Florida Department of
TRANSPORTATION

Terrestrial Mobile LiDAR (TML) Guidelines

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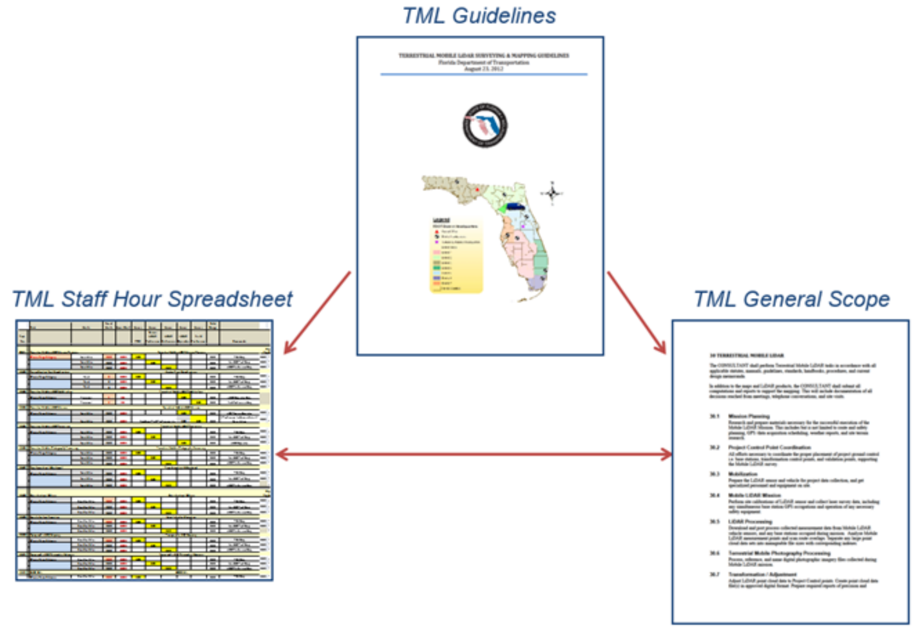
Agenda

- Why Guidelines?
- A few key Terms and Definitions
- Brief review of Mobile Laser Scanning (MLS) survey methods, accuracies and applications.
- Combining Image Technologies
- TRB
  - Guidelines for the Use of Mobile LIDAR in Transportation Applications
- Look at recent revisions to the TML Guidelines
- Discussion:
  - Impact on current projects
  - Future Revisions
  - Questions / Suggestions

Why Guidelines?

Recent advances in Light Detection and Ranging (LiDAR) technology have brought it into the Design Survey world. Mobile scanning vehicles and low altitude aircraft can now collect large amounts of survey data in a very short time with accuracies within a few centimeters. Along with this new tool comes the need for guidelines the Department can use to insure the quality, storage, and cost effective use of the large datasets produced.

- Improve planning, scoping, and staff hour estimation of MLS projects
- Reduce Department risk by establishing greater consistency of MLS products
- Reduce duplication of effort
- Provide greater quality control and confidence in Department use of MLS products
- Improve the Department’s ability to respond to changes in technology.
- Guideline Format
  - Initial Findings
  - Dynamic
  - Best Practices
  - Less Formal



Terms and Definitions

Lidar Definition

- LIDAR (***Li**ght **D**etection **a**nd **R**anging*) is an optical remote sensing technology which measures properties of scattered light to find range and/or other information of a distant target.
- The prevalent method to determine distance to an object or surface is to use laser pulses.
- Similar to radar technology, which uses radio waves instead of light, the range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal.

USGS

http://en.wikipedia.org/lidar

Terms and Definitions

Laser Operating Principles

- Pulsed Lasers
  - Most commonly used for ranging applications
  - Consists of a pulsed laser transmitter, an optical telescope receiver that amplifies the backscatter, and photomultiplier tube to convert optical energy into electrical impulses.
  - Distance to object is determined by recording the time taken by the transmitted pulse to the target and back (at the speed of light)
- Continuous Wave (CW) Lasers
  - Transmits a continuous signal, and ranging is carried out by modulating the intensity of the laser light.
  - Travel time is directly proportional to the phase difference between the received and transmitted sinusoidal signal.

USGS

Terms and Definitions

- **LAS** - A binary file standard supported by ASPRS for storing point location and attribute information primarily used for LiDAR data.
- **Orthophotograph** - A photographic copy, prepared from a perspective photograph, in which the displacements of images due to tilt and relief have been removed. *(Source: American Congress on Surveying and Mapping and the American Society of Civil Engineers. Definitions of Surveying and Associated Terms. Library of Congress Catalogue Card Number 72-76807. Washington 1972, 1978.*
- **Remote Sensing** - The process of detecting and/or monitoring the chemical or physical properties of an object without physically contacting the object. *(Source: American Congress on Surveying and Mapping and the American Society of Civil Engineers. Definitions of Surveying and Associated Terms. Library of Congress Catalogue Card Number 72-76807. Washington 1972, 1978.*
- **Image** - A pattern formed by electromagnetic radiation that approximately duplicates the pattern formed by a real object or a physical field detectable by the radiation. This definition is more general than the usual definition because many instruments used for detection operate at other than light frequencies but in ways similar or analogous to those used for forming optical images. The kind of radiation forming an image is usually specified by adding a word that identifies the part of the spectrum involved, e.g., radio image, infrared image, optical image, and X-ray image. However, the terms "radar image" and "X-ray image" are used to refer to optical images of the images formed by radar or X-ray. *Source: National Geodetic Survey: Geodetic Glossary. Library of Congress Catalogue Card Number 86-61105. 1986.* http://www.ngs.noaa.gov/CORS-Proxy/Glossary/xml/NGS_Glossary.xml

  1) ACTIVE – Emits and receives
  2) PASSIVE – Receives only

Laser Scanning in Surveying

- ❑ The significant increase in collected information gives the resulting point cloud intrinsic image qualities similar to other remote sensing technologies.

- ❑ The value of point cloud data can be extended when it is "mined" for topographic features and information beyond what was required of the intended survey.

Bridge Inspection

http://www.aibotix.com/bridge-inspection.html

What is Mobile Laser Scanning?

- Mobile Laser Scanning (MLS) uses a laser scanner(s) in combination with Global Navigation Satellite Systems (GNSS) and Inertial Measurement Unit (IMU) to produce accurate and precise geospatial data from a moving platform both in the air and on the ground.

- Traditionally the term Airborne LiDAR System (ALS) is associated with higher altitude airborne collection over a large area for surface mapping. In this document MLS from the air refers to low altitude scanning of higher accuracy from fixed wing and helicopter used for corridor projects.

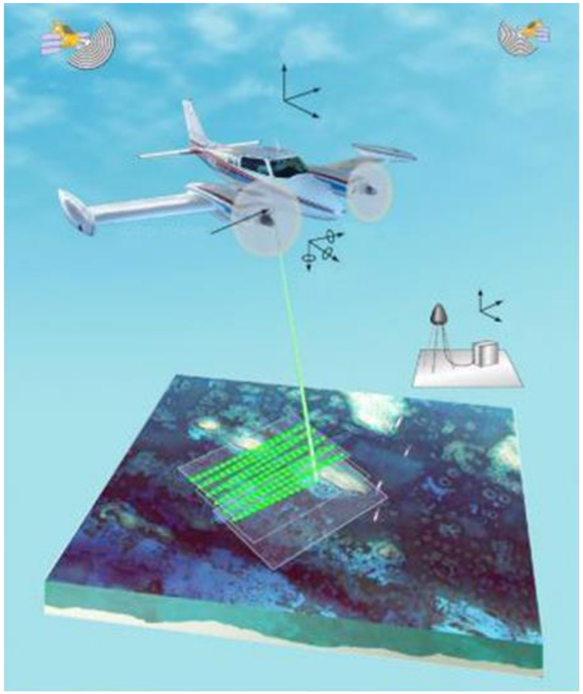
Mobile Scanning Systems have the following critical components in common:

Laser Sensor

GPS

IMU

Base Station



http://soundwaves.usgs.gov/2007/09/meetings2.html

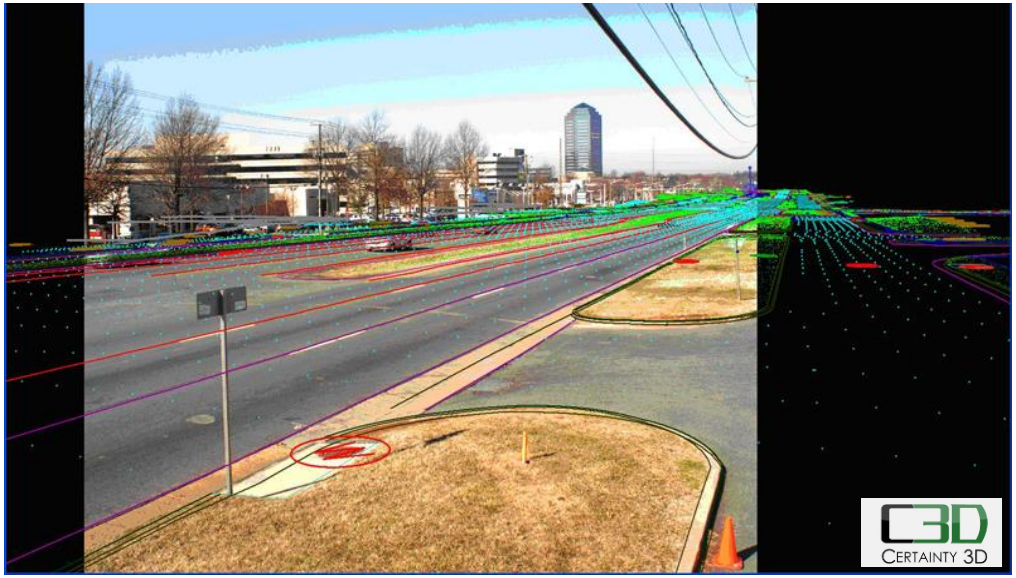
General Expectations of Vertical Accuracy

- These generalizations are changing rapidly and at some point will only be differentiable by their metadata and the perspective of their collected point cloud.

❑ Fixed Wing Aerial LiDAR Mapping (ALS)	= +/- 0.5 ~ 1.0 feet
❑ Low Altitude MLS	= +/- 0.1 ~ 0.2 feet
❑ Vehicle MLS	= +/- 0.050 ~ 0.1 feet
❑ Static Laser Scanning	= +/- 0.005 ~ 0.05 feet
❑ Differential Leveling / Total Station	= +/- 0.01 ~ 0.05 feet*

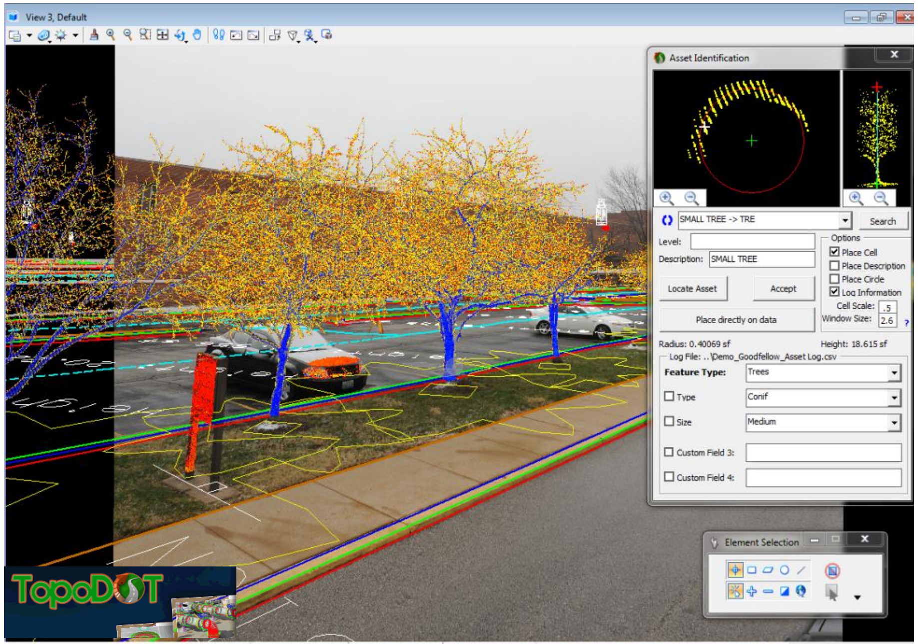
* Recent improvements use Imagery to isolate where the measurement was taken.

Benefits of Combining Image Technologies



- Safety and efficiency of data collection are compelling reasons to use mobile laser scanning. The potential to acquire a great deal of data in a relatively short time is enormous, especially in areas that are not conducive to other methods of data collection.

- The value of combining photography and laser scanning imagery methods can exceed the sum of their parts.



TRB Guidelines

NCHRP
REPORT 748

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Guidelines for the Use of Mobile LIDAR in Transportation Applications

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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 inspections	• *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 tourism
	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

**Network accuracies may be relaxed for applications identified in red italics.*
**BIM/BRIM: BIM = Building Information Modeling; BRIM = Bridge Information Modeling.
These are only suggestions; requirements may change based on project needs and specific transportation agency requirements.

TRB Guidelines

- To determine the sample spacing (i.e., distance between sample points) from point density values, the following equation can be used:

$$\text{Sample spacing} = \sqrt{1/\text{point density}}$$

- Request intensity values to be provided with scan data so that information can be used for visualization purposes to identify relative differences between objects in the point cloud.

- Geometric correction is best applied through re-processing of the system navigation trajectory.

TML Guidelines

- Most Transportation Design Projects will have very few point classifications.

- The only required class at this time is "Erroneous" used for points with compromised accuracies. The ASPRS Classification Value of 64 should be used for this class

- The Department continues to review classifications for TML surveys on transportation projects. District Survey Managers should be consulted before point classification begins.

The most developed TML point cloud data has been adjusted, verified, and classified by subject type. A Classified point cloud has the added value of having the individual points within it identified by class. All required classes should be specified in the contract scope as this task can be very time consuming.

Table 6.2a

ASPRS Standard LIDAR Point Classes	
Classification Value	*Meaning*
0	Created, never classified
1	Unclassified3
2	Ground
3	Low Vegetation
4	Medium Vegetation
5	High Vegetation
6	Building
7	Low Point (noise)
8	Reserved
9	Water
10	Rail
11	Road Surface
12	Reserved
13	Wire – Guard (Shield)
14	Wire – Conductor (Phase)
15	Transmission Tower
16	Wire-structure Connector (e.g. Insulator)
17	Bridge Deck
18	High Noise
19-63	Reserved
64-255	User definable

Note: The Department continues to review classifications for TML surveys on transportation projects. District Survey Managers should be consulted before point classification begins.

The only required class at this time is "Erroneous" used for points with compromised accuracies. The ASPRS Classification Value of 64 should be used for this class

64	Erroneous

Whenever possible the current ASPRS classifications should be followed at this time.

The point cloud data is now ready to be imported into various software packages for further data analysis and feature extraction as well as fusing with other types of data and analytical tools creating a variety of value-added products.

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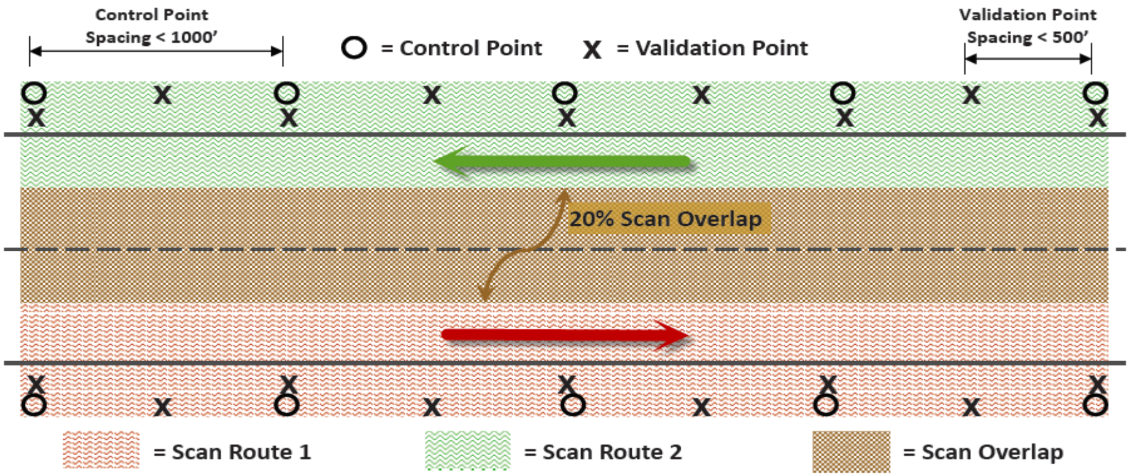
TML Guidelines

- **Type A** – High Accuracy Surveys
  - Design Engineering topographic
  - As-built
  - Structures and bridge clearance
  - Deformation surveys
- **Type C** – Lower Accuracy Mapping
  - Preliminary Planning
  - Transportation Statistics
  - General Asset inventory surveys
- **Type B** – Medium Accuracy Surveys
  - Design Engineering topographic Corridor Study / Planning
  - Detailed Asset inventory and management surveys
  - Environmental
  - Earthwork
  - Urban mapping and modeling Coastal zone erosion analysis

Figure 5.6a ** Typical TML Type "A" Local Control and Validation Point Layout*



*Adapted from CALTRANS Surveys Manual 2011

TML Guidelines - NSSDA

- National Standard for Spatial Data Accuracy (NSSDA)
  - The accuracy of finished MLS geospatial data shall conform to the NSSDA requirements: http://www.fgdc.gov/standards/projects/FGDC-standards-rojects/accuracy/part3/chapter
  - A minimum of 20 independent check points of greater accuracy than the MLS survey requirements shall be distributed to reflect the geographic area of interest and of the distribution of error in the data sets. The resulting comparisons shall meet the positional accuracy requirements for the survey at the 95% confidence level based on the NSSDA and shall be included in the Survey Report.
  - Where possible the Validation points may serve as check points to meet the requirements of this section. However if areas of the point cloud are to be used outside of the locations of the Validation points, then additional check points will be required in those areas to meet this requirement.

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TML Guidelines – Table 5.6b

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 mid sections of tunnels and urban canyons.
4) GNSS coverage of less than 5 satellites in view must not exceed the uncorrected position time or distance travelled capabilities of the TML system IMU.
5) Sufficient for TML survey data and products to meet or surpass accuracy requirement of the project.
6) Validation points may also 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, then additional check points will be needed in those areas to meet this requirement.

Table 5.6b - TML Survey Requirements

Operation/Specification	TML Survey		
	TML Type A	TML Type B	TML Type C
Bore sight calibration of TML system per manufacturers' specifications before and after project data collection.	Required		
Dual-frequency GNSS	Required; See Note 6		
Inertial Measurement Unit	Required; See Note 6		
Distance Measurement Instrument	Required; See Note 6		
GPS Azimuth Measurement Subsystem (GAMS)	Recommended; See Note 8		
GNSS positioning should be constrained to local project control.	Yes		
Minimum horizontal (H) and vertical (V) accuracy for GNSS control base stations.	Must meet or surpass TML local accuracy requirement of the project.		
Minimum accuracy of Local Transformation Points and Validation Points	See Note 5		
TML project positional accuracy requirements relative to Local Transformation Points and Validation Points	H < 0.06' V < 0.06'	H ≤ 0.10' V ≤ 0.10'	H and V See Note 5
Maximum post-processed baseline length	5 miles		10 miles
GNSS base stations located at each end of project	Recommended		

7) Validation points may also 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, then additional check points will be needed in those areas to meet this requirement.

8) A second onboard GNSS dual frequency receiver is recommended. This allows for establishing a GPS Azimuth Measurement Subsystem (GAMS). The GAMS solution is more robust than a single receiver system as it assists in vehicle heading determination

TML Guidelines – Table 5.6b *Continued*

Notes

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Operation/Specification	TML Survey		
	TML Type A	TML Type B	TML Type C
Minimum number of common healthy satellites in view for GNSS base stations and mobile scanner	See Notes 1 thru 5		
Maximum PDOP during TML data acquisition	5		
Allow sufficient time between runs to ensure that the satellite constellation has at least 3 different satellites in view	Each Overlapping Pass		
Minimum overlapping coverage between adjacent runs	20%		
Minimum orbit ephemeris for kinematic 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	4		
LiDAR point density requirements (see note 9)	FINE ($\geq$ 10 pts/ft^2)		See note 10
Local control point maximum station spacing throughout the project on each side of scanned roadway	1000 foot intervals	1500 foot intervals	See note 5
Validation point maximum station spacing throughout the project on each side of scanned roadway for QA purposes as safety conditions permit. (See Note 3)	500 foot intervals	800 foot intervals	N/A
Minimum NSSDA Horizontal and Vertical Check Points	20 points (see note 7)		

9) Point density should be verified through sample point spacing analysis using the formula:

$$Sample\ spacing = \sqrt{1/point\ density}$$

National Cooperative Highway Research Program (NCHRP) : Report 748. (2013). *Guidelines for the Use of Mobile LIDAR in Transportation Applications.* Washington D.C.: Transportation Research Board of the National Academy of Sciences.

10) Unlike TML Type A and B surveys which both reside in the NCHRP Data Collection Category (DCC) “1A”, TML Type C surveys may fall in any one of several DCCs (see APPENDIX – A). Therefore the scope of work and resulting TML Survey Report must specify which DCC accuracy is desired and achieved based on point cloud accuracy and density.

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Discussion

- Impact on current projects
- Future Revisions
- Questions / Suggestions
- Contact Information:

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