determines the camera (focal point) location and sensor attitude for each exposure. Finally, a least squares adjustment is applied to the entire block, refining relative orientations of each image, and registering the block to ground control for absolute orientation.

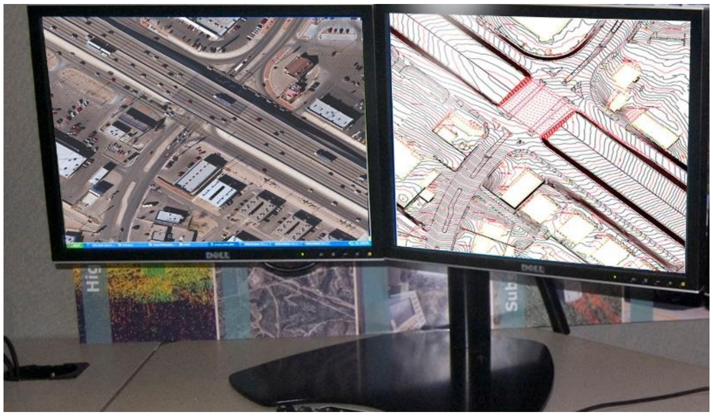


Image Courtesy of Colorado Department of Transportation

The aerial triangulation output allows analysis of stereo models using a digital workstation to produce photogrammetric mapping and terrain modeling. Digital workstations allow the operator to accurately compile and record data in 3D. The aerial triangulation data can also be used in combination with the camera calibration data and DTM to produce orthophotography.

More modern aerial survey acquisitions apply AGPS or a combination of AGPS and IMU technology. This is supported by collection of data at static ground base stations during the aerial survey. AGPS provides additional control to aerial photography by establishing a coordinate value for each photo center. In addition to AGPS, aerial imagery may be combined with IMU data to provide a more accurate photo center along with the camera attitude and heading, (tip, tilt, swing), also known as direct geo-referencing. For photogrammetry, the direct geo-referencing provides additional input to aerial triangulation process, facilitating more automation. Modern aerial triangulation software automates the selection of photogrammetry tie points. This allows a much larger number of tie points to be incorporated into the aerial triangulation solution improving overall results.

7.8.4 Equipment Checking and Calibration

Checks and calibrations on all types of electronic survey equipment are essential to obtain and maintain the minimum tolerances required for aerial surveys. Equipment must be properly maintained, regularly checked, and calibrated for accuracy at the beginning of any aerial survey project to ensure that the equipment is operating properly in accordance with Chapter 5 – Surveying Equipment, and Chapter 4 – GPS Surveys of this manual. It is the aerial consultant’s responsibility to ensure no errors due to poorly maintained or malfunctioning equipment will affect the project. For surveys lasting longer than six months, the checking, and calibration of equipment shall be repeated once every six months to ensure equipment will meet the needs and specifications for the project.

7.8.5 Aerial Ground Control Monumentation

Survey crews establish ground control points for aerial surveys. Targets are placed over the control points on the ground so that the location of the point is easily identified in the aerial survey. Depending on the contract scope of work, control survey may be performed by either the aerial mapping consultant or by NJDOT survey staff. In addition, the aerial consultant or NJDOT survey staff will be responsible for the targeting of control points to ensure identification in the aerial imagery.

Photo control points typically consist of the following:

1. Photo Center points
2. Photo Wing points

Center (i.e. flight line) point control is established as close to the center of the flight line as possible. Their location and configuration is dependent upon the flight height. For highway work the closest to the flight line center that is most often achievable on the ground is on the shoulder of the highway. Whenever possible NJDOT existing control monuments that have been previously established on the ground by a control survey shall be used for project control monuments. This allows the aerial control survey to be horizontally and vertically referenced and tied directly to the primary control established on the ground as the framework for the survey control network without having to install additional monuments. This can also greatly reduce the amount of field surveying needed to establish photo ground control since the primary control monuments need only to be targeted. The surveyor shall contact the NJDOT Geodetic Survey Unit for any new control established in the project area before commencing any field work. The surveyor shall also request copies of the existing plans covering the project limits from the NJDOT Engineering Documents Unit. Depending on the project scope the following is a list of the information that may be requested from the EDU:Key Sheet

- Tie and Alignment Sheets
- Construction Plans
- Profiles
- Drainage Plans
- Grading Plans
- ROW Plans

Whenever possible the surveyor shall research and use existing monuments within the project limits to establish project control.

Examples of these types of monuments may include the following:

1. Existing Baseline monuments
2. Right of Way monuments
3. Federal, State, or local agency monuments
4. Benchmark monuments

Photo control points shall be set flush with the pavement using a PK nail (or other type) with a distinguishable center point, or a Photo ID (PID) point. The NJDOT strongly discourages the use of drill holes, “X” cuts, or “Box” cuts as survey control points. Project Control pairs shall be of a semi-permanent nature such as a rebar and cap.

Examples of these types of monuments may include the following:

1. Types of monuments listed above
2. 5/8 inch diameter rebar with cap (set for temporary monuments only)
3. Nail set in asphalt (set for temporary photo control points only)

7.8.6 Wing Point Control

Wing point control is established at the right or left outer edge of the flight lines. These points become more critical for flight plans that include multiple flight strips run parallel to one another. Their location and configuration is dependent upon the flight plan.

7.8.7 Aerial Control Targets (Paneling)

Targets (i.e. paneling) shall be placed on the ground symmetrical and centered over aerial control points in order that the location of the point is easily identified in the imagery. The paneling width and configuration is dependent upon the flight height for aerial photography. The material or biodegradable paint used to target the control should contrast surface surrounding the target. (White in most instances, however, if the surface is very light colored, a black target may be preferable.)

7.8.8 Photogrammetry

For photogrammetric measurements made during the aerial triangulation process, the target must be clearly visible on multiple images. A minimum of two adjacent images allows measurement but accuracy increases with the number of images the target can be seen from. Ideally, targets should be visible from aerial view between 90 and 60 degrees above horizon in all directions. Trees or structures may obscure view of the target. See below:

Example of a visibility problem: Target visible on only one of two possible image pairs.

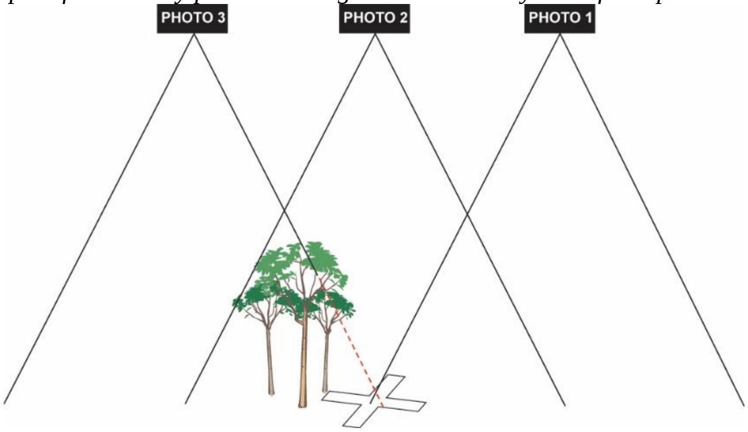


Image Courtesy of Colorado Department of Transportation

Ideally, the targets should be placed on the ground just prior to the aerial survey and should be maintained until the aerial mission has been flown and the data has been accepted. This reduces the risk of the targets being disturbed prior to the aerial survey.

7.8.9 Aerial Control Target Design & Material

The target design shall be symmetrical and centered on the aerial control point. There are three designs commonly applied for aerial surveys. These include four-legged “X” targets, three-legged “Y” targets), and two-legged “L” targets. More than one type can be used for a project if there is a need to distinguish between different types of control, such as wing and center control point targets. The length and width of the target legs will depend on the specifications of the flight mission. The principal drivers will be flying height or GSD of the resulting data.

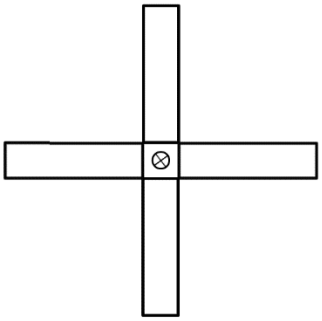


Diagram 1: "X" Type Target

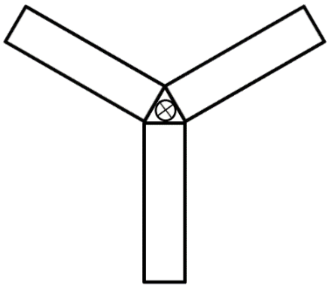


Diagram 2: "Y" Type Target

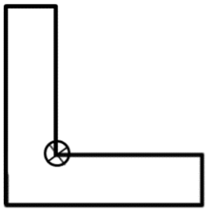


Diagram 3: "L" Type Target

If paint is used to target aerial control point locations, it must be of a type that is biodegradable and washes away within six months. Suggested materials for targeting include opaque polyethylene film, unbleached white muslin, or white cotton bunting. In flat terrain, plywood or masonite, painted flat white, may be used. When using either polyethylene film or material, it may be necessary to secure the target to the ground, either by stakes or nails. Placing rocks or dirt along the edges of the material may also help to keep it flat on the ground.

Natural target features, also known as Photo ID points or PID's may be used in lieu of artificial targets provided that a reasonably large angle of intersection exists to positively identify a point. Examples include sidewalk intersections, corner of concrete slabs, corners of inlets, existing paint markings on asphalt, or other clearly visible features from which a precise location can be interpreted. Examples of a painted target and a PID are shown below. The nailhead should be flush with the pavement and the horizontal and vertical position should be taken at the center of the nail. The PID elevation should be measured at the sidewalk surface at the edge of the where it aligns with the sidewalk surface extending to the right.

The aerial mapping consultant is responsible for determining and specifying target dimensions, material, and configurations for the survey crews to layout. The NJDOT Survey SME or designee shall work closely with the aerial mapping consultant when determining how monuments are to be targeted.

Example of Painted Target

Example of Photo Identifiable Point (PID)

Images Courtesy of Colorado Department of Transportation

7.8.10 Removal of Aerial Control Target Material

To maintain proper public relations all manmade target material placed over aerial control points shall be removed and the site cleaned up within seven days of confirmation that aerial survey was successfully acquired, and no re-flights are necessary.

Unless directed otherwise, all aerial control monuments on public property shall be left in place and undisturbed for future use if needed. Monuments set on private property may require removal depending on what has been agreed to by the property owner or tenant. The removal must be completed on a schedule agreed to by the owner or tenant. Aerial control monuments shall only be removed with the approval of the NJDOT Survey SME or designee.

7.8.11 Aerial Control Horizontal Survey Datum

All aerial control horizontal surveys shall be referenced to the National Spatial Reference System (NSRS) and the NJSPCS and tied into the NJDOT primary control survey. Any supplemental or additional project surveys shall also be tied to the primary project control survey.

As defined in NJDOT Survey Manual, Chapter 2 – Control Surveys, the purpose of a primary control survey is to establish a network of physically monumented coordinate points in and along a highway corridor that provide a common horizontal and vertical datum for the entire project. The primary control survey provides the means for tying all of the geographic features and design elements of a project to one common horizontal and vertical coordinate system. The primary control survey is performed at a higher level of accuracy than the aerial control survey, as such the aerial control survey shall be considered secondary control.

For all projects an NJDOT primary control survey will be required and shall be established as part of the survey effort for the aerial photogrammetric control. The NJDOT Survey SME shall be contacted if there are any questions regarding the primary control survey prior to commencing any field survey effort. NJDOT discourages the practice of performing any aerial control survey without establishing a primary control survey as well. Any consideration for not providing a primary control survey shall be reviewed by the NJDOT Survey SME and approved by the Manager Roadway Design Group 2.

All control horizontal and vertical surveys shall be referenced to and tied into the National Spatial Reference System (NSRS) as defined by the National Geodetic Survey (NGS).

The National Geodetic Survey defines and manages the National Spatial Reference System (NSRS). The NSRS is a consistent coordinate system that defines latitude, longitude, height, scale, gravity, and orientation throughout the United States and is designed to meet the nation's economic, social, and environmental needs. The NSRS has traditionally been defined by survey marks in the ground. More recently, the horizontal datum is defined by the Continuously Operating Reference Stations (CORS).

The current datums are the latest realization of the horizontal datum (NAD83 (2011) and the North American Vertical Datum of 1988 (NAVD 88).

To improve the NSRS, NGS will replace all three North American Datum of 1983 (NAD 83) frames and all vertical datums, including the North American Vertical Datum of 1988 (NAVD 88), with four new terrestrial reference frames and a geopotential datum.

The new reference frames will rely primarily on Global Navigation Satellite Systems (GNSS), such as the Global Positioning System (GPS), as well as on a gravimetric geoid model resulting from our Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project.

Refer to the NGS link for additional datum information.

https://geodesy.noaa.gov/datums/newdatums/index.shtml

See NJDOT Survey Manual Chapter 4 - GPS Surveys, for additional information.

7.8.12 Global Navigation Satellite System (GNSS) Photo Control Horizontal Survey Methods

Unless field conditions do not permit, (e.g. obstructions of the sky by trees, buildings, etc.) only Global Navigation Satellite System (GNSS) survey methods shall be performed for all aerial control horizontal surveys.

Those aerial control horizontal surveys performed by survey methods other than GNSS shall be approved in advance by the NJDOT Survey SME.

All aerial control horizontal surveys performed by GPS methods shall be performed in accordance with Chapter 4 – GPS Surveys, and shall meet the Minimum Horizontal Accuracy Tolerances as indicated in the NJ DOT Survey Manual in chapters 4.4.3.2.1 through 4.4.3.2.2.2.3.

Unless approved otherwise by the NJDOT Survey SME, all GNSS aerial control monuments (center and wing points) shall be observed by survey methods and procedures in accordance with Chapter 4 - GPS Surveys.

Real Time Kinematic (RTK) or Real Time Network (RTN) GNSS techniques, based on the National Spatial Reference System (NSRS) may be utilized for aerial projects. The latest National Geodetic Survey (NGS) guidelines as found on their homepage website: (https://www.ngs.noaa.gov/) must be used for procedures for RTK/RTN projects.

Current resource guidelines (6/2019) are as follows:

- User Guidelines For Single Base Real Time GNSS Positioning:

  www.ngs.noaa.gov/PUBS_LIB/UserGuidelinesForSingleBaseRealTimeGNSSPositioningv.3.1APR2014-1.pdf

- National Geodetic Survey Guidelines for Real Time GNSS Surveys:

  www.ngs.noaa.gov/PUBS_LIB/NGS.RTN.Public.v2.0.pdf

RTN precision expectations as noted in above referenced publication:

Since RTN positioning is a differential solution from a base station to a point of interest, the results are displayed in the data collector as measures of the precision, or repeatability, of the solution. On the other hand, the alignment of the base station to the user-selected datum (as part of the NSRS or otherwise) can be considered the level of accuracy. Many data collectors will show a position precision from the base station (whether non-physical or master) at the 68% confidence level (or "1 sigma" statistically), although some actually do show a 95% or even 99% confidence level. Typically, this is shown as horizontal, vertical (orthometric), and root-mean-square (RMS) values resulting from the baseline solution. It would be wise for the user to ascertain which confidence level is indeed displayed to have a realistic sense of the precision. Current empirical results suggest: Typical RTN precisions at the 95% confidence level are: horizontal 2-3 cm, vertical (ellipsoid) 3-5 cm, orthometric heights 5-7 cm (typical using the NGS hybrid geoid model). Exceptional RTN derived precisions are at the current limit of the RT technology: horizontal: ≤ 1 cm, vertical (ellipsoid) ≤ 1 cm, possible orthometric height ≤ 2 cm. This is a direct citation (William Henning, team leader, editor, and others (March 2011, p. 54).

- RTN Field Procedures and Best Practices:

  www.ngs.noaa.gov/web/science_edu/presentations_library/files/rtn_field_procedures.pptx

7.8.13 Conventional Aerial Control Horizontal Survey Methods

All aerial control horizontal surveys performed by conventional survey methods shall consist of a closed traverse or closed loop survey in accordance with Chapter 2 Control Surveys and State Ground Coordinate Systems.

7.9 Aerial Control Vertical Survey

7.9.1 Photo Control Vertical Survey Datum (NAVD 88) (Second Order Class II)

All aerial control vertical surveys shall be referenced and tied to the North American Vertical Datum of 1988 (NAVD 88) or the latest vertical datum produced by NGS. This is typically accomplished when referencing and tying the aerial control vertical survey to a NJDOT primary control survey that has been previously referenced and tied to NAVD 88 datum in accordance with Chapter 3.

For projects where no NJDOT primary control survey has been completed, elevations for any aerial control vertical survey shall be established from existing national benchmarks and referenced and tied to the North American Vertical Datum of 1988 (NAVD 88) in accordance with the methods and procedures as defined in Chapter 3.

7.9.2 Minimum Aerial Control Vertical Accuracy Tolerance

All aerial control vertical surveys shall meet the Minimum Vertical Accuracy Tolerance for a NJDOT Second Order Class 2 in accordance with Chapter 3.7. All photo control points shall meet Third Order Vertical Control.

7.9.3 GPS Aerial Control Vertical Survey Methods

All aerial control vertical surveys performed by GPS methods shall be performed in accordance with Chapter 4 – GPS Surveys, and shall meet the Minimum Vertical Accuracy Tolerance for a NJDOT Second Order Class 2 in accordance with Chapter 3.7. As required in NJDOT Survey Manual Chapter 4 – GPS Surveys. All GPS derived elevations shall be verified or supplemented with elevations by a more accurate survey method as follows:

1. Differential leveled elevations in accordance with the methods and procedures as stated in NJDOT Survey Manual Chapter 3.
2. The use of commercial RTK and RTN networks based on NAD83 and NAVD88 with proper techniques can also be utilized.
3. Trigonometric elevations by conventional survey methods such as a total station in accordance with the methods and procedures as stated in NJDOT Survey Manual Chapter 3.

7.9.4 Conventional Aerial Control Vertical Survey Methods

All aerial control vertical surveys performed by conventional survey methods shall consist of a closed loop survey in accordance with Chapter 3 and shall meet Third Order Tolerance.

7.9.5 Photogrammetric Advantages / Disadvantages

Surveys collected by aerial photogrammetry methods have both advantages and disadvantages when compared with ground survey methods as follows:

Advantages:

1. Photos provide a permanent record of the existing terrain conditions at the time the photograph was taken.
2. Photos can be used to convey information to the general public, and other federal, state, or local agencies.
3. Photos can be used for multiple purposes within NJDOT such as reconnaissance, preliminary design, environmental, and Right of Way.
4. Topographic mapping and DTMs of large areas can be accomplished relatively quickly and at a lower cost when compared to ground survey methods.
5. Photogrammetry can be used in locations that are difficult or impossible to access from the ground.

Disadvantages:

1. Seasonal conditions, including weather, vegetation, and shadows can affect both the taking of photographs and the resulting measurement quality. If the ground is not visible in the photograph it cannot be mapped.
2. Overall accuracy is relative to camera quality, ground control, and flying height. Elevations derived from photogrammetry are less accurate than ground surveys

(when compared to conventional or GPS ground survey methods using appropriate elevation procedures).

3. Identification of planimetric features can be difficult or impossible (e.g. type of curb and gutter, size of culverts, type of fences, and information on signs).
4. Underground utilities cannot be located, measured, or identified.
5. Right of Way and property boundary monuments cannot be located, measured, or identified.

Since photogrammetric features are compiled from a plan view, buildings are measured around overhangs and eaves rather than at building footprints, resulting in some areas of DTM occlusion under overhangs, eaves, and overhead walkways. Areas under bridges are similarly affected.

7.10 Equipment Maintenance

Checks and calibrations on all types of electronic survey equipment are essential to obtain and maintain the minimum tolerances required for aerial surveys. In accordance with the manufacturers’ specifications equipment must be properly maintained, regularly checked, and calibrated for accuracy at the beginning of any aerial survey project to ensure that the equipment is operating properly. This includes but not limited to GPS units (airborne and ground), IMU, and aircraft. It is the aerial consultant’s responsibility to ensure no errors due to poorly maintained or malfunctioning equipment will affect the project.

7.11 Deliverables and Documentation

The desired deliverables from an Aerial Photogrammetry project should be identified in the planning stage. The mapping consultant should refer to the NJDOT CADD Standards available online at the NJDOT website:

(https://www.state.nj.us/transportation/eng/CADD/v8/)

Contact the CADD Manager if they have any questions regarding the CADD Standards and CADD deliverables.

Any use of the data other than its intended use should be approved by the NJDOT CADD Manager and NJDOT PM before any other use of the data.

7.12 Deliverables

Different projects and customers require different types of deliverables, which can range from a standard CADD product to a physical three-dimensional (3D) scale model of the actual subject.

Deliverables for Aerial Photogrammetric surveys may include, but are not limited to:

- Mapping in current NJDOT CADD Standards for Roadway, Bridge, Electrical
- Digital photo mosaic files
- Survey narrative report (refer to Chapter 11 of the NJDOT Survey Manual)
- Aerial Triangulation Report
- QA/QC Files

7.13 Aerial Survey – Photogrammetric Feature Identification

Required features that cannot be identified by aerial survey methods will be field collected by means of a post-aerial or pre-aerial ground survey. Likewise, required features mapped within the aerial project scope that could not be positively or fully identified by the photogrammetrist shall be field identified in a Post-Aerial survey. The map compilation process shall use latest NJDOT MicroStation Levels with feature descriptors to ensure their identification for the post-aerial ground survey. It should be anticipated that completion of the feature identification will require ground surveys.

The aerial mapping consultant is responsible for determining which features can be identified. The NJDOT Survey SME or designee shall work closely with the aerial mapping consultant when determining which features require further identification.

7.14 Obscured Areas

Obscured areas are defined as areas within the aerial mapping project limits where vegetation or tree canopy, dense smoke features are obscuring the aerial perspective. These areas will be identified in such cases where planimetric feature compilation cannot be completed or where there is insufficient elevation data to meet the specified vertical accuracy tolerance for vegetated areas. The areas will be identified by the Aerial Photogrammetrist and provided to the surveyor for field survey data collection.

7.15 Supplemental Surveys

Supplemental surveys shall be performed on the ground to compliment the aerial survey within the existing constructed transportation corridor template, and shall be performed in accordance with the methods, procedures, horizontal and vertical accuracies tolerances as required. The supplemental survey fieldwork may be performed by the consultant or by NJDOT survey crews as required in the project scope and shall utilize NJDOT Level Structure.

The purpose of the supplemental survey is to locate those features that require a higher level of accuracy than that of the aerial survey, to locate those features that cannot be located by the aerial survey, and to collect information not apparent to the photogrammetrist from the aerial survey.

The aerial mapping consultant is responsible for determining which aerial survey features may need supplemental identification, the NJDOT Survey SME or designee shall work closely with the aerial mapping consultant when determining which features require supplemental surveying.

7.16 Minimum Horizontal and Vertical Accuracy Tolerance for Supplemental Survey

All supplemental surveys performed on the ground to complete the aerial survey shall be performed in accordance with the methods, procedures, and the Minimum Horizontal and Vertical Accuracy Tolerance as required in Chapter 3 – Surveying Measurements Aerial Mapping Tolerances

The American Society for Photogrammetry and Remote Sensing (ASPRS) has published aerial map accuracy standards titled ASPRS Positional Accuracy Standards for Digital Geospatial Data. The first edition was published in 2014, (Edition 1, Version 1.0 – November, 2014). Below is a link to the ASPRS standards:

http://www.asprs.org/a/society/committees/standards/Positional_Accuracy_Standards.pdf

7.17 Vertical Accuracy Testing - Method of Verifying Accuracy Tolerance

7.17.1 Photogrammetry

Accuracy tolerance requirements are evaluated by comparing a cross section string, or a series of random checkpoints taken in the field with the same cross section location, or series of random point locations, extracted from a terrain TIN model produced from the original aerial survey data. The field cross section string is collected by conventional topographic survey methods and is held as the true representation of what exists in the field in relation to the primary control monuments. The interval between observations on the cross section shall be taken at a minimum of 30 feet, include all changes of slope, and shall not exceed the interval of the aerial mapping at the particular cross section.

The field cross section string or random checkpoints are then processed and compared to the TIN model aerial survey cross section or random points. The difference between the sections is evaluated to determine if the delivered product is within the minimum horizontal and vertical aerial mapping tolerances.

The number and location of random checkpoints or cross section strings will vary according to project size, field conditions and specific project requirements. The scope of work shall include a description of the verification requirements on a project-by-project basis.

7.18 Documentation: Aerial Control Survey Report

7.18.1 General

Upon completion of the aerial control survey, whether performed by the consultant or NJDOT survey crews, an Aerial Control Survey Report shall be completed and filed with the NJDOT Survey SME. The project shall not be accepted as final without the Aerial Control Survey Report.

Documentation of surveys is an essential part of surveying work. Survey data not properly documented could result in additional field and office time to redo or correct what was not performed or documented properly.

The survey narrative report (refer to Chapter 11 of the NJDOT Survey Manual), completed by the PLS in responsible charge of the survey, shall contain the following general information, the specific information required by each survey method, and any appropriate supplemental information.

- Project Name and UPC Number: Route, Beginning and Ending Milepost, Project UPC Identification, Municipality, County, etc.
- Survey date, limits, and purpose
- Datum, epoch, and units

  Final coordinate values for control points shall be produced and tabulated in four formats to satisfy NJDOT requirements. All coordinates are based on the latest realization of NAD83 adjustment datum. Currently: NAD83 (2011).
  - GEOGRAPHIC POSITIONS *(Latitude, Longitude and Ellipsoidal Heights in meters).*
  - NJSPC (METRIC) *(State Plane Coordinates in meters).*
  - NJSPC (U.S. SURVEY FEET) *(State Plane Coordinates in U.S. Survey Feet).*
  - GROUND/MODIFIED *(Ground Coordinates in U.S. Survey Feet).*

- Control found, held, and set for the survey.
- Personnel, equipment, and surveying methods used.
- Field notes including scan diagrams, control geometry, instrument and target heights, atmospheric conditions, etc.
- Problems encountered.
- Any other pertinent information

- QA/QC reports
- Dated signature and seal of the Professional Land Surveyor in responsible charge.

Chapter 8 - Terrestrial Laser Scanning

8.1 Laser Scanning

Laser scanning or Light Detection and Ranging (LiDAR) systems use lasers to make measurements from a tripod or other stationary mount, a mobile mapping vehicle, or an aircraft. The term LiDAR is sometimes used interchangeably with laser scanning. This chapter deals with Terrestrial Laser Scanning methods.

The NJDOT Survey Manual provide specifications, describe methods and procedures needed to attain a desired survey accuracy standard. For complete accuracy standards, refer to NJDOT Survey Manual Chapter 4, NJDOT survey specifications shall be used for all NJDOT projects.

There are many uses for LiDAR in a multitude of disciplines. The following table demonstrates many of the uses and recommended accuracies and point cloud density for each use. Although most NJDOT projects will fall into Blocks 1A, 1B or 1C, there may be some that will not. The actual determination of the required accuracy and point cloud density will be based on recommendations from the mapping consultant and the concurrence of the NJDOT Survey SME and the NJDOT PM will be on a project-by-project basis.

This technology can minimize impacts to traffic and improve the safety for the surveyors in the field. Thus, reducing costs for attenuator vehicles and other safety devices and field time for the surveyors. In addition, it will take less time to collect the data and longer time to process the data, however the overall time could be significantly less than conventional survey methods.

Projects could employ one or more of these technologies depending on time, cost, and priority of each project:

- Aerial Photogrammetry
- Airborne LiDAR
- Mobile Terrestrial Laser Scanning (MTLS)
- Stationary Terrestrial Laser Scanning (STLS)
- Conventional Survey

Matrix of application and suggested accuracy and resolution requirements. Network accuracies may be relaxed for applications identified in *red italics*. Note that these are only suggestions and may change based on project needs and specific transportation agency requirements. The accuracy and density values are to serve as a guideline.

TABLE 8-1

Accuracy	**HIGH** **< 0.05 m** **(< 0.16 ft)**	**MEDIUM** **0.05 to 0.20 m** **(0.16 to 0.66 ft)**	**LOW** **> 0.20 m** **(> 0.66 ft)**
Density	**1A**	**2A**	**3A**

FINE **>100 pts/m^2** **(>9 pts/ft^2)**	- **Engineering surveys** - **Digital Terrain Modeling** - **Construction Automation/ Machine Control** - **ADA compliance** - ***Clearances*** - ***Pavement analysis*** - **Drainage\flooding analysis** - **Virtual, 3D design** - **CAD models\baseline data** - **BIM\BRIM** - **Post-construction quality control** - **As-built/As-is/repair documentation** - **Structural inspection**	- ***Forensics/Accident Investigation*** - ***Historical Preservation*** - **Power line clearance**	- **Roadway condition assessment (general)**
	1B	**2B**	**3B**
INTERMEDIATE **30 to 100 pts/m^2** **(3 to 9 pts/ft^2)**	- **Unstable slopes** - **Landslide assessment**	- **General Mapping** - ***General measurements*** - **Driver Assistance** - **Autonomous Navigation** - **Automated\semi-automatic extraction of signs and other features** - **Coastal change** - ***Safety*** - **Environmental studies**	- **Asset Management** - **Inventory mapping (*e.g.* GIS)** - **Virtual Tour**
	1C	**2C**	**3C**
COARSE **<30 pts/m^2** **(<3 pts/ft^2)**	- ***Quantities (e.g., Earthwork)*** - **Natural Terrain Mapping**	- ***Vegetation Management***	- **Emergency Response** - **Planning** - **Land Use\Zoning** - **Urban modeling** - **Traffic Congestion\ Parking Utilization** - **Billboard Management**

The above table is from the: NCHRP 15-44 Guidelines for the Use of Mobile LIDAR in Transportation Applications. Although the guidelines in the above table were developed for Mobile LiDAR. They can also serve as a guideline for Stationary Terrestrial Laser Scanning (STLS) as well. Actual point cloud densities and accuracies will be determined on a project-by-project basis.

Any mapping project that requires survey control to be established or utilizes a RTN network will require a Licensed Land Surveyor

8.2 Stationary Terrestrial Laser Scanning (STLS)

Stationary Terrestrial Laser Scanning (STLS) refers to laser scans that are performed from a static location(s).

The raw data product of a laser scan survey is a point cloud. When the scanning control points are georeferenced to a known coordinate system (i.e. NJSPCS), the entire point cloud can be oriented to the same coordinate system. All points within the point cloud have X, Y, and Z coordinates and Laser Return Intensity values (XYZI). If image overlay is available the points may be in an XYZIRGB (X, Y, Z coordinates, return Intensity, and Red, Green, Blue color values). The positional error of any point in a point cloud is equal to the accumulation of the errors of the scanning control and errors in the individual point measurements.

Laser scan measurements that are perpendicular to a surface will produce better accuracies than those with a large angle of incidence to the surface. The larger the incidence angle, longer distances, (see Figure 8-1), the more the beam can elongate resulting in divergence of the laser, producing errors in the distance returned. Data points will also become more widely spaced as distance from the scanner increases and reflect off a larger area the less laser energy is returned. At a certain distance, the error will exceed standards and beyond that no data will be returned. Atmospheric factors such as heat radiation, rain, snow, dust, and fog will also limit scanner effective range. It is recommended that the surveyor refer to the manufacturer specifications regarding the acceptable distance for any scanner.

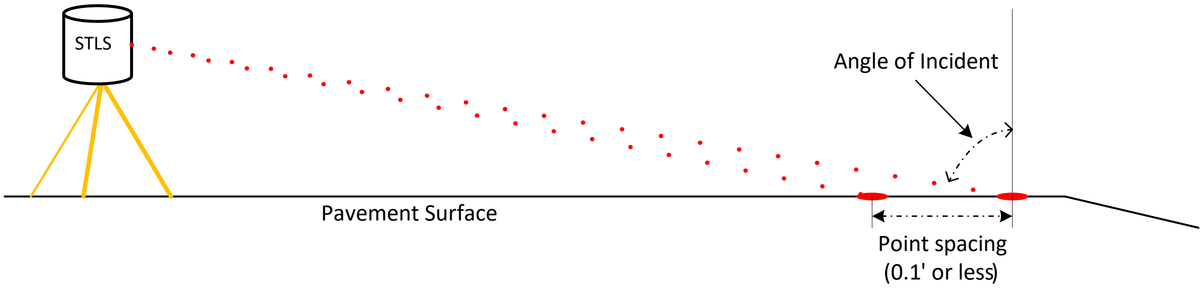


Figure 8-1 Example of Incidence Angle
Image Courtesy of California Department of Transportation.

8.3 Applications

There are many different applications for this technology. This section will deal with what is required for NJDOT projects. As indicated in Table 8-1 there are many different applications for laser scanning. Some of the major uses this technology could be used for are pavement evaluation, drainage issues, bridge inspection, evaluation and clearance, intersection improvements, traffic signal, and controller locations and clearance. The type of project and the accuracy required will determine the density of the point cloud and number of targets.

8.4 Selecting a Project

Not every project will be suited for this technology. Below are some factors that should be considered when determining whether the project is suitable or not.

- Safety (see NJDOT Safety Manual and MUTCD for guidelines)
- Project deliverables desired
- Project time constraints
- Site or structure complexity or detail required
- Length/size of project
- Traffic volumes and best available observation times
- Forecast weather and atmospheric conditions at planned observation time
- STLS system
- Availability of equipment and staff

- Accuracy required
- Technology best suited to the project and desired final products (as determined by the NJDOT Survey SME and NJDOT PM)

Some significant advantages of STLS is the minimizing the effects on traffic and the safety of the survey crew.

8.5 STLS Types of Scans

In general, there are two types of scans, Type A and Type B. Below are some examples of each type of scans. The NJDOT PM should consult with the Survey SME to determine what type of scan is required for each project.

8.5.1 Type A – Hard Surface and High Accuracy – Topographic Surveys

- Engineering topographic surveys
- As-built surveys
- Structures and bridge clearance surveys
- Pavement analysis
- Forensic surveys

8.5.2 Type B – Earthwork and Low Accuracy – Topographic Surveys

- Corridor Study and Planning Surveys
- Asset Management and Inventory Surveys
- Environmental Surveys
- Sight Distance Analysis Surveys
- Earthwork Surveys such as rock slopes, borrow pits, stock piles
- Soil and Coastal Erosion Analysis
- Street Scape Design and Analysis

Type A and B list Courtesy of California Department of Transportation

8.6 STLS Equipment and Uses

The equipment used to collect STLS data, to control the data, and to collect the quality control validation (check) points should be able to collect the data at the accuracy standards required for the project. This determination will be from the stated specifications for the equipment by the manufacturer. It is recommended that all survey equipment be properly maintained and regularly checked for accuracy and proper function. Ancillary equipment may include tribrachs, tripods, targets, target poles, etc.

8.7 Eye Safety

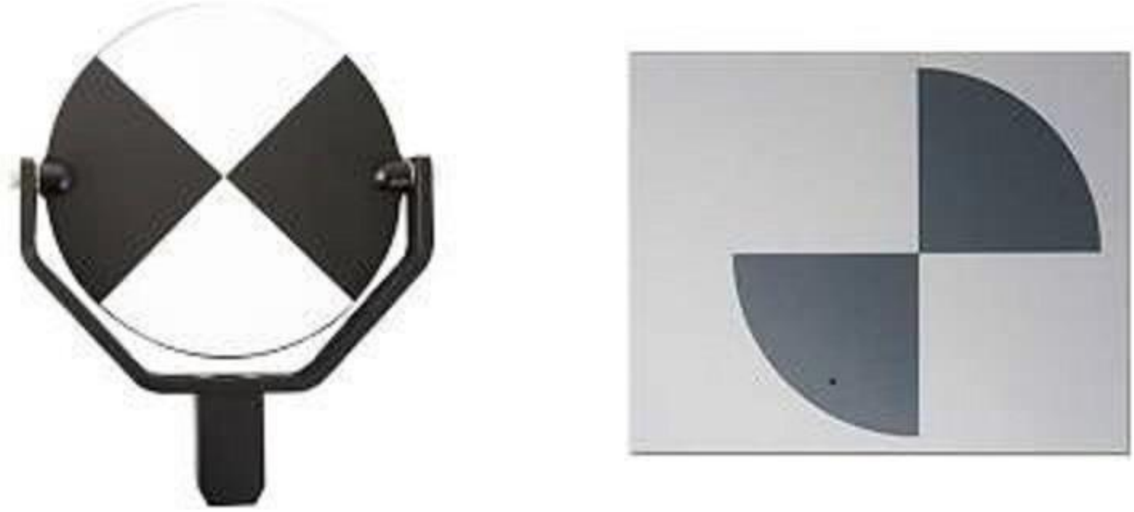
One major concern is that of eye safety for both the survey crew and the general public. The survey crew should follow all appropriate OSHA, State and manufacturers' recommendations when using any laser equipment. Never stare into the laser beam or view laser beams through magnifying optics, such as telescopes or binoculars. STLS equipment operators should never direct the laser toward personnel operating instruments with magnifying optics such as total stations or levels. The eye safety of the traveling public and other people should be considered at all times and the equipment operated in a manner to ensure the eye safety of all and refer to the manufacturer specifications.

8.8 Useful Range of Scanner

A laser is capable of scanning features over long distances, and since the accuracy of the scan data diminishes beyond a certain distance, care should be taken to ensure that the final dataset does not include any portion of point cloud data whose accuracy is compromised by measurements outside the useful range of the scanner. The useful range is influenced by factors such as the range and accuracy specifications of the individual scanner as well as the accuracy requirements of the final survey. Methods for accomplishing this might include the implementation of range and/or intensity filtering during data collection or removal of any out-of-useful range data during post-processing. Surface properties including color, surface reflectivity, surface texture, and angle of incidence can limit scanner useful range, divergence and low angular accuracy.

8.9 Scanner Targets

Total station targets reduce pointing error when placed at long distances. Laser scanning targets, however, are designed for a specific range of distance. Most laser scanners do not have telescopes to orient the instrument to a backsight. STLS targets must be scanned with a sufficient density to model their target reference locations. The size of the target, laser spot size, distance from the scanner, and target scan resolution determine how precisely the target reference locations can be determined. If the distance from the scanner to the target exceeds the manufacturer’s recommended distance, the error may increase dramatically. Manufacturer specific recommended targets may differ in size and shape. The operator should follow the manufacturer’s recommended targets, distance for placement of targets, and target scan resolution.



Sample STLS Targets

8.10 STLS Specifications and Procedures

STLS collected survey data points are checked by various means including:

1. comparing the scan to the quality control validation points,
2. reviewing the DTM and data terrain lines in the profile,
3. and redundant measurements. Redundant measurements with a laser scanning system can only be accomplished by multiple scans, either from the same set-

up, or from a subsequent set-up that offers overlapping coverage (see Figure X-2).

8.10.1 Planning

Before the STLS project commences, the project area shall be inspected to determine the best time to collect data to minimize excessive interference from traffic or other factors, and to identify obstructions that may cause data voids or shadows. Check weather forecast for fog, rain, snow, smoke, or blowing dust. Tall tripod set-ups may be used to help reduce artifacts and obstructions from traffic and pedestrians, and to reduce incident angle (see Figure 8-1). Areas in the project that will be difficult to scan should be identified including standing water, and a plan developed to minimize the effect on the final data, through additional set-ups or alternate methods of data collection. Safety should always be taken into consideration when selecting setup locations. If additional safety is required, the surveyor should follow the guidelines in the NJDOT Safety Manual and the MUTCD.

Site conditions should be considered to determine expected scanning distance limitations and required scan density to adequately model the subject area. Pavement analysis scans to identify issues such as surface irregularities and drainage problems require a scan point density of 0.10’ or less (see Figure 8-1). Typically, density diminishes over the scanners effective range. Pavement analysis scans also require shorter maximum scanning distances and closer spacing of scanner control and validation points (see Figure X-2) than other Scan Type A applications.

8.10.2 Project Control and Target Placement

When performing Type A STLS surveys, the STLS control (scanner occupation and targeted control stations) points that will be used to control the point-cloud adjustment and validation points that will be used to check the point-cloud adjustment of the STLS data, shall meet 0.05’ local network accuracy or better horizontal and third order or better vertical accuracy standards as defined in Chapter 3 of the NJDOT Survey Manual. Best results are typically seen when the targeted control stations are evenly spaced horizontally throughout the scan. Variation in target elevations is also desirable. Targets should be placed at the recommended optimal distance from the scanner and scanned at high-density as recommended by the STLS manufacturer. Maximum scanner range and accuracy capabilities may limit effective scan coverage.

Pavement analysis survey scans to identify issues such as surface irregularities, such as rutting and drainage problems, may require shorter maximum scanning distances and closer spacing of scanner control and validation points than other Scan Type A applications (see Figure 8-2).

All Type A, hard surface topographic STLS surveys require control meet the 0.05’ local network accuracy and third order vertical accuracy, and validation point surveyed local positional accuracies of X, Y, (horizontal) ≤ 0.03’ & Z (vertical) ≤ 0.02’. Scan Type B, earthwork and other lower-accuracy topographic surveys require validation point surveyed local positional accuracies of X, Y, & Z ≤ 0.10’ (see Table X-1). All STLS control and validation points shall be on the project datum and epoch.

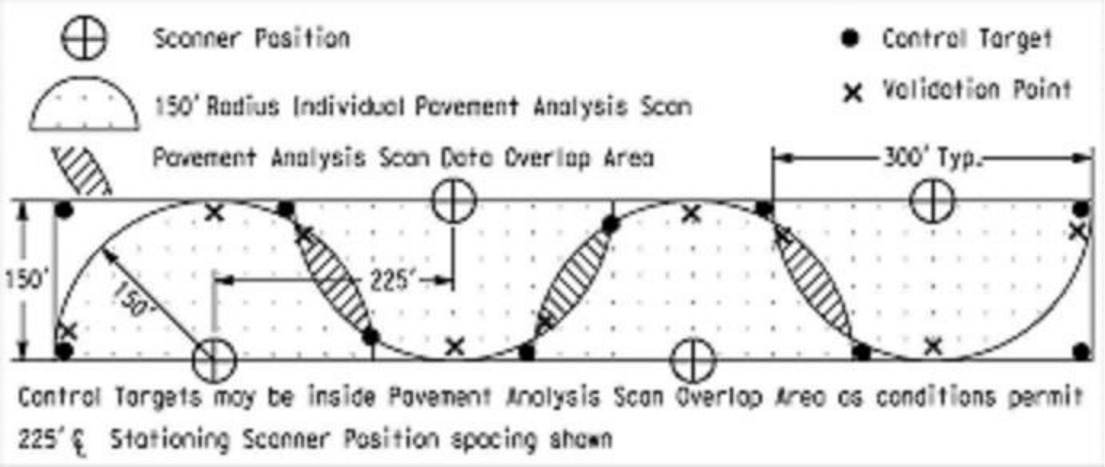


Figure 8-2 Target Placement and Scan Coverage – Type A Applications
Image Courtesy of California Department of Transportation.

8.10.3 Equipment Setup and Calibration

When occupying a known control point, ensure the instrument is over the point, measure and record the height of instrument (if required) and height of targets (if required) at the beginning of each set-up. It is advisable to check the plummet position for targets at the completion of each set-up. Scanners that do not have the ability to occupy known points require additional targets incorporating good strength of figure to control each scan and establish scanner position by resection. Three targets per resection is preferred, although less may be utilized if cloud – cloud registration is used in areas of hardscape. Setting up the laser scanner as high as practical on a tall tripod would reduce the angle of incidence and consequently improve scanner's effective range and accuracy points on the pavement surface. Ensure automatic STLS system calibration routines are functioning per the manufacturer's specifications before beginning any scanning.

8.10.4 Redundancy

STLS data collection shall be conducted in such a manner as to ensure redundancy of the data through overlapping scans. The data should be collected so that there is a minimum 10% to 20% overlap (percentage of scanner's useful range) from one scan to the next adjacent scan. When using cloud to cloud registration overlap can be as much as 75%.

8.10.5 Monitoring During the STLS Operation

Monitoring STLS operations during the scanning session is a critical step in the process. The operator should note if and when the STLS system encountered difficulties and be prepared to take appropriate action to ensure data quality. These could include significant change in weather conditions, temporary obstructions between the scanner and the target (i.e. large parked vehicle) that could interrupt the scan. When obstructions do occur, it is recommended that the scanning occur twice from the same location before moving, otherwise additional setups may be required.

8.10.6 Quality Control

Engineering survey data points collected using STLS data are checked by various means including comparing scan points to validation points, reviewing the digital terrain model, reviewing data terrain lines in plan and profile, and redundant measurements. Redundant measurements with STLS can only be accomplished by scanner set-ups that offer overlapping coverage. Plan and profile views of overlapping registered point clouds should indicate precise alignment and data density of less than 0.03 ft vertical at scan seams. Elevation comparison may be performed using profile, Digital Elevation Model (DEM) differences determined from point grid or Triangular Interpolation Network (TIN) data. An STLS Quality Management Plan (QMP) shall include descriptions of the proposed quality control (QC) and quality assurance (QA) plan. The QMP shall address the requirements set forth in this document and any other project-specific QA/QC measures. The QA/QC report shall list the results of the STLS including but not limited to the following documentation:

1. Project Control reports (see NJDOT Survey Manual Chapter 11).
2. STLS registration reports that contains registration errors reported from the registration software (cloud – cloud and target areas).
3. Elevation comparisons of two or more point clouds from overlapping scan area (see Figure 8-2).
4. Statistical comparison of point cloud data and redundant control point(s) if available.
5. Statistical comparison of registered point cloud data with validation points from conventional surveys if available.
6. Either item 4 or 5 shall be performed for QC. Completing both item 4 and 5 is highly recommended.

8.11 STLS Deliverables and Documentation

The desired deliverables from a scanning project should be identified in the planning stage. The mapping consultant should refer to the NJDOT CADD Standards available online and contact the CADD Manager if they have any questions regarding the CADD Standards and CADD deliverables.

Any use of the data other than its intended use should be approved by the NJDOT CADD Manager and NJDOT PM before any other use of the data.

8.11.1 STLS Deliverables

Different projects and customers require different types of deliverables, which can range from a standard CADD product to a physical three-dimensional (3D) scale model of the actual subject.

Deliverables specific to STLS surveys may include, but are not limited to:

- Registered point clouds in XYZI or XYZIRGB files in ASCII, CSV, LAS, LAZ, ASTM E57 3D Imaging Data Exchange Format (E2761) or other manufacturer’s specified format
- Current NJDOT CADD Standards for Roadway, Bridge, Electrical
- Current NJDOT Drafting Software files
- Digital photo mosaic files
- 3D printing technology physical scale models of the subject

- Survey narrative report (refer to Chapter 11 of the NJDOT Survey Manual)
- QA/QC Files

8.11.2 STLS Documentation

Documentation of surveys is an essential part of surveying work. Survey data not properly documented could result in additional field and office time to redo or correct what was not performed or documented properly.

The survey narrative report (refer to Chapter 11 of the NJDOT Survey Manual), completed by the PLS in responsible charge of the survey, shall contain the following general information, the specific information required by each survey method, and any appropriate supplemental information.

- Project Name and UPC Number: Route, Beginning and Ending Milepost, Project UPC Identification, Municipality, County, etc.
- Survey date, limits, and purpose
- Datum, epoch, and units
- Control found, held, and set for the survey
- Personnel, equipment, and surveying methods used
- Field notes including scan diagrams, control geometry, instrument and target heights, atmospheric conditions, etc.
- Problems encountered
- Any other pertinent information
- QA/QC reports
- Dated signature and seal of the Professional Land Surveyor in responsible charge

Table 8 – 2 Stationary Terrestrial Laser Scanning Specifications

Table Courtesy of California Department of Transportation

As revised by NJDOT

Operation/Specification	**STLS Scan Application (See Section XX)**	
	Scan Type A	**Scan Type B**
Level compensator should be turned ON unless unusual situations require that it be turned OFF	Each set-up	
Minimum number of targeted control points required	Follow manufacturer's recommendations	
STLS control and validation point surveyed positional local accuracy. (See note 1 below)	$H \leq 0.02$ foot $V \leq 0.03$ foot	H and V ≤ 0.10 foot
Strength of figure: α is the angle between each pair of adjacent control targets measured from the scanner position	Recommended $60^\circ \leq \alpha \leq 120^\circ$	Recommended $40^\circ \leq \alpha \leq 140^\circ$
Target placed at optimal distance to produce desired results	Each set-up	

Control targets scanned at density recommended by vendor	Required	
Measure instrument height and target heights	If required	
Fixed height targets	Recommended	
Check plummet position of instrument and targets over occupied control points	Begin and end of each set-up	
Be aware of equipment limitations when used in rain, fog, snow, smoke or blowing dust, or on wet pavement	Each set-up	
Distance to object scanned not to exceed best practices for laser scanner and conditions - Equipment dependent	Manufacturer’s specification	
Distance to object scanned not to exceed scanner capabilities to achieve required accuracy and point density	Each set-up	
Observation point density	Sufficient density for feature extraction	
Overlapping adjacent scans (percentage of scan distance)	10% to 20%	
Registration of multiple scans in post-processing	Required	
Registration errors not to exceed in any horizontal dimension. (See note 1 below)	0.03 foot	0.15 foot
Registration errors not to exceed in vertical dimension. (See note 1 below)	0.04 foot	0.10 foot
Independent validation points from conventional survey to confirm registration Not including BM’s or Control tie points used in registration * (See note 1 below)	Minimum of 3 per mile	Minimum of 2 per mile

* This refers to Target Registration

Notes:

1. These values have been revised to meet NJDOT requirements. They do not match the original values in the California DOT Survey Manual.

Chapter 9 - Mobile Terrestrial Laser Scanning

9.1 Mobile LiDAR Laser Scanning

Laser scanning or Light Detection and Ranging (LiDAR) systems use lasers to make measurements from a tripod or other stationary mount, a mobile mapping vehicle, or an aircraft. The term LiDAR is sometimes used interchangeably with laser scanning. This chapter deals with Terrestrial Laser Scanning methods.

The NJDOT Survey Manual provide specifications, describe methods and procedures needed to attain a desired survey accuracy standard. For complete accuracy standards, refer to NJDOT Survey Manual Chapter 4, NJDOT survey specifications shall be used for all NJDOT projects.

There are many uses for LiDAR in a multitude of disciplines. The following table demonstrates many of the uses and recommended accuracies and point cloud density for each use. Although most NJDOT projects will fall into Blocks 1A, 1B or 1C, there may be some that will not. The actual determination of the required accuracy and point cloud density will be based on recommendations from the mapping consultant and the concurrence of the NJDOT Survey SME and the NJDOT PM will be on a project-by-project basis.

This technology can minimize impacts to traffic and improve the safety for the surveyors in the field. Thus, reducing costs for attenuator vehicles and other safety devices and field time for the surveyors. In addition, the time it will take less time to collect and longer time to process the data will be significantly less than conventional survey methods.

Projects could employ one or more of these technologies depending on time, cost and priority of each project:

- Aerial Photogrammetry
- Airborne LiDAR
- Mobile Terrestrial Laser Scanning (MTLS)
- Stationary Terrestrial Laser Scanning (STLS)
- Conventional Survey

Matrix of application and suggested accuracy and resolution requirements. Network accuracies may be relaxed for applications identified in *red italics*. Note that these are only suggestions and may change based on project needs and specific transportation agency requirements. The accuracy and density values are to serve as a guideline.

TABLE 9-1

Accuracy	**HIGH** **< 0.05 m** **(< 0.16 ft)**	**MEDIUM** **0.05 to 0.20 m** **(0.16 to 0.66 ft)**	**LOW** **> 0.20 m** **(> 0.66 ft)**
Density	**1A**	**2A**	**3A**

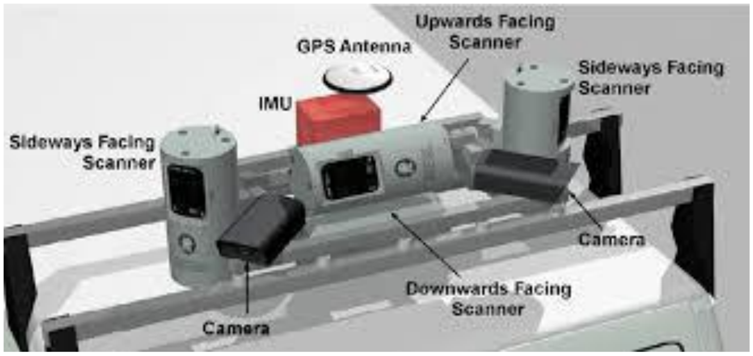
FINE >100 pts/m^2 (>9 pts/ft^2)	• Engineering surveys • Digital Terrain Modeling • Construction Automation/ Machine Control • ADA compliance • *Clearances* • *Pavement analysis* • Drainage\flooding analysis • Virtual, 3D design • CAD models\baseline data • BIM\BRIM • Post-construction quality control • As-built/As-is/repair documentation • Structural inspection	• *Forensics/Accident Investigation* • *Historical Preservation* • Power line clearance	• Roadway condition assessment (general)
	1B	**2B**	**3B**
INTERMEDIATE 30 to 100 pts/m^2 (3 to 9 pts/ft^2)	• Unstable slopes • Landslide assessment	• General Mapping • *General measurements* • Driver Assistance • Autonomous Navigation • Automated\semi-automatic extraction of signs and other features • Coastal change • *Safety* • Environmental studies	• Asset Management • Inventory mapping (*e.g.* GIS) • Virtual Tour
	1C	**2C**	**3C**
COARSE <30 pts/m^2 (<3 pts/ft^2)	• *Quantities (e.g., Earthwork)* • Natural Terrain Mapping	• *Vegetation Management*	• Emergency Response • Planning • Land Use\Zoning • Urban modeling • Traffic Congestion\ Parking Utilization • Billboard Management

The above table is from the: NCHRP 15-44 Guidelines for the Use of Mobile LIDAR in Transportation Applications. The guidelines in the above table were developed for Mobile LiDAR. Actual point cloud densities and accuracies will be determined on a project-by-project basis.

Any mapping project that requires survey control to be established or utilizes a RTN network will require a Licensed Land Surveyor

9.2 Mobile Terrestrial Laser Scanning (MTLS)

Mobile terrestrial laser scanning (MTLS), also referred to as Mobile LiDAR, uses LiDAR technology in combination with Global Navigation Satellite Systems (GNSS), Distance Measuring Instrument (DMI), and Inertial Measurement Unit (IMU) to produce accurate and precise georeferenced point cloud data and digital imagery from a moving vehicle. MTLS platforms may include Sport Utility Vehicles, Pick-up trucks, Vans, Hi-rail vehicles, Boats, and other types of vehicles. MTLS improves the safety and efficiency of data collection.



Depiction of Various Mobile LiDAR Equipment Mounted on Vehicle

The scanner(s) position is determined by post-processed kinematic GNSS procedures using data collected by GNSS antenna(s) mounted on the vehicle and GNSS base stations occupying project control (or CORS stations) throughout the project area. The GNSS solutions are combined with the IMU data to produce precise geospatial locations and orientations of the scanner(s) throughout the scanning process. The point cloud generated by the laser scanner(s) is registered to these scanner positions and orientations. In addition, the use of cameras georeferenced to the point cloud can provide a very detailed data set.

In order to meet the vertical accuracy requirements for the project additional control points (local transformation points) within the scanned area are required to register the point cloud data. The point cloud is adjusted by a local transformation to well defined control points throughout the project area to produce the final geospatial values. The final scan values are then compared to independently measured validation points for quality control.

9.3 Selecting a Project

Not every project will be suited for this technology. The following are factors to consider when determining if MTLS is appropriate for a particular NJDOT project:

- Safety (see NJDOT Safety Manual and MUTCD for guidelines)
- Project deliverables desired
- Project time constraints
- Site or structure complexity or detail required
- Length/size of project
- Will Traffic slowdowns be required, are state or local police required to assist in slowdowns
- Traffic volumes and best available observation times
- Forecast weather and atmospheric conditions at planned observation time
- MTLS system
- Availability of equipment and staff
- Accuracy required
- Technology best suited to the project and desired final products (as determined by the NJDOT Survey SME and NJDOT PM)

9.4 MTLS Applications

In general, there are different types of scans, Type A, B & C. Below are some examples of each type of scans. The NJDOT PM should consult with the Survey SME to determine what type of scan is required for each project.

9.4.1 Type A – High Accuracy/Hard Surface – Topographic Surveys

- Design engineering topographic surveys
- As-built surveys
- Structures and bridge clearance surveys
- Pavement analysis
- Deformation surveys

9.4.2 Type B – Medium Accuracy – Topographic Surveys

- Corridor Study and Planning Surveys
- Asset Management and Inventory Surveys
- Environmental Surveys
- Sight Distance Analysis Surveys
- Earthwork Surveys such as rock slopes, borrow pits, stock piles
- Soil and Coastal Erosion Analysis
- Street Scape Design and Analysis

9.4.3 Type C – Low Accuracy Mapping

- Preliminary Planning
- Transportation Statistics
- General Asset Inventory

9.5 MTLS Equipment and Use

All of the equipment used to collect MTLS data, to control the data, and to collect the quality control validation points should be able to collect the data at the accuracy standards described below. This determination will be from the stated specifications for the equipment by the manufacturers.

9.5.1 Eye Safety

One major concern is that of eye safety for both the operators and the general public. The operators should follow all appropriate OSHA, State 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. MTLS equipment operators should never direct the laser toward personnel operating instruments with magnifying optics such as total stations or levels. The eye safety of the traveling public and other people should be considered at all times and the equipment operated in a manner to ensure the eye safety of all.

9.5.2 Useful Range of MTLS System

A laser scanner is capable of scanning features over long distances, and the accuracy of the scan data decreases as scan range increases. Since the scan data accuracy diminishes with range and would not meet the accuracy requirements beyond a certain distance, care should be taken to ensure that the final dataset does not include any portion of point cloud data whose accuracy is compromised by measurements outside the useful range of the MTLS system. The useful range will be determined by factors such as the range and accuracy specifications of the individual MTLS system, GNSS signal reception during data collection, and the accuracy requirements of the individual project.

9.5.3 Local Registration and Validation Points

Local registration points serve as control for adjustment of the point clouds. Validation points allow for QC checks of the adjusted scan data. Local registration and validation points may be targeted control points, recognizable features, or coordinate positions within the scans. When used, highly reflective targets, marked by reflective tape, white paint with glass beads, or reflective thermoplastic, should be located as close to the MTLS vehicle travel path as possible without compromising safety of the survey crew surveying the painted target locations. The MTLS vehicle operator(s) should adjust the vehicle speed so that the target(s) will be scanned at sufficient density to ensure good target recognition.

9.6 MTLS Specifications and Procedures

MTLS GNSS equipment must correspond with the requirements stated in NJDOT Survey Manual Chapter 4, "GPS Surveys". MTLS kinematic post-processing must comply with these specifications. MTLS kinematic GNSS/IMU data must be post-processed in forward and reverse directions (from beginning-to-end and end-to-beginning). Table XX lists the specifications required to achieve general order MTLS accuracy.

9.6.1 Mission Planning

Before the MTLS project data collection commences, a mission planning session should be conducted to assure adequate GNSS satellites availability during the data collection especially for GNSS-challenged locations. During the data collection there shall be a minimum of six (6) satellites in view for the GNSS Base Stations at all time during data collection. The project area shall be reconnoitered to determine the best time to collect the data to minimize traffic impact and reduce excessive "artifacts" from surrounding traffic as well as to identify obstructions that may cause GNSS signal loss.

MTLS systems require a safe location for a "static session" in an area with relatively open sky before and after collecting data. This may be as simple as parking for several minutes to collect static GNSS/IMU data for sensor alignment. Some MTLS systems may require a larger area such as a parking lot to perform a series of "figure-8" maneuvers.

Project areas that have poor satellite visibility due to terrain and local obstruction should be identified, and a mitigation plan should be developed for GNSS-challenged areas. A mitigation plan could include a densified network of transformation points and validation points. In addition, an area with open sky view suitable for static session nearby should be identified. The MTLS operator should stop in an open sky area for a short static session (3 to 5 minutes) after driving and collecting data through a GNSS-challenged area so that the GNSS/IMU system can reacquire GNSS signals before the next data recording session.

- Mission Planning should include:
- Control targets placement plan
- Quality Management plan
- MTLS data collection drive route plan

- Safety plan
- Traffic control plan (if traffic control is required)

9.6.2 GNSS Project Control

The GNSS Base Station data at the time of MTLS data collection is required in the post processing of GNSS/IMU data. The GNSS base station location shall be placed near the middle of the project in order to keep the GNSS baseline as short as possible/practical.

The GNSS baseline shall not exceed 12.5 miles in length. Shorter baseline (9 miles or less) would contribute to the best possible positional accuracy outcome. Dual redundant GNSS base stations are highly recommended to guard against the possibility of wasted effort and useless data from GNSS base station failure due to equipment failure, accident, loss of battery power, or human error in station setup. In a dual redundant GNSS base station setup, both GNSS base stations should be located near the middle of the project to minimize baseline length. The horizontal accuracy standard of the GNSS base stations shall meet the 0.07’ local network accuracy.

9.6.3 Equipment Calibration

Before collecting the MTLS data, all of the equipment in the MTLS system shall be calibrated to the manufacturer’s specifications and serviced according to the manufacturer’s recommendations. Sensor alignment (bore sighting) procedures shall be performed prior to scanning if the sensor(s) has been disassembled for transport or service. User should follow the manufacturer’s recommended sensor alignment procedures.

9.6.4 Redundancy

MTLS data collection shall be conducted in such a manner as to ensure redundancy of the data. The data should be collected so that there is an overlap, which means more than one pass in the same direction along the roadway, overlapping passes in opposite directions, or both shall be collected. Overlap dimensions: minimum of 25% sidelap (see Figure X-1). The redundant overlap data provides data for quality control.

9.6.5 Monitoring Equipment during the Data Collection

Monitoring various component operations during the scan session is an important step in the QA/QC process. The system operator should be aware and note when the system encountered the most difficulty and be prepared to take appropriate action in adverse circumstances. The MTLS equipment shall be monitored throughout the data collection to track the following as well as any other factors that need monitoring:

- Distance traveled during, or time duration, and location of degraded or lost GNSS reception. The operator must not exceed the uncorrected position time or distance travelled capabilities of the MTLS system’s IMU as recommended by the manufacturer.
- Data storage availability
- Proper functioning of the MTLS system including but not limited to: power supply, vehicle power voltage, laser scanner(s), and digital camera(s).
- Vehicle speed appropriate for desired point density.

9.6.6 Local Registration and Validation Requirements

In order to increase the accuracy of the collected and adjusted geospatial data, a local registration of the MTLS point clouds shall be conducted. Different types of local registration may be employed. For example, one common method is single elevation adjustment of vertical values between established local registration points and the corresponding values from the point clouds. This method works well only for small projects. A long corridor scan would require adjustment to the vehicle trajectory using registration targets and/or points along the roadway. The painted local registration points may also be used to adjust the positional values (X, Y, and Z) of the point cloud. Points on horizontal flat planes (vertical registration points) may be used for vertical (Z)-only adjustment. The MTLS manufacture's painted target recommendations and specifications (size and shape) should be followed. The painted targets are often white with embedded high reflectivity material (glass beads) and borders painted in flat black. Reflective tape may be used for the painted targets. Flat black target borders enable easier target point classification. Painted local registration point targets shall be located at the beginning, end, and evenly spaced throughout the project and each MTLS data recording or pass. Vertical registration points shall be located evenly spaced in between the painted local registration point targets (see Figure 9-1).

For Type A MTLS surveys, bracket the scanned area on both sides of the roadway with painted local registration point targets at a maximum of 1500-foot spacing. Vertical local registration points should be on both sides of the scanned roadway at a maximum of 500-foot spacing in between the painted local registration point targets (see Figure X - 1). Type A MTLS surveys require local transformation points and validation points to have surveyed local positional accuracies of Hz ≤ 0.03 foot & Z ≤ 0.02 foot or better. The preferred method of establishing Type A MTLS local transformation point elevations is differential leveling to NJDOT third order or better specifications.

For Type B MTLS surveys, bracket the scanned area on both sides of the roadway with painted local registration point targets at a maximum of 3000-foot spacing. Vertical local registration points should be placed in between the painted local registration point targets (1500 foot from the painted local registration point target). Type B MTLS surveys require local transformation and validation points to have surveyed local positional accuracies of Hz & Z ≤ 0.10 foot or better (see Table 9-2).

In GNSS-challenged areas, where GNSS signal is severely limited due to terrain and/or obstruction from structures and trees, painted local registration point targets should be densified to 500 foot spacing. Example GNSS-challenged environments are tunnels, tree canyons, and urban canyons.

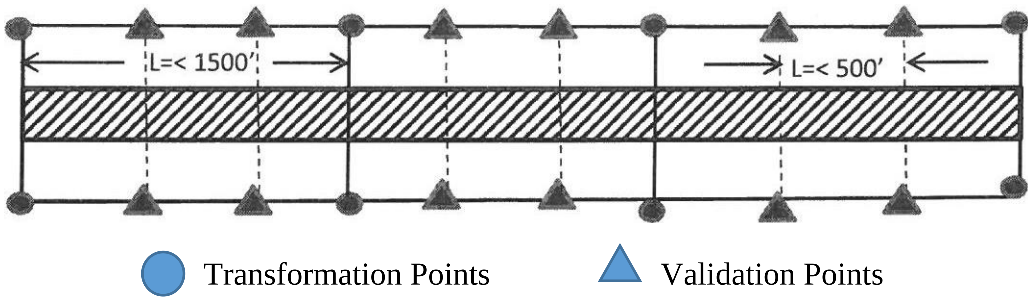


Figure 9-1 Typical MTLS Type A Local Transformation Layout

Image Courtesy of California Department of Transportation

Table 9-2 Terrestrial Mobile LiDAR (TML) Applications Requirements

Operations/Specifications	TML Applications		
	TML Type A	TML Type B	TML Type C
Bore sight calibration of TML system per manufacturer's specifications before and after project data collection Adds cost and is not practical	Required		
Dual frequency GNSS	Required: See note 6		
Inertial Measurement Unit	Required: See note 6		
Distance Measuring Instrument	Required: See note 6		
GNSS positioning should be constrained to local project control	Yes, not for C		
Minimum horizontal (H) and vertical (V) accuracies for GNSS control base stations	Must meet or surpass TML accuracy requirements of the project		
Minimum accuracy of Local transformation Points and Validation Points	$H \leq 0.07'$ $V \leq 0.05'$	$H \leq 0.12'$ $V \leq 0.10'$	Hand V See Note 5
Maximum post-processed baseline length	(5 miles)	10 miles	20 miles
GNSS base stations located to minimize baseline lengths.	Required A & B Recommended C		
Minimum number of common healthy satellites in view for GNSS base stations and mobile scanner	See Notes 1 thru 5		
Sustained Maximum POOP during TML data acquisition	5		
Overlapping coverage between adjacent runs	Required		
Minimum orbit ephemeris for kinetic post-processing	Broadcast		
Observations - Sufficient point density to model objects	Each pass		
Vehicle speed - limit to maintain required point density	Each pass		
Minimum number of local transformation points required	8	8	As Scoped
Local transformation point maximum spacing throughout project on either side of scanned roadway	750' interval	1500' interval	See Note 5
Validation point maximum spacing throughout project on either side of scanned roadway for QA purposes as safety conditions permit (see Note 3)	750' interval	1500' interval	**N/A**
Minimum NSSDA Horizontal and Vertical Check Points	20 (See Note 7) As needed for Type C		

Table 9-2 is courtesy of North Carolina Department of Transportation

Table 9-2 Notes:

1. Areas in the project that have poor satellite visibility should be identified and a plan to minimize the effect on the data developed.
2. If necessary project area shall be reconnoitered to determine the best time to collect the data to minimize GNSS outages and excessive artifacts in the data collection from

surrounding traffic or other factors.

3. If safety conditions permit, additional validation points should be added in challenging GNSS environments such as near structures, and overhead obstructions where GPS visibility is poor.
4. GNSS coverage of less than 5 satellites in view must not exceed the uncorrected position time or distance traveled capabilities of the TML system IMU.
5. Sufficient for data collected by TML system to meet or surpass accuracy requirement of the project.
6. Manufacturer's specifications for precision must be sufficient for TML system to meet or surpass accuracy requirements of the project.
7. Validation points may serve as NSSDA check points to meet the requirements of this section. However, if critical areas of the point cloud are to be used outside of the locations of the Validation points, the additional check points will be needed in those areas to meet this requirement.

9.6.7 Quality Control

Quality control (QC) measures must be performed to ensure the accuracy of the registered MTLS point clouds meets the required accuracy of the project. Survey data points collected using MTLS are checked by various means including comparing scan points to validation points, reviewing the digital terrain model, reviewing data terrain lines in profile, and comparing redundant measurements. Redundant measurements with MTLS can only be accomplished by multiple scan runs or passes that offer overlapping coverage.

The MTLS data provider shall provide a Quality Management Plan (QMP) that includes descriptions of the proposed plan for quality control. The QMP shall provide all methods and means in detail to ensure the point cloud data meets the required accuracy of the project.

There are three common QC methods for MTLS point clouds:

1. Using validation points (targets and/or vertical control points not used for registration) to check the errors at the validation points after the registration. These errors are XYZ for painted target or Z only for a vertical control point.
2. Compare the point cloud location differences (vertically Z only on road surface and/or horizontally with vertical surface) of overlap area from two registered point clouds collected from two different times. 6” to 1” wide cross-sections every 50 to 100 feet are often used in the comparison throughout the point cloud.
3. Using data points from conventional survey to check the (X, Y or Z only) error(s) at the conventional survey points after the registration. Five (5) or more points per mile is recommended.

The QC process must employ two or more of the above methods. Point cloud areas with larger than expected errors would require additional quality control examination or supplemental survey by conventional survey or static laser scanning.

The QC report shall list the results of the MTLS including but not limited to the following documentation:

1. The GNSS/IMU post-processing accuracy report should contain the following from the GNSS/IMU post-processing software:
    a. The location coordinates, datum, vertical datum, and epoch date of the GNSS base station used for GNSS/IMU post-processing. The base station location NGS data sheet should be attached if available.
    b. Number of satellites
    c. Solution status plot
    d. GNSS baseline distance plot
    e. Best estimated post-processed position and orientation error estimates plot
    f. Forward/Reverse Separation plot. Separation of forward and reverse solutions (difference between forward and reverse post-processed XYZ positions solution). Forward and reverse refers to time: processing from beginning-to-end and end-to-beginning.
    g. Narrative on location(s) with large error and migration if applicable.
2. Registration report
    a. Adjustments (horizontal and vertical) made to the MTLS point cloud
    b. If cloud-to-cloud registration was performed, the reference cloud and the adjustments made should be provided.
    c. Average magnitude and standard deviation errors of ground controls and adjustment if available.
3. QC report on the registered point clouds

    The Control report should contain the following:
    a. Table showing the delta Z and/or delta XY differences between validation target points and MTLS registered point cloud.
    b. Comparison of elevation data from overlapping (sidelap) runs.
    c. Comparison of points at the area of overlap (endlap) if more than one GNSS base station is used for the project.
    d. Statistical comparison of registered point cloud data and validation points from conventional survey. The ground truth survey shall be independent of the target control survey and utilize the same horizontal and vertical constraints.
    e. Average, minimum and maximum dZ for each run (optional).
    f. Narrative of QC methods employed and their results.

9.7 MTLS Deliverables and Documentation

Different projects and customers require different types of deliverables. One of the inherent features and fundamental advantages of laser scan data is that it is acquired, processed and delivered in digital format allowing the user to generate laser scan-derived end products for a very wide range of applications and customers beyond the original intent.

The deliverables from a MTLS project should be specified in the NJDOT Survey Request or contract task order.

Deliverables specific to MTLS surveys may include, but are not limited to:

- Registered point clouds in other specified format. ASCII CSV (XYZI or XYZIRGB files), LAS, LAZ.
- MTLS raw data files
- Current NJDOT CADD Standards for Roadway, Bridge, Electrical
- Digital video or photo files with data files supported by TopoDOT
- Survey narrative report including project metadata and GNSS base station data sheet
- Project Control report (see NJDOT Survey Manual Chapter 11)
- MTLS QC report

Chapter 10 - Airborne LiDAR

10.1 AIRBORNE LiDAR

The purpose of this chapter is to identify and define the specifications that shall be followed while performing Airborne LiDAR for NJDOT.

NJDOT contracts out all aerial surveys as the Airborne LiDAR and mapping equipment is not available in the department. As such NJDOT relies upon the expertise and experience of the aerial mapping consultant to provide guidance and products that will meet the needs of the project. The survey fieldwork is most often performed by the aerial consultant or survey subconsultant however it may also be performed by NJDOT survey staff.

The guidelines and specifications described in this chapter are geared towards development of design scale mapping that has been historically referred to as 1″=30′ scale mapping with 1′ contours. The vast majority of aerial mapping contracted by NJDOT calls for mapping standards associated with this scale. Where requirements differ from this scale, the necessary equipment, ground control, flight planning and other key components of the project design may need to be modified. This may be accomplished either to ensure a higher standard is met or to realize efficiencies that may be offered to meet a lower standard. Any variation from the specifications in this chapter shall have the prior approval of the NJDOT Survey SME and Project Manager.

With the rapidly occurring technology developments in Airborne LiDAR, the applications are becoming more widely used for design scale mapping. This chapter provides specifications and guidelines for Airborne LiDAR to be used alone or in conjunction with Aerial Photogrammetry for highway design scale mapping as well as other uses.

Lidar is a Light Detection and Ranging System. It is analogous to radar except that light waves (lasers) are used instead of radio waves. These systems consist of Airborne GPS (AGPS), an Inertial Measurement Unit (IMU), and a laser measurement device mounted in either a fixed-wing aircraft, helicopter, or a drone. LiDAR is collected using a laser that measures distance to an object by emitting timed pulses and measuring the time between emission and reception of reflected pulses. Phase Shift/Phase Based measure the wavelength of a continuous beam to calculate the distance the laser traveled. The Time of Flight (TOF) measures the time it takes for the laser to return to the sensor. Modern LiDAR sensors are capable of recording several returns per pulse. Multiple returns occur when the beam footprint strikes multiple targets before terminating. The sequence of returns from a single pulse, (For example, first, 2nd, 3rd, last or first and last), is also recorded along with an intensity value.

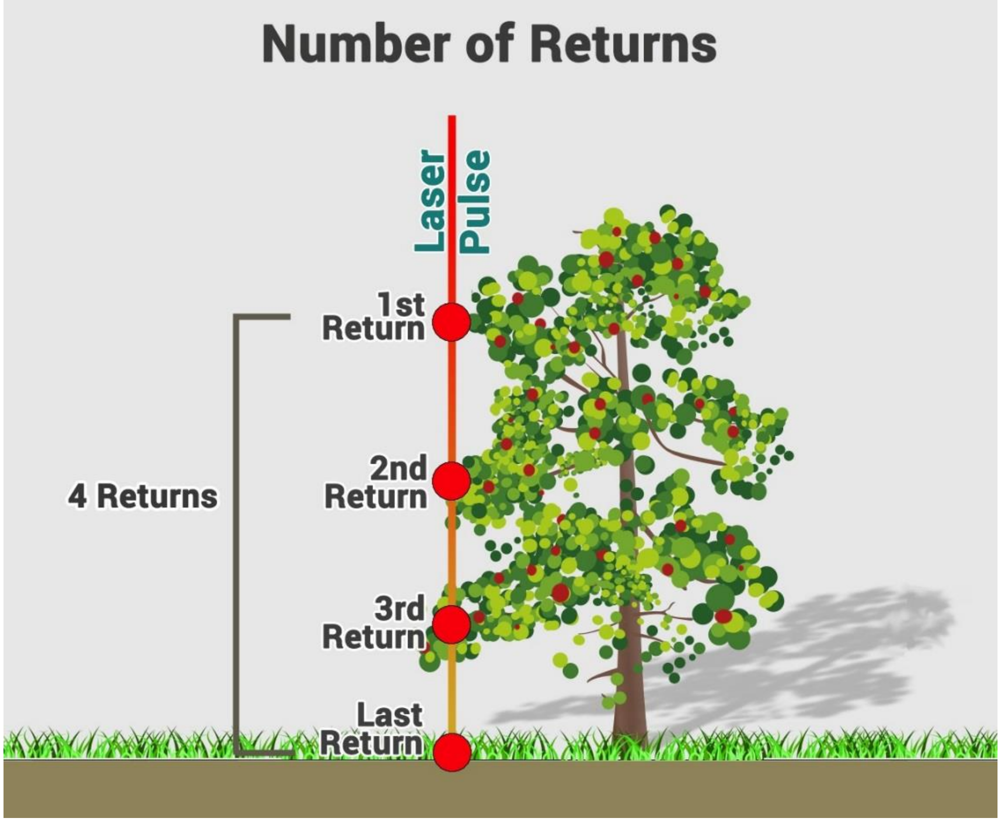


Image Courtesy of GISGeography.com

AGPS and IMU data are collected on board the aircraft during the flight. Base station information must be collected on the ground during the flight. It is recommended that the Base Station not be more than 25 miles from the sensor at any time. These data sets provide the input necessary to provide initial geo-referencing. Swath to swath calibration is then performed to refine the relative accuracy of the resulting point cloud. To achieve high levels of accuracy and quality control, application of ground control is applied in the data calibration process. Elevation data is converted from ellipsoid to orthometric values, completing the process (see note 1).

Note 1: In NJ the CORS Network consists of 15 CORS Units, 12 of which have established orthometric heights on the CORS ARP. This can be a significant time saver when establishing vertical control for Airborne LiDAR and Aerial Photogrammetry mapping projects and could minimize if not eliminate the need to perform leveling across the mapping control targets.

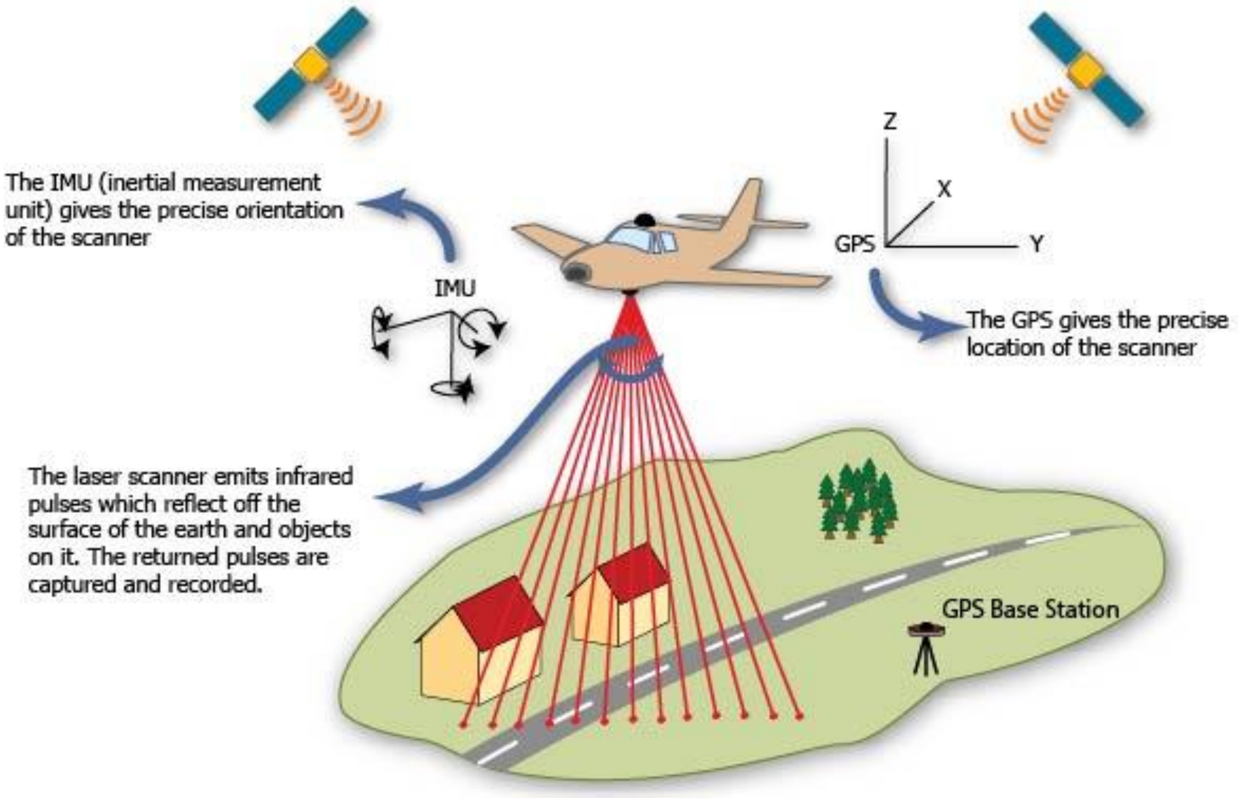


Image Courtesy of Modeling & Visualization, University of Arkansas

The raw data points then undergo a classification process which identifies the type of return (structure, vegetation, pavement, bare earth, water, etc.). The final product is a point cloud which has an X, Y, Z position for each return. Post-processing of the points is required to reduce the point data to final output and to filter the data to bare earth (last return) or first return (or both) data points. In addition to bare earth, terrain data also can extract elevation data for above-ground features such as vegetation heights, building heights, and transmission towers/lines.

This technology has the potential of greatly decreasing the turnaround time for the production of digital orthophoto base mapping and digital terrain model creation for preliminary highway design and study purposes. Its speed of acquisition and processing to usable terrain data surfaces is an order-of-magnitude faster than currently available by field surveys or photogrammetric mapping methods.

LiDAR has rapidly become a valuable tool for 3D mapping. Similar to photogrammetry, it can relieve survey crews of the most tedious time-consuming tasks required to produce topographic maps and DTMs. It can provide detailed terrain data and other information that would be too time-consuming using photogrammetry or field surveys. Just as aerial photogrammetry, LiDAR must be controlled by ground survey and cannot replace ground topographic survey methods where the ground is obstructed from a top view. Final “ground” class returns, are quality checked against a set of ground surveyed checkpoints that were not used in the registration process, (also known as blind checkpoints).

The LiDAR technology has few constraints compared to conventional topographic survey methods. It can survey day and night, at altitudes between 300 and 900 m (1,000 to 3,000 ft) above ground, over any terrain, and through most vegetation and canopy. Most of the highway application surveys are conducted at a height of 300 m (1,000 ft) above ground level to develop 1″=30′ scale mapping. The flexibility of day and night missions is subjected to usual constraints of flying aircraft at relatively low altitudes due to applicable aviation rules. An airborne platform provides non-intrusive operation and no interference with highway traffic. Flight planning determines optimal LiDAR settings and aircraft parameters.

From an aircraft flying a pattern over the survey area, a high-accuracy scanner sweeps the laser pulses across the flight path and collects the reflected light. By varying the aircraft altitude, the aircraft speed, the scanner angle, and the scanner frequency, the operator is able to program ground point spacing to fit the particular survey for the mapping project.

10.2 Project Requirements

Prior to the commencement of any field work the consultant shall contact the Geodetic Survey Unit to determine if there is any new control available and to discuss the control to be used for the project. If necessary, a meeting should be held with the NJDOT PM, NJDOT Survey SME, and the consultant to discuss and review the project mapping requirements and final deliverables. In addition, a tentative delivery date shall be established for all deliverables. Given that the weather can play a significant role in the final delivery it is the responsibility of the consultant to update the NJDOT PM and SME of the progress during the data capture and establishment of the survey control for the project and to inform them of any delays that have occurred that will affect the final delivery date.

10.2.1 General

The aerial mapping consultant shall provide specifications meeting the project needs for the following:

1. Camera/Sensor(s)
2. Film or digital imaging requirements, for example: 3-band (RGB), 4-band (RGB&NIR)
3. Scanner type and resolution if film used.

All aerial surveys will be conducted in full compliance with FAA rules and regulations. It is the aerial mapping consultant’s responsibility to obtain necessary FAA or military authorizations to fly in Special Use Airspace as defined by the FAA’s aeronautical charts. The aerial mapping consultant shall work closely with the NJDOT Survey SME when determining the aerial mapping specifications.

10.2.2 Project Location and Limits

The location and limits of the aerial survey project is indicated in the initial request for mapping. The NJDOT Survey SME or designee is responsible for determining the aerial survey location and limits. The aerial mapping consultant shall work closely with the NJDOT Survey SME when determining the aerial survey location and limits.

Location and limits of the aerial survey project need to be clearly defined to ensure complete coverage is acquired. There are several alternative methods to define the location and limits such as on hard copy maps or electronic maps such as GoogleEarth or Bing Maps. (Please note that web-based maps should only be used for planning and general illustration purposes since their spatial accuracy is limited and inconsistent.) Further clarification of the aerial survey location and limits may be provided with some text descriptions. The location and limits of the aerial survey should specify the following:

1. Beginning and end mileposts
2. Required width
3. Minimum distance on either side of the existing transportation corridor (i.e. 15’-20’ beyond edge of pavement)

The aerial survey location and limits shall include the following in addition to the project provisions:

1. For crossroad interchanges with grade separations, the aerial survey shall also include a minimum of 1000 feet of the crossroad on each side of the existing transportation corridor centerline and shall usually include any ramps within the interchange limits.
2. For at-grade intersections, the aerial survey shall also include 750 feet of the crossroad on each side of the existing transportation corridor centerline and shall include all turning movements such as jughandles, turning lanes, etc.
3. The aerial survey shall also include the area necessary for a complete hydraulic design as required in the project specifications.
4. Aerial Photography and Aerial LiDAR shall extend ½ mile beyond the end of the aerial survey location and limits of the highway corridor.

10.3 Project Control

The aerial mapping consultant is responsible for determining control requirements for the aerial survey. Final control monument locations, spacing, and configurations for the survey may be influenced by conditions. It is important that the aerial mapping consultant and field survey teamwork in close coordination to ensure control requirements for the project are met. Additional considerations include the type of sensor employed, the technology applied, and the required positional accuracy of the data.

Airborne LiDAR must be controlled with ground survey similar to Aerial Photogrammetry. Although the number of ground survey control points for Airborne LiDAR can be significantly less than what is required for Aerial Photogrammetry, control points and check points are required. Airborne LiDAR can be collected practically anytime during the year, day or night, unlike Aerial Photogrammetry. The weather still will have an impact as to when the LiDAR data can be collected (i.e. rain, fog, wind, snow cover, etc.) When collected alone there are few if any seasonal restrictions for highway projects. Also, Airborne LiDAR collected in conjunction with

Aerial Photogrammetry must be flown during daylight hours to accommodate the photography.

In order to provide the required accuracies for the mapping project it is recommended that a pair of control points be established not more than 1000 feet apart along the highway corridor edge of pavement (i.e. shoulders), in addition to all control points required to control the entire imagery to develop 1”=30’ scale mapping. The number of control points and their locations will be determined by the aerial consultant.

All control shall be tied to the NAD83 Horizontal and NAVD88 Vertical control networks latest NGS adjustments. In New Jersey, the use of the Mid-Atlantic SMARTNET Network can be a significant time saver in establishing horizontal and vertical control for a project provided proper GPS techniques are followed (see NJDOT Survey Manual Chapter 4). When establishing control using GPS for Airborne LiDAR the surveyor should follow the same general procedures as Aerial Photogrammetry.

10.3.1 Aerial Ground Control Monumentation

Survey crews establish ground control points for aerial surveys. Targets are placed over the control points on the ground so that the location of the point is easily identified in the aerial survey. Depending on the contract scope of work, control survey may be performed by either the aerial mapping consultant or by NJDOT survey staff. In addition, the aerial consultant or NJDOT survey staff will be responsible for the targeting of control points to ensure identification in the aerial imagery.

Airborne LiDAR control points typically consist of the following:

1. Aerial Center control points
2. Aerial Wing control points

Center (*i.e.* flight line) point control is established as close to the center of the flight line as possible. Their location and configuration is dependent upon the flight height. For highway work the closest to the flight line center that is most often achievable on the ground is on the shoulder of the highway. Whenever possible NJDOT existing control monuments that have been previously established on the ground by a control survey shall be used for project control monuments. This allows the aerial control survey to be horizontally and vertically referenced and tied directly to the primary control established on the ground as the framework for the survey control network without having to install additional monuments. This can also greatly reduce the amount of field surveying needed to establish aerial ground control since the primary control monuments need only to be targeted. The surveyor shall contact the NJDOT Geodetic Survey Unit for any new control established in the project area before commencing any field work. The surveyor shall also request copies of the existing plans covering the project limits from the NJDOT Engineering Documents Unit. Depending on the project scope the following is a list of the information that may be requested from the EDU:

Key Sheet

- Tie and Alignment Sheets
- Construction Plans
- Profiles
- Drainage Plans
- Grading Plans
- ROW Plans

Whenever possible the surveyor shall research and use existing monuments within the project limits to establish project control.

Examples of these types of monuments may include the following:

1. Existing Baseline monuments
2. Right of Way monuments
3. Federal, State, or local agency monuments
4. Benchmark monuments

Photo control points shall be set flush with the pavement using a PK nail (or other type) with a distinguishable center point, or a Photo ID (PID) point. The NJDOT strongly discourages the use of drill holes, "X" cuts, or "Box" cuts as survey control points. Project Control pairs shall be of a semi-permanent nature such as a rebar and cap.

Examples of these types of monuments may include the following:

1. Types of monuments listed above
2. 5/8 inch diameter rebar with cap (set for temporary monuments only)
3. Nail set in asphalt (set for temporary photo control points only)

10.3.2 Wing Point Control

Wing point control is established at the right or left outer edge of the flight lines. These points become more critical for flight plans that include multiple flight strips run parallel to one another. Their location and configuration is dependent upon the flight plan.

10.3.3 Aerial Control Targets (Paneling)

Targets (*i.e.* paneling) shall be placed on the ground symmetrical and centered over aerial control points in order that the location of the point is easily identified in the imagery. The paneling width and configuration is dependent upon the flight height for the LiDAR sensor. The material or biodegradable paint used to target the control should contrast surface surrounding the target. (IE: White in most instances, however, if the surface is very light colored, a black target may be preferable.)

10.3.4 Global Navigation Satellite System Photo Control Horizontal Survey Methods

Unless field conditions do not permit, (e.g. obstructions of the sky by trees, buildings, etc.) only Global Navigation Satellite System (GNSS) survey methods shall be performed for all aerial control horizontal surveys.

Those aerial control horizontal surveys performed by survey methods other than GNSS shall be approved in advance by the NJDOT Survey SME.

All aerial control horizontal surveys performed by GPS methods shall be performed in accordance with Chapter 4 – GPS Surveys, and shall meet the Minimum Horizontal Accuracy Tolerances as indicated in the NJ DOT Survey Manual in chapters 4.4.3.2.1 through 4.4.3.2.2.2.3.

Unless approved otherwise by the NJDOT Survey SME, all GNSS aerial control monuments (center and wing points) shall be observed by survey methods and procedures in accordance with Chapter 4 - GPS Surveys.

Real Time Kinematic (RTK) or Real Time Network (RTN) GNSS techniques, based on the National Spatial Reference System (NSRS) may be utilized for aerial projects. The latest National Geodetic Survey (NGS) guidelines as found on their website (https://www.ngs.noaa.gov/) must be used for procedures for RTK/RTN projects.

Current guidelines (6/2019) are as follows:

- User Guidelines For Single Base Real Time GNSS Positioning:

  www.ngs.noaa.gov/PUBS_LIB/UserGuidelinesForSingleBaseRealTimeGNSSPositioningv.3.1APR2014-1.pdf

- National Geodetic Survey Guidelines for Real Time GNSS Surveys:

  www.ngs.noaa.gov/PUBS_LIB/NGS.RTN.Public.v2.0.pdf

- RTN Field Procedures and Best Practices:

  www.ngs.noaa.gov/web/science_edu/presentations_library/files/rtn_field_procedures.pptx

10.3.5 Aerial Survey Field Conditions

Field conditions during aerial surveys shall be conducive to the preparation of the final aerial survey products within the required tolerances.

Aerial surveys shall not be conducted when the ground is obscured by clouds, haze, fog, dust, snow, or vegetation, when streams are not within their normal banks, or when flooding conditions exist unless specific waiver is given by the NJDOT Survey SME.

Aerial survey approach using AGPS must also consider Positional Dilution of Precision (PDOP) during the flight mission. PDOP should be lower than 3.0 and at least six (6) GPS satellites must be available at 10 degrees or more above the horizon at all times throughout the mission. Space weather in the form of excess charged ions entering the earth's magnetic fields can also present an issue. While this condition is rarely at a level that causes significant disruption to signal accuracy, it should be checked before the flight. The National Oceanic and Atmospheric Agency's website, http://www.swpc.noaa.gov/, provides forecasts for this condition. As a guideline, aerial surveys will be accomplished during the period when deciduous trees are barren, and between 10 A.M. and 2 P.M. (when the sun angle is not less than 30 degrees).

Note: If a project plan calls for a LiDAR-only flight, sun angle becomes irrelevant.

10.3.6 Flight Plan

Prior to any aerial survey the mapping consultant shall submit a flight plan showing the proposed flight lines on a topographic map of the project area or in a digital file that can be geo-referenced with existing mapping or a web-based GIS application. The aerial mapping consultant is responsible for the flight plan and shall work closely with the NJDOT Survey SME when establishing the flight plan. NJDOT reserves the right to comment on the elements of the flight plan but is not responsible for approval. The consultant is responsible for ensuring that the aerial survey coverage will be adequate to produce the final results required for all the deliverable products.

The flight plan shall at a minimum include the following:

1. Flight lines labeled to show flight height and negative scale or nominal Ground Sample Distance (GSD), resolution (point spacing).
2. NJDOT primary control monument locations labeled by number or name.
3. Airborne LiDAR control monuments to be targeted, labeled by number or name.
4. The flight plan should be accompanied by a statement describing the intended data acquisition and map production approach to be applied (i.e. AGPS data acquisition).
5. LiDAR sensor calibration report and calibration file as appropriate to sensor(s) planned.
6. Manufacturer's Specification sheets for LiDAR systems planned.

10.3.7 Aircraft

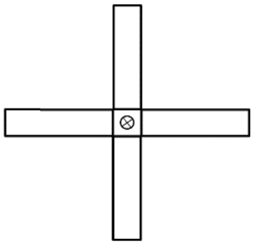
Aircraft maintenance and operation shall be in accordance with Federal Aviation Administration (FAA) and Civil Aeronautics Board (CAB) regulations. This includes UAV (see Section 10.10).

10.3.8 Aerial Data Acquisition

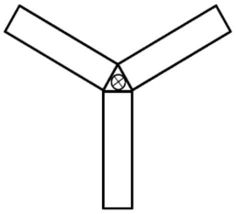
The planning and aerial data acquisition will follow relevant guidelines and shall meet or exceed all of the current American Society for Photogrammetry & Remote Sensing (ASPRS) standards.

10.4 Aerial Control Targets

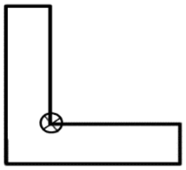
The target design shall be symmetrical and centered on the aerial control point. There are three designs commonly applied for aerial surveys. These include four-legged "X" targets, three-legged "Y" targets), and two-legged "L" targets. The targets should be easily visible in the imagery, such as black/white. More than one type can be used for a project if there is a need to distinguish between different types of control, such as wing and center control point targets. The length and width of the target legs, and type of targets and color will depend on the specifications of the flight mission as determined by the aerial consultant. The principal drivers will be flying height or the GSD of the resulting data.



"X" Type Target



"Y" Type Target



"L" Type Target

Painted Control Point Target

Photo Identifiable Point Target

Images Courtesy of Colorado Department of Transportation

As reasonably as possible the targets should be placed just prior to the flight taking place and should be maintained until the flight has occurred and the imagery accepted. LiDAR Identifiable Points (targets) should be clearly identifiable in the scans and have a large angle of intersection to positively identify the points. Some examples are corners of concrete slabs, sidewalk intersections (as shown above), existing paint markings on asphalt pavement or other clearly identifiable features which can provide a precise location. The surveyor should confer with the aerial consultant before moving any targets due to obstructions in the field (i.e. tree canopy, on street parking, etc.). Care should be taken when setting control points on private property. In the event that a material target (vinyl, wood, etc.) is required the target should be placed as close to the scheduled flight date as possible to avoid any possible damage or vandalism to them. Also, they should be removed as soon as possible after the flight has occurred. Any material targets set should be surveyed immediately to establish their X, Y, Z coordinates.

Prior to the commencement of any field survey work to be performed the surveyor shall:

- Contact the Geodetic Survey Unit for any new control within the project area.
- Request any available plans from the NJDOT Engineering Document Unit (EDU) for any existing monument locations. These monuments can be a significant time savings for establishing the project control within the project limits.

10.5 Airborne LiDAR Advantages/Disadvantages

Surveys collected using Airborne LiDAR have both advantages and disadvantages when compared with ground survey methods as follows:

Advantages:

1. Like aerial photography, LiDAR data sets provide a permanent record of the existing terrain conditions and topographic features at the time of aerial survey.
2. The information extraction may be limited to bare-earth terrain or extend to other data on an as needed basis. It is possible to extract planimetric data from LiDAR as well. Vegetation may be extracted as 3D points, (or cloud data), defining the vegetation extents in 3d space. The vegetation classed points can also be sub-classified based on height which may be useful for identifying line of sight issues.
3. The information extracted from a LiDAR point cloud provides more detailed information to designers and environmental personnel with respect to topography. It can also offer 3D point cloud visualization opportunities that could prove useful for line-of-sight analysis and alignment study.
4. When collected in combination with aerial photography, the LiDAR point cloud can be colorized based on the orthophoto rectified imagery to create realistic 3D models. This is especially effective when using high-density LiDAR data sets. The 3D models offer any number of views that might be useful for conveying information to the general public or other governmental agencies.
5. LiDAR can be used for multiple purposes within NJDOT such as, preliminary design, drainage analysis, and roadway clearance for power lines, vegetation, and environmental concerns.
6. Topographic mapping and DTMs of large areas can be accomplished with more detail than using photogrammetry, relatively quickly, and may be more economical than ground survey methods depending on project size and ground conditions.
7. Data points in a LiDAR point cloud are geographically referenced by means of GPS/IMU technology. Each point is solved for in ellipsoid elevation. The most current geoid information is then applied to the elevations to arrive at orthometric values (see note 1). There is no initial least squares adjustment application as required for the relative orientation of photographs. Secondly, there is no interpolation of positional values by visual means; therefore, the

relative accuracy is higher than that which can be achieved photogrammetrically. It should be noted that final achievable absolute accuracy is a dependent on the application of aerial project control that has been tied to the primary control network. LiDAR can be used in locations that are difficult or impossible to access from the ground.

8. LiDAR is more successful than photogrammetric methods at achieving ground returns in vegetated areas. As a rule, if any sky can be seen when looking straight up from ground level, some ground returns can be expected.
9. If collected as a stand-alone data set, (without aerial photography), it can be collected at any time of day or night.

Disadvantages:

1. LiDAR must be collected in appropriate weather conditions. While not as demanding as aerial photography, there must be no rain, snow, fog or smoke between the sensor and the ground. While LiDAR has more opportunity to provide ground data than photogrammetry in wooded areas, it doesn’t penetrate full cover. Heavy vegetation canopy may completely obscure the ground.
2. Classification of LiDAR ground returns in areas of thick, low vegetation becomes less reliable. The last return from a pulse could be erroneously classified as ground when the last reflection was just short of ground. Using photogrammetry, these land cover types are subject to visual interpretation and points may be interpolated by an experienced photogrammetrist with greater success.
3. Since LiDAR data is dependent on Airborne GPS, accuracy is limited to the accuracy of the Airborne GPS solution and applied geoid model until calibrated to the project ground survey control. This makes it more dependent on low satellite PDOP (Positional Dilution of Precision) levels than aerial photography. It should be noted that conventional ground survey methods using appropriate procedures, still provide the most accurate measurements.
4. Depending on the density of the data set, without the aid of photogrammetry, identification of planimetric features can be difficult, (e.g. curb and gutter, hydrants, manholes, small road signs, etc.) Since it is an aerial view, size of culverts may be difficult if not at all possible along with any other feature that cannot be seen or measured from above.
5. Processed LiDAR data sets are very large. Point clouds delivered in LAS or ASCII format to NJDOT as project source data must be tiled to manageable file sizes. Consultants should deliver the point clouds just as they would deliver film or raw imagery to NJDOT for a photogrammetry project archive. The consultant should contact the NJDOT CADD Manager if they have any questions regarding the deliverables.
6. The type of material used for construction of fences, buildings, or other man-made features is not interpretable from aerial LiDAR.
7. Underground utilities cannot be located, measured, or identified.

8. Right of Way and property boundary monuments cannot be located, measured, or identified.
9. Building overhangs, overhead walkways and bridges will result in ground data occlusions.
10. Any feature or object not visible from the air must be surveyed by other methods such as STLS, MTLS or conventional survey methods and must utilize the same project control.

Below is a list of items that Airborne LiDAR may be used for:

1. Highly detailed DTM
2. Drainage analysis
3. Preliminary design and design scale mapping
4. 3D vegetation mapping
5. Flood plain mapping
6. Planimetric feature extraction
7. In combination with photogrammetry for large scale mapping

10.6 Equipment Maintenance

Checks and calibrations on all types of electronic survey equipment are essential to obtain and maintain the minimum tolerances required for aerial surveys. In accordance with the manufacturer's specifications equipment must be properly maintained, regularly checked, and calibrated for accuracy at the beginning of any aerial survey project to ensure that the equipment is operating properly. This includes but not limited to GPS units (airborne and ground), IMU, and aircraft. It is the aerial consultant's responsibility to ensure no errors due to poorly maintained or malfunctioning equipment will affect the project.

10.7 Deliverables and Documentation

The desired deliverables from an Airborne LiDAR project should be identified in the planning stage. The mapping consultant should refer to the NJDOT CADD Standards available online at the NJDOT website (https://www.state.nj.us/transportation/eng/CADD/v8/) and contact the CADD Manager if they have any questions regarding the CADD Standards and CADD deliverables.

Any use of the data other than its intended use should be approved by the NJDOT CADD Manager and NJDOT PM before any other use of the data.

10.8 Deliverables

Different projects and customers require different types of deliverables, which can range from a standard CADD product to a physical three-dimensional (3D) scale model of the actual subject.

Deliverables for Airborne LiDAR surveys may include, but are not limited to:

- Mapping in current NJDOT CADD Standards for Roadway, Bridge, Electrical

- Digital photo mosaic files (if requested)
- Survey narrative report (refer to Chapter 11 of the NJDOT Survey Manual)
- Aerial Triangulation Report
- Point Cloud Files
- QA/QC Files

10.8.1 Obscured Areas

Obscured areas are defined as areas within the aerial mapping project limits where vegetation or tree canopy, dense smoke features are obscuring the aerial perspective. These areas will be identified in such cases where planimetric feature compilation cannot be completed or where there is insufficient elevation data to meet the specified vertical accuracy tolerance for vegetated areas. The areas will be identified by the aerial mapping professional and provided to the surveyor for field survey data collection.

10.8.2 Aerial Survey – Feature Identification

Required features that cannot be identified by aerial survey methods will be field collected by means of a post-aerial or pre-aerial ground survey. Likewise, required features mapped within the aerial project scope that could not be positively or fully identified by the aerial mapping professional shall be field identified in a Post-Aerial survey. The map compilation process shall use latest NJDOT MicroStation Levels with feature descriptors to ensure their identification for the post-aerial ground survey. It should be anticipated that completion of the feature identification will require ground surveys.

The aerial mapping consultant is responsible for determining which features can be identified. The NJDOT Survey SME or designee shall work closely with the aerial mapping consultant when determining which features require further identification.

10.8.3 Supplemental Surveys

Supplemental surveys shall be performed on the ground to compliment the aerial survey within the existing constructed transportation corridor template, and shall be performed in accordance with the methods, procedures, horizontal and vertical accuracies tolerances as required. The supplemental survey fieldwork may be performed by the consultant or by NJDOT survey crews as required in the project scope and shall utilize NJDOT Level Structure.

The purpose of the supplemental survey is to locate those features that require a higher level of accuracy than that of the aerial survey, to locate those features that cannot be located by the aerial survey, and to collect information not apparent to the photogrammetrist from the aerial survey.

The aerial mapping consultant is responsible for determining which aerial survey features may need supplemental identification, the NJDOT Survey SME or designee shall work closely with the aerial mapping consultant when determining which features require supplemental surveying.

10.8.4 Minimum Horizontal and Vertical Accuracy Tolerance for Supplemental Survey

All supplemental surveys performed on the ground to complete the aerial survey shall be performed in accordance with the methods, procedures, and the Minimum Horizontal and Vertical Accuracy Tolerance as required in Chapter 3 – Surveying Measurements. Aerial Mapping Tolerances.

The American Society for Photogrammetry and Remote Sensing (ASPRS) has published aerial map accuracy standards titled ASPRS Positional Accuracy Standards for Digital Geospatial Data. The first edition was published in 2014, (Edition 1, Version 1.0 – November 2014). Below is a link to the ASPRS standards:

http://www.asprs.org/a/society/committees/standards/Positional_Accuracy_Standards.pdf

10.8.5 Vertical Accuracy Testing - Method of Verifying Accuracy Tolerance

Accuracy tolerance requirements are evaluated by comparing a cross section string, or a series of random checkpoints taken in the field with the same cross section location, or series of random point locations, extracted from a terrain TIN model produced from the original aerial survey data. The field cross section string is collected by conventional topographic survey methods and is held as the true representation of what exists in the field in relation to the primary control monuments. The interval between observations on the cross section shall be taken at a minimum of 30 feet, include all changes of slope, and shall not exceed the interval of the aerial mapping at the particular cross section.

The field cross section string or random checkpoints are then processed and compared to the TIN model aerial survey cross section or random points. The difference between the sections is evaluated to determine if the delivered product is within the minimum horizontal and vertical aerial mapping tolerances.

The number and location of random checkpoints or cross section strings will vary according to project size, field conditions and specific project requirements. The scope of work shall include a description of the verification requirements on a project-by-project basis.

10.9 Documentation

10.9.1 Project Survey Report

Documentation of surveys is an essential part of surveying work. Survey data not properly documented could result in additional field and office time to redo or correct what was not performed or documented properly.

The survey narrative report (refer to Chapter 11 of the NJDOT Survey Manual), completed by the PLS in responsible charge of the survey, shall contain the following general information, the specific information required by each survey method, and any appropriate supplemental information.

- Project Name and UPC Number: Route, Beginning and Ending Milepost, Project UPC Identification, Municipality, County, etc.
- Survey date, limits, and purpose
- Datum, epoch, and units
- Control found, held, and set for the survey

- Personnel, equipment, and surveying methods used
- Field notes including target diagrams, control geometry, instrument and target heights, atmospheric conditions, etc.
- Problems encountered
- Any other pertinent information
- QA/QC reports
- Dated signature and seal of the Professional Land Surveyor in responsible charge

10.10 UNMANNED AERIAL VEHICLES MAPPING For LiDAR IMAGERY

The use of Unmanned Aerial Vehicles (UAV) or Drones is becoming more prevalent for certain types of projects. The use of UAV's is governed by the Federal Aviation Administration (FAA) Code of Federal Regulations (CFR) Part 107. The use of an UAV for any NJDOT project shall be coordinated with the NJDOT Survey SME and follow all of these regulations. The following is a link to the regulations:

https://www.ecfr.gov/cgi-bin/text-idx?SID=dc908fb739912b0e6dcb7d7d88cfe6a7&mc=true&node=pt14.2.107&rgn=div5

10.10.1 Lidar Uses

Through the use UAV lidar mapping, there is a large range of products, which can be extracted from the aerial imagery. These products include;

- DEM/ DTM / DSM (surface models).
- 3D bridge and building models.
- Contour maps.
- Planimetric features (road edges, heights, signs, building footprints, etc).
- Volumetric Surveys

Here are some of the best uses of lidar. All of these sectors benefit for having precision 3D images of their projects. They also benefit with increased efficiency and reduced costs than using traditional aircraft.

- Forestry management and planning.
- Bridge and Structural Inspections.
- GIS Applications.
- Flood modelling.
- Pollution modelling.
- Mapping and cartography.
- Urban planning.
- Coastline management.
- Transport planning.
- Oil and gas exploration.
- Quarries and minerals (Volumetrics and Exploration).
- Archaeology.
- Cellular network planning.

Some of the restrictions are:

- Must be operated within line of sight of the operator.
- Cannot operate over any pedestrians or highways unless the pedestrians/motorists are active participants in the operation.
- Cannot operate in a manner that interferes with operations and traffic patterns at any airport, heliport, or seaplane base.

Image of a UAV (Drone) for Mapping

(Image courtesy of POB Magazine, POB.com)

When preparing to utilize a UAV for mapping purposes the Aerial Mapping consultant and the Survey SME will determine:

- the limits of the mapping
- flight elevation
- amount of ground control and check points required
- scale of mapping required for project
- size and shape of grid patterns
- point cloud density
- determine lateral and forward overlap

Any Aerial Mapping utilizing UAV’s should follow the requirements Airborne LiDAR.

10.10.2 Drone Mapping and Lidar Explained

UAV lidar involves mounting a laser scanner on a UAV to measure the height of points in the landscape below the UAV. Lidar actually means (Light Detection and Ranging). Lidar scanners can capture hundreds of square kilometers in a single day.

By measuring 10 to 80 points per square meter, a very detailed digital model of a landscape can be created.

The accuracy of the measurements allows the 3D models created using the lidar drone to be used in planning, design and decision-making processes across various sectors.

Lidar sensors can also pierce dense canopy and vegetation, making it possible to capture bare earth structure which satellites cannot see, as well as ground cover in enough detail to allow vegetation categorization and change monitoring. It is essential to have a UAV which has a navigation technology.

Chapter 11 - Survey Report

A survey report must be submitted for each project that requires survey work.

11.1 General

Prior to commencing any field work the Consultant and/ or Sub-Consultant /Designer /Surveyor must:

- Research the published geodetic control from the National Spatial Reference System (NSRS) / National Geodetic Survey (NGS) database at: https://geodesy.noaa.gov/
- Contact the New Jersey Geodetic Survey (NJGS) Unit if further information is necessary.
- Evaluate the Geodetic Survey information and incorporate it into the field survey work.
- Research and recover the NGS data.
- Submit to NGS directly, using the on-line recovery form (https://geodesy.noaa.gov/surveys/mark-recovery/index.shtml), the condition of your pertinent researched published NGS data used in your project.
- Contact the Regional Survey Office(s) for information that is available for existing alignment, monumentation and Right of Way (ROW) plans and survey information.
- Contact the Engineering Document Unit in the Main Complex in Ewing, NJ should be contacted for additional documentation.
- Provide copies of NJDOT Survey Manual related, BDCs, CANs, NJDOT Photogrammetric Guidelines (if applicable), and materials related to the Survey portion of the work to the Sub-contractor. The Survey Team Leader and crew chief must have a copy of this manual and be made aware of the content.

Immediately after collecting field data the Consultant and /or Sub-Consultant /Designer /Surveyor must furnish to the NJDOT, before the submission and acceptance of base maps, and survey control schematic plans, a list and description of the location and coordinate values of each control survey point, a copy of the original field notes showing the horizontal distance, angular measurements, and vertical measurements and a copy of the original computations for the adjustment of horizontal distance, angular measurements, and vertical measurements for proper closure of each control survey and level loop or line.

This preliminary data submission shall be electronically forwarded to Geodetic Survey Office, DOT.GeodeticSurvey@dot.nj.gov for control reports, and to the appropriate Regional Survey Office (North-973-770-5151) DOT-FieldRequest.Survey@dot.nj.gov ; (South-856-486-6777) DOT-FieldRequest.Survey@dot.nj.gov) for general survey reports.

Update submission data electronically with email address?

Include all survey control, baseline, and ROW monumentation in the Survey Report that was used. Prior to submittal, it must be field verified by the Consultant, and discrepancies shall be addressed in the report.

Prior written approval needs to be received from the Survey Services Manager in order to utilize the superseded North American Datum of 1927 (NAD27), and the National Geodetic Vertical Datum of 1929 (NGVD29), or an assumed datum.

The use of coordinates and elevations for final base mapping are to be adjusted to ground coordinates utilizing the appropriate scale factor(s). These adjusted coordinates shall be included in a tabular form in the survey report. These adjusted coordinates and elevations shall be identified as "Ground/Modified Coordinates".

Final coordinate values are to be produced and tabulated in the following four formats to satisfy NJDOT requirements. All coordinates will be based on the latest horizontal realization, currently: NAD83 (2011).

The geographic positions are based on the GRS80 Ellipsoid.

All orthometric heights are based on the NAVD88 adjustment datum using the latest geoid model, (currently: GEOID18).

• GEOGRAPHIC POSITIONS	(Latitude, Longitude and Ellipsoidal Heights in meters).
• NJSPC (METRIC)	(State Plane Coordinates in meters).
• NJSPC (U.S. SURVEY FEET)	(State Plane Coordinates in U.S. Survey Feet).
• GROUND/MODIFIED	(Ground Coordinates in U.S. Survey Feet).

All data, supporting data, and final survey report will be provided in a digital format (CD) that will be 100% compatible with NJDOT computer systems. PDF or DOC extensions are suitable for use in a "read only" format.

11.2. Projects Based on the New Jersey State Plane Coordinate System (NJSPCS)

The Consultant shall provide Project Survey Control based on the classification standards for Horizontal Control, Second Order, Class II accuracy and Vertical Control, Second Order, Class I accuracy. The standards of accuracy shall meet the requirement of the Federal Geodetic Control Committee Publication:

- Standards and Specifications for Geodetic Control Networks (September 1984) or its most recent revision.

  https://www.ngs.noaa.gov/FGCS/tech_pub/1984-stds-specs-geodetic-control-networks.pdf

Pertinent supplemental publications for Global Navigation Satellite System (GNSS) related positioning techniques, i.e. Static; Real Time Kinematic (RTK) and Real Time Network (RTN) to be used to complement the aforementioned publication are issued by NGS:

- User Guidelines For Single Base Real Time GNSS Positioning:

  (www.ngs.noaa.gov/PUBS_LIB/UserGuidelinesForSingleBaseRealTimeGNSSPositioningv.3.1APR2014-1.pdf)

- National Geodetic Survey Guidelines for Real Time GNSS Surveys:

  (www.ngs.noaa.gov/PUBS_LIB/NGS.RTN.Public.v2.0.pdf).

- RTN Field Procedures and Best Practices:

  (www.ngs.noaa.gov/web/science_edu/presentations_library/files/rtn_field_procedures.pptx)

- Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques, Version 5.0, dated May 11, 1988, reprinted with corrections, August 1, 1989

(https://www.ngs.noaa.gov/PUBS_LIB/GeomGeod.pdf)

- Guidelines for Establishing GPS-derived ellipsoid heights (Standards: 2 cm and 5 cm), NOAA Technical Memorandum NOS NGS-58, version 4.3, November 1997, or most recent revisions.

  (https://www.ngs.noaa.gov/PUBS_LIB/NGS-58.pdf)

The horizontal datum will be the New Jersey State Plane Coordinate System of 1983 (NJSPCS 1983), which is based on the North American Datum of 1983 (NAD83) latest adjustment tag. The NJSPCS of 1927, which is based on the North American Datum of 1927 (NAD27), shall no longer be utilized unless prior written approval has been received from the Survey Services Manager.

The vertical datum will be the North American Vertical Datum of 1988 (NAVD88) or its most recent revision. The previous datum, National Geodetic Vertical Datum of 1929 (NGVD29), has been superseded by NAVD88 and shall no longer be utilized unless prior written approval has been received from the Survey Services Manager.

The survey traverse and the level bench runs shall originate and terminate on existing monuments and/or benchmarks that are part of, or directly established from the NSRS. These points meet or exceed Second Order, Class I, classifications and were directly established from the database that is maintained by NGS. These initial survey tie monuments have been previously established by US Coast and Geodetic Survey (USCGS), NGS, National Ocean Survey (NOS), NJGS and other approved agency or private Contractor.

Leveling runs not otherwise specified shall comply with requirements in the Federal Geodetic Control Committee publication for Third Order Geodetic Leveling. The Project Survey Control shall be tied to the New Jersey State Plane Coordinate System. The above standards apply to projects which require the establishment, determination or reestablishment of ground control, horizontal and vertical, which are based or tied into the N.J. State Plane Coordinate System.

11.3. Projects Based on Other Systems

Projects which do not require the establishment of horizontal and vertical control, such as Safety Improvements, Maintenance projects, Guide Rail Installations, and Street Intersection Improvement, are not required to meet the N.J. State Plane Coordinate System standards. Guide Rail projects may require horizontal and vertical Control. Survey provider should contact the Prime Consultant/Designer to determine if it is required. These projects should eliminate any reference to the NJSPCS. In projects such as street improvements, resurfacing, road widening and bridge rehabilitation, a local or assumed system may be used.

The local system shall meet the following requirements:

• Position Closure	1:20,000 Minimum after adjustment
• Angles Accurate to	5 Seconds or less
• Azimuth Closure	(8 Seconds) times (Sqrt of N), where N is the number of angle stations

The local control survey traverse shall be established and measured by accepted National Geodetic Survey methods with proper consideration of tape calibration, all equipment and instrumentation calibration, and all corrections. The error in position closure after distribution of azimuth errors will not exceed 1:20,000. The bench level runs will not exceed 0.05 of a foot times the square root length of the runs in miles or will not exceed 12 millimeters times the square root length of the run in kilometers. All bench runs should be based upon the North American Vertical Datum of 1988 (NAVD88). The use of any other vertical datum requires the approval of the Manager of Survey Services prior to work commencing.

11.4. Survey Report Content and Preparation

A survey report must be submitted for each project that requires survey work. There are **four** times during the project that a report or modification to the existing report may be needed.

- Aerial control portion,
- Project control portion (including how the existing baseline(s) was reestablished),
- Topographic survey portion
- Supplemental survey portion

The following format shall be used:

A. Introduction

1. Purpose - Describe the purpose for which the survey was conducted.
2. Point of Contact - Supply to the NJDOT Project Manager the name, phone number, and mailing address of the point of contact within the submitting organization, and the Professional Licensed Surveyor in responsible charge of the work. Supply the same information for all organizations that participated in the survey.
3. Accuracy Standards - Provide the accuracy standards (vertical and horizontal) specified for the project.
4. Signature and seal of the surveyor in responsible charge.
5. Prime Consultant certifies in writing that the report was reviewed and found to meet project requirements.

B. Location - Indicate briefly the geographic location and scope of the project in general terms.

C. Field Work

1. The Consultant shall describe the work performed to sufficiently research information to recover the existing monumentation on the highway project. Describe and delineate the existing baseline, right of way and center line monumentation and how it is tied into the project traverse and adjusted into the project survey network. The Consultant shall describe how the existing right of way line, and baseline were established.
2. Chronology - Give a brief description of the progression of the project. A narrative detailing the methodology utilized to establish all existing Baselines and ROW lines within the project limits is required.

3. Instrumentation - Describe the make, model and serial number of each instrument, and accessory equipment such as tripods, tribrachs, leveling rods, etc., age of all equipment, condition of equipment, and date of last calibration, collimation or repair work used on the project.
4. Deviation from instructions - Describe any deviation from the procedures and specifications stated in the project instructions.

D. Data Processing Performed

Describe the data processing that was performed. Include tasks such as transferring of data to different storage media, data quality checking, station descriptions, baseline determinations and closure computations.

Complete the following sections as appropriate:

1. Software Used - Specify all software by program name and version number which was used to acquire, manage, reduce, adjust, and submit field data. If the project data were reduced or acquired with different versions of a program, specify which version was used with which block of data.
2. Rejected Data - Specify any data which was rejected and re-surveyed. Include the reasons why the data from a particular field day were rejected.
3. Adjustment - Discuss in detail the type of adjustment performed. Indicate weighting technique used, and stations constrained. All analyses shall be reviewed and analyzed by the Licensed Professional Surveyor in responsible charge.
4. Closures - Tabulate the results of all loop mis-closure computations performed. Include the baselines used, base line length, maximum closure in each component, and average closure error in each component. Tabulate closure component error in terms of Cartesian coordinates and in terms of the local terrestrial system. Tabulate comparisons of repeat base lines observed indicating base line length, and maximum and average closure for each base line component. Closures will be stated in feet and parts per million including any scale factor applied.
5. The above data, supporting data, and **final** survey report will be provided in a digital format (pdf or doc read only files) on a CD that will be 100% compatible with NJDOT computer systems.

E. Attachments and Enclosures

1. The Consultant will provide a survey report including an alignment plan for all projects.
2. The Consultant shall include the previously furnished list and description of the location and coordinate values of each control survey point, the original field notes showing the horizontal and angular measurements, and vertical measurements and the original computations for the adjustment of horizontal and angular measurements, and vertical measurements for proper closure of each control survey and level loop or line.
3. Station List - Include a table, which lists the station name, coordinates, elevation and station type for all stations surveyed.

4. Field Project Sketch - Attach a copy of the project sketch. If there are multiple copies of the sketch showing different data, attach a copy of each. The project sketch shall include the following:
   - All stations occupied during survey.
   - A border drawn around the edge with grid ticks for latitude and longitude.

   In addition to the stations surveyed, the sketch should show other stations of the existing network located within or near the project area. Indicate in the survey report whether any attempt was made to recover these stations. The report and/or recovery notes must indicate why the recovered stations were not surveyed. To indicate a station that was not recovered use “NR” next to that station’s symbol.

   Survey points will be shown in an inset sketch when they are too closely together to be depicted clearly on the network sketch.
5. Digital photo/ rubbings of monuments (control stations) shall be included in survey report.
6. Field Logs - Provide dated copies of field survey notes and record books.
7. Quality Control Checklists- Geodetic & General Report- (formats in Appendix C)
8. Quality Assurance Checklist- Geodetic and General Reports- (formats in Appendix C)

11.5. Right of Inspection

The State reserves the right to inspect at any time during or after the control survey each or any field or office phase of the work and to check each or any operation in the field or the office.

11.6. Survey Crews

The Consultant shall perform all field survey work in accordance with the latest NJDOT Safety Manual. Special attention shall be paid to the proper placement of traffic control devices and flag persons and the need for retro reflective vests. Perform all field survey services in accordance with the *NJDOT Design Manual, Roadway*, as revised.

Appendix F

Surveying Terms and Glossary

Glossary (Edited from http://www.auslig.gov.au/corpinfo/info/glossary.htm)

AGL Above Ground Level.

AGPS Airborne Global Positioning System (See also the application of GPS in this document.)

AMI Active Microwave Instrument - active sensing system on-board ERS-1 and ERS-2 satellites which consists of two separate radars, operating at a frequency of 5.3ghz (c-band) with three modes of operation - a Synthetic Aperture Radar (SAR) for image and wave mode and a three antenna Wind Scatterometer.

AOS - Acquisition of Signal.

ARC/INFO - GIS Software.

Array Sensor - an imaging device employing an array of electronically sampled detectors in the focal plane.

Ascending node - the point on a satellite's orbit when a satellite crosses the Earth's Equatorial plane from South to North.

ASCII American Standard Code for Information Exchange.

ASPRS American Society for Photogrammetry and Remote Sensing.

ATC Air Traffic Control.

Atmospheric correction - image processing procedure that compensates for the effects of scattered and absorbed radiation by the atmosphere.

Attribute accuracy - component of data quality describing the likelihood of an attribute of a spatial feature being erroneous.

AUTOCAD - Drafting Software.

Automated cartography - the preparation and presentation of maps using machines controlled by computers.

AVHRR Advanced Very High Resolution Radiometer - sensor on-board the NOAA series of satellites.

Azimuth - geographic orientation of a line given as an angle measurement in degrees clockwise from north.

Azimuth range - for radar images this term represents the distance measured along a line between the limits of the radar beam in the direction of the satellite or aircraft.

Band - a selection of a wavelength interval in the electromagnetic spectrum.

Band-pass filter - a wave filter that has a single transmission band extending from a lower cutoff frequency greater than zero to a finite upper cutoff frequency.

Bandwidth - the number of cycles per second between the limits of a frequency band. usually associated with topographic mapping covering country or region at different scales.

Bathymetric surveying - is the measure of the depth and shape of the ocean floor. Usually associated with the mapping of the resources of the seabed.

BMP - an abbreviation for Windows Bitmap. BMP is a common raster data format supported by many Microsoft Windows products and applications.

Brightness - the attribute of visual perception in accordance with which an area appears to emit more or less light.

Cadastral survey - a survey of the boundaries of land parcels.

Cadastre - a public register usually recording the quantity, value, and ownership of land parcels in a country or jurisdiction.

Calibration - the act or process of comparing certain specific measurements in an instrument with a standard.

Cartography - the art and science of producing maps, charts, and other representations to spatial relationships.

CADD - computer aided design

CCD Charged Coupled Device - a device in which electrons are stored at the surface of a semiconductor.

CCRS Canadian Centre for Remote Sensing

Cell - an area on the ground from which electromagnetic radiation is emitted or reflected.

CEOS Committee on Earth Observation Satellites

Change detection - sensing of environmental changes.

Characteristic curve - a curve showing the relationship between exposure and resulting density in a photograph image, usually plotted as density (D) against the logarithm of the exposure (log E) in candela- meter-seconds. It is also called the H and D curve, the sensitometric curve, and the D log E.

Chemical fog - density produced on photographic paper or films by chemical means, such as too energetic or contaminated developer.

CNES Centre National d'Etudes Spatiales (French Space Agency)

Completeness - component of data quality describing the completeness of coverage within a data set(s).

Contour - an imaginary line drawn on a map joining all the points on the earth that are the same height above sea level.

Control - a system of points which are used as fixed references for positioning other surveyed features.

Control, ground - control obtained by ground surveys as distinguished from control obtained by photogrammetric methods; may be for horizontal or vertical control, or both. Ground (in-situ) observations to aid in the interpretation of remote sensing data.

Control point - any station in a horizontal and/or vertical control system that is identified on a photograph and used for correlating the data shown on that photograph.

Coordinates - linear or angular quantities which designate the position of a point in a given reference or grid system.

Coordinate, geographic - a system of spherical coordinates for describing the positions of points on the earth. The declinations and polar bearings in this system are the latitudes and longitudes, respectively.

Coordinates, grid - a plane-rectangular coordinate system based on and mathematically adjusted to a map projection in order that geographic positions (latitudes and longitudes) may be readily transformed into plane coordinates and the computations relating to them made by the ordinary methods of plane surveying.

COPYFILE - shareware software owned and copyright by Informatix Inc, USA. Used by GEODATA RASTER-250K to reformat the raster data.

CORS Continuously Operating Reference Stations.

CP Centering Point or Control Point

CSA Canadian Space Agency

DCX - a raster image format and is a variation of PCX file. DCX is used by many MS-DOS fax boards.

DEM Digital Elevation Model - a geographic grid of an area where the contents of each grid cell represent the height of the terrain in that cell. Consists of X, Y and Z coordinates.

Descending node - point on the orbit of a satellite when a satellite crosses the Earth's equatorial plane while moving from north to south. Using two GPS satellite receivers with one at a known position it is possible to increase the accuracy from a roving receiver by applying corrections derived from the fixed receiver.

DIGEST Digital Geographic Information Exchange Standard: a system for compiling spatial data directly in digital form.

Distortion - any shift in the position of an image on a photograph which alters the perspective characteristics of the photograph. Compression or expansion of the scale of the imagery in the azimuth direction. Change in scale from one part of the imagery to another.

DGN - This is a reference to a Bentley MicroStation file format. The term is based on the file name extension used for this format.

DMA Defense Mapping Agency - United States of America

Downlink - a communication link between a satellite and a ground station.

DORIS Doplar Orbitography and Radiopositioning Integrated by Satellite

DPI - dots per inch.

DTM Digital Terrain Model.

Dynamic range - the ratio of maximum measurable signal to minimum detectable signal.

EDM Electronic Distance Measurement - measurement of distance by means of electro-magnetic transmissions, including radio, visible high, laser and infrared light.

Elevation - the angle above the horizon, measured from the horizontal plane.

EMR Electromagnetic Radiation - energy propagated through space or through material media in the form of an advancing interaction between electric and magnetic fields.

Engineering surveying - surveying associated with the setting out and monitoring of engineering or construction works.

Enhancement, image - the process of altering the appearance of an image to extract additional information. It may be accomplished by digital or photographic (optical) methods.

ERC Earth Rotation Correction

ERS European Remote Sensing Satellite - ERS-1was launched 17 July 1991 and operates in a near circular sun synchronous orbit with a period of 100 minutes. The satellite altitude is 785km. The repeat coverage cycle varies, depending on mission requirements, and includes 3, 35, and 168 day cycles. ERS-2 was launched 20 April 1995 and has the same orbit parameters as ERS-1.

ESA European Space Agency

FAA Federal Aviation Administration.

FIG Federation Internationale des Geometres or International Federation of Surveyors

FMC Forward Motion Compensation.

Frequency - the number of oscillations per unit time or number of wavelengths that pass a point per time.

Geocentric Datum - a datum based on the Earth's centre of mass (or geocentre); as distinct from a regional datum, such as the AGD, whose origin does not coincide with the Earth's centre of mass.

GEODATA products - comprise map information converted into digital format. Used in conjunction with geographic information systems GEODATA products assist applications such as resource management, environmental assessment, mineral prospecting, communications, and transportation planning.

Geodesy - the study of the size and shape of the Earth's surface, the measurement of the position and motion of points on the surface and the configuration and area of large portions of its surface.

Geodetic control - a network of sites for which precise positions and/or heights are known and for which the shape and size of the Earth are taken into account.

Geodetic surveying - surveying which takes into account the shape and size of the earth. The result of a geodetic survey is a continuous series of accurately marked points on the ground, to which topographic, land and engineering surveys can be related to provide additional coordinated points for mapping and other purposes.

Geographical Grid - grid derived from geographical coordinates (commonly referred to as longitude and latitude).

Geometric correction - the removal of sensor, platform, or scene induced geometric errors such that the data conforms to a desired projection. This involves the creation of a new digital image by resampling the input digital image.

GEOREFERENCED - digital spatial data (and non-digital map features) for which the coordinates or location can be determined.

GICS Geocoded Image Correction System - an image processing system employed at ACRES.

GIF Graphics Interchange Format - the image file format originally developed by CompuServe as a machine-independent image file format. GIF files are a popular way of storing 8 bit, scanned or digitized images, and the compression ratios achieved are commonly better than other 8 bit formats. This format is commonly used in Internet applications.

GIS Geographic Information System - a computer-based system used to capture, create, maintain, display, and analyze spatially related information.

GNSS Global Navigation Satellite System (See also the application of GPS in this document.)

GPS Global Positioning System - is a satellite based navigation system developed by the United States Department of Defense and widely used for civilian navigation and positioning. (In this document it refers generically to space satellite system positioning. See Chapter 4 for application of specific space satellite systems.)

Grey scale - a monochrome strip of tones ranging from white to black with intermediate shades of gray. The scale is placed in a setup for a color photograph and serves as a means of balancing the separation negatives and color dye images.

Ground Station - a facility capable of receiving signals from earth observation satellites such as LANDSAT, SPOT, ERS, JERS, and MOS.

Ground Resolution Cell - the area on the ground that is covered by the **IFOV** of a detector.

GRS Grille de Reference SPOT - the system of using a path and row combination to identify nominal scene positioning for data from the SPOT satellites.

GSD Ground Sampling Distance

HDDT High Density Digital Tape - one inch magnetic tape containing data from a remote sensing satellite and recorded in a compressed format.

HRV Haute Resolution dans le Visible - the name given to the multispectral radiometer designed for SPOT spacecraft and offering high resolution in the visible and near-infrared. The first three SPOT spacecraft (SPOT-1,-2,-3) carry two identical HRVs designed for operation in a number of viewing configurations and in different spectral modes.

HRVIR Haute Resolution Visible Infra Rouge (proposed SPOT4).

Hydrographic surveying - the measurement and description of the physical features offshore and adjoining coastal areas with special reference to their use for the purpose of navigation.

Hypsometric tints - colors on a map depicting variations in the height of the earth's surface above sea level.

Hz hertz (frequency per second)

IFOV Instantaneous Field of View - is the pixel dimensions of the bulk (Level 1) product not the pixel dimensions of the resampled product.

IGAE Intergovernmental Agreement on the Environment

IMAGINE - software owned and copyright to ERDAS, USA. Used to update RASTER-250K map images.

IMU Inertial Measurement Unit

INS Inertial Navigation System

IR Infra-Red

LANDSAT - earth resources satellites operated by NOAA, United States. LANDSAT 5 was launched 1 March 1994 and operates in a near polar sun synchronous orbit at an altitude of 705km. Repeat cycle is 16 days.

LAS This is a reference to an industry standard LiDAR point cloud file format. The term is based on the file name extension used for this format.

Legal cadastre - a cadastre compiled so that the jurisdiction may have a record of ownership of all land parcels.

LiDAR Light Detection and Ranging

Lineage - component of data quality describing the history or origin of features within the described data set.

LIS Land Information System - synonymous with GIS although more often associated with cadastral based systems.

Look angle (radar) - the direction of the look, or direction, in which the antenna is pointing when transmitting and receiving from a particular cell.

LOS Loss of Signal

LUT Look-Up Table

LZW compression - a compression routine for raster data, patented and owned by Unisys Corporation of the United States of America.

Map - a representation of the earth's surface. A cadastral map is one showing the land subdivided into units of ownership; a topographic map is one showing the physical and superficial features as they appear on the ground; a thematic map displays a particular theme, such as vegetation or population density.

Mbps Megabits per second - the rate of transfer of binary information in millions of bits per second and commonly referred to in data transmission rates from satellites to ground stations.

Metadata - summary information describing the content of a dataset.

Mining surveying - associated with the construction, monitoring and mapping of mines and associated works.

MLA Multispectral Linear Array

MMOFE Mission Management Organization Front End - NASDA's mission management computer.

MOS Marine Observation Satellite (Japan)

Mosaicing - the assembling of photographs or other images whose edges are cut and matched to form a continuous photographic representation of a portion of the earth's surface.

MOSS Modelling of Surface Systems

MQS Microimage Quicklook System - image cataloguing system employed at ACRES.

MSS Multi-spectral Scanning System - a scanner on board LANDSAT 4 and 5 that records four bands of digital data.

MTLS – Mobile Terrestrial Laser Scanning

Multipurpose cadastre - a cadastre containing a variety of parcel-based information considered necessary for good land administration.

Multispectral - generally used for acquisition of remote sensing data in two or more spectral bands.

MUTCD Manual of Uniform Traffic Control Devices

MW Microwave

NAD North American Datum

Nadir - that point on the ground vertically beneath the perspective centre of the camera lens.

NASA National Aeronautics and Space Administration

NAVD North American Vertical Datum

NIR Near Infra-Red: Used in reference to a part of the light spectrum.

NGS National Geodetic Survey

NJDOT New Jersey Department of Transportation

NJSPC New Jersey State Plane Coordinates

NOAA National Oceanic and Atmospheric Administration

NSRS National Spatial Reference System

NSSDA National Standard for Spatial Data Accuracy

NVA Non-vegetated Vertical Accuracy

Number of looks (radar) - this term refers to the successive observations of the same area as the antenna moves along its designated path. Many observations may be required in order to characterize the backscatter properties of a surface.

Orbit - path of a satellite around the earth.

Orbital elements - a set of parameters defining the orbit of a satellite. Also called orbital parameters.

Orbital period - the time taken by a satellite to make one revolution around the earth. Also referred to as the anomalous or nodal period.

Orthographic projection - the projection by parallel rays onto a plane at right angles to the rays.

Orthophotomaps - aerial maps, true to scale.

Path - the number of the north/south track of the satellite in its specific satellite grid. LANDSAT uses the WRS and SPOT the GRS. For LANDSAT, in the visibility circle for the Alice Springs receiving station, the path range is 84 to 117, from east to west.

PC - IBM or compatible personal computer.

PCX - raster data format originally developed by Zsoft and extensively used in IBM PC computer applications.

PDOP Positional Dilution of Position

Photogrammetry - the science and art of obtaining measurements from photographs.

PHOTOSHOP - software owned and copyright to ADOBE, USA. Used to edit and enhance GEODATA RASTER-250K map images.

PID Photo ID, used in reference to aerial mapping ground control points naturally identifiable in aerial imagery without the need to target, (or panel) the control point.

Pixel - a contraction of the words 'picture element'. A data element having both spatial and spectral aspects. The spatial variable defines the size of the resolution cell (i.e. the area on the ground represented by the data values), and the spectral variable defines the intensity of the spectral response for that cell in a particular channel.

PLA Panchromatic Linear Array - the single band sensor onboard the SPOT 1, 2, and 3 spacecraft.

Polarisation - the direction of vibration of the electrical field vector of **electromagnetic radiation**.

Positional Accuracy - component of data quality describing the planimetric accuracy of features.

PPR Prior Permission Request

PSMA Public Sector Mapping Agencies.

Quantization - the process of converting from continuous values of information to a finite number of discrete values.

RADARSAT - the earth observation satellite launched 4 November 1995 and operated by the Canadian Space Agency (CSA). RADARSAT is equipped with a C-band SAR which can be operated in a variety of modes with swath widths ranging from 35 kilometers to 500 kilometers and with resolutions from 10 meters to 100 meters, respectively.

Radiance - a measure of the energy radiated by an object together with the frequency distribution of that radiation.

Raster Data - a picture or image composed of rows and columns of data cells (pixels). Satellite data and GEODATA RASTER-250K are examples of raster data.

Raster Image - a cellular data structure composed of rows and columns. Each cell has a value which represents an attribute value for the feature represented by that group of cells.

Relief Displacement - a shift in position of the optical image of an object caused by the height of the object above or depth below a datum plane.

Remote sensing - the acquisition of information about an object without physical contact. Usually associated with the acquisition of information about the Earth's surface by electronic and/or optical instruments from satellites, airborne platforms, or ground observation.

Repeat Cycle - cycle time for a satellite to pass over a given point on the earth.

RGB Red, Green, Blue, used in reference to parts of the visible light spectrum.

RMSE Root Mean Square Error (may be followed by lower-case “z” as referred to elevation or an “r” if referencing a radial distance - x & y combined)

Row - the number of the east/west grid line in the specific satellite grid. LANDSAT uses the WRS and SPOT the GRS. For LANDSAT, in the visibility circle for the Alice Springs receiving station, the row range is 61 to 91, from north to south.

RTK Real-Time Kinematic

RTN Real-Time Network(s)

SAR Synthetic Aperture Radar - type of instrument on recently launched satellites which can "see" through clouds and make it possible to acquire satellite imagery day and night.

SATOPS Satellite Operations Section (ACRES) - the primary responsibilities include the management of all client future acquisition requests and also long and short term acquisition planning for the ACRES archive program.

Scale - the indication given on a map, either as a linear scale or representative fraction, of the ratio between a given distance on the map and the corresponding distance on the earth's surface.

SDTS Spatial Data Transfer Standard

Sensor - any device which gathers EMR or other energy and presents it in a form suitable for obtaining information about the environment.

Slant Range - for radar images this term represents the distance measured along a line between the antenna and the target.

SLR Satellite Laser Ranging - the measurement of the distance to a satellite fitted with retro-reflectors, by measuring the time taken for a laser beam to travel to the satellite and back. These measurements are used to determine satellite orbits and to monitor the movement of the earth.

SME Subject Matter Expert

Spectral band - an interval in the electromagnetic spectrum defined by two wavelengths, frequencies, or wave numbers.

SPOT Satellite Pour L'Observation de la Terre - the SPOT series of earth observation satellites are operated by CNES, France. SPOT 1 was launched 22 February 1986, SPOT 2 was launched 21 January 1990 and is currently operational and SPOT 3 was launched 26 September 1993 and is currently fully operational. SPOT satellites are operated in a sun synchronous near polar orbit. Satellite altitude is 830km and the repeat cycle is 26 days. SPOT 4 is proposed for launch in December 1997.

Stereoscopic pair - two images of the same area taken from different camera stations so as to afford stereoscopic vision; frequently called stereopair.

Stereoscopic plotting instrument - an instrument for plotting a map or obtaining spatial solutions by observation of stereoscopic models formed by stereopairs of images.

STLS – Stationary Terrestrial Laser Scanning

Sun synchronous - earth satellite orbit in which the orbital plane is near polar and the satellite passes over points on the earth at the same latitude at the same local sun time.

Surveying - measurement of dimensions (contour, position, boundaries, area, height etc.) of any part of the earth's surface (land or water) or any cultural feature. Depending on the type of survey undertaken and the degree of accuracy required, "surveys" may involve the application of the theory, principles and techniques of geodesy, photogrammetry, and cartography.

SWIR Short Wave Infra-Red

Telemetry - radio signals transmitted between satellites and ground stations.

TIFF Tagged Information File Format - raster image format created by Aldus and Microsoft Corporations and designed to be a universal format. It is used extensively in desktop publishing packages. TIFF can be compressed using a wide range of compression routines. The most common of these is LZW.

Title - the evidence of a person's right to land.

TM Thematic Mapper - a scanner on-board the LANDSAT 4 and 5 satellites that records seven bands of digital data.

Topographic surveying - involves establishing the contour level and interval of the earth's surface above and below sea level based on a particular control survey system. These surveys may be done by aerial, photogrammetric and ground survey and involves recording of natural features such as hills, streams, valleys and cultural features, such as roads, bridges, railways, etc. These surveys are used to produce topographic maps.

Topography - description or representation on a map of the physical and cultural surface features.

UAV Unmanned Aerial Vehicle

UV Ultra-Violet

Vector data - spatial data in which the location of features is defined by points and straight lines (vectors). A road network would be described by vector data.

VLBI Very Long Baseline Interferometry

VVA Vegetated Vertical Accuracy

Wavelength - the least distance between particles moving in the same phase of oscillation in a wave disturbance. For electromagnetic waves wavelength is influenced by the environment in which the waves are propagating (e.g. air versus a vacuum).

WGS84 World Geodetic System 1984 Geocentric datum used by GPS systems.

WRS World Reference System - the system of using a path and row combination to identify nominal scene positioning for data from the MSS and TM sensors on the LANDSAT satellite.

GPS/GIS/LIS Glossary of Terms

FROM ASHTECH http://www.ashtech.com/pages/gps/glossary.html

Aerotriangulation (phototriangulation) - a complex process vital to aerial photogrammetry that involves extending vertical and/or horizontal control so that the measurements of angles and/or distances on overlapping photographs are related to a spatial solution using the perspective principles of the photographs. Aerotriangulation consists of mathematically extending the vectors/angles of a triangular pattern of known reference points on or near the designated photo-block terrain upward through a rectangle representing the area of the photo-block (as seen by the camera's optical center) in such a way that the three-point terrain triangle and the camera's eye three-point triangle (within the photographic frame) are analogous.

Almanac - a set of parameters used by a GPS receiver to predict the approximate locations of a GPS satellite and the expected satellite clock offset. Each GPS satellite contains and transmits the almanac data for all GPS satellites. (See ephemeris).

Ambiguity - the initial bias in a carrier-phase observation of an arbitrary number of cycles; the uncertainty of the number of cycles a receiver is attempting to count. If wavelength is known, the distance to a satellite can be computed once the number of cycles is established via carrier-phase processing.

Antenna - a variety of GPS antennas ranging from simpler microstrip devices to complex choke ring antennas that mitigate the effects of multipath scattering.

Anti-Spoofing (AS) - the process of encrypting the P-Code modulation sequence so that the code cannot be replicated by hostile forces. When encrypted, the P-Code is referred to as the Y-Code (see Y-Code & Spoofing). **Error! Reference source not found.**

Atomic clock - a clock whose frequency is maintained using electromagnetic waves that are emitted or absorbed in the transition of atomic particles between energy states. The frequency of an atomic transition is very precise, resulting in very stable clocks. A cesium clock has an error of about one second in one million years. For redundancy purposes, GPS satellites carry multiple atomic clocks. GPS satellites have used rubidium clocks as well as cesium clocks. The GPS Master Control Station uses cesium clocks and a hydrogen maser clock.

Baseline - the measured distance between two receivers or two antennas.

Bipolar biphase shift key (BPSK) - the modulation technique used on GPS satellites. In this method, a binary bit transition results in a 180-degree shift of the carrier.

Cadastral survey - a survey that defines boundaries, property lines, etc., and pertains to cadastre, an official register of ownership, the extent and value of real property. Cadastral surveys usually determine taxation.

Carrier frequency - the basic frequency of an unmodulated radio signal. GPS satellite navigation signals are broadcast on two L-band frequencies, L1 and L2. L1 is at 1575.42 Mhz, and L2 is at 1227.6 Mhz.

Carrier phase - the fraction of a cycle, often expressed in degrees, where 360 degrees equals a complete cycle. Carrier phase can also mean the number of complete cycles plus a fractional cycle. In a survey-grade GPS receiver, the receiver can lock on to a satellite and, keeping track of the number of whole cycles of the carrier, creates a cumulative phase of the signal which is often referred to as integrated Doppler.

C/A (clear acquisition) Code - consists of a sequence of 1023 bits (0 or 1) that repeats every millisecond. Each satellite broadcasts a unique 1023-bit sequence that allows a receiver to distinguish between various satellites. The C/A-Code modulates only the L1 carrier frequency on GPS satellites. The C/A-Code allows a receiver to quickly lock on to a satellite.

Carrier phase - the cummulative phase of either the L1 or L2 carrier of a GPS signal, measured by a receiver while locked-on to the signal (also known as integrated Doppler).

Channel - refers to the hardware in a receiver that allows the receiver to detect, lock-on and continuously track the signal from a single satellite. The more receiver channels available, the greater number of satellite signals a receiver can simultaneously lock-on and track.

Circular Error Probable (CEP) - the radius of a circle, centered at the true location, within which 50% of position solutions fall. CEP is used for horizontal accuracy (see SEP).

Constellation - refers to the collection of orbiting GPS satellites. The GPS constellation consists of 24 satellites in 12-hour circular orbits at an altitude of 20,200 kilometers. In the nominal constellation, four satellites are spaced in each of six orbital planes. The constellation was selected to provoke a very high probability of satellite coverage even in the event of satellite outages.

Conventional Terrestrial System (CTS) - a standardized reference system, originating at the planet's center of mass, that is designed to allow uniformity in geodetic measurements and computations.

Cycle slip - a loss of count of carrier cycles as they are being measured by a GPS receiver. Loss of signal, ionospheric interference and other forms of interference cause cycle slips to occur (see carrier phase).

Differential GPS (DGPS) - a technique whereby data from a receiver at a known location is used to correct the data from a receiver at an unknown location. Differential corrections can be applied in either real-time (see RTCM SC-104 format) or by post-processing. Since most of the errors in GPS are common to users in a wide area, the DGPS-corrected solution is significantly more accurate than a normal SPS solution.

Dilution of Precision (DOP) - a measure of the receiver-satellite(s) geometry. DOP relates the statistical accuracy of the GPS measurements to the statistical accuracy of the solution. Geometric Dilution of Precision (GDOP) is composed of Time Dilution of Precision (TDOP) & Position Dilution of Precision (PDOP), which are composed of Horizontal Dilution of Precision (HDOP) & Vertical Dilution of Precision (VDOP).

Doppler shift - a shift similar to that experienced by audio phenomena, except occurring in the electromagnetic spectrum, where an apparent change in signal frequency occurs as the transmitter and receiver move toward or away from one another.

Double difference - (see single difference) the arithmetic differencing of carrier phases measured simultaneously by a pair of receivers tracking the same pair of satellites. Single differences are obtained by each receiver from each satellite; these differences are then differenced in turn, which essentially deletes all satellite and receiver clock errors.

Earth Centered, Earth Fixed (ECEF) - a Cartesian coordinate system centered at the earth's center of mass. The Z-axis is aligned with the earth's mean spin axis. The X-axis is aligned with the zero meridian. The Y-axis is 90 degrees west of the X-axis, forming a right-handed coordinate system.

Elevation mask - an adjustable feature of GPS receivers that specifies that a satellite must be at least a specified number of degrees above the horizon before the signals from the satellite are to be used. Satellites at low elevation angles (five degrees or less) have lower signal strengths and are more prone to loss of lock thus causing noisy solutions.

Ellipsoid of revolution (often referred to simply as ellipsoid) - a mathematical representation of the earth that is an ellipse that is rotated about its minor axis. An ellipsoid is an equipotential surface of a rotating, homogeneous body. Various ellispoid models have been determined to approximate the geoid in local areas and in a global sense. GPS uses the WGS84 earth model which is based on the GRS80 ellipsoid.

Ephemeris (plural: ephemerides) - a set of parameters used by a GPS receiver to predict the location of a GPS satellite and its clock behavior. Each GPS satellite contains and transmits ephemeris data its own orbit and clock. Ephemeris data is more accurate than the almanac data but is applicable over a short time frame (four to six hours). Ephemeris data is transmitted by the satellite, every 30 seconds. (See almanac).

Firmware - the electronic heart of a receiver, where coded instructions relating to receiver function, and (sometimes) data processing algorithms, are embedded as integral portions of the internal circuitry.

Frequency - the number of times that a periodic event occurs per unit of time. For GPS, frequency usually refers to the radio frequency, in Hz, of either of two basic carriers transmitted by each satellite (see L1 & L2).

Geodetic coordinates - a coordinate system whose elements are latitude, longitude and geodetic height. The latitude is an angle based on the perpendicular to the ellipsoid. Longitude is the angle measured in the XY plane (see ECEF).

Geodetic datum (horizontal datum) - a specifically oriented ellipsoid typically defined by eight parameters which establish its dimensions, define its center with respect to Earth's center of mass and specify its orientation in relation to the Earth's average spin axis and Greenwich reference meridian.

Geodetic height (ellipsoidal height) - the height of a point above an ellipsoidal surface. The difference between a point's geodetic height and its orthometric height equals the geoidal height.

Geoid - the equipotential surface of the Earth's gravity field which best fits mean sea level. Geoids currently in use are GEOID84 and GEOID90.

Geoidal height (geoidal separation; undulation) - the height of a point on the geoid above the ellipsoid measured along a perpendicular to the ellipsoid.

GIS Geographic Information System.

Global Orbiting Navigation Satellite System (GLONASS) - the Russian version of GPS.

GNSS Global Navigation Satellite System (See also the application of GPS in this document.)

GPS Global Positioning System (In this document it refers generically to space satellite system positioning. See Chapter 4 for application of specific space satellite systems.)

GPS week - GPS time started at Saturday/Sunday midnight, January 6, 1980. The GPS week is the number of whole weeks since GPS time zero.

Gravity - a force that is the vector sum of gravitational attraction of the various masses within the planet (gravitation) plus the centrifugal force caused by the rotation of the Earth. Unit of measurement: the gal = 1 cm per m/sec2.

GSD Ground Sampling Distance.

Hydrographic and bathymetric surveying - surveying or mapping of harbors, inlets or deep water locations. Hydrography is the study of the physical characteristics of oceans, lakes, and rivers as well as the elements affecting safe navigation. Bathymetry is the measurement and study of water depths.

Hz hertz (frequency per second).

INS Inertial Navigation System.

IMU Inertial Measurement Unit.

Ionosphere - refers to the layers of ionized air in the atmosphere extending from 70 kilometers to 700 kilometers and higher. Depending on frequency, the ionosphere can either block radio signals completely or change the propagation speed. GPS signals penetrate the ionosphere but are delayed. The ionospheric delays can be either predicted using models, though with relatively poor accuracy, or measured using two frequency receivers.

Julian date - the number of days that have elapsed since 1 January 4713 B.C. in the Julian calendar. GPS time zero is defined to be midnight UTC, Saturday/Sunday, 6 January 1980 at Greenwich. The Julian date for GPS time zero is 2,444,244.5.

Kinematic surveying - a method which initially solves wavelength ambiguities and retains the resulting measurements by maintaining a lock on a specific number of satellites throughout the entire surveying period.

L1 & L2 - designations of the two basic carrier frequencies transmitted by GPS satellites that contain the navigation signals. L1 is 1,575.42 Mhz and L2 is 1,227.60 Mhz.

LAS This is a reference to an industry standard LiDAR point cloud file format. The term is based on the file name extension used for this format.

L-band - a nominal portion of the microwave electromagnetic spectrum ranging from 1 to 2 Ghz.

LiDAR Light Detection and Ranging.

Multipath - the reception of a signal both along a direct path and along one or more reflected paths. The resulting signal results in an incorrect paseudorange measurement. The classical example of multipath is the "ghosting" that appears on television when an airplane passes overhead.

Multiplexing - a technique used in some GPS receivers to sequence the signals of two or more satellites through a single hardware channel. Multiplexing allows a receiver to track more satellites than the number of hardware channels at the cost of lower effective signal strength.

MUTCD Manual of Uniform Traffic Control Devices.

NAD North American Datum.

Navigation messages - data modulated onto the satellite's signals. The navigation data is transmitted at 50 bits per second and contains ephemeris and clock data for that particular satellite, other data required by a receiver to compute position velocity and time and almanac data for all NAVSTAR satellites. The data is transmitted in 1500 bit frames, each requiring 30 seconds to transmit. A complete set of data to include all almanacs, timing information, ionospheric information and other data requires 12-1/2 minutes to transmit.

NAVD North American Vertical Datum.

NAVigation Satellite for Timing and Ranging (NAVSTAR) - Another term for GPS or sometimes used in conjunction with GPS as in "NAVSTAR GPS.".

NIR Near Infrared: Used in reference to a part of the light spectrum.

NGS National Geodetic Survey.

NJDOT New Jersey Department of Transportation.

NJSPC New Jersey State Plane Coordinates.

NSRS National Spatial Reference System.

NSSDA National Standard for Spatial Data Accuracy.

NVA Non-Vegetated Vertical Accuracy.

On-the-Fly (OTF) - a term used to describe the technique of resolving differential carrier-phase integer ambiguities without requiring a GPS receiver to remain stationary.

Orbit - the path a satellite takes in space.

Orthometric height (orthometric elevation) - the height of a point above the geoid.

P-Code - "precise" or "protected" code which is bi-phase shift modulated on both the L1 and L2 carrier frequencies. P-code has a 10.23MHz bit rate and, as implemented in GPS, has a period of one week. Each satellite has a unique P-code that is used to distinguish the satellite from all other GPS satellites.

PDOP Positional Dilution of Position.

PID Photo ID, used in reference to aerial mapping ground control points naturally identifiable in aerial imagery without the need to target, (or panel) the control point.

Photogrammetry - an aerial remote sensing technique whose latest innovations employ a high-resolution aerial camera with forward motion compensation and uses GPS technology for pilot guidance over the designated photo block(s). Photogrammetry forms the baseline of many Geographic Information Systems (GIS) and Land Information System (LIS) studies and endeavors.

Post-processing - - the reduction and processing of GPS data after the data was actually collected in the field. Post-processing is usually accomplished on a computer in an office environment where appropriate software is employed to achieve optimum position solutions.

PPR Prior Permission Request.

Precise Positioning System (PPS) - the more accurate GPS capability that is restricted to authorized, typically military, users.

Pseudo-kinematic surveying - a variation of the kinematic method where roughly five-minute site occupations are repeated at a minimum of once each hour.

Pseudorandom noise (PRN) - the P(Y) and C/A codes are pseudo-random noise sequences which modulate the navigation signals. The modulation appears to be random noise but is, in fact, predictable hence the term "pseudo" random. Use of this technique allows the use of a single frequency by all GPS satellites and also permits the satellites to broadcast a low power signal.

Pseudorange - the measured distance between the GPS receiver antenna and the GPS satellite. The pseudorange is approximately the geometric range biased by the offset of the receiver clock from the satellite clock. The receiver actually measures a time difference which is related to distance (range) by the speed of propagation.

Quartz oscillator - the timing device within a receiver that synchronizes the receiver's operation and maintains time for the receiver.

Ratio - a measure of the precision of observations that takes into account the resolution of ambiguities and arrives at an RMS value during the processing computations.

Real-time - refers to immediate, "on the spot," GPS data collection, processing and position determination (usually) within a receiver's firmware, rather than post-processing "after the fact" via a computer in an office environment.

Real-time kinematic (RTK) - a DGPS process where carrier-phase corrections are transmitted in real-time from a reference receiver at a known location to one or more remote "rover" receiver(s).

Reference Network - a series of monuments or reference points with accurately measured mutual vectors/distances that is used as a reference basis for cadastral and other types of survey.

Reference Station - a point (site) where crustal stability, or tidal current constants, have been determined through accurate observations, and which is then used as a standard for the comparison of simultaneous observations at one or more subordinate stations. Certain of these are known as Continuous Operating Reference Stations (CORS) and transmit reference data on a 24-hour basis.

RGB Red, Green, Blue, used in reference to parts of the visible light spectrum.

RINEX - the Receiver-INdependent EXchange format for GPS data, which includes provisions for pseudorange, carrier-phase, and Doppler observations.

RMSE Root Mean Square Error (may be followed by lower-case “z” as referred to elevation or an “r” if referencing a radial distance - x & y combined).

Root mean squared (RMS) - a statistical measure of the scatter of computed positions about a "best fit" position solution. RMS can be applied to any random variable.

RTCM SC-104 format - a standard format used in the transmission of differential corrections.

RTK Real-Time Kinematic.

RTN Real-Time Network(s).

Satellite Image Mapping (SIM) - a product of remote sensing where discrete blocks of orbital photography are "mosaicked" into a comprehensive whole, then "geocoded" or computer-linked to specific Mercator, Lambert Conformal, or other types of projections that include a scale factor and reference geoid, with each pixel related to a specific latitude and longitude.

Selective Availability (SA) - the process whereby DoD "dithers" the satellite clock and/or broadcasts erroneous orbital ephemeris data to create a pseudorange error (see Standard Positioning System).

Spherical Error Probable (SEP) - a navigational measure of accuracy equaling the radius of a sphere, centered on the true location, inside which 50% of the computed solutions lie. (See CEP.)

Sidereal Time - is defined by the hour angle of the vernal equinox. Taking the mean equinox as the reference yields true or apparent Sidereal Time. Neither Solar nor Sidereal Time are constant, since angular velocity vary due to fluctuations caused by the Earth's polar moment of inertia as exerted through tidal deformation and other mass transports.

Single difference - the arithmetic "differencing" of carrier phases simultaneously measured by a pair of receivers tracking the same satellite (between-receivers and satellite), or by a single receiver tracking two satellites (between-satellite and receivers); the former essentially deletes all satellite clock errors, while the latter essentially deletes all receiver errors.

SME Subject Matter Expert.

Software - usually refers to a set of advanced modules, such as Ashtech's PRISM II Package, that allows the user to plan efficient surveys, organize and acquire GPS data, verify and download GPS data into a computer, process and analyze the measurements, perform a network adjustment, and report/archive the final results.

Spoofing - the process of replicating the GPS code in such a way that the user computes incorrect position solutions.

Standard Positioning System - the less accurate GPS capability which is available to all. (See Anti-Spoofing and Selective Availability).

Static observations - a GPS survey technique that requires roughly one hour of observation, with two or more receivers observing simultaneously, and results in high accuracies and vector measurements.

Triple difference - the arithmetic difference of sequential, doubly-differenced carrier-phase observations that are free of integer ambiguities, and therefore useful for determining initial, approximate coordinates of a site in relative GPS positioning, and for detecting cycle slips in carrier-phase data. (See single difference & double difference)

Universal Time Coordinated (UTC) - time as maintained by the U.S. Naval Observatory. Because of variations in the Earth's rotation, UTC is sometimes adjusted by an integer second. The accumulation of these adjustments compared to GPS time, which runs continuously, has resulted in an 11 second offset between GPS time and UTC at the start of 1996. After accounting for leap seconds and using adjustments contained in the navigation message, GPS time can be related to UTC within 20 nanoseconds or better.

World Geodetic System 1984 (WGS 84) - a set of U.S. Defense Mapping Agency parameters for determining global geometric and physical geodetic relationships. Parameters include a geocentric reference ellipsoid; a coordinate system; and a gravity field model. GPS satellite orbital information in the navigation message is referenced to WGS 84.

VVA Vegetated Vertical Accuracy.

Y-Code - the designation for the end result of P-Code during Anti-Spoofing (AS) activation by DoD.

Y-Code tracking, civilian - several methods of obtaining valid data from encrypted Y-code are available:

1. Signal squaring (now obsolete) multiplies the signal by itself, thus deleting the carrier's code information and making distance measurement (ranging) impossible. Carrier phase measurements can still be accomplished, although doubling the carrier frequency halves the wavelength, further weakening an already weak signal. This method required collecting data over a much longer period.

2. Cross correlation, where no local (receiver) code is generated to match the L1 & L2 encrypted Y-codes. The ionosphere "slows" the L2 Y-code slightly in respect to the L1 Y-code, hence the difference between these distances can be measured and, once known, matched, and multiplied to remove the codes and leave pure carrier frequencies for measurement. This does away with the half-wavelength problem, but again results in a weakened signal that necessitates longer observation periods.

3. Code correlation & squaring. Here, the L1 & L2 Y-Codes are compared against a locally generated P-Code; the difference (the encrypting Y-code signal) is thus revealed, measured, and squared so that pure carrier frequencies can be measured. Squaring once again weakens the resulting half-wavelengths of both carrier frequencies, and once again requires longer observation periods.

4. Ashtech's "Z-Technique" (see Z-Tracking ™).

Z count - a 29-bit binary number consisting of the fundamental GPS time unit. The (10) most significant bits carry the GPS week number, and the (19) least significant bits give the time of week (TOW) count in units of 1.5 seconds.