STANDARDS OF PRACTICE
MICHIGAN DEPARTMENT OF TRANSPORTATION
May 2014

DESIGN SURVEYS

This document sets forth general standards of practice governing ground surveys conducted by and for the Design Division of the Michigan Department of Transportation (MDOT). It outlines the level of effort to be used by MDOT and Consultant Surveyors in obtaining various types of information. These standards are to be used in the absence of project specific instructions in recognition of the fact that a consistent approach will provide dependable results. The following definitions and levels of effort are intended to be the basis of reference for a complete design survey. **Any deviation from these standards, not addressed in the Scope of Survey for a project, shall be completed only with the approval of the MDOT Survey Consultant Project Manager for the project or Region Survey Manager. Any decisions may be appealed in writing to the MDOT Supervising Land Surveyor**.

The Standards of Practice is to be used in conjunction with the MDOT Design Survey Manual, which explains details in depth. Revisions because of technology are covered in this document, which may be in conflict with the Manual. If a conflict exists between the two documents, the latest Standards of Practice will supersede. If a conflict exists between a specific scope and the Standards of Practice or the MDOT Design Survey Manual, contact an MDOT Survey Consultant Project Manager or Region Survey Manager for clarification.

The **purpose of these standards** is to assure consistent results from all surveys done for the preliminary engineering and design of MDOT facilities. The standards are designed to produce reliable results at the required level of accuracy using today's technology. Uniformity in methods, accuracy specifications, and deliverables specified in this document will ensure that all engineers and surveyors; both MDOT and consultant, researching the MDOT Survey file archives should expect the same results in approximately the same format regardless of whether the survey is performed by MDOT personnel or a consultant firm.

There are six general “categories” of surveys done for MDOT Design. The six categories are: Photogrammetric Control Survey (PPMS Task 3320), Road Design Survey (PPMS Task 3330), Structure Survey (PPMS Task 3340), Hydraulics Survey (PPMS Task 3350), Right of Way Survey (PPMS Task 4510), and Geodetic Control and Leveling (No PPMS Task number assigned). Deliverables for each category should not be packaged separately for transmittal, unless otherwise specified by the MDOT Survey Project Manager. Photo Control notes are NEVER submitted as part of a Road Design Survey.

GENERAL UNITS OF MEASURE

The following units of measure are to be used unless specified IN WRITING by the MDOT Survey Consultant Project Manager or Region Survey Manager.

Distance measure:	International feet
Angular measure:	degrees, minutes and seconds
Horizontal datum:	State plane GRID coordinates for North, Central or South Zone* NAD 83 (2011), Michigan Coordinate System
Vertical datum:	NAVD 88
Geoid Model:	Most current NGS Geoid Model available (presently Geoid 2012A)

* Prescribed by Act 9 of 1964, as amended.

STATE PLANE COORDINATES & DISTANCES

State Plane Coordinates (SPC) are GRID coordinates. According to NGS, "ground" coordinates are NOT SPC. **When reporting SPC to MDOT, the coordinates are given along with the combined scale factor at that point.** If a ground distance is needed between two or more points, an average combined scale factor needs to be calculated, as well as the grid distance between the two points. Scale factors are usually reported with at least 12 digits right of the decimal, and all digits should be used in the averaging computation. The following relationship is then applied:

Ground distance = Grid distance / Average combined scale factor

For example, at the largest separation between grid and ground, the effect in distance would be:
100.00 feet grid = 100.009312867 feet ground at 42 degrees 57 minutes latitude (South Zone).
Using this scenario, a horizontal distance would exceed a tolerance of 0.05 feet at 537 feet. This error will decrease as the latitude (movement North and South) approaches the standard parallels. In areas between the standard parallels and the edges of the zone, the error will increase. For more information on Lambert Conformal Projections, see Section 4.4 of the MDOT Survey Design Manual.

If ground coordinates are required, the Consultant Surveyor should contact the MDOT Survey Consultant Project Manager or Region Survey Manager specific reporting format and conversion process from State Plane Grid Coordinates.

For projects over 5 miles in length with a North-South orientation contact the Survey Project Manager to discuss scale factor issues.

REQUIRED SOFTWARE

Software required for output submittal to MDOT includes the latest versions accepted by MDOT of the following (check the MDOT ftp website whose address is on Page 4 for the latest list):

- Bentley PowerGEOPAK (MDOT Current Version)
- Adobe Acrobat Professional
- Microsoft Word
- Approved horizontal least squares adjustment software: LGO (Leica Geomatics Office), TGO (Trimble Geo Office), TBC (Trimble Business Center), Starnet (Plus/Pro), MicroSurvey's Starnet. Any other horizontal adjustment program will need **prior approval** for use on an MDOT project.
- Approved vertical least squares adjustment software: Levproc, Starlev (Starnet Pro), and MicroSurvey's Starnet are the only vertical adjustment programs that are acceptable at this time. Any other vertical adjustment program will have to be presented for evaluation by MDOT.

SAFETY

The surveyor must adhere to all applicable OSHA and MIOSHA safety standards, including the appropriate traffic signs for the activities and conditions of the project. MDOT safety expectations include:

- Surveyors shall discuss the project with the Region or local TSC Safety Engineer BEFORE the price proposal is submitted. Additional fees for traffic control will not be reimbursed once the project costs are accepted.
- Surveyors shall obtain the appropriate permits for working within the road Right of Way from the closest TSC.
- ALL field personnel shall wear job-specific protective equipment, including safety-toed boots, eye protection, hard hats, appropriate vests and other apparel as specified by OSHA and MIOSHA any time they are within the MDOT Right of Way performing any task.
- Each crew shall have at least one cell phone to contact emergency personnel if necessary. A map should be in each vehicle with the location of the nearest hospital(s) located. A copy of emergency procedures should accompany the map indicating at least three (3) people to contact at the Surveyor's office to report safety issues.
- The Surveyor should refer to the Related Documents & Websites Section of this document, specifically the links provided for Traffic & Safety, and The Michigan Manual for Uniform Traffic Control Devices (Part 6).

RIGHT OF ENTRY, USE OF SURVEY PAINT AND MARKINGS

Act 115 of 1976 gives Surveyors the right of entry. It does not give Surveyors the right to cut or trim trees for any reason. Permission from the owner to enter their property is an MDOT requirement as well as a courtesy. Sample door-hanger notification cards are available upon request. Destruction of property is forbidden.

The use of paint should be minimal, if used at all on an MDOT project. Paint dots cannot be used as benchmarks, and do not need to be used to label benchmarks in the field. The use of paint on trees is considered destructive.

The use of lath and stakes to mark control points is permitted during the collection of field data. Once field work is completed, it is the responsibility of the Surveyor to remove all lath and stakes used.

RELATED DOCUMENTS & WEBSITES

Documents	Websites
MDOT Design Survey Manual	http://mdotcf.state.mi.us/public/design/surveymanual/
National Geodetic Survey	http://www.ngs.noaa.gov
MDOT Plans Preparation Guidelines Road	http://mdotcf.state.mi.us/public/design/englishroadmanual/ The MDOT Drafting Customizations are found at: http://www.michigan.gov/mdot/0,4616,7-151-9625_21540_36037-259870--,00.html
MDOT Plans Preparation Guidelines Bridge	http://mdotcf.state.mi.us/public/design/englishbridgemanual/
Traffic & Safety	http://www.michigan.gov/mdot/0,1607,7-151-9623_26663_27281---,00.html
Michigan Manual for Uniform Traffic Control Devices (Part 6)	http://mdotcf.state.mi.us/public/tands/plans.cfm
MDOT FTP Website	ftp://ftpmdot.state.mi.us/ For "Username and Password" : Contact Greg Guikema at (517) 373-0060 or Carolyn Kieft at (517) 241-4634.
PPMS Task Information	http://www.michigan.gov/documents/MDOT_PPMS_Combined_Manual_120556_7.pdf
MDOT Right of Way information	http://mdotcf.state.mi.us/public/ROWFiles/
MDOT CORS	www.mdotcors.org
MDOT Survey Listserv	http://listserv.michigan.gov// MDOT Survey Support Unit will provide messages related to changes and updates in doing business with and providing project information to MDOT. The Survey specific email listserv will be used for this purpose. Go to the web site above, then to Subscribers Corner, and login. Select the MDOT-SURVEY list to join.

ELECTRONIC PORTFOLIO CONTENTS

The electronic portfolio shall include all deliverables in an Adobe Acrobat Master file**.** Three sets of electronic media are required to be sent to the MDOT Survey Consultant Project Manager or Region Survey Manager. Upon acceptance of the submittal the MDOT Survey Consultant Project Manager or Region Survey Manager will update the ProjectWise network and forward the electronic media as follows: one for the engineer, one for the Region Survey Manager and one for the Lansing Survey Support Unit for archival purposes.

The survey submittal shall be on the required electronic media necessary to contain all the project data. For guidelines on electronic media refer to Appendix F. The number of portfolios needed should be used to contain all the required papers and CDs. Each submittal shall be labeled individually on the outside as follows:

SURVEY NOTES FOR:

Structure Number B01
CONTROL SECTION 99999 JOB NUMBER 99999C
ROUTE M-99
LOCATION AND PROJECT LIMITS
DATE
BY Organization SURVEYOR John J. Doe
LICENSE # 12345
Electronic Media Copy ______ of _______

Sections in the electronic portfolio shall be labeled as to the type of data contained in that section. Every page in the PDF file shall be marked with Control Section, Job Number, Section and Page Number. Electronic media shall be labeled with the same information and clearly show the Date of the latest revision and placed in the Administration Folder.

There are six general types or sections of information obtained in each of the five categories above for a deliverable MDOT Design survey. When the survey is completed, the notes are to be assembled in a portfolio for hard copy record, if requested / required by the Project Manager and on electronic media to submit to the designer arranged in "sections" or folders. Organization shall follow the format of the MDOT QA/QC Checklist.

SURVEYOR'S REPORT

A Surveyor's Report shall be prepared for all projects and shall include the information listed in the "MDOT QA/QC CHECKLIST AND CERTIFICATION STATEMENT" and have the following statement at the end of said report.

I (NAME) being a Professional Surveyor in the State of Michigan do hereby certify that the Surveyor's Report accurately describes the survey performed; that the electronic PDF Reports, PowerGEOPAK files contained on the provided Electronic Media, dated (DATE) have been developed from survey data collected under my direct supervision; and that the survey deliverables submitted are in accordance with the project scope and the MDOT Design Survey Standards of Practice dated, __May 2014__(insert date). The PowerGEOPAK files correctly represent the existing conditions at the time the survey was completed.

I also certify that [list annotated names of all alignments for project] have been developed from [list all sources used, including survey data collected, previous plans, deeds, etc.] and that accuracy standards are in accordance with current MDOT Design Survey Standards. This/These alignment(s) correctly represent(s) the conditions at the time the survey was completed and represent an accurate and careful retracement.

PLACE PROFESSIONAL SEAL HERE

(Signature and Date)

____

(Name of Professional Surveyor and License Number)

RESEARCH

At least two NGS first or second order benchmarks, checking within tolerance, are required for Road Design and Structure Survey Categories. An adequate search for any NGS horizontal or vertical monuments must be made within 3 miles of the project site. MDOT Primary Control from other projects nearby can be used if it complies with the datum requirements outlined on page 2 of this document.

The Consultant Project Surveyor is responsible for conducting thorough and accurate research prior to beginning the field survey. The Consultant Project Surveyor must first determine exactly what is required for the specific project through the scope and consultation with the MDOT Survey Consultant Project Manager or Region Survey Manager. The Consultant Project Surveyor should review the scope with the MDOT Survey Consultant Project Manager or Region Survey Manager and clarify any uncertainties before the price proposal is submitted and work begins.

The MDOT Survey Support Unit (Greg Guikema at 517-373-0060) may assist surveyors in obtaining information on file in the department. Information available from MDOT includes:

- Previous MDOT survey notes and PLSS corner information
- MDOT Design and As-Built Road, Structure and Right of Way plans
- Older survey notes which are archived at the Record Center may take a week to retrieve.

Horizontal and vertical control monument data published by NGS is available online. Any NGS control used or searched for must be updated on the NGS website, using the "Submit Recovery" section on the NGS Datasheets Page.

Research needs to start early for all aspects of the project. Witnesses for government corners, plats, condominiums and certified surveys are generally available at the county courthouse. Utility information can be obtained by calling the region Utility Engineer for any information and discussing the project location with the county Drain Commissioner.

All research data shall be placed in the section of the notes to which the research applies.

Project Scenarios
Since one method does not fit all scenarios, three situations have been developed to describe field conditions. The project scope should identify which situation best fits the field conditions. If not, it is up to the Surveyor to specify which situation will be used through various sections of the project.

FREEWAY refers to an interstate or similar highway with gentle curves and limited canopy problems.

RURAL ARTERIAL refers to an M-type highway with high canopy cover and a road winding over hill and dale.

URBAN ARTERIAL refers to an M-type highway through a city, town or village.

CONTROL

This section describes the method and sequencing needed to provide control on MDOT projects.

LOCATION GUIDELINES FOR CONTROL

Project control monuments are recommended to:

- Be positioned relative to NGS control or the Michigan Spatial Reference Network (CORS).
- When required, Primary Control points should be set, prior to other control establishment, as an intervisible pair, preferably perpendicular, to the project route to improve project geometry.
- Intermediate Control should be positioned along the project path to provide check points for RTK rover work / total station work at regular intervals.
- Have a clear view of the horizon above 15 degrees if used for GPS observations.
- Be located on stable ground.
- Be readily accessible.
- Be located off the traveled portion of road but within the road Right of Way, or located on public property.
- Be set in anticipation of any future tree or shrub growth.
- Be set in order to avoid tall structures which could cause multipath.
- Be set to avoid radio towers, power transmission lines, and other sources of RF interference.
- Be set so they are intervisible for use with conventional survey methods.
- NOT be located in medians or ramp gores, when construction is imminent for those areas.
- Be located on back slopes 1-5 feet above the centerline elevation in cut sections.
- Be located 10-15 feet from the edge of pavement in fill sections.
- Be set at a location which ensures the safety of surveyors and others.
- Be set and witnessed as described below.

IMPLEMENTATION SEQUENCE

The following sequence is recommended for successful project flow:

1. Set all primary horizontal and vertical control.
2. Set all intermediate horizontal and vertical control.
3. All equipment used is tested and adjusted as necessary.
4. Perform leveling to all primary and intermediate control points and benchmarks.
5. Establish State Plane Coordinates on primary and intermediate control.
6. Adjust horizontal and vertical networks.
7. Acquire EDM distances for check observations.

1. SET ALL PRIMARY HORIZONTAL & VERTICAL CONTROL

The purpose of the Primary Control is to act as a basis of horizontal and vertical components to be perpetuated throughout the design and construction phases. Primary Control monuments will be used as base station locations if RTK methods are employed, and can be used for mapping purposes. When properly done, a Primary Control monument can last more than 30 years.

Primary Control consists of a metal disk oriented north, set in poured concrete as defined in Figure 7-3 of the MDOT Design Survey manual. The Primary Control monuments will be set in intervisible pairs at the spacing of 2640 to 5280 feet apart. Each pair will be located 3-5 miles apart along the length of the project. At least two Primary Control monuments will be set on each project unless Primary Control exists from a neighboring project. Once locations are determined, MISS DIG must be contacted for utility location prior to point construction. Once set, each Primary Control point must be witnessed and appear in the field notes and the Survey Info Sheet.

Scenarios for FREEWAY & RURAL ARTERIAL apply as written above. URBAN ARTERIAL will require one pair if the pair are intervisible. Two pair will be required if no intervisibility is achieved.

Witnesses are required for all horizontal project control to help find design control during construction phases, but not to reset the point. Witnesses will be measured to the nearest foot and the magnetic bearing recorded to the nearest five degrees. Witnesses shall be within 200 feet of the point referenced. A minimum of four witnesses will be required for each horizontal control point if no stationing is established for a project; otherwise, three witnesses and a station and offset will suffice. An acceptable witness will be a solid, permanent, physical object such as edge of asphalt, centerline, building corner, sign post, or a nail with tag or shiner in a tree or utility pole. Stakes and hubs are not acceptable witnesses. When no stationing is provided, the **point's location must be sufficiently described** to recover easily.

Witnesses are not required for primary vertical control. For components to be included within an adequate description refer to, "4. C. Vertical Control Deliverables."

2. SET ALL INTERMEDIATE HORIZONTAL & VERTICAL CONTROL

The location of Intermediate Control will supplement the Primary Control. The purpose of Intermediate Control is to provide a framework for design mapping, photo control and construction activities. These control points should hold horizontal location within 0.05 feet over a time span of 10-15 years. Intermediate Control points should not be established in locations where the Primary Control point will suffice for mapping or construction activities. Once established, Intermediate Control points need to be witnessed as described above.

Intermediate Project Control consists of semi-permanent marks set during the survey for a project. Intermediate Control also includes the points set for highway alignment. An Intermediate Control point is made up of a #5 rebar rod 36 inches in length with a survey cap stamped "TRAVERSE POINT" or similar phrase. Intermediate project control is covered in

Section 7 of the MDOT Design Survey Manual.

Benchmarks consist of chiseled squares in concrete abutments or headwalls or other immovable objects. Benchmarks may be set on top of anchor bolts. Chiseled marks of any kind in galvanized sign bolts are not acceptable due to the destructive nature and corrosion it subsequently causes. Use of fire hydrants and spikes in trees is discouraged. Spikes in sign posts and power poles are not acceptable.

FREEWAY will require an Intermediate Control point to be set every 650-1320 feet apart from each other and any Primary Control and must be intervisible. Benchmarks must be set every 300-1500 feet apart.

RURAL ARTERIAL will require an Intermediate Control point to be set every 350-900 feet apart from each other and any Primary Control and must be intervisible. Benchmarks must be set every 300-900 feet apart, preferably at high and low points of vertical curves.

URBAN ARTERIAL will require an Intermediate Control point to be set at least every 300 feet in grassy areas and must be intervisible. When possible, Intermediate Control should be set on existing property corners and noted as such. Benchmarks must be set every block, with no more than 600 feet apart.

3. TEST AND ADJUST ALL SURVEY EQUIPMENT

Equipment used to establish project control shall be tested and adjusted prior to beginning any project, and as needed throughout. A record of the testing shall be included in the notes. The notes must reflect the date, instrument type, serial number, method of testing used and results.

4. PERFORM LEVELING

Unless otherwise specified, leveling will be performed using a conventional method for all Scenarios.

A. Conventional Method

Following is a preferred method for conventional leveling:

1. Locate at least two NGS first or second order benchmarks, checking within tolerance, for Road Design and Structure Survey categories. Ideally, the NGS benchmarks should be situated with two on each side of the project.
2. All turns not occupying a benchmark must be made on turning turtles weighing at least 16 pounds each and/or turning pins. Turning pins are acceptable when they comply with Figure SP 1 below. If turtles are used or if equipment does not look like the figures provided, contact the Survey Consultant Project Manager with a photo of the proposed devices for approval.
3. All loops must be closed. For a closed loop to exist, it must start at a known elevation and end at a known elevation. The error of closure must not exceed 0.05 $\sqrt{\text{miles}}$, or 9.469 ppm.
4. Start on an NGS benchmark.

5. Loops must not exceed 5 miles in length. If no existing station exists within 2.5 miles, a temporary benchmark must be set and the loop be closed back to its original point.
6. This procedure is repeated until at least one primary monument is reached and looped to its beginning. The procedure is repeated until a second NGS benchmark is reached.
7. Pick up at the other end of the project and repeat the procedure outlined in 5 and 6 above.
8. If additional NGS benchmarks are found near the middle of the project, they should be tied in to primary monuments using the same procedure.
9. Pick up at a primary point with a known elevation and continue the process through the Intermediate Control and tie into all Primary Control with known elevations.

Please note: The allowable error calculation has changed from the Design Survey Manual. It now matches the allowable error of the FGCS Specifications noted in Table 7.2 of the Design Survey Manual when converted from metric to English units.

A loop should be completed the same day it is started.

Leveling error of closure will be distributed throughout the system by means of a least squares adjustment program acceptable to the Supervising Land Surveyor of MDOT Survey Support Unit. The adjustment is to be made **only** if the error of closure of the unadjusted observations is less than or equal to the above standards. Errors greater than required limits will require re-leveling the affected loops in the opposite direction or extending the loop to the original published bench mark. The leveling shall be adjusted between all published bench marks for which the accuracy criteria is met.

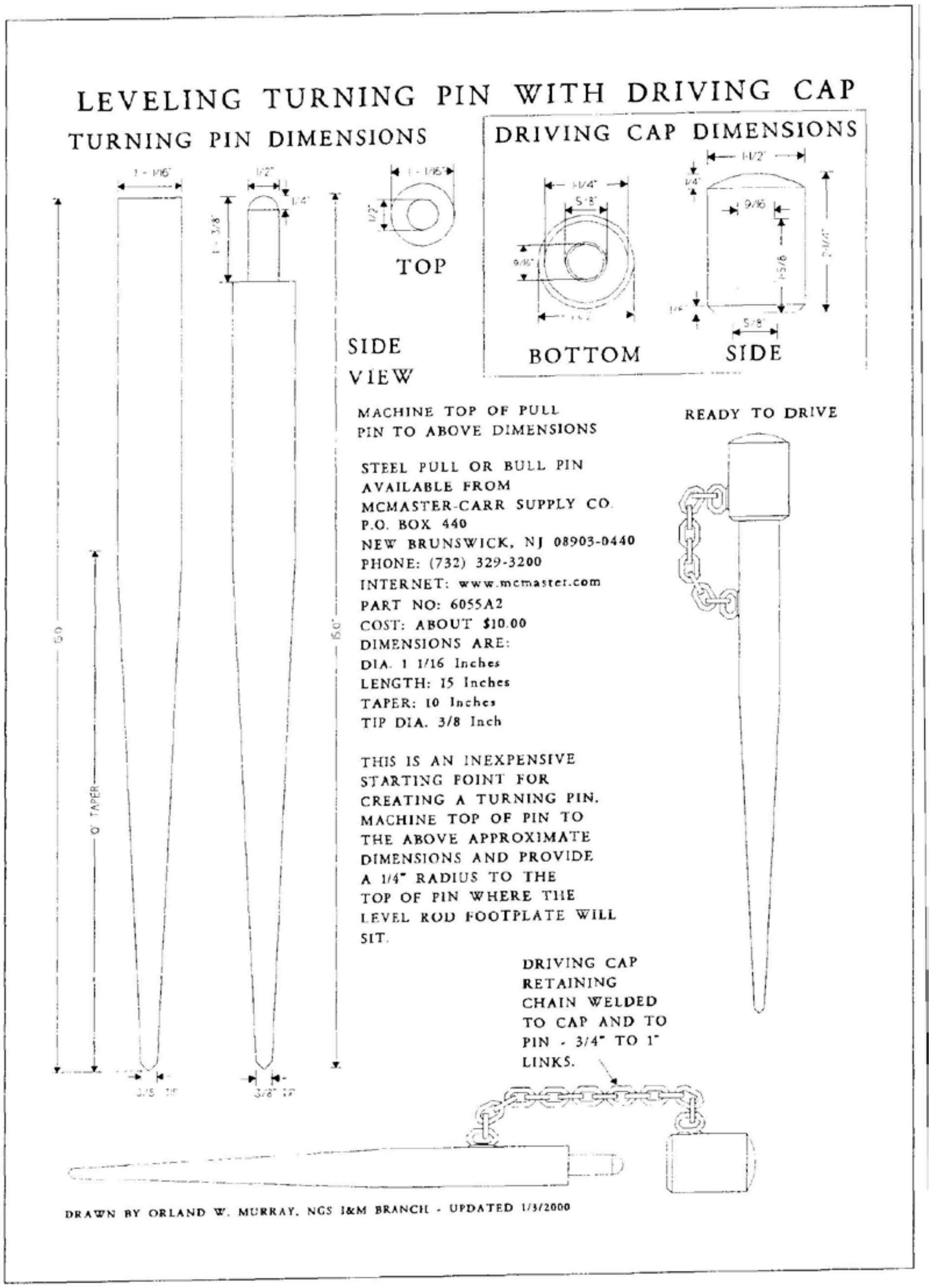

LEVELING TURNING PIN WITH DRIVING CAP
TURNING PIN DIMENSIONS
DRIVING CAP DIMENSIONS
TOP
SIDE
VIEW
BOTTOM
SIDE
MACHINE TOP OF PULL
PIN TO ABOVE DIMENSIONS
STEEL PULL OR BULL PIN
AVAILABLE FROM
MCMASTER-CARR SUPPLY CO.
P.O. BOX 440
NEW BRUNSWICK, NJ 08903-0440
PHONE: (732) 329-3200
INTERNET: www.mcmaster.com
PART NO: 6055A2
COST: ABOUT $10.00
DIMENSIONS ARE:
DIA. 1 1/16 Inches
LENGTH: 15 Inches
TAPER: 10 Inches
TIP DIA. 3/8 Inch
THIS IS AN INEXPENSIVE
STARTING POINT FOR
CREATING A TURNING PIN.
MACHINE TOP OF PIN TO
THE ABOVE APPROXIMATE
DIMENSIONS AND PROVIDE
A 1/4" RADIUS TO THE
TOP OF PIN WHERE THE
LEVEL ROD FOOTPLATE WILL
SIT.
READY TO DRIVE
DRIVING CAP
RETAINING
CHAIN WELDED
TO CAP AND TO
PIN - 3/4" TO 1"
LINKS.
DRAWN BY ORLAND W. MURRAY, NGS I&M BRANCH - UPDATED 1/3/2000

Figure SP 1

B. GPS Method for establishing Vertical Control

GPS can be used for vertical control establishment **with the approval of the Survey Consultant Project Manager or Region Survey Manager** when NGS benchmarks are not close to the project**.** The following method will be used:

1. Locate four second order or better NGS benchmarks which can also be observed using GPS that surround the project.
2. A four hour simultaneous observation must be made consisting of all four NGS benchmarks and at least two Primary Control monuments. This can be done at the same session for horizontal positioning.
3. RINEX files or OPUS extended output results for all stations must be forwarded to the Survey Consultant Project Manager or Region Survey Manager for their approval as soon as they are available with the following table:

Station Name	**ARP**	**Record Elevation**	**Measured Elevation**	**Delta**	**Adjusted Elevation**
NGS #1					
NGS #2					
NGS #3					
NGS #4					
Primary #1					
Primary #2					

4. Additional level runs can be conducted using the conventional method described above prior to approval of the primary elevations. **No more than two elevations can be determined using this method.** No mapping can start until primary approval is made by the Survey Consultant Project Manager or Region Survey Manager.

When the above procedures are followed, the resultant elevations will meet or exceed third order vertical control. Primary Vertical Control Networks and Standards of Accuracy are covered in Sections 7.2.2 and 7.2.3 of the MDOT Design Survey Manual.

Leveling error of closure will be distributed throughout the system by means of a least squares adjustment program acceptable to the Supervising Land Surveyor of MDOT Survey Support Unit. The adjustment is to be made **only** if the error of closure of the unadjusted observations is less than or equal to the above standards. Errors greater than required limits will require re-leveling the affected loops in the opposite direction or extending the loop to the original published bench mark. The leveling shall be adjusted between all GPS derived bench marks for which the accuracy criteria is met.

C. Vertical Control Deliverables

The surveyor shall develop a listing of bench marks which includes name of company, month and year of collection and datum in the header. A comment should appear on the list disclosing the source of elevations. Specific information for the benchmark includes designation, elevation, and description of what was found or set. Benchmark descriptions shall include the type of mark, any stamping on the mark, coordinates, and stationing and offset from an alignment. Location of benchmarks must be determined by measurement from primary or intermediate horizontal control points. Primary Vertical Control / NGS benchmarks not within project limits, but used to control the survey, shall appear in the list with a description and elevation. All benchmarks held fixed in the final adjustment should be designated as such in the benchmark list and Survey Info Sheet. GPS-derived NAVD88 elevations should be noted as such, on the Survey Information Sheet, when used as the elevation source.

5. ESTABLISH STATE PLANE COORDINATES ON CONTROL

The Project Surveyor shall insure that each horizontal position determined by the survey is correctly located in the project's coordinate system. Measurements may be made by ground traverse with conventional surveying instruments suitable for the purpose, or with GPS equipment. The control network should be measured and adjusted before computations are made for other purposes and prior to mapping.

Primary Horizontal Control requires two (2) static observations of no less than two hours and no more than 4 hours as a minimum, with the observation time depending on the distance to the CORS sites. The following is a guideline for calculating the observation time:

Distance from farthest CORS (in miles)	Horizontal only
Under 25	2 hours
25 – 43	3 hours
44 and over	4 hours

Each Primary Control pair should be observed simultaneously. An NGS horizontal monument being considered for use as a Primary Control point must also be tied into the primary network with a static observation.

Processing of vectors, relating the Primary Control to the NSRS, may be done using OPUS. Elevations obtained from the leveling procedure must be used and held fixed on all Primary Control monuments. An OPUS solution that meets the criteria outlined in Appendix B of this document is acceptable to be used for the adjustment of Intermediate Horizontal control. If blunders exist or any point does not meet the specification, re-observe the data.

Intermediate Horizontal Control will be positioned typically with GPS (Reference 7.7.4 of the Survey Manual), using either of two approaches to network configuration, radial or non-radial.

A radial network consists of observations that are tied to base stations without multiple interconnections; each new point is connected directly to at least two controlling stations (NGS and/or MDOT Primary).

A non-radial network consists of multiple interconnected closed figures, with each station tied directly or indirectly to at least two controlling stations. (If classical traversing is used instead of GPS to determine positioning of Intermediate Control, refer to Section 7.7.3 of the MDOT Survey Design Manual for guidance.)

For either of these approaches to network configuration, GPS observation type will be static or rapid-static, with a minimum 30-minute simultaneous observation time between receivers. If using the radial approach, RTK is also acceptable, per MDOT RTK Guidelines (see Appendix A).

NGS and/or MDOT Primary Control stations will be the basis for all Intermediate Horizontal Control. No new station in the network shall be outside of a closed loop; only an NGS or MDOT Primary Control station may have a single line connected to it (in that case the adjusted single line must be the result of at least two occupations).
In any case the controlling stations must essentially surround and enclose the new Intermediate Control network.

Definition of "GPS occupation" as it applies to this document:

An "occupation" results in at least one GPS baseline vector that is included in the network adjustment. An observation that is rejected from the adjustment for any reason cannot be considered to be derived from a valid occupation.

Network configuration approaches:

All controlling NGS and/or MDOT Primary Control stations, and all new Intermediate Control stations, will be independently observed at least twice; a minimum of 20% will be independently occupied at least three times (Replaces item 3 of Section 7.7.4 of the Survey Manual). For occupations of any given NGS and/or MDOT Primary Control station, a repeat occupation can only occur after a minimum of 4 hours has elapsed from the prior occupation, using a different instrument setup. The final network shall ensure that all points have at least two vectors from independent sessions connecting them to the rest of the network.

Radial network:
Subsequent point occupations cannot occur until a minimum of 4 hours has elapsed from the prior occupation of any one point in the network.

Non-radial (interconnected) network:
A subsequent occupation of any given point may occur at any time, but the subsequent occupation cannot occur without changing the receiver setup. This includes using a distinctly different height of instrument when using conventional tripods, manually recorded, to verify that the independent setup took place. Use of fixed height tripods is encouraged, therefore, the setup

verification / change comes down to reaffirming that the level bubble is still within tolerance at the beginning and end of the session.

All observed vectors may be processed but only NON-TRIVIAL vectors shall be used in the adjustment. The “trivial vector” in a GPS observation session can be any one vector which would close a simultaneously occupied loop; the number of independent vectors is **n-1**, where **n** equals the number of receivers being used in the simultaneous observation session.

To understand the concept of independent and trivial vectors, it is important to keep in mind the fact that baseline vectors are not true observations; they are 3D inverse solutions, derived from calculated 3D positions. The actual observation is between the GPS constellation and the receiver, therefore simultaneous occupations result in baseline vectors derived from identical (more or less) observation conditions, most of which are beyond the control of the surveyor. Reference section 7.2.1 of the Survey Manual.

Positional tolerance:

The 0.07 foot positional tolerance (95% confidence level) specified in the MDOT Design Survey Manual for Intermediate Horizontal Control may be difficult to achieve under some circumstances (near buildings, tree cover, etc.); it may be necessary to augment the GPS network with 3D conventional total station observations to achieve that level of accuracy. If that approach is taken, the least squares adjustment must simultaneously adjust both types of 3D observations, at which point great care must be taken to properly integrate appropriate weighting of conventional observations into the solution.

6. ADJUSTMENT OF DATA

It is impossible for anyone to collect perfect data. The following allowable error should be taken into account for any adjustment:

Centering error cannot exceed 0.02 feet
Baseline measurement error cannot exceed 1:20,000, or 50 ppm

Three types of adjustment reports are required.

The first adjustment will process all Primary Control, holding the OPUS results for two points the farthest away from each other. No CORS site data is required in this adjustment, but the OPUS results and the CORS RINEX files must be submitted. Results of the remaining Primary Control will be compared to the OPUS results.

The second adjustment will process the Intermediate Control in a minimally constrained adjustment. This adjustment will hold one Primary Control point fixed, and will process the baselines to the primary and intermediate points.

Elevation of the Intermediate Control should be compared to the elevation obtained through the leveling procedures before constraining to the leveled values. Analysis of comparative EDM observations should also occur prior to the final adjustment.

The third and final adjustment is a fully constrained adjustment of the Intermediate Control holding fixed the position of as many Primary Control monuments as needed. The maximum standard deviation of a single coordinate must not exceed 0.10 feet. Any differences over 0.05 feet must be addressed in the Surveyors Report. The leveled elevation must be the reported elevation. If the results are unsatisfactory, re-observe the data.

7. EDM CHECK OBSERVATIONS

Distances between Primary Control points must be observed by EDM for each pair. These observations must be reported in a concise format showing the GPS grid distance, combined scale factor, EDM ground distance and the adjusted EDM grid distance. A recommended table is as follows:

Point Designation	Average Combined Scale Factor (ACSF)	Measured GPS Grid Distance (GPS)	Calc. Ground Distance = GPS / ACSF	Measured EDM Ground Distance	Δ Distance
33304 to 33305	0.99987655	600.77	600.84	600.89	0.05
33304 to 33306	0.99987655	772.94	773.04	772.99	0.05

Error resolution must be described in the Surveyor's Report.

TEMPORARY CONTROL

Temporary control can be used on MDOT projects within the following guidelines. Temporary control is only valid for no more than 5 calendar days without verification and can only be used for its original intent.

Temporary benchmarks can be a keel square on a concrete step or a paint spot on the RIM of a catch basin or manhole. They must be defined in field notes as temporary in nature. They are to be used in large bench loops when the distance is great. Hubs are NOT acceptable as temporary benchmarks or turn points.

Temporary control points can be an 18 inch #4 rod or 5 inch 60d nail in the ground, or a MAG-NAIL in asphalt. These points can be set for various reasons, including additional topo in areas where RTK cannot observe locations accurately. Temporary control points can be set using classical traversing or RTK methods and may be removed after use. If temporary control is to be used after 5 calendar days, it will need to be re-observed for its location. Hubs and tacks are acceptable for temporary horizontal control with a limit of one day.

SUMMARY OF STANDARD PARAMETERS FOR CONTROL TASKS

Precision of scale factors:	12 digits to the right of decimal
Witness measurements:	nearest foot, nearest 5 degrees
Primary Control monument material:	concrete w/metal cap (see Figure 7-3 in Survey Manual)
Intermediate Control monument material:	#5 rebar -36" long w/cap "TRAV POINT"
Temporary control material:	#4 rebar; 5" 60d nail; Mag Nail
Temporary benchmarks:	see discussion above
Primary Control pair spacing:	3 to 5 miles
Primary Control intervisible pair spacing:	2640 to 5280 feet
Intermediate Control spacing:	650 to 1320 feet (Freeway) 350 to 900 feet (Rural Arterial) 300 feet and intervisible (Urban Arterial)
Primary GPS observation time from CORS:	See table above
Primary Control - max S.E. (2σ):	0.05' (each coordinate)
Intermediate Control max S.E. (2σ):	0.07' –average; 0.10' max (each coordinate)
Setup max centering error:	0.02'
Setup max H.I. error:	0.01'
Baseline max measurement error:	50ppm
Benchmark material:	on concrete structures (see Survey Manual)
Benchmark spacing:	300 to 1500 feet (Interstate) 300 to 900 feet (Rural Arterial) Less than 600 feet (every block) (Urban Arterial)
Benchmark Loop –max loop closures:	0.05'$\sqrt{\text{Miles}}$ (9.469ppm)

ALIGNMENT

The Michigan Department of Transportation defines a road alignment as a series of tangents and geometric curves incremented in 100 foot stations that defines the location and direction of the roadway or proposed roadway improvement.

Most Michigan roadways were first laid out and created 75 to 100 years ago or more. Generally, since that time, several road improvement projects may have been conducted on these roads using various methods of establishing the route location and acquiring property. Because of this, it is important to determine which alignment was used to acquire the original Rights-of-Way. It is also important to identify and re-establish alignments used on the subsequent construction projects conducted since that time as they may impact the current project. In some cases, multiple alignments along the same route over differing time periods have been used to purchase property. It is, therefore, important to carefully research and substantiate the previous alignments and supporting documents used to describe and acquire property for improvement projects conducted over a particular route. Field evidence in addition to record documents is key to this verification process and further assists in redefining the design and/or physical location of the roadway.

In practice, the terms ‘alignment’ and ‘centerline’ are frequently used interchangeably; though when standing alone these terms are generic in nature and are not synonymous. When preceded by a descriptive term such as “Survey’ or ‘Legal’, however, it is generally assumed that the term ‘centerline’ is a reference to an alignment. In the past, and up to the present, these terms have often been used synonymously. As illustrated by the definitions below, this should not be the case. Legal alignments, as implied by their name, are intended to define the legally correct location of Rights-of-Way, parcels, easements, etc. that are either explicitly or implicitly tied to them by statute, description or instrument of conveyance. In this way legal alignments are very similar in standing to Government Section Lines since they control the location of the property described from them.

Typically, there are three different types of data described as ‘Horizontal Alignments’ that are used for MDOT design, any of which may or may not be considered a legal alignment. These three types of alignments are: Survey, As-constructed, and Construction. Any or all of these three may have been used as a legal alignment in the past. When re-establishing legal alignments, it is the surveyor’s responsibility to gather and evaluate all the evidence necessary to determine the original location of the pertinent alignments for the specific project area. Alignments must be discussed fully in the Surveyor’s Report. All alignments shall be referenced to the coordinate system of the project. The following definitions briefly describe the three alignment types:

Survey Alignment:

Historically, a survey alignment was primarily used as a baseline for locating topographic features, cross-sections, etc., along a proposed route. This was an alignment provided to or created by survey crews to lay out a preliminary location and collect data relative to that route. The design of roads and bridges was developed from the topography tied to these alignments. Frequently the construction alignment developed by the design engineer would vary from the survey alignment. It is important to understand that determining which of these two alignments the legal alignment is will depend upon which alignment was used to describe the Right of Way parcels. Frequently the construction alignment has become the legal alignment, as it has been the general policy of MDOT Real Estate Division to describe parcel conveyances from the construction alignment. If the Survey Alignment is provided as a historical reference, it may be re-traced from data recorded on historic (or original) plans, ROW sheets, previous surveys or other sources. Unless explicitly defined otherwise, the survey alignment should NOT be considered a legal alignment and new parcel takes should NOT be described from a survey alignment.

As-Constructed Alignment:

This is frequently referred to as a “best fit” alignment, which represents the current physical road location. These alignments are typically computed using survey points collected along the actual roadway centerline (crack, crown, paint stripe, curb split, etc.). The points are used to compute best fit tangents and curves using data processing algorithms designed for such purposes, hence the reference to ”best fit”. The curves and tangents are usually compared to record alignment data from old plans and adjusted to create an alignment that best approximates both the intended construction alignment *and* the actual location where the road was placed during construction (as-constructed). Stationing is usually matched to existing plans. An as-constructed alignment is primarily used to give the designer a sense of where the actual roadway lies and to provide a baseline for survey and design. The physical center of the existing road is considered evidence but does not necessarily define the legal alignment, unless specifically called for in a conveyance. The rationale used to determine this alignment, as well as it's standing (legal, non-legal) should be clearly explained in the alignment section of the surveyor's report.

The term "as-constructed" may also refer to a **historic** alignment location that is not related to the **current** physical centerline of a roadway. When retracing alignments that are referenced on older conveyances (with terms such as: "as now surveyed," "as now established," "as now surveyed and constructed" etc.), a present day retracement involves the determination of the old road location ***at the time of conveyance*** (e.g. "1932 as-constructed alignment") which often varies considerably from the present day physical centerline of the roadway. This often involves extensive consideration of historical evidence pertaining to the conveyance itself. This evidence may be in the form of field measurement, purchase agreements, marked final Right of Way plans, survey notes, etc.

Construction Alignment:

An alignment (horizontal and vertical) developed for the purpose of constructing a roadway. The construction alignment is proposed by an engineer. As the design of the project is based upon the construction alignment, any additional ROW needed for the project was frequently described from this line.

Legal vs. Non-legal

A **legal alignment** defines actual location of the Right of Way based on either a survey alignment, as-constructed alignment, and/or a construction alignment as referenced in property descriptions, conveyances, i.e. legal documents. It is considered a property controlling entity similar in standing to government section lines. Often, the description of this line is used as part of these descriptions. A survey to re-establish the location of the legal alignment is absolutely necessary when the purchase of additional ROW is required. Re-establishing a legal alignment is considered a boundary determination since the existing Right of Way is defined by, and described from, the **legal** alignment. As described above, there may be several "legal" alignments on any particular project from which different parcels have been purchased over time. Considerable research and survey work may be required. Retracement of a legal alignment restores and perpetuates the original location of the Right of Way for a particular portion of a route, from a particular time period, and a specific property acquisition. Right of Way plans, conveyance, previous construction plans, existing monumentation including Public Land Survey System (PLSS) corners (see Property Section), and other recorded and physical evidence is used to determine the proper location of the legal alignment. It should be understood that the legal alignment and the physical location of the roadway may vary considerably. When performing legal alignment surveys, the relationship of the legal alignment and the physical centerline should be clearly defined. Generally if property is purchased, the Department's past policy has been to describe the conveyance from the construction alignment, potentially creating yet another "legal" alignment. In order to minimize the creation of multiple legal alignments and thereby the confusion and added cost of future surveys, future ROW acquisitions should be based on ***previously established*** **legal alignments whenever possible.** It is left to the judgment of the Real Estate personnel to determine when it will be necessary to utilize the construction alignment for ROW acquisition descriptions. It is strongly recommended that the assistance of the project Professional Surveyor be employed for this determination.

An alignment that is designated as '**non legal**' is used primarily to locate features for the purpose of design. It can be considered a line that provides direction and stationing for locating features, determining quantities, and staking out the project. A non-legal alignment is not intended to relate to the location of the Right-of Way and is not used for property acquisition.

MDOT Alignment Standard

Alignments will be designated in CAD only as ***legal*** *or* ***non-legal*** by the surveyor/engineer. Differentiation and perpetuation of existing alignments will be done through annotation. Design alignment deliverables will be designated on CAD levels *RdWay_Ali_Legal_Line_GS* or *RdWay_Ali_NonLegal_Line_GS* in MicroStation for the plan alignment sheets.

It is of primary importance that MDOT alignments are properly perpetuated. Relevant alignments from jobs in the project area shall be researched, retraced and appropriately tied to one another and the project control. These ties shall be shown on the alignment plan sheet(s) and referenced in the surveyor's alignment reports. Multiple alignments may be required to properly describe all situations within the project area. All alignments shall be annotated with the description and year of any previously established alignment which is being retraced, as well as the year of the current survey retracement. Any new alignment which is established and is completely independent from other alignments shall be annotated with the current year it is established. Annotation shall be consistent with the guidance document released as an attachment to MDOT Design Advisory 2012-5 titled "Adaptation of Proposed Alignment / ROW Concepts." This document is on page 19 at the following link: http://www.michigan.gov/documents/mdot/MDOT_Design_Plan_and_Process_Changes_102512_402398_7.pdf

When a legal property survey is required for the purpose of describing Right of Way, the final alignment data shall be certified by a Professional Surveyor, within the survey report certification language, as follows:

"I hereby certify that [list annotated names of all alignments for project] have been developed from [list all sources used, including survey data collected, previous plans, deeds, etc.] and that accuracy standards are in accordance with current MDOT Design Survey Standards. This/These alignment(s) correctly represent(s) the existing conditions at the time the survey was completed."

It is of the utmost importance that the Surveyor discusses the alignment requirements with the Survey Consultant Project Manager or Region Survey Manager to determine the type or extent of alignment data required for a given project. This discussion should take place prior to the submission of a price proposal. If there is any question with regard to what may be needed for alignment, the Lansing Survey Office or Region Survey Manager should be contacted.

The surveyor shall make sure that new alignment angles and distances reflect the accuracy with which the underlying control was established. Generally, this means bearings should be rounded to the nearest second and distances defined to the nearest 0.01 feet.

If establishment of alignment monumentation is outlined in the scope, at least two alignment control points shall be found or set and witnessed on the points of curvature and tangency. The points on tangents shall be intervisible and not be more than 3000 feet apart. When structures hinder the line of site, an alignment point must be set on line at least 200 feet from the Structure on both sides. An 18 inch #5 or larger rebar may be set in the hard surface road protected by a monument box with cover. Offsets, ideally on the Right of Way, may be used with authorization obtained from the MDOT Survey Consultant Project Manager / Region Surveyor before their physical location is staked in the field.

The alignment point must be double tied from a minimum of two primary or Intermediate Control points. The standard deviation between the two locations of these alignment points should not exceed 0.10 feet. Since a legal alignment point is considered a property controlling corner, a Land Corner Recordation Certificate must be filed showing its relationship to the nearest section line by bearing and distance. The job number and control section information should be included on the PA74 form if available.

PROPERTY

The property section contains Government Corner and Property information. This information is used to identify ownership of parcels affected by the project and to prepare legal descriptions for deeds, easements and agreements. Included are recorded Land Corner Recordation Certificates (LCRC's), plats, tax mapping and tax parcel descriptions, recorded and unrecorded surveys by local surveyors, and all measurements and calculations relating property monuments found or set during the survey and tied to the coordinate system of the project.

All existing property corners and monuments from plats and other previous surveys within the project area shall be tied into the survey coordinate system by measurements and their positions computed on the project control system. Significant differences between the project measurements and record data shall be resolved and explained by the surveyor in the project report.

GOVERNMENT CORNERS

The Public Land Survey System (PLSS) is the basis for most land ownership in Michigan. Most MDOT Right of Way is described from PLSS corners or property controlling corners. **For**

purposes of this document, **PLSS corners shall also include** the center of section, meander corners and any corners of private claims which are considered as property controlling corners.

All PLSS corners within the Right of Way shall be recovered or re-established and tied to the coordinate system of the project. If PLSS corners outside the Right of Way are required or used, such corners will also be tied to the coordinate system of the project and valid LCRCs shall be included in the portfolio. Standards for surveying intermediate project control will be applied. The Professional Surveyor in charge shall prove the location of existing monuments. Any lost or obliterated corners shall be re-established when required for purchase of Right of Way.

All PLSS positions shall be processed in accordance with PA 74 of 1970 and all applicable administrative rules. The following MDOT criteria also apply:

1. All PLSS corners located in hard surface roads are to be protected by a monument box, **regardless of proposed road construction.**
2. All PLSS corners used in the survey for any purpose must be recorded with the Register of Deeds on the approved form, unless a recent LCRC is on file which accurately documents the corner **and at least three valid witnesses remain**.
3. The recordation form shall detail the history of the corner and list all evidence used to prove its location.
4. A copy of each **recorded** LCRC with liber and page clearly stamped on the document shall be submitted within the .pdf portfolio.
5. If any PLSS corner exists in MDOT Right of Way, the corner must be brought to the attention of the MDOT Survey Consultant Project Manager or Region Surveyor for a determination of participation with the County's Remonumentation Plan under Act 345 of 1990, as amended.
6. If Remonumentation is included in the scope, the consultant surveyor, MDOT Survey Consultant Project Manager or Region Survey Manager and a County Remonumentation Committee Representative must be contacted before a price proposal is submitted and a time scheduled for their review. **All fees for Remonumentation efforts are part of the contract with MDOT. The Remonumentation Committee is not responsible for any costs for this service by the Surveyor.** Full payment will be withheld until the PLSS corners are recorded and copies are received and filed in the portfolio.

If mapping is required for the project, all government corners and property information shall be included in the topographic file. The PLSS corners should be connected by lines. The map must show the bearing and distance in the units defined above between adjacent PLSS corners and the distance along the section or quarter section line from the corners to the alignment. A section corner monument and monument box must be observed and noted independently to account for MDOT's Pay Item structure.

MAPPING

The mapping process involves gathering data about the shape of the land and the location of features on, above and below the surface. From this data, a planimetric map, contour map and a digital terrain model are prepared which show the site conditions at the time of the survey. All surface topography (planimetric data), elevations, surface utility locations, and drainage, both surface and underground will be located with feature IDs as outlined in Section 12.3 of the MDOT Design Survey Manual. The electronic files developed for this section serve as a base for designers for much of their work.

PLANIMETRICS

Planimetric features are usually required for a road improvement to be designed. All features that might affect the design shall be shown on a complete planimetric map prepared from field survey measurements. All maps must utilize the current version of the MDOT Design Division Workspace which includes the correct levels, cells, linestyles, etc. **No additional (Non-MDOT) Feature Codes or symbols are to be used**. Points and lines are to be displayed according to MDOT specification in Plans Preparation Guidelines. The map must be in digital form. PowerGEOPAK drawings shall use the appropriate MDOT seed file. The digital file will also contain control, alignment and type, and property data. The map shall present the data in a clear and legible manner. Street names as they appear in the field should be labeled for all cross roads. Multiple road names should also appear. Overlapping text, incorrectly drawn curves, crossing lines, etc., should be corrected prior to submission.

TERRAIN ELEVATIONS

Elevation data will be obtained as needed for project design, quantity computations and drainage studies. As a general rule, there should not be more than 100 feet between random shots to obtain elevations. Elevations of ground surfaces (dirt) should be recorded to the nearest 0.01 feet. The accumulated standard error for ground elevations should be no greater than 0.10 feet. All hard surfaced roads, curbs and sidewalks and water surface elevations shall be recorded to the nearest 0.01 feet. The relative error between adjacent elevations shall have an accumulated standard error of no more than 0.05 feet for hard surface shots. If the total station method is used, instrument heights and target heights must be measured to the nearest 0.01 feet and recorded. Sights must be taken to targets on prisms. Distances for shots taken to determine hard surface elevations must not exceed 650 feet. No distances for any topographic data collection shall exceed 1300 feet.

When doing mapping field work, all horizontal and vertical control shall be checked into as random shots with the designation recorded. The difference between mapping check coordinates and previously adjusted coordinates shall not exceed 0.05 feet in x, y or z.

When requested, the surveyor shall produce a digital terrain model (DTM) of the project site. Break lines and high/low points shall be used to make the model an accurate representation of the shape of the ground. In many cases cross sections at a set interval will not yield an accurate representation of the terrain. Careful attention should be given to observation of the terrain as it breaks in the field. Building interiors shall be excluded from the DTM. The surveyor shall examine the model for accuracy and completeness. A contour map of the site will be produced from this model. The project surveyor shall certify the accuracy of the contour map. The map should show the alignment and horizontal control as a reference.

When terrain elevations are obtained to supplement photogrammetric or LiDAR mapping, both the ground survey and the photo / LiDAR mapping must use the same horizontal and vertical control. A digital terrain model and contour map must be produced as described above but limited to hard surface observations and obscured areas. Any DTM assembled to supplement photo / LiDAR mapping under this section will be identified with file naming consistent with the requirements set forth in the mapping section of the QA/QC checklist.

MAPPING with RTK GPS and SCANNERS

Mapping can be done using RTK and laser scanning methods as outlined in Appendices A, C and D of this document. Employment of these methods (RTK, Mobile and Static Scanning) should be thoroughly discussed with the MDOT Survey Consultant Project Manager for the project or Region Survey Manager. All surveys by and for the Department must meet accuracy standards and follow approved methods as described in this document.

UTILITIES

Public safety and good design practice requires that the design engineer know the location of utilities in the project area. A listing of companies with utilities in the area should be furnished to the consultant from the MDOT Utility Engineer or obtained via the MISS DIG Design Ticket Program. The consultant should validate the accuracy of the contact list and update if necessary.

The surveyor must locate and identify all visible utilities. Before starting the survey, the project surveyor shall determine whether the designer requires all utilities to be located or just those visible above the ground. All utilities shall be related to the coordinate system of the project and shown on the topographic map.

The surveyor shall provide, if requested, a list of utilities with installations located in the project area, noting address, phone number and contact person for each utility.

If underground sanitary (gravity flow) or storm sewer information is necessary, the point number, station & offset, composition, size, and invert elevation of each pipe at each manhole must be provided in a Utility Inventory Spreadsheet and connectivity must be plotted in PowerGEOPAK. It may be necessary to prepare separate plots to show connectivity. Plots of underground utilities may be combined if not too cluttered.

DRAINAGE

When required, surface and underground drainage information is assembled by the project surveyor. The surveyor shall contact the local officials to obtain plans of any drains crossing the project and to inquire about any known drainage problems within the project area. The surveyor shall report any observed drainage problems and provide photographs of the problem areas. Any information freely offered by the residents relating to potential drainage issues should also be reported.

The composition, size and invert elevation of each pipe at each drainage structure is required for design of improvements in critical areas. The construction material and condition of each structure and connecting pipe shall be fully described. Connections to drainage structures may be determined as outlined in the scope. Culvert descriptions shall include material type, size, and end section treatment, invert and flowline elevation, if different. Notes and photographs detailing the general condition, including deterioration, pipe alignment and infiltration shall also be included. The above information should appear in a spreadsheet format.
The location of all drainage structures at the center of cover and center of the bottom of structure as well as connectivity of drainage pipes are to be plotted in PowerGEOPAK. Outlet structures must be noted with the invert elevation and a photograph must be imported into PowerGEOPAK (*Note: CAD Import applies to SS3 deliverables*). It may be necessary to prepare separate plots to show underground storm drain systems. Plans and maps obtained from local officials are to be included with the notes. Reports from these officials regarding drainage problems and the surveyor's observations will be documented in a separate drainage report.

Confined space entry is restricted to personnel with proper training and equipment when necessary. Payment for confined space entry will not be made unless specified in the price proposal.

SUMMARY OF STANDARD PARAMETERS FOR MAPPING TASKS

Planimetric point – soft ground measurements recorded at:	nearest 0.01’
Planimetric point –soft ground accumulated S.E. (2σ):	0.10’
Planimetric point – hard surface measurements recorded at:	nearest 0.01’
Planimetric point – hard surface accumulated S.E. (2σ):	0.05’
Instrument/target H.I. measured to:	nearest 0.01’
Instrument/target centering error:	0.02’
Distance to shots on hard surfaces- maximum:	650’
Distance to all other shots-maximum :	1300’
Max difference (X,Y,Z) between original and check shots:	0.05’

MISCELLANEOUS

Any information that is not control, alignment, property or mapping is contained in this section. Photographs, local newspaper articles and project related correspondence are examples of miscellaneous data.

The surveyor shall describe data included in the miscellaneous section in the Surveyor's Report.

QUALITY ASSURANCE/QUALITY CONTROL

Each survey submitted to MDOT must be accompanied by the following certification statement contained in a letter format on the Consultant letterhead and signed by the lead QA/QC person in responsible charge on this contract. If the submittal does not contain the following statement, the project is subject to a reduction in the QA/QC costs for the submittal at the MDOT Project Manager's discretion.

I _________________________ certify as lead QA/QC person in charge on this contract authorization that I have thoroughly reviewed the project and corrections have been identified and completed.

______________________________ ______________________________

Name of Professional Surveyor *Date*
Project QA/QC Officer
Michigan PS # ____________

APPENDIX A
MDOT Real Time Kinematic (RTK) GPS Standards

Purpose:

This appendix provides technical specifications, guidelines, and quality control criteria for performing RTK type surveys. Static and Rapid Static techniques utilize different types of specifications which are described in the Design Survey Manual.

Since NGS Geoid models are calculated without using a NGS data station in some areas of the state, the relationship of the Geoid to true orthometric heights as defined by the NGS benchmarks in a particular project area may be unknown. The suitability of the Geoid for RTK vertical accuracy on any project must be determined by the Consultant or the Department before using RTK for elevations.

RTK GPS consists of a data transfer link and at least one GPS unit set over a known (Base/Reference/MDOT CORS) station which remains stationary, while the rover(s) unit(s) are moved from point to point. In an RTK survey, shots are taken "radially" from a fixed base station to a rover unit. A delta X, delta Y and delta Z are produced from the base station which is then transferred to the rover unit. Occupation time at the rover station ranges from generally a few seconds to a few minutes.

Uses of RTK positioning and site requirements:

RTK is not the tool for everything.

Following is a list of applications for which RTK would be a reasonable choice:

- Temporary traverse points for engineering and construction surveys for mapping in obstructed areas using conventional methods.
- Portions of photogrammetric control targets surveys. (Can be used for horizontal control and a portion of vertical control. Mainline of the photo control project will still need to be leveled.)
- Collection of topographic and planimetric data.
- Construction surveys / staking. (Except for major structures.)
- Right of Way surveys (NOT for primary project control)
- Section breakdown and government corner locations.
- GIS type surveys. (Structure inventories etc...)
- Environmental type surveys. (Wetland boundary location and delineation etc.)

Numerous factors affect the performance of GPS. Care and diligence needs to be observed when selecting a project for use with RTK GPS positioning techniques. Listed are some of the factors that affect the quality of the final coordinates generated by RTK GPS.

- Visibility of the horizon. (Obstructions above 15 degrees.)
- Multipath radio frequency interference from reflective surfaces
- Instrument setup error. (Height reading blunders, improper leveling etc...)
- Improper mission planning. (Poor satellite geometry.)
- Inadequate observation times.
- Improper initialization of receivers. (Wrong ambiguity resolution.)
- Type of terrain could affect the communication links.
- Radio frequency interference. (Can be checked by using a scanner of the same freq.)
- Instrument calibration. (Bubbles adjusted on rods and tripods.)
- Improper field survey procedures.
- **With proper planning**, some obstructions near a GPS station may be acceptable.
- Satellite Geometry affects both horizontal and vertical coordinates in GPS/RTK type surveys. For RTK type surveys, the following factors are to be considered (See appended table):
    - Number of common satellites at the base and rover unit.
    - Satellite elevation mask
    - PDOP (Positional Dilution of Precision)
    - GDOP (Geometric Dilution of Precision)
    - VDOP (Vertical Dilution of Precision)

Equipment Requirements:

- Geodetic grade receiver capable of logging observables concurrently while broadcasting / receiving.
- Must be capable of containing the following:
    - A map projection. (Lambert Conformal)
    - Ellipsoidal model. (GRS80 or WGS84)
    - Geoid model. (Must be Geoid 12A or later.)
    - Must be capable of performing a 3D Helmert transformation.
- Dual frequency GPS receivers L1/L2 capable of OTF (On The Fly) initialization. These receivers can tolerate loss of lock since they are capable of solving integer ambiguities instantly. All equipment must be properly maintained and regularly checked for accuracy.
- Level vials, optical plummets, and collimators shall be calibrated at the beginning and end of each project.
- If the survey duration exceeds a week, the calibrations shall be conducted on a weekly basis.

Antenna Height Measurements:

Blunders in the measurement of antenna heights are the most common source error in GPS surveys. All GPS surveys are performed in 3D even if the final result is a 2D position. The height measurements determine the height from the survey monument to the antenna electrical phase center. Keep in mind that the GPS manufactures software generally allows for a direct height measurement to be entered. If mixing receiver and processing software, reduce all the antenna heights to the Antenna Reference Plane (A.R.P.) also known as Mechanical reference plane (M.R.P.) The A.R.P. is generally the lowest mechanical surface on the antenna itself. A.R.P. diagrams for your particular antenna can be obtained from the National Geodetic Survey website.

Field Procedure:

Proper field procedure produces a successful RTK survey. Problems will occur if proper field procedures are not employed during the course of an RTK survey. MDOT realizes error resolution is a professional judgment call. Procedures for resolving errors must be discussed in the work plan. If a conflict between the accepted procedure and its application exists, contact the MDOT Survey Consultant Project Manager for the project or Region Survey Manager.

- A base station should occupy a Primary Control monument with known coordinates. A direct link to a CORS site or base station location over an Intermediate Control point is acceptable with permission of the MDOT Survey Consultant Project Manager for the project or Region Survey Manager.
- Transformation sets are only allowed when trying to match surveys which do not have Michigan State Plane Coordinates. Rotations should be specified in the Surveyors Report completely with Δx, Δy, rotation angle and scale.
- A check shot shall be observed on Intermediate Control by the rover unit(s) immediately after the base station is set up and before the base station is taken down.
- A minimum of 5 satellites must be observed at the base and the rover(s).
- PDOP must be below 5.0.
- The second occupation of a new station shall have a maximum difference in coordinates from the first occupation of 0.05ft.
- Two independent vectors shall be used to verify the check shots. Vectors can be generated from CORS within 9 miles or on-site base stations.
- At least 5 percent or 5 shots, whichever is greater, shall be taken on hard surface so the points that can be re-visited and re-observed as check shots the same day. Check shots shall be spaced uniformly throughout the area, not grouped together, and re-observed from the second base.
    - Check shots to the re-visited hard surface points must agree to within 0.05ft.
    - The re-visited points must be named such that they have a unique name but can be correlated to the initial point. For instance, LL30456 becomes CHK30456.
    - A minimum of 30 minutes between the original shot and the check shot is required.
    - A table must be created on a daily basis comparing the original shot with the check shot. Figure SP 3 shows an example.
- At the end of the day, the RINEX file from the base station should be submitted to OPUS.

Table SP 2 illustrates the number of check shots generally needed for a given distance.

Table SP 2
Check shots per distance

	0.5 miles	**1 mile**	**2 miles**
2 lane roadway with 5 observations per section			
50' cross sections – shots/checks	264/13	528/26	1056/53
100' cross sections – shots/checks	132/7	264/13	528/26
200' cross sections – shots/checks	66/5	132/7	264/13

Figure SP 3
RTK Check Comparison Sheet

Point #	**Initial Observation**			**Point #**	**Check**			**Delta**		
	X	Y	Z		X	Y	Z	dX	dY	dZ

RTK GPS Survey Specifications Guidelines					
PROCEDURE	**Intended Application**				
	Project Control (except primary)	**Photo Control**	**Govt. & Property Corners**	**Topographic Mapping**	**Construction Stakeout (except major structures)**
Minimum number of Primary Control project control stations*. *Primary project control established using static or rapid static GPS procedures.	2	2	2	2	2
Number of quadrants: location of Primary Control points.	2	2	2	2	2

RTK GPS Survey Specifications Guidelines					
PROCEDURE	**Intended Application**				
	Project Control (except primary)	**Photo Control**	**Govt. & Property Corners**	**Topographic Mapping**	**Construction Stakeout (except major structures)**
Geometry of RTK control stations established.	Surround and Enclose the project.	Surround and Enclose the project.	Surround and Enclose the project.	Surround and Enclose the project.	Surround and Enclose the project.
Minimum number of RTK control stations established or used for intended application. (Can substitute a Primary Control station.)	4	4	4	3	3
Minimum number of RTK vertical control stations established or used for vertical RTK surveys. (Can use the same monuments used for the RTK control stations.)	4	4	N/A	3	3
Location of known control points, number of quadrants relative to center of project.	4	4	4	3	3
Fixed height tripod at base	Recommended	Recommended	Recommended	Recommended	Recommended
Fixed height rod at Rover.	YES	YES	YES	YES	YES
Required use of Bipod with fixed height rod at rover.	YES	YES	YES	NO	NO
Minimum number of measurements per occupation	4	4	4	2 (Depends on feature being collected.)	2

RTK GPS Survey Specifications Guidelines					
PROCEDURE	**Intended Application**				
	Project Control (except primary)	**Photo Control**	**Govt. & Property Corners**	**Topographic Mapping**	**Construction Stakeout (except major structures)**
Percent of stations occupied 2 or more times. (Can use a different base station for second occupation)	100%	100%	100%	0%	100%
2nd Rover occupation must be done from a second base station.	YES	YES	YES	NO	NO
Minimum time before repeat station observations from a different base station location.	20 min.	20 min.	20 min.	N/A	N/A.
Maximum PDOP during station occupation.	5	5	5	6	6
Minimum observation time at rover. (epochs)	60	30	30	6	6
Minimum number of SV's observed simultaneously (Base and Rover)	5	5	5	5	5
Sampling Interval (Seconds)	1	1	1	1	1
A satellite visibility chart with PDOP displayed. The chart shall be created with an ephemeris that is no more than a week from the date(s) of the observation(s).	YES	YES	YES	YES	YES

RTK GPS Survey Specifications Guidelines					
PROCEDURE	**Intended Application**				
	Project Control (except primary)	**Photo Control**	**Govt. & Property Corners**	**Topographic Mapping**	**Construction Stakeout (except major structures)**
Vertical precision of the data for each observation. (ft.) (Reading at the rover.)	< 0.04'	< 0.04'	< 0.04'	< 0.04'	< 0.04'
Minimum elevation mask. (degrees)	15	15	15	15	15
Minimum distance between adjacent stations (monuments.)	1300'	900'	N/A	N/A	N/A
Maximum distance between known to unknown stations, known to check stations, and between adjacent stations.	3 mi	3 mi	3 mi	3 mi	3 mi
Antenna height measurements in feet and meters at the beginning and end of each session.	YES	YES	YES	YES	YES
All raw data observables stored at base and rover.	YES	YES	YES	YES	YES
Obstructions shall be limited to the following:					
No Obstructions projecting more than 45 degrees above the horizon. Obstruction projecting between 15 degrees and 30 degree in no more than 1 quadrant.	YES	YES	YES	YES	YES

RTK GPS Survey Specifications Guidelines					
PROCEDURE	**Intended Application**				
	Project Control (except primary)	**Photo Control**	**Govt. & Property Corners**	**Topographic Mapping**	**Construction Stakeout (except major structures)**
Obstructions less than 15 degrees in at least 2 quadrants post process base location as a check relative to Michigan Spatial Reference Network (MSRN) by using OPUS, or through post processing techniques. (If using State plane coordinates.)	YES	YES	YES	YES	YES
Equipment Checks / Calibrations	WEEKLY	WEEKLY	WEEKLY	WEEKLY	WEEKLY
Surveyors report listing methodology, equipment, procedures, point differences, statistical analysis & certification by a Professional Surveyor provided.	YES	YES	YES	YES	YES

APPENDIX B

OPUS Specifications for performing MDOT Control Work

OPUS can be used for establishing the horizontal datum within the project area at a minimum of two locations. The intent is to have OPUS positions at strategic locations throughout the project to be held fixed in the processing and adjustment of the project control network.

1. Observation Procedures.
    a. Antenna Height measurement at the beginning and end of the observation session.
    b. Amount of time will be dependent on the density of MSRN stations in the vicinity of the project. Observation times even in the ideal configuration of stations shall not be less than 2 hours.
2. Deliverables
    a. An observation Log sheet showing the following:
        i. Manufacturer Make and Model of the Antenna and GPS receiver used.
        ii. The corresponding NGS antenna definition for the Antenna used.
        iii. Direct antenna height readings taken and the location where taken.
        iv. A reduction of the direct antenna height reading to the ARP (Antenna Reference Plane)
    b. OPUS extended output:
        i. Output shall have peak to peak Errors of less than 2 cm (0.06 feet)
        ii. IGS Rapid or precise orbits must be used. The use of Ultra Rapid Orbit is not acceptable.
        iii. Overall RMS of Observation must be under 2 cm (0.06 feet)
        iv. 95% or greater of the ambiguities must be fixed.
        v. 90% or greater of the observations shall be used.
        vi. All reference stations used as control must be MSRN Stations. If not possible, contact the MDOT Survey Consultant Project Manager for the project or Region Survey Manager.
        vii. State plane coordinates for the point must all be displayed.
3. The raw data file from the GPS receiver in its native format and the RINEX converted file must be submitted.
4. The RINEX files for the MSRN stations used by OPUS must also be provided, these files are available from www.mdotcors.org
5. All of the files must be submitted in electronic format; in addition a hard copy of the OPUS output and the observation sheet must be submitted.
6. Solutions are not to be used for Ellipsoidal heights unless 3 independent observations of 5.5 hour sessions are employed.
7. For groups of control points spaced less than 1500 feet apart, the following procedures shall be followed:
    a. All of the points may be submitted to OPUS.
    b. The baselines between the groups of points shall be calculated using conventional post processing techniques, using the OPUS derived values as a check
8. All other positioning and monumentation requirements as specified by the MDOT survey manual remain in effect.
9. An independent manual conversion of the metric SPC to international feet must be made and compared to the OPUS computation.

APPENDIX C

Static Terrestrial Laser Scanning (STLS) Standards and Guidelines

As laser scanning evolves over time, these standards will be modified to reflect the adoption of advancements and more efficient procedures. The following was developed with no brand of scanner in mind. Until the industry settles on standard format, MDOT has a generic formatted deliverable. The following guidelines should be followed in order to obtain satisfactory results for MDOT standards. It is the Project Surveyor's / Consultant's responsibility to discuss targeting, merging, registration, geo-referencing, QA/QC checks, and importation into PowerGEOPAK of the scans with the MDOT Survey Consultant Project Manager for the project or Region Survey Manager before work begins.

It is important for the project surveyor to keep in mind that the ultimate goal is to use the scan data to produce an accurate survey DTM that is representative of actual field conditions. Scan data shall be exported into a format that may be used to prepare the DTM surface and Planimetric Data. Scan data and 3D models will be considered as supplements to, and ***NOT*** replacements for the required MDOT PowerGEOPAK deliverables.

All surveys for control and geo-referencing to support and establish STLS surveys by and for MDOT must meet accuracy standards and follow approved methods as described in the "Control" section of this document. Following these standards helps ensure the product deliverables meet MDOT requirements.

It is not MDOT's intention to limit a company's internal practices or the innovation of a company. Input from scanning consultants may be considered for a project, at MDOT's discretion, to deviate from these guidelines. If appropriate, and at MDOT's discretion, changes and new methods tested on projects with a good result may be placed in the next update of the standards. All deviations from these standards are required to be explained in the scanning report at the time of submission of the scan data for review.

1. SCANNING PROJECT FOLDER REQUIREMENT INFORMATION:

a. When scanning is used for data collection, all scanning data must have a separate folder and not a section in the main job portfolio.

b. A scanning report will be placed in the Scan folder with any notes, or deviations from the standards. The surveyor's report in the job portfolio must still state that scanning was used, but does not need to be elaborate. A Scanning Report shall include at minimum:

   i. The equipment Model, Type, Serial Number, Software, and Version.

   ii. A discussion about data tolerance issues and errors in creation of DTM, from the registration of the scans and geo-referencing from measured QA/QC checks.

   iii. Any information pertaining to scanning that will eliminate possible questions.

c. Provide a hand sketched or CAD generated network diagram showing the location and label of each control target, Scanner setup, and related metadata (target heights, target type, etc.).

d. A Scanning Control Point list will be created for Control points used for the scanning project not considered or included in Primary/Intermediate Control list. This file must be an ASCII (P, N, E, and Elev) and associated residuals (ΔN, ΔE, ΔElev) for each control point must be provided.

e. A copy of the registration residuals between control points of adjacent scan setups must be included in the report.
f. Comparison Spreadsheet showing resulting data coordinates from the scan, check observation coordinates and the coordinate differences. The high and low tolerances shall be shown.
g. Provide an NSSDA type report showing the 95 % results of a comparison of a minimum of 20 validation or check points to the final processed/registered point cloud.
h. Provide an NSSDA type report showing the 95% results of a comparison of a minimum of 20 validation or check points to the final GEOPAK DTM surface to be provided for design.
i. Documentation of any changes from standards approved by Survey Consultant Project Manager or other approved MDOT employee
j. A copy of each original scan must be provided on CDs, DVDs or USB high-speed peripheral devices. Each item will be labeled with the Job Number and scan data label.
k. Copies of the database in native format as well as an XYZ format (ASCII text file) shall be provided.

2. SCANNING DATA REQUIREMENTS:

a. Individual points should have a final scan density spacing not exceed 0.1 ft. on structures and not exceed 0.3 ft. on road surfaces.
b. The Geo-referenced point cloud proprietary database must be provided as part of the deliverables and in addition, an electronic ASCII comma delimited file X, Y, Z format, and intensity. If Geo-referenced database has the ability to view independent original data, separate copies of scans may be omitted.
c. The scanner shall not exceed a maximum of 500 feet between setup positions (Scanner dependent and provided Item 2.a is met.)
d. Scan setups must overlap by a minimum of 20%.
e. At each scan location and for each scan, hang or place next to each target, a white board with annotation providing the MDOT Job Number, Pt. Name of the target, Date, Scan Name or Number, HI of the target, and any other pertinent information about the point. This data shall be present when the scan and the scanner pictures are collected to assist in processing the project.
f. Environmental conditions (rain) and material being scanned affects the scan quality. Wet pavement conditions and low reflective materials (new bituminous) must be avoided, or will require the maximum distances measured from the scanner to be shortened to meet the minimum density requirement.
g. Any proprietary "Homemade" targets will be required to have a sample to be submitted for acceptance for use. It will also have full documentation (size, shape, materials list, etc...) and have full photographs showing construction and use in field.
h. Any targets approved as "Proprietary" must be left on site until approved for removal by the Survey Consultant Project Manager or other approved MDOT employee.
i. All areas scanned must have an associated high quality digital photograph overlaid on

the scans. Note: digital photographs need to be taken in some instances multiple times to eliminate excess obstructions of the area. (i.e. traffic and vehicles).

j. It is recommended that fixed height tripods with standard targets be used for scanning.

3. SCANNING CONTROL AND QA/QC:

a. All control points shall be traversed via conventional means. The control points on the extremities of the project may be positioned using GPS to tie the scan to state plane coordinates, following MDOT accepted methods.

b. Elevations to control points must be leveled to NAVD 88.

c. Scan control must be numbered differently than Primary and Secondary control to show geo-referencing points in QA/QC.

d. A minimum of 4 (four) control points for geo-referencing shall be visible and in common between adjacent scans.

   i. Instruments with traverse function can be used, but the equipment location does not count as a control point. You will need a backsight, foresight, and a minimum of two sideshots.

   ii. All the positions of the control points list shall be provided to physical marks on the ground and not the scan target center.

   iii. The targets shall be located such that targets do not form a linear pattern. It is intended that the targets be properly spaced within the scan world to control the tilt and elevations of the scan and provide the necessary geometric strength.

   iv. Monumented primary, intermediate or mapping points must coincide with every tripod/target holder location.

   v. At each scan location and for each scan, hang or place next to each target, a white board with annotation providing the MDOT Job Number, Pt. Name of the target, Date, Scan Name or Number, HI of the target, and any other pertinent information about the point. This data shall be present when the scan and the scanner pictures are collected to assist in processing the project.

e. Exceptions:

   i. Any additional ground targets in excess of the minimum (4), used to aid in geometry of registration of scans, must have coordinates published in the scanning control point list.

   ii. Magnetic targets can be placed on bridge structures where 4 or more ground targets exist. Coordinates for these items are optional.

   iii. Temporary marks (i.e. paint, lumber crayons [keil], or permanent markers) of any kind are not approved in road line applications

   iv. Additional Tie points for registration are always recommended.

f. <u>Control points used for scan targets must be monumented in the field with:</u>

   i. Using Main Project Intermediate Control (#5x 36" rebar)

   ii. 18" long #4 rebar rod with a plastic cap (Preferred & Minimum two per scan)

   iii. Magnetic Survey Nails (Use in limited access areas)

      1. Minimum length in Asphalt is 1½"

      2. Minimum length in Concrete is ¾"

g. <u>Uses of Intermediate Control in scans on road types:</u>

i. FREEWAY will require a minimum of 1 (one) Intermediate Control point to be used in every 3rd (Third) scan along the corridor. Exceptions can be made for area with steep inclines to max of 4 (four) scans with Survey Consultant Project Manager or other approved MDOT employee.
ii. RURAL ARTERIAL will require a minimum of 1 (one) Intermediate Control point to be used in every other scan along the corridor. Exceptions can be made for area with steep inclines to max of 3 (Three) scans with Survey Consultant Project Manager or other approved MDOT employee approval.
iii. URBAN ARTERIAL AND SINGLE BRIDGE AREAS will require a minimum of 1 (one) Intermediate Control point to be used in every scan. No exceptions can be made for areas with steep inclines

h. At minimum of four hard surface check observations need to exist per scan with overlap. Check shots via total station must be provided to verify the point cloud. The observations do not need to be on a given line, and can reside on a PAVED shoulder or any hard surface that exist in the DTM.
i. The check observations need to reside in a separate segments labeled in the description as "Scanning QA/QC."
j. All check points are to be coded as "CHK" and be verified they are not part of the DTM surface. Validation elevations should be within 0.05 feet of the calculated DTM.

APPENDIX D

INTERIM Mobile Terrestrial LiDAR (MTL) Standards and Guidelines

The intent of this document is to provide guidelines and standards related to the use of Mobile Terrestrial LiDAR (MTL) on design engineering projects for the Michigan Department of Transportation. These standards and guidelines are also intended to provide the methodology and procedures that will help ensure products produced with MTL will meet MDOT's needs for design engineering for transportation corridors.

The standards and guidelines in this Appendix D are to be considered an initial guidance document that will be updated and modified as the MTL technology matures. The intent of Appendix D is to provide specifications and guidance relative to MDOT projects and outline the expected deliverables to be provided to MDOT for each MTL project.

The following references are good sources of information regarding the application of MTL. It is recommended these sources be referred to in preparing MDOT MTL projects. Where conflicts occur between these reference sources and MDOT documents, this Appendix D (MTL Standards and Guidelines) and the MDOT scope take priority and the MDOT Survey Support Unit and MDOT Survey Project Manager should be contacted for clarification.

References

This document was prepared based on experience from MTL projects done to date at MDOT and from adaptions of information from the following sources:

Where possible Appendix D is intended to coincide with the 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.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_748.pdf

CALTRANS Surveys Manual 2011
(*http://www.dot.ca.gov/hq/row/landsurveys/SurveysManual/Manual_TOC.html*)

The Florida DOT document entitled Terrestrial Mobile LiDAR Surveying & Mapping Guidelines, August 23, 2012 (*http://www.dot.state.fl.us/surveyingandmapping/Manuals/20120823_TML_Guidelines.pdf*)

Advanced Highway Maintenance and Construction Technology Research Center report entitled "Using Mobile Laser Scanning to Produce Digital Terrain Models of Pavement Surfaces" prepared by the University of California at Davis Department of Mechanical and Aerospace Engineering for the California DOT, November 30, 2010. (*http://ahmct.ucdavis.edu/pdf/UCD-ARR-10-11-30-01.pdf*)

MDOT MTL Project Information

Mobile Terrestrial LiDAR (MTL) (mobile mapping or mobile laser scanning) methods will be considered for use to complete portions of MDOT projects provided a savings in schedule, time and costs, improved safety and reduced traffic control and costs, among other benefits can be shown while providing the required data accuracy to meet or exceed conventional surveying methods. The length/size of the project, GPS/GNSS collection environment, traffic volumes and available observation times are also considerations that affect the decision to use Mobile Terrestrial LiDAR.

Mobile Terrestrial LiDAR (MTL) generally consists of one or more LiDAR scanning units or sensors combined with multiple Global Navigation Satellite System (GNSS) receivers, an Inertial Measurement Unit (IMU), Distance Measuring Instrument (DMI) and multiple digital image or video cameras mounted on a moving terrestrial platform that collects highly accurate measurements and geospatial data.

LiDAR sensors use a moving projected light signal to measure the relative x, y, z, position and reflective properties of a point on an object. This results in a group of 3 dimensional points called a point cloud that can be colorized with information from the intensities or photo images to provide a product that is similar to other remote sensing products. To provide the point cloud in accurate real world coordinates that can be compared to previous surveyed positions, highly accurate ground surveys (that are tied to a known datum) are required. The geospatial data obtained with the collection of a point cloud can be extracted for a multitude of uses beyond the collection of topographic features required for typical corridor surveys. However, the point cloud data must be accompanied by a survey report describing the origin and accuracy of the data, for it to be used with confidence and to ensure the survey information, with any byproducts, are not misused.

The accuracy of individual points within point cloud data decreases as the distance from the LiDAR sensor increases. LiDAR sensor manufacturers provide specifications of precision for a given range. The overall range of the MTL system equipment will be dependent upon the acceptable accuracy required for the project, the precision of the LiDAR sensor, errors in GNSS measurement, errors in IMU measurements, errors in DMI measurement, errors in establishing horizontal and vertical control for the project and other similar error sources. Terrain, foliage, and other obstructions or partial obstructions may affect the point density/spacing and therefore the quality/accuracy of the resulting points in a portion of the point cloud. Care should be taken to ensure that the final point cloud(s) does not include any points with compromised accuracy caused by these conditions. Points collected beyond the limits of accuracy acceptable for the project shall be filtered out and separated from the valid project data by classifying them as **erroneous or invalid** after processing.

Point density or spacing of collected data depends upon the measurement rate of the sensor and the speed of the sensor platform during measurement. The required point density for a project should be sufficiently close to be able to identify and extract physical detail to the accuracy specified for the project.

Refer to Table 1 on page 11 of the NCHRP Report 748(2013), *Guidelines for the Use of Mobile LIDAR in Transportation Applications* for general accuracy and point spacing requirements. The majority of MDOT Design Survey projects will likely fall in the 1A category requiring **High** accuracy and **Fine** point density.

MTL Control and Geo-Referencing

In order to increase the accuracy of the collected MTL geospatial data, a local transformation of the point clouds shall be conducted on MDOT projects, unless otherwise specified IN WRITING by the MDOT Survey Consultant Project Manager or Region Survey Manager. There are many different types of local transformations that may be employed, however, the most common is a least squares adjustment of the horizontal and vertical residuals between established Local Transformation (adjustment) Points and the corresponding values from the point clouds to produce the transformation parameters of translation, rotation, and scale for the horizontal values and an inclined plane for the vertical values. These parameters are then applied to the point cloud to produce more accurate final geospatial data within the localized area of control.

Targets occupying known horizontal and vertical control incorporated in MTL surveys shall serve as known local transformation points for point cloud adjustment and validation points for QA/QC.

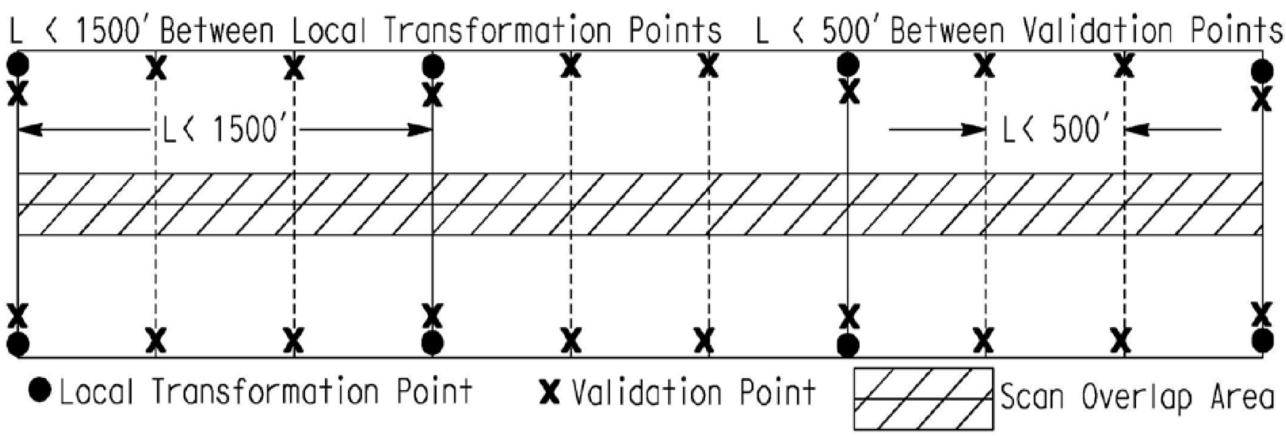
Targets must be of sufficient size and reflectivity to ensure redundancy of scan points sufficient for target identification and correct measurement within the point cloud.

The Local Transformation Points shall be located at the beginning, end, and evenly spaced throughout the project to ensure that the project MTLS collection area is bracketed. The maximum distance with respect to route centerline stationing spacing between these points shall be based on the type of survey. See diagram below.

Validation Points are used to check the geospatial data adjustment to the Local Transformation Points. Validation Points shall be located at the beginning, end, and evenly spaced throughout the project. The maximum distance with respect to route centerline stationing spacing between these points shall be based on the type of survey. See diagram below.

Variations to the spacing and layout scheme for Local Transformation Points and Validation Points are permitted to accommodate challenges or opportunities on projects, however any variation must be discussed and approved, in writing, by the Survey Consultant Project Manager or Region Survey Manager.

Typical MTL Control and Validation Point Layout (CALTRANS Surveys Manual 2011)



Mobile Terrestrial LiDAR Equipment

MTL equipment and systems must be capable of providing data and results that meet MDOT engineering grade design requirements. **More specific information in this section will be forthcoming.**

Table 1 Mobile Terrestrial LiDAR Specifications

Mobile Terrestrial LiDAR Operation/Requirement	Mobile Terrestrial LiDAR Application
MTL system equipment capable of collecting data at the intended accuracy and precision for the project.	Required
Bore site calibration of MTL system when composed of multiple separate sub-units assembled on project site. Bore site per manufacturer's specifications before and after project data collection.	Required
Bore site calibration of MTL system when system is constructed as an integral package system with fixed orientation of component parts and a factory or company Bore Site prior to system use and no components have been changed.	Optional but Suggested
Dual-frequency GNSS recording data at 1 Hz or faster	Required
Inertial measurement unit (IMU)	Required
Distance Measuring Instrument (DMI)	Suggested

Specific Application of MTL on MDOT Projects

Any use of MTL technologies shall conform to and utilize the information in this document and the following documents in the preparation of MDOT projects and deliverables:

- **2014 MDOT Standards of Practice for Design Surveys**
- **NCHRP REPORT 748 "Guidelines for the Use of Mobile LIDAR in Transportation Applications", April 2013**
- **Caltrans Survey Manual Chapter 15 Terrestrial Laser Scanning Specifications**

When Mobile Mapping is approved to be used on an MDOT project, the following shall apply:

A Mobile Mapping trajectory plan and a ground control target layout plan (including the locations of any CORS GPS Stations and/or any local GPS base stations and how they are/were established) shall be submitted with the work plan and priced proposal and prior to start of work for review by Lansing Design Survey Support and the MDOT Survey Project Manager.

- LiDAR acquisition shall be done when pavement is dry.
- LiDAR acquisition should be obtained at traffic speeds to avoid impeding traffic but also ensuring adequate spacing from surrounding traffic so LiDAR collection is not obscured by traffic.
- Multiple passes may be needed to eliminate as much obscured areas as possible.
- LiDAR acquisition settings and operating speed shall be done in a manner to maintain accurate data and consistent data spacing throughout the project. Data extracted from LiDAR shall be delivered with a consistent spacing used by all operators. No significant spacing differences should be detectable in the extracted mapping throughout the project.
- LiDAR acquisition shall include collecting images along the trajectory routes to colorize the point cloud. Images will also be required for supplemental viewing by designers. These images shall be rotated to an upright view, if needed, indexed, geo-referenced and delivered with associated trajectory and with the LiDAR data.
- The trajectories, as driven, shall be processed/refined, and, combined with the LiDAR data that has been acquired, shall be registered to the ground control targets. A portion of the ground

control targets (typically about 1/3 to 2/3 of the total targets) shall be withheld from the registration process and used as independent points solely for validation of the point cloud and derived project data.

Interim Early Deliverables

Upon completion of the raw LiDAR processing and registration and **prior to mapping** extraction, copies of the following shall be provided to Lansing Design Surveys and the Survey Project Manager for review:

- Project report describing in detail how the mobile mapping project was done, number and general location of passes to acquire data, equipment used, datum surveyed on, and results of the processing.
- The trajectory plan and a ground control target layout plan (including the locations of any CORS GPS Stations and/or any local GPS base stations) use to complete the LiDAR data acquisition. Provide a copy of manufacturer's trajectory plot, a set of TopoDOT TopoMission project files and set of .kml/.kmz files.
- Reports and printouts from the processing software showing the results of the registration process.
- Target to cloud registration – Statistics and comparison of the point cloud to the targets
- Cloud to cloud registration – Statistics and comparison of adjoining overlapping point clouds.
- Separation of forward and reverse solution (difference between forward and reverse post-process roll, pitch, yaw and XYZ positions solution).
- Areas of the project that the data collected exceeded the maximum elapsed time or distance traveled of uncorrected IMU drift due to GNSS signal loss or obstruction.
- Comparison of elevation data from overlapping (side lap) runs
- Comparison of points at the area of overlap (end lap) if more than one GNSS base is used.
- Primary control list and least squares adjustment reports (i.e. LGO, Starnet, etc.) for the control.
- Intermediate control list and least squares adjustment reports (i.e. LGO, Starnet, etc.) for the control.
- Point listing of the Targets used for the Mobile mapping and the least squares adjustment reports (i.e. LGO, Starnet, etc.) for these points.
- Point listing of the Validation points used for the Mobile mapping and the least squares adjustment reports (i.e. LGO, Starnet, etc.) for these points.
- Project Accuracy reports of IMU data.
- Project Accuracy reports of GNSS data as well as PDOP and SV visibility.
- Project Trajectory reports showing forward/reverse comparison and amount of difference between runs, final results of combined forward/reverse adjusted trajectory and report of accuracies to the project control.
- Comparison spreadsheet showing the differences (fit) of the point cloud to the validation points. This spreadsheet shall include a resultant summary in NSSDA format showing the 95% difference in horizontal X and Y, and Vertical Z for the project.
- 3D Microstation DGN file and a .kmz file providing the graphical representation of the resulting differences between the project Point Cloud dataset and the targets and validation points.

Final Deliverables

Copies of the final deliverables shall be provided to the Survey Project Manager and to Lansing Design Surveys and shall include the following:

- Project report describing in detail how the mobile mapping project was done, number and general location of passes to acquire data, equipment used, datum surveyed on, and results.
- Complete listing of the Registration processing reports listed above.

- Comparison spreadsheet showing the fit of the control points/targets to the point cloud. (The TopoDOT Control points to point cloud analysis tool that outputs a spreadsheet and chart diagram is one accepted option.)
- Comparison spreadsheet showing the fit of the validation points/targets to the processed point cloud.
- Comparison spreadsheet showing the differences (fit) of the final project DTM surface to the validation points. This spreadsheet shall include a resultant summary in NSSDA format showing the 95% difference in horizontal X and Y, and Vertical Z for the project.
- 3D Microstation DGN file and a .kmz file providing the graphical representation of the resulting differences between the final project DTM surface and the targets and validation points.
- 3D Microstation DGN file containing all mapping extracted from LiDAR point cloud.
- 3D Microstation DGN triangle file containing the terrain surface triangles created from the point cloud data.
- Terrain surface saved as a Geopak .TIN file generated from the point cloud data.
- LiDAR data tiled and saved in scanner native file format (such as Riegl .3dd, Cyclone .pts/.imp, etc.)
- LiDAR data with RGB and Intensity values tiled and saved as colorized .POD (Point Tools/Microstation point cloud file) files.
- DGN file showing the tile layout and naming of the .POD files. (If possible, use the same tile layout for both .POD and .LAS files.)
- LiDAR data collected shall be submitted in .LAS format with RGB values and intensity values.
- DGN file showing the tile layout and naming of the .LAS files. (If possible, use the same tile layout for both .POD and .LAS files.)
- Photo mosaic/Images along route that support the LiDAR .LAS point cloud. Provide a kml/kmz file, dgn index or direct folder naming that describes the organization of the images for easy access.

Point cloud files shall be provided on electronic media of an appropriate size to contain all project information. Two (2) copies shall be provided to MDOT Lansing Survey Support Unit. A third (3rd) copy shall be provided for use by the MDOT Region Surveyor.

LiDAR and Mobile Mapping information should be prepared and placed in a separate sub-folder named "LiDAR/Mobile Mapping" under the Project Mapping Folder and shall contain all information and LiDAR/Mobile Mapping deliverables relative to the project.

When other methods of survey and mapping are also employed for the project, the data shall be combined and merged with the mobile mapping data and the merged information provided in the appropriate electronic files per the project's scope and requested deliverables.

Additional MTL specifications and guidance will be forthcoming.
Contact MDOT Design Survey Support for clarification related to all MTL applications.

APPENDIX E
Photogrammetric Control Surveys

There are generally three types of photogrammetric control surveys used to support aerial photography projects: High Level Aerial Photography (HLAP), Standard Aerial Photography (SAP), and Low Level Aerial Photography (LLAP) [also referred to as Very Low Level Photography (VLAP)]. HLAP is generally flown for planning and project development with flying heights greater than 4900 feet. SAP is flown for road design with flying heights between 1400 to 3000 feet. VLAP is flown with a helicopter for very accurate mapping on busy highways with flying heights of 500 feet or less. Each of these types has different requirements for control.

TARGETING - See Section 9.2.2 of the MDOT Design Survey Manual.

The following table (**Table SP 4**) gives dimensions for some typical target sizes. Some situations in wooded areas may require larger sizes or longer legs to identify targets. Target sizes shall be confirmed with the MDOT Survey Support Unit or the Photogrammetric Project Manager prior to being placed.

TABLE SP 4

Photo Altitude Type	Photo Scale (RF) 1:xxx	Photo Scale (Ft) 1”=xxx’	Flight Altitude (Feet)	Target Width of Leg	Target Leg Length	Target Total Length
LLAP or VLAP	1:480 to 1:1000	1”=40’ to 1”=83’	240’ to 500’	2”	5”	10”
Low STD	1:2000 to 1:2500	1”=167’ to 1”=208’	1000’ to 1250’	4”	24”	4 feet
STD	1:3000 to 1:4000	1”=250’ to 1”=333	1500’ to 2000’	6”	3 feet	6 feet
STD	1:4000 to 1:5000	1”=333’ to 1”=417’	2000’ to 2500’	9”	4 feet	8 feet
High STD	1:6000 to 1:8000	1”=500’ to 1”=667’	3000’ to 4000’	12”	8 feet	16 feet
HLAP	1:10000 to 1:20000	1”=833’ to 1”=1667’	5000’ to 10,000’	24”	12 feet	24 feet

Note: The dimensions and configurations for targets shown in figures **9.11**, **9.12**, and **9.13** of the Design Survey Manual will be used unless otherwise specified in the project scope **except that**

chevron style targets are no longer acceptable for use on aerial mapping projects. (Small chevrons of the VLAP size may be used for mobile mapping projects if approved by the Survey Project Manager). The dimensions of targets will vary based on the flight altitude planned for the project.

Sketches for all targets shall be prepared and submitted showing the location and vicinity of the target and any offsets and directions from the target to the actual point surveyed. All target monuments shall be witnessed with ties to a minimum of two objects so others may locate the points for subsequent work.

For painted targets, a Mag nail and washer shall be counter sunk into the pavement so that the top of nail is flush or about 1/8" below the surface of the pavement to help protect the nail from being pulled out.

Ideally for Paneled targets, a square piece of black material with dulled finish or rough texture or a black plastic material that will absorb, not reflect light shall be placed under the cloth target as a background.

PHOTO IDENTIFIABLE POINTS - See Section 9.2.1 of the MDOT Design Survey Manual.

All "pick point" locations shall be fully described, sketched and witnessed with a minimum of two witness ties.

OBTAINING COORDINATES - See Section 9.2.4 of the MDOT Design Survey Manual.

For larger projects requiring more than 100 targets, the 600 series is extended to use 700 series numbering. Numbering also includes the 900 series numbers that will be used for "check points." "Check points" are most always painted targets. Obtaining coordinates on photo targets and check points will follow the same method as determining coordinates on Intermediate Control outlined above.

Because of new technologies such as GPS, the 500 series numbering is rarely used.

DELIVERABLES - See Section 9.3 of the MDOT Design Survey Manual.

Submit sketches and witnesses for all targets.
Return all contact prints marked with control point numbers, if provided.
Provide a target diagram containing the final locations of all targets surveyed and note all changes in location from the planned target layout.

In addition to the requirements for Intermediate Control, an ASCII text file listing of the target coordinates shall be provided in the following format and named JNxxxxxx_PhotoControl.txt:

601	x.coordinate	y.coordinate	z.coordinate	**x** std.dev.	**y** std.dev.	**z** std.dev.
901	x.coordinate	y.coordinate	z.coordinate	**x** std.dev.	**y** std.dev.	**z** std.dev.

APPENDIX F
Electronic Media Standards and Guidelines

Storage of Survey data and especially mobile and static LiDAR data often requires large capacity and long term storage. The following standards and guidelines apply to deliverables and submittals for MDOT survey projects.

Conventional Survey Data Deliverables: (3 identical complete copies)
Minimum of 1 copy provided to the MDOT Region Surveyor.
1 Copy provided to the MDOT Project Manager for Design
1 Copy provided to MDOT Design Survey Support in Lansing

Static Terrestrial Laser Scanning (STLS) Data Deliverables: (4 identical, complete copies)
2 copies provided to MDOT Design Survey Support in Lansing.
Minimum of 1 copy provided to the Region Surveyor.
1 Copy provided to the MDOT Project Manager for Design

Mobile Terrestrial LiDAR (MTL) Data Deliverables: (4 identical, complete copies)
2 copies provided to MDOT Design Survey Support in Lansing.
Minimum of 1 copy provided to the Region Surveyor.
1 Copy provided to the MDOT Project Manager for Design

All copies of electronic media shall be labeled with Control Section, Job Number, Route, Project location or limits, Professional Surveyor/Project Manager, Name of Consultant Firm, Date of electronic data submittal and/or date of latest revisions being submitted.

Conventional Ground Survey (small projects under 4GB) > > Submit CD-ROM(s) or DVD-Rom(s)

STLS - Static Terrestrial Laser Scanning projects > Submit Solid State Drive(SSD) or USB 3.0 Flash Drive/Thumb Drive capable of holding entire project (typically 8GB to 64GB)

MTL - Mobile Terrestrial LiDAR projects > Submit Solid State Drive or USB 3.0 Flash Drive/Thumb Drive capable of holding entire project (typically 32GB to 1TB)

(Projects shall not be submitted on Flash, SDHC or similar memory cards.)

Place CD-ROM(s) and DVD-Rom(s) in CD or DVD Jewel or slim plastic cases and label both the case(s) and the disk(s) with the project information listed above.

USB Flash Drives shall be marked with identification correlating it to a case or container to be used for storage. It is preferred that USB Flash Drives also have a key chain tag attached that is labeled with the project information. Storage containers, if used, shall be labeled with the project information listed above. It is preferred that USB Flash Drives shall be submitted in a key ring type USB Flash Drive case. Multiple USB Flash Drives may be delivered in one USB Flash Drive Case containing all USB Flash Drives for the project.

Solid State Drives shall be delivered in SSD Protective Transport/Storage Case Covers. These cases are rectangular video cassette style storage containers that may be easily stacked. Solid State Drives shall be affixed with a label or marking correlating it to the Protective Case Covers to place the SSD in for storage. This Storage Case Cover shall be labeled with the project information listed above.