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Adapting Construction Staking to Modern Technology

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16. Abstract

This report summarizes the tasks and findings of the ICT Project R27-163, Adapting Construction Staking to Modern Technology, which aims to develop written procedures for the use of modern technologies (such as GPS and civil information modeling) in construction staking of highway projects, for inclusion in the Illinois Department of Transportation's (IDOT's) *Construction Manual.* Six primary research tasks were completed: (1) conducting a comprehensive literature review on the use of modern technologies in construction staking by state departments of transportation (DOTs) and contractors; (2) conducting a survey to gather information from state DOTs and contractors on current practices employed by other states; (3) identifying a set of potential practices for employment in Illinois; (4) conducting a survey to gather feedback from IDOT staff and Illinois contractors; (5) developing draft summarized written procedures for review by the Technical Review Panel (TRP); and (6) developing complete written procedures for the use of modern technologies in construction staking of highway projects, for inclusion in IDOT's *Construction Manual.* The written procedures are intended to support construction-staking processes when a contractor employs such technologies. The procedures are expected to enable the employment of these technologies in Illinois and, in turn, to offer major opportunities for quality improvements, cost savings, and expediting project delivery.

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Members of the Technical Review panel were the following:

- Kell, Tim, IDOT, TRP Chair
- Griffin, Bernard, IDOT
- Sheley, Ryan, IDOT
- Wick, Joe, IDOT
- Cox, James, IDOT
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EXECUTIVE SUMMARY

The main goal of this research project was to develop written procedures for the use of modern technologies in construction staking of highway projects in the state of Illinois, for inclusion in the Illinois Department of Transportation's (IDOT's) *Construction Manual*, which would enable the employment of these technologies in Illinois and, in turn, offer major opportunities for quality improvements, cost savings, and expediting project delivery.

To accomplish this goal, six primary research tasks were completed: (1) conducting a comprehensive literature review on the use of modern technologies in construction staking by state departments of transportation (DOTs) and contractors, including a review of relevant construction manuals, regulations, guidelines, protocols/policies, and research studies; (2) conducting a survey to gather information from state DOTs and contractors on current practices employed by other states that successfully adopted these technologies for construction staking of highways; (3) identifying a set of potential practices for employment in Illinois, based on the literature review and the survey results (i.e., based on the results of tasks 1 and 2); (4) conducting a survey to gather feedback from IDOT staff and Illinois contractors on the potential success and suitability of these practices in Illinois; and (5) developing draft summarized written procedures, based on the data collected and the survey results (i.e., based on the results of tasks 3 and 4) for review by the Technical Review Panel (TRP); and (6) developing complete written procedures for the use of modern technologies in construction staking of highway projects, for inclusion in IDOT's *Construction Manual.* These written procedures are intended to support construction-staking processes when a contractor employs such technologies.

For task 1, the research team conducted a comprehensive literature review to gather and analyze the most current resource materials, regulations, guidelines, protocols/policies, and best practices on the use of modern technologies in construction staking by state DOTs and contractors, including a review of other state DOTs' relevant construction manuals that cover the use of these modern technologies; relevant federal and state regulations, guidelines, protocols/policies on the use of these technologies; and relevant research studies. The scope was focused on methods and technologies that could support construction staking of highway projects such as GPS, CADD, civil information modeling, laser scanning, photogrammetry, handheld computing devices, and data analysis systems. The scope was also focused on current practices employed by other states that successfully adopted these technologies.

For task 2, the research team conducted a survey to gather information from other state DOTs and contractors on current practices employed by states that successfully adopted these technologies for construction staking of highways, including information on (1) extent of use of the technologies by the state DOT and construction contractors, (2) practices for successful implementation, (3) barriers to implementation, and (4) relevant written procedures/documents followed by each state DOT (e.g., the state DOT's construction manual). This task was composed of the following subtasks: (1) designing the questionnaire, (2) identifying the list of potential respondents, (3) conducting the survey, and (4) analyzing the survey results. A set of four questionnaires was developed and used—one per respondent group: (1) state DOT construction staff, (2) state DOT design staff, (3) state DOT

surveying staff, and (4) state contractors. The questionnaires included seven main sections: (1) respondent information; (2) extent of use, satisfaction, benefits, success factors, and barriers of/with GPS technology in construction surveying; (3) control surveying using GPS technology and the real-time kinematic (RTK) method; (4) construction surveying using GPS equipment; (5) conventional staking when automated machine guidance (AMG) is used; (6) digital models and electronic data exchange practices; and (7) laser scanning. The survey was conducted from June 6 to July 31, 2016; and the target respondents included (1) members of the AASHTO Subcommittee on Construction and (2) district engineers and contractors referred by the members. A total of 36 responses, from 20 states, was received. The results of the survey served as a basis for identifying potential practices for employment in Illinois (task 3).

For task 3, the research team identified the potential practices for employment in Illinois (by IDOT and Illinois contractors), based on the analysis of the results of the literature review and the survey. The research team identified twelve primary potential practices and developed a description of the procedures for implementing each practice. These practices were the basis for developing the written procedures related to the use of modern technologies for construction staking of highway projects (tasks 4, 5, and 6).

For task 4, the research team conducted a personal interview survey (using a questionnaire) to gather feedback from IDOT staff from all the nine districts and Illinois contractors on the potential practices to use in Illinois for automated machine guidance (AMG) and digital models, which were identified and developed in the previous tasks. This task was composed of the following subtasks: (1) designing the questionnaire, (2) identifying the list of potential respondents, (3) conducting the interviews, and (4) analyzing the interview survey results. The questionnaire included twelve main sections: (1) respondent information, (2) evaluation of construction methods, (3) AMG equipment, (4) AMG work plan, (5) training, (6) digital models used for AMG, (7) electronic design files, (8) project control, (9) accuracy and tolerance, (10) quality assurance, (11) site calibration and checks, and (12) final checks. The questions aimed to gather expert feedback on the details of technology implementation such as responsibilities, submissions, timelines, methods and equipment, work planning, training, use of digital models and electronic files, project control, accuracy and tolerances, quality assurance, site calibration, and checking. The questions also aimed to gather feedback on whether a certain practice is suitable for being included in the *Construction Manual*. The survey was conducted from October 28 to December 1, 2016. The respondents included engineers, surveyors (including the survey crew chief), inspectors, supervisors, and technicians—from all nine IDOT Districts. A total of 79 responses were received.

For task 5, the research team revised the potential practices based on the results of the survey (task 4) and developed the practices into draft written procedures for the use of modern technologies in construction staking of highway projects, for inclusion in IDOT's *Construction Manual.* The aim of this draft was to seek the TRP's feedback on the main practices and procedures prior to developing the complete/final written procedures. The draft written procedures was organized into twelve sections: (1) general, (2) evaluation of construction methods, (3) AMG equipment, (4) AMG work plan, (5) training, (6) electronic design files, (7) digital models used for AMG, (8) project control, (9) accuracy and tolerance, (10) site calibration and checks, (11) spot checks, and (12) final checks.

For task 6, the research team developed the complete written procedures for the use of modern technologies in construction staking of highway projects, for inclusion in IDOT's *Construction Manual.* The written procedures are intended to support construction-staking processes when a contractor employs such technologies. The procedures are expected to enable the employment of these technologies in Illinois and, in turn, to offer major opportunities for quality improvements, cost savings, and expediting project delivery. The complete written procedures are included in chapter 7.

CONTENTS

CHAPTER 1: INTRODUCTION

1.1 PROJECT MOTIVATION

The Illinois Department of Transportation (IDOT) has no written specifications, guidelines, or policies for the use of the global positioning system (GPS), 3D computer-aided design and drafting (CADD), information modeling for highways [known as civil information modeling (CIM)], or other modern technologies that have developed over the past 10 years for highway construction. Such technologies could support various construction processes (e.g., staking) and could offer major opportunities for quality improvements, cost savings, and expediting project delivery. Many contractors also request the project electronic design files for positioning devices used on their construction equipment for grading and paving. However, IDOT's policies and guidelines (e.g., IDOT's *Construction Manual*) do not address this practice and are out of date with modern technologies. As such, IDOT needs to develop written procedures for the use of these modern technologies in construction staking of highway projects, for inclusion in IDOT's *Construction Manual.*

1.2 PROJECT OBJECTIVES

The main goal of this research project was to develop written procedures for the use of modern technologies (such as GPS, CADD, and CIM) in construction staking of highway projects in Illinois, for inclusion in IDOT's *Construction Manual,* which would enable the employment of these technologies in Illinois and, in turn, offer major opportunities for quality improvements, cost savings, and expediting project delivery.

To accomplish this critical goal, the research objectives of this project were to

1. Provide a comprehensive literature review of the use of modern technologies in construction staking by state DOTs and contractors, including a review of other state DOTs' relevant construction manuals that cover the use of these modern technologies (e.g., WisDOT's 2015 *Construction and Material Manual*); relevant state and federal regulations, guidelines, and protocols/policies on the use of these technologies; and relevant research studies. The scope was focused on the methods and technologies such as GPS, CADD, and CIM that could support construction staking of highway projects.
2. Conduct a survey to gather information from state DOTs and contractors on current practices employed by other states that successfully adopted these technologies for construction staking of highways.
3. Identify a set of potential practices for employment in Illinois, based on the literature review and the survey results (i.e., based on the results of objectives 1 and 2).
4. Conduct a survey to gather feedback from IDOT staff and Illinois contractors on the potential success and suitability of these practices in Illinois.
5. Develop recommendations for IDOT's written procedures for the use of these technologies in construction staking of highway projects, to be included in IDOT's *Construction Manual,* based

on the data collected and the survey results (i.e., based on the results of Objectives 3 and 4). These written procedures are intended to support construction-staking processes when a contractor employs such technologies.

1.3 PROJECT TASKS AND DELIVERABLES

The research methodology included six primary tasks that led to four project deliverables, as illustrated in Figure 1.

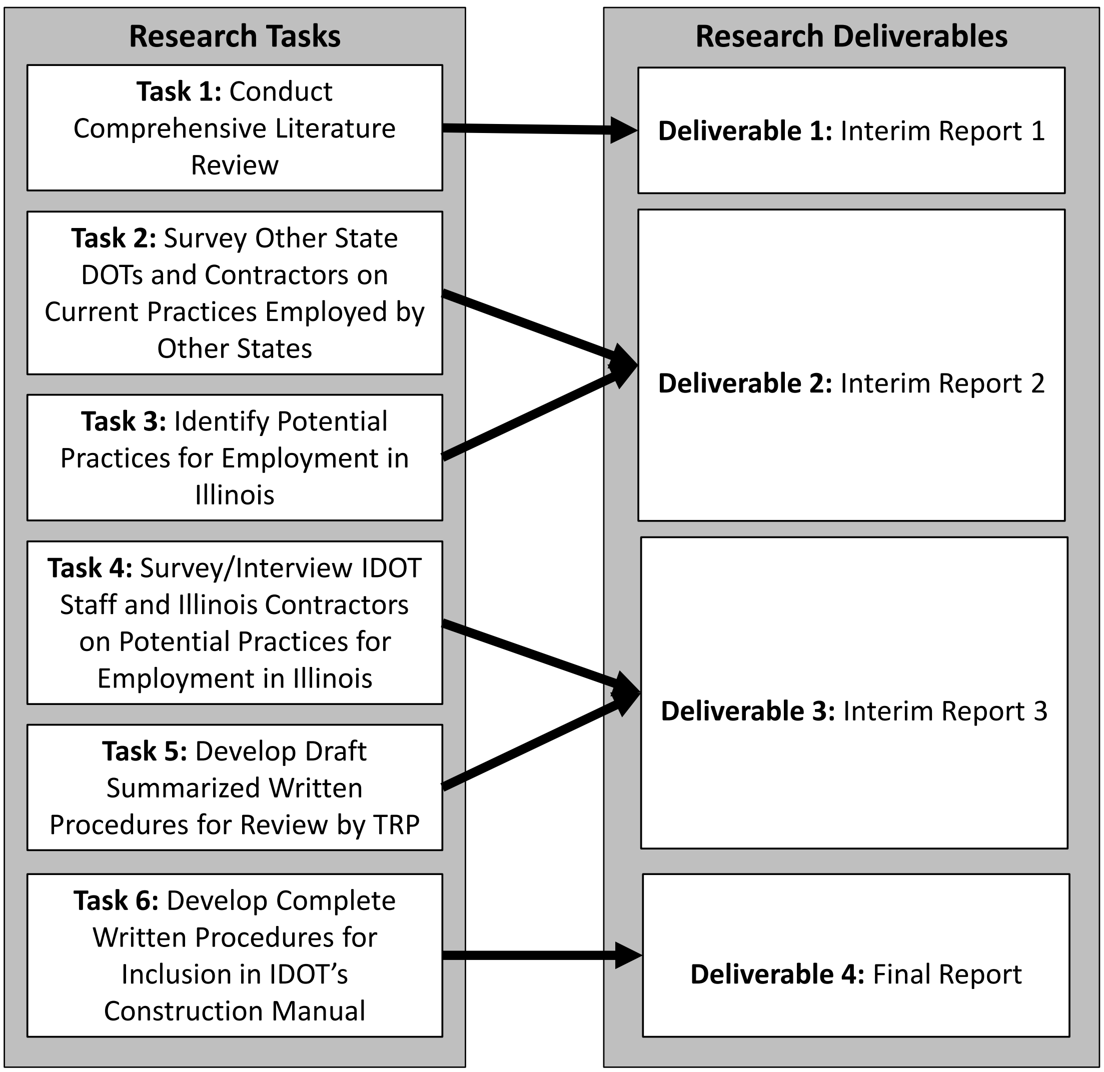


Figure 1. Research methodology.

CHAPTER 2: CONDUCT A LITERATURE REVIEW (TASK 1)

The results of the literature review are included in Appendix H. The following subsections provide a summary of the relevant literature that was reviewed.

2.1 LITERATURE REVIEW ON GPS SURVEYING

2.1.1 Relevant State DOT Manuals

Potentially relevant manuals by all 50 state DOTs were reviewed, including construction manuals and survey manuals. Based on their level of detail, the manuals were classified into three groups for further investigation:

- Level 1: The investigated technology does not appear in the manual.
- Level 2: The manual has an introduction or specification for the technology.
- Level 3: The manual has detailed user guidance for the technology.

The criteria for classification included

- How many times the technology (e.g., GPS) is mentioned in the manual
- How many times the technology is specifically mentioned in the context of construction surveying/staking, not only general surveying
- How many different aspects of the use of the technology (e.g., definition and principles, equipment and personnel, field and office procedures, specifications and deliverables) are included in the manuals

Table 1 summarizes the content of the documents and shows their classifications.

Table 1. Summary of Relevant Manuals for GPS Surveying

State	Manual	Reference	Introduction of GPS/GNSS	Equipment operation/ maintenance	Field and office procedures	Deliverables	Planning	Specifications and tolerances	Specific to construction surveying	Level of detail*
Arizona	*Manual for Field Surveys*	Arizona DOT 2010	√		√					2
Arkansas	*Requirements and Procedures for Control, Design, and Land Survey*	ASHTD 2013		√	√					2
California	*Survey Manual*	Caltrans 2012	√	√	√	√	√	√		3
Colorado	*Survey Manual*	CDOT 2008a	√	√	√	√	√	√	√	3
Georgia	*Automated Survey Manual*	GDOT 2015	√		√		√	√		3
Michigan	*Design and Survey Manual*	Michigan DOT 2015	√	√	√					2
Minnesota	*Survey and Mapping Manual*	MnDOT 2007b	√		√					2
Mississippi	*Survey Manual*	Mississippi DOT 2008		√	√					2
Montana	*Survey Manual*	Montana DOT 2005			√		√	√		2
Nevada	*Construction Survey Manual*	Nevada DOT 2012	√		√					2
North Carolina	*Location and Surveys Manual*	NCDOT 2010			√		√			2
North Dakota	*Training Manual for GPS Operations*	NDDOT 2008	√	√	√					2
Oregon	*Construction Survey Manual for Contractor*	ODOT 2014		√	√					2
Pennsylvania	*Surveying and Mapping Manual*	PennDOT 2010		√	√	√	√			3
South Dakota	*Survey Manual*	SDDOT 2015			√					2
Tennessee	*Survey Manual*	TDOT 2011			√					2
Texas	*Survey Manual*	TxDOT 2011			√	√	√	√		3
Utah	*Survey and Geomatics Standards Manual*	UDOT 2015			√		√	√		2
Virginia	*Survey Manual*	VDOT 2015	√		√	√		√		3
Washington	*Survey Manual*	WsDOT 2005	√	√	√			√		2
Wisconsin	*Construction and Material Manual*	WisDOT 2015		√		√	√		√	3
Wyoming	*Construction Manual*	WYDOT 2012	√		√	√	√		√	2

*Manuals classified as level 1 are not shown in this table.

2.1.2 Other Relevant Documents

Other relevant documents were collected from the website of each state DOT. These documents can be classified into four groups:

- Work-guidance documents: guidance documents providing detailed job requirements, such as the responsibility of personnel, specific software and hardware to be used in the work, and format of the deliverables
- Special provisions: provisions for the use of GPS techniques in a unique event or a certain situation
- Strategic plans and protocols: plans for the use of GPS in highway-construction surveying
- Studies about the use of GPS surveying in highway construction

Table 2 shows the list of the reviewed documents.

Table 2. Other Documents Relevant to GPS Surveying

Type of document	Name of document
Work-guidance document	*Guideline and Summary of Requirements for Montana Department of Transportation Surveying* (Montana DOT 2015)
Special provisions	*Revision of Section 625 Survey Control of Grading by GPS or RTS Method,* https://www.codot.gov/business/manuals/survey/chapter-6/chapter6appendix/Revision%20625%20Machine%20Control.pdf (CDOT 2008b)
	Special Provision for Construction Surveying by the Contractor (MnDOT 2015)
Strategic plan and protocol	*Development of GPS Survey Data Management Protocols/Policy* (Alaska DOT 2010)
Studies about the use of GPS surveying in highway construction	*An Investigation of the Use of Global Position System (GPS) Technology and Its Augmentations within State and Local Transportation Departments* (FHWA 2000)
	GPS in Construction Staking (WisDOT 2006)
	Emerging Technologies for Construction Delivery (Hannon, John J. 2007)
	Memorandum, Design-Bid-Build Best Value Procurement Under Special Experimental Project No. 14 (SEP-14), http://www.fhwa.dot.gov/construction/contracts/sep14ny150818.pdf (FHWA 2015)

2.2 LITERATURE REVIEW ON THE USE OF CADD AND CIM IN CONSTRUCTION STAKING

To gain a comprehensive understanding of the use of CADD and CIM in highway-construction staking, the following relevant documents were reviewed:

- Relevant manuals from state DOTs, including construction manuals, surveying and mapping manuals, CADD manuals, and CIM manuals. For those manuals, the research team mainly focused on existing policies, standards, and procedures for the use of CADD and CIM models in highway surveying, the software used, and the required deliverables.
- Relevant introductory webpages of CADD and CIM software products. From those webpages, the research team summarized how the CADD or CIM is used in construction surveying, what the benefits and barriers of using CADD or CIM are, and the availability and popularity of those software products to users.

- Relevant research about the use of CADD and CIM in highway-construction surveying. From those research reports, the research team identified the potentially successful procedure for the use of CADD and CIM in highway surveying.

The documents reviewed are listed in Table 3.The literature review covered the following topics:

- Description of CADD and CIM, benefits and barriers of using CADD and CIM, and how CADD and CIM are used in automated machine guidance (AMG) and in construction surveying
- Summary of 3D model development and electronic data exchange practices and requirements by DOTs, especially when AMG is used in construction surveying
- Summary of procedures and policies by DOTs for the use of AMG in construction surveying, especially when contractor staking is adopted

This review focused on the development and exchange of 3D models, CIM models, and other electronic engineered data for both the Department and the contractor during the whole construction-surveying process.

Table 3. Documents Reviewed for CADD and CIM

Reference	Name of documents
Autodesk 2015	*Autodesk BIM Solutions for Roads and Highways* http://static-dc.autodesk.net/content/dam/autodesk/www/industries/civil-infrastructure/road-highway-design-infrastructure/Docs/autodesk_roadsandhighways_us_final.pdf
Caltrans 2014	*Advanced Modeling Techniques for Enhanced Constructability Review, Phase II: A Survey of State Practice and Related Research*
Dunston and Monty 2009	*Practices for Seamless Transmission of Design Data from Design Phase to Construction Equipment Operation—A Synthesis Study*
FHWA 2013b	*The Interoperability of Computer-Aided Design and Geographic Information Systems in Transportation—Case Studies of Select Transportation Agencies*
FHWA 2016	FHWA-HRT-16-002 *Leveraging A Data-Rich World*
Hannon and Sulbaran 2010	*MDOT Implementation Plan for Global Positioning Systems (GPS) Technology in Planning, Design, and Construction Delivery*
Hovey and Lubliner 2012	*KDOT's Evaluation of Sharing Electronic Data with Contractors and GPS Construction Procedures*
IDOT 2014	*CADD Roadway and Structure Project Deliverables Policy*
Iowa DOT 2015	*Standard Specification for Highway and Bridge Construction,* Section 2526
KDOT 2015	*Standard Specifications,* Section 802, "Contractor Construction Staking"
MnDOT 2007a	*Best Practices—Machine Control Evaluation*
Mississippi DOT 2013	Special Provision No. 907-699-5 *Construction Stakes*
PennDOT 2016	Publication 408/2016 *Specifications*
Portland Environmental Services 2014	*CAD Standards and Guidelines*
Richins et al. 2010	*Construction Machine Control Guidance Implementation Strategy*
TOPCON 2015	LN-100 *3D Layout Navigator* https://www.topconpositioning.com/sites/default/files/product_files/ln-100_broch_7010_2153_reva_utr_sm.pdf
Vonderohe 2007	*Implementation of GPS Controlled Highway Construction Equipment*
Vonderohe 2009	*Status and Plans for Implementing 3D Technologies for Design and Construction in WisDOT*
WisDOT 2016	*Standard Specifications,* Section 650
Yan and Damian 2008	*Benefits and Barriers of Building Information Modeling*

CHAPTER 3: SURVEY STATE DOTS AND CONTRACTORS ON CURRENT PRACTICES (TASK 2)

3.1 SURVEY PURPOSE AND METHODOLOGY

The purpose of the survey was to gather information from other state DOTs and contractors on current practices employed by states that successfully adopted modern technologies for construction staking of highways, including information on (1) extent of use of the technologies by the state DOT and construction contractors, (2) practices for successful implementation, (3) barriers to implementation, and (4) relevant written procedures/documents followed by each state DOT (e.g., the state DOT's construction manual).

The research team conducted the survey using a set of online questionnaires. The research team first developed a list of potential questions based on the results of the literature review (task 1). The questions were then organized into five sections based on content (as described in section 3.2). Four questionnaires were then developed—one for each of the following target groups: (1) state DOT construction staff, (2) state DOT design staff, (3) state DOT surveying staff, and (4) state contractors. Each questionnaire included only the questions that were relevant to the respective target group. The online questionnaires were developed using Google Forms. In the March 30, 2016, TRP meeting, the research team discussed the draft questionnaires with the TRP. Based on the comments/discussions during the meeting, the research team revised the questionnaires. After the questionnaires were approved by the TRP, the research team conducted a pilot survey to test the effectiveness of the questionnaires. Three respondents from IDOT District 9 participated in the pilot survey. Feedback was solicited on different aspects of the questionnaire, such as question wording, response options and evaluation scale, and clarity of instructions to respondents. The questionnaires were then revised based on the feedback. For example, a "do not know" option was added for each multiple-choice question. The final questionnaires were then approved by the TRP; and the survey was launched on June 6, 2016. The target respondents included (1) members of the AASHTO Subcommittee on Construction and (2) district engineers and contractors referred by the members. The survey was conducted online. The survey-invitation emails were sent to the members of the AASHTO Subcommittee on Construction by the TRP chair, Tim Kell, on June 6, 2016. The original response deadline was July 15, 2016. The research team received 33 responses by that date. Accordingly, the research team and the TRP chair decided to extend the deadline to July 31, 2016, with the aim to increase the response rate. Three additional responses were received during the extension period. The research team considered extending the deadline for a second time; but with the low response rate during the 2-week extension, the team decided to proceed with the analysis of the survey results. Thus, a total of 36 responses were received.

3.2 QUESTIONNAIRE DESIGN

A set of questions was developed and organized into seven sections: (1) respondent information; (2) extent of use, satisfaction, benefits, success factors, and barriers of/with GPS technology in construction surveying; (3) control surveying using GPS technology and real-time kinematic (RTK) method; (4) construction surveying using GPS equipment; (5) conventional staking when conducting construction surveying using GPS equipment; (6) digital models and electronic data exchange practices; and (7) laser scanning.

The sections were assembled, forming the four questionnaires. As mentioned in section 3.1, four questionnaires were developed—one for each targeted respondent group. The complete set of questions is included in Appendix B, and the four questionnaires are included in Appendices C to F. The following shows which sections were sent to the four groups:

- Questionnaire sent to DOT construction staff: sections 2, 4, and 5
- Questionnaire sent to DOT design staff: sections 2 and 6
- Questionnaire sent to DOT surveying staff: sections 2 and 3, and part of section 4
- Questionnaire sent to contractors: all seven sections

Three types of questions were developed: (1) multiple-choice questions, which asked the respondents to select one or more options among a number of options/alternatives; (2) dichotomous questions, for which there were two possible responses (e.g., yes/no); and (3) short-answer questions, which asked the respondents to provide specific information (e.g., link to a document). For multiple-choice questions that required the respondent's rating (e.g., rating of satisfaction level), a six-point Likert scale was used, with 6 being the most favorable (e.g., "very satisfied") and 1 being the least favorable (e.g., "very dissatisfied"). For each question, a "do not know" option was added so that the respondent did not answer a question randomly when he or she had no information/knowledge about the answer. For most multiple-choice questions, an "other" option was added—with a blank—so that the respondents could provide additional responses/information without being limited by the response options provided. If a respondent started filling out a section, all questions in that section were required; but respondents were able to skip whole sections.

Section 1 solicited respondent information including name, agency, job title, role, years of experience, phone, and email.

Section 2 (Respondent Information) aimed to gather respondent feedback on the extent of use, satisfaction, benefits, success factors, and barriers associated with the use of GPS technology in construction surveying. A multiple-choice question format was used to capture the responses (with some questions using a six-point Likert scale, as mentioned above). Figure 2 shows an example of the questions that were included in section 2. All questions in section 2, except question 1 (which is relevant only to contractors), were included in the questionnaires sent to DOT construction staff, DOT design staff, and DOT surveying staff. All questions in section 2, except question 2 (which is relevant only to DOT staff), were included in the questionnaire sent to contractors.

1. Based on your agency's experience in the past year, how many highway projects regulated by your agency utilized GPS technology in construction surveying? *

- ◯ None
- ◯ Less than 25%
- ◯ 25% to 50%
- ◯ 50% to 75%
- ◯ More than 75%
- ◯ All projects
- ◯ Do not know

Figure 2. Task 2 questionnaire—an example question in section 2 (Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying).

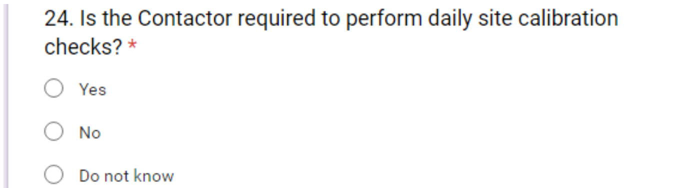
Section 3 [Control Surveying Using GPS Technology and Real-Time Kinematic (RTK) Method] aimed to gather respondent feedback on control surveying using GPS technology and the RTK method. The questions covered the following aspects: responsibility for performing secondary control surveys, use of additional control surveys if AMG is used, office procedures, types of base station networks utilized, and deliverables. Respondents were also requested to provide the link(s) to the manual(s) or document(s) that include(s) the DOT's respective specifications. Multiple-choice, dichotomous, and short-answer question formats were used to capture the responses, depending on the type of feedback needed. For example, for question 6, a short-answer format was used, in which the respondents were asked to provide the links to the manuals or documents that include the DOT's respective specifications of GPS surveying. Figure 3 shows an example of the questions that were included in section 3. All questions in section 3 were included in the questionnaire sent to DOT survey staff. All questions in section 3, except question 6, were included in the questionnaire sent to contractors.

3. If Automated Machine Guidance (AMG) is used, are additional horizontal and vertical control surveys required?

- ◯ Yes
- ◯ No

Figure 3. Task 2 questionnaire—an example question in section 3 [Control Surveying Using GPS Technology and Real-Time Kinematic (RTK) Method].

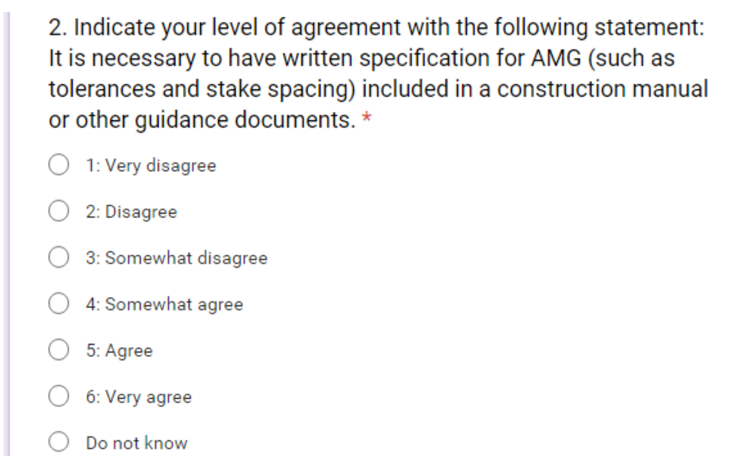
Section 4 (Construction Surveying Using GPS Equipment) aimed to gather respondent feedback on construction surveying when AMG (GPS-guided machines) is used. The questions covered the following aspects: the use of AMG, use of conventional staking along with AMG, use of GPS equipment list, GPS equipment vendors, specifications, tolerances, GPS equipment maintenance, calibration, spot checks, final checks, and training. Similar to the approach used in previous sections, multiple-choice and dichotomous question formats were used, depending on the type of feedback needed. Figure 4 shows an example of the questions that were included in section 4. All questions in section 4, except question 2 (which is relevant only to DOT staff), were included in the questionnaire sent to contractors. All questions in section 4, except question 3 (which is relevant only to contractors), were included in the questionnaire sent to DOT construction staff. The questionnaire sent to DOT surveying staff included only three questions (questions 14 to 16).


24. Is the Contactor required to perform daily site calibration checks? *

- Yes
- No
- Do not know

Figure 4. Task 2 questionnaire—an example question in section 4 (Construction Surveying Using GPS Equipment).

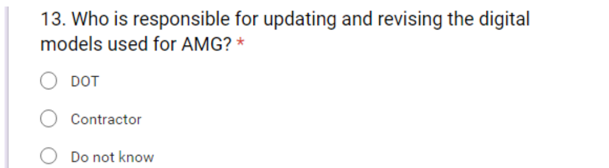
Section 5 (Conventional Staking When Conducting Construction Surveying Using GPS Equipment) aimed to gather respondent feedback on conventional construction staking when AMG (GPS-guided machines) is used. The questions covered the following aspects: conventional construction-staking procedures and specifications, the degree that conventional staking is needed when AMG is used, how electronic devices are used to facilitate staking, and the references that are used for staking procedures and specifications such as tolerances and spacing. Similar to the approach used in previous sections, multiple-choice, dichotomous, and short-answer question formats were used, depending on the type of feedback needed. For example, the respondents were asked to select the option that corresponded to the current type of specifications for construction staking. The respondents were also asked whether conventional staking is still utilized when AMG is used for construction work. In some questions, a six-point Likert scale was used to measure the level of agreement with certain statements (e.g., see Figure 5). The respondents were also asked to provide the links to the manuals or documents that include the DOT's respective staking specifications and procedures. Figure 5 shows an example of the questions that were included in section 5. All questions in section 5 were included in the questionnaire sent to DOT construction staff. All questions in section 5, except questions 3 and 6, were included in the questionnaire sent to contractors.


2. Indicate your level of agreement with the following statement: It is necessary to have written specification for AMG (such as tolerances and stake spacing) included in a construction manual or other guidance documents. *

- 1: Very disagree
- 2: Disagree
- 3: Somewhat disagree
- 4: Somewhat agree
- 5: Agree
- 6: Very agree
- Do not know

Figure 5. Task 2 questionnaire—an example question in section 5 (Conventional Staking When Conducting Construction Surveying Using GPS Equipment).

Section 6 (Digital Models and Electronic Data Exchange Practices) aimed to gather respondent feedback on digital models and electronic data exchange practices in construction surveying. The questions covered the following aspects: the use of digital models and associated practices and specifications, satisfaction, benefits and barriers, success factors, impact of digital models on project time and cost, responsibilities regarding digital models when AMG is used, electronic data provided by the DOT, and deliverables submitted by the contractor. In some questions, a six-point Likert scale was used to measure the level of satisfaction with the use of certain CADD software and electronic data to support construction surveying. Figure 6 shows an example of the questions that were included in section 6. All questions in section 6 were included in the questionnaire sent to DOT design staff. All questions in section 6, except question 23, were included in the questionnaire sent to contractors.


13. Who is responsible for updating and revising the digital models used for AMG? *

- DOT
- Contractor
- Do not know

Figure 6. Task 2 questionnaire—an example question in section 6 (Digital Models and Electronic Data Exchange Practices).

3.3 DISTRIBUTION OF RESPONSES

The research team received 36 responses from 20 states, including Illinois: 14 from DOT construction staff, 6 from DOT design staff, 10 from DOT surveying staff, and 6 from contractors. The distribution of responses by state and agency is shown in Table 4.

Table 4. Distribution of Responses by State and Agency

State	Contractor	DOT Construction	DOT Design	DOT Survey	Total
Illinois	1	2	1	2	6
Florida	4			1	5
Michigan			2	3	5
Colorado		1	1	1	3
Massachusetts				1	1
Arizona				1	1
Arkansas		1			1
California		1			1
Connecticut			1		1
Indiana	1				1
Kentucky		1			1
New Hampshire		1			1
New Jersey		1			1
North Carolina		1			1
Oregon		2			2
Pennsylvania				1	1
South Carolina		1			1
Virginia			1		1
West Virginia		1			1
Wyoming		1			1
Total	6	14	6	10	36

3.4 SURVEY RESULTS AND ANALYSIS

This section of the report provides a summary of the main findings of the survey. All questions and a summary of their response results are shown in Appendix H.

3.4.1 Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying

This section of the survey collected respondent feedback on the extent of use, satisfaction, benefits, success factors, and barriers associated with the use of GPS technology in construction surveying. Table 5 provides a summary of the main findings. All questions and a summary of their response results are shown in Appendix H.

Table 5. Summary of Survey Results of Section 2 (Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying)

Topic	Responses
Use of GPS technology	(1) Only one respondent reported not using GPS technology during the past year, and over 40% of all respondents reported the use by more than 75% of the projects. (2) Users are satisfied with the use of GPS technology in highway construction works, except for structure work. (3) Other than the listed uses of GPS technology, the technology is also used for as-built work.
Barriers	(1) The top-ranked reported barrier is GPS not being required by the DOT. For example, MDOT CPM jobs (mill/fill paving) do not require positioning. (2) The second-ranked reported barrier is the cost of acquiring and operating GPS equipment. (3) Limited accuracy, lack of GPS equipment (DOT), lack of GPS equipment (contractor), lack of specifications by the DOT, and lack of end-user technical skills (DOT and contractor) were also highly reported as barriers. (4) As reported, sometimes GPS is not the most appropriate method for the item being built. This reflects the limitation of the technology itself.
Benefits	(1) The main benefits that were reported are decrease in crew size, decrease in duration of surveying, decrease in staking workload, and decrease in cost. (2) Other reported benefits include saving time by eliminating multiple instrument setups, no line-of-sight issues, and never worrying about horizontal control getting destroyed.
Factors for successful implementation	(1) The factors that were ranked as important for successful implementation are cooperation of surveyors, cooperation of DOT designers, experience with GPS technologies (DOT and contractor), clear and comprehensive description of workflow and responsibilities, clear and comprehensive specifications, hardware/software vendor support, and end-user training (DOT and contractor). (2) Additional reported factors include FHWA awareness and support through Every Day Counts (EDC) rounds 2 and 3, which was rated as somewhat important.
Challenges and difficulties	(1) The challenges that were ranked the highest are equipment operators with insufficient training, all parties need to be on the same site calibration, all parties need to use the same data files. (2) Other challenges that were reported include unstable GPS signal, inefficient communication between contractor and DOT, reading and recording a wrong antenna height, harsh weather, and interruption due to power failure. (3) Additional reported difficulties include not matching existing control when trying to calibrate the site.

3.4.2 Control Surveying Using GPS Technology and Real-Time Kinematic (RTK) Method

This section of the survey collected respondent feedback on control surveying using GPS technology and the RTK method. Table 6 provides a summary of the main findings. All questions and a summary of their responses are shown in Appendix H.

Table 6. Summary of Survey Results of Section 3 (Control Surveying Using GPS Technology and Real-Time Kinematic Method)

Topic	Responses
Secondary control surveys	The majority of respondents reported that the contractor is responsible for performing secondary control surveys. It was also reported that either the DOT or the contractor could be responsible for performing secondary control surveys, which is project specific and depends on the pay item.
Additional control surveys	When AMG is used, the majority of respondents reported that additional horizontal and vertical control surveys are required.
Office procedures	(1) The majority of respondents reported that the following office procedures are conducted: comparing check shots with the known values, checking the base station coordinates and ellipsoid height for correctness, analyzing the GPS site calibration for a high scale factor and high residuals, and checking the data collector file for correctness and completeness. (2) Other reported procedures include checking all reports for high residuals.
Deliverables	(1) The majority of respondents reported that the following deliverables are required to be submitted by the surveyors for a GPS control survey: coordinates, primary control checks, GPS raw and solution files, coordinate metadata, project site map, and project narrative summary. (2) Other reported deliverables include post-process report, equipment logs, names of individuals and duties, calibration report for all points used in the survey, weather-condition report, and project-control diagram (PCD).
GPS survey specifications	The specifications for GPS control survey (including deliverables, base station network, accuracy, and tolerances) are included in the survey manual of most DOTs (e.g., Illinois DOT's *Survey Manual*). Only one respondent reported that no one monitors the GPS surveying work.

3.4.3 Construction Surveying Using GPS Equipment

This section of the survey collected respondent feedback on construction surveying when AMG (specifically GPS-guided machines) is used. Table 7 provides a summary of the main findings. All questions and a summary of their responses are shown in Appendix H.

Table 7. Summary of Survey Results of Section 4 [Construction Surveying When Automated Machine Guidance (AMG) Is Used]

Topic	Responses
Use of AMG	(1) More than 73% of the respondents reported that AMG is used in 50% of the projects or more. (2) Responses show that AMG is allowed to be used in grading, paving, and other highway construction work requiring excavation. However, one DOT reported having no experience with AMG. (3) It was also reported that (a) the contractor decides where to use the technology, and DOT works with them; (b) AMG is used for compaction on soils and pavement; and (c) a decision would have to be made when approached with AMG for each type of construction.
Conventional staking	(1) Most of the respondents reported that the DOT is requiring conventional staking when AMG is used. (2) There was a split opinion about the extent of use/requirement of conventional staking when AMG is used: 54% of the respondents agreed or somewhat agreed that the DOT is requiring too much traditional staking when AMG is used, whereas 46% of the respondents very disagreed, disagreed, or somewhat disagreed with this statement.
Equipment	(1) Essentially all respondents (17 of 18, with 1 not knowing) reported that no list of approved GPS equipment is provided by the DOT. (2) Responses show that the most commonly used vendors of AMG equipment are Trimble, Topcon, and Leica. (2) The majority of respondents reported that there is no specified frequency for equipment maintenance, with only one reporting a weekly maintenance requirement during the survey. Among those who reported no specified frequency, 33% maintain equipment irregularly; and 17% maintain equipment at the beginning of each survey. (3) The majority of contractors reported that all GPS-equipment components are maintained. Respondents reported that periodic manufacturer maintenance checks, cleaning, and calibration are performed.
Checking	(1) The primary control check was the top-reported check, among both the checks that are specified/required by the DOT and those that are voluntarily performed. (2) More than one-third of the respondents (including half of the surveyed contractors and half of the surveyed DOT surveying staff) reported that they perform GPS equipment checks at the beginning and end of each survey. Some respondents (including 40% of the surveyed DOT surveying staff) reported that they perform GPS equipment checks every 6 months, and others (10% of the surveyed contractors) reported that they perform the checks by request of the engineer or contractor. (3) All contractors reported that they perform daily site-calibration checks, even if not be required by the DOT (about half of the responses indicated that daily site-calibration checks are not required by the DOT). One respondent reported that the horizontal tolerance is 0.03 ft and the vertical tolerance is 0.065. (4) All contractors reported that the contractor conducts the spot checks, while DOT construction staff reported that both the contractor and the engineer conduct the spot checks. (5) Contractors reported that the contractor conducts the final checks, while DOT construction staff reported that either the contractor (witnessed by the engineer) or the engineer conducts the final checks. One respondent reported that the DOT has the final decision about the final acceptance checks. About 30% of the respondents reported that the vertical tolerance is 0.05 ft, and the horizontal tolerance is 0.04 ft. The majority of the rest of the respondents were not clear about the tolerances or reported that tolerance depends on pay item and varies on material.

Table 7 (Continued)

Topic	Responses
Training	(1) The majority of respondents reported that training on the use of the GPS system for both the contractor and the DOT staff is not required, but contractors voluntarily provide training to contractor staff. (2) When training of contractor staff is required, all respondents reported that multiple trainings are provided by the contractor, with the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT. (3) When training of DOT staff is required, all respondents reported that one training is provided by the contractor, prior to beginning the use of the GPS equipment.
Tolerances and specifications	The majority of respondents reported that the DOT specifications require that construction surveying/staking using GPS equipment has to achieve the same level of accuracy/tolerance as conventional staking.

3.4.4 Conventional Staking When Automated Machine Guidance (AMG) Is Used

This section of the survey collected respondent feedback on conventional staking when AMG is used. Table 8 provides a summary of the main findings. All questions and a summary of their responses are shown in Appendix H.

Table 8. Summary of Survey Results of Section 5 [Conventional Staking When Automated Machine Guidance (AMG) Is Used]

Topic	Responses
Staking specifications	The majority of respondents reported that the DOT has no written specifications for conventional staking when conducting construction surveying using GPS equipment and agreed that it is necessary to have such written specifications. The reported documents that include such specifications are included in Appendix H.
Staking procedures	About half of the respondents reported that there is no written staking procedure when conducting construction surveying using GPS equipment, and the majority agreed that it is necessary to have such written procedures. The reported documents that include such procedures are included in Appendix H.
Staking required or not	About half of the respondents reported that subgrade, pavement, and slope staking are still required by the DOT when conducting construction surveying using GPS equipment, while most of the others reported the opposite. The majority of respondents reported that structure layout staking is still required by the DOT.
Electronic devices used in staking	(1) The majority of respondents reported that electronic devices are used to collect and compute positions and distances when staking; and that to understand how to operate electronic devices or software, they refer to the manufacturer's manual. A few respondents reported the construction manual and the company guidance as references. (2) The majority of respondents reported that electronic devices with digital models and the actual ground elevation are used to compute and show the cut/fill of slope. (3) The most reported approach to measuring the ground is at each grade break. Some respondents reported that ground-measurement intervals vary and are as needed. One respondent reported that the ground is measured both at random points and at grade breaks. Some respondents reported that the measurement should not stop until the profile grade line for the station is reached, and others reported that the measurement should stop when the difference between the measured ground elevation and the elevation computed is less than the tolerance.

3.4.5 Digital Models and Electronic Data Exchange Practices

This section of the survey collected respondent feedback on digital models and electronic data exchange practices. Table 9 provides a summary of the main findings. All questions and a summary of their responses are shown in Appendix H.

Table 9. Summary of Survey Results of Section 6 (Digital Models and Electronic Data Exchange Practices)

Topic	Responses
Use of digital models	(1) Half of the respondents reported the use of digital models in some but less than 25% of the projects during the past year. (2) Respondents reported that MicroStation, GEOPAK, Trimble Business Center, InRoads, AutoCAD Civil 3D, and AutoCAD Map 3D are utilized in highway-construction surveys that are using digital modes. The majority of respondents reported satisfaction with those applications.
Benefits	(1) The majority of respondents reported the following benefits for the use of digital models in construction surveying of highways: simulating and visualizing the project more accurately, delivering models of higher quality to the contractor for AMG, combining multiple types of data such as CADD and geospatial data, standardizing the as-built data-collection process, improving access to highway-project information, and improving bid accuracy. (2) Other reported benefits include more quickly performing quantity takeoffs, facilitating information exchange among stakeholders, streamlining the different project phases such as design and construction, and decreasing the risk of redoing. (3) Different ranges of time savings (from less than 25% to over 50%) were reported. However, other respondents reported that the use of digital models does not save or add time but results in spending more time on earlier stages and less on later stages. The main activities reported as associated with time savings are grading, earth work and excavation, and site calibration and checks. Other activities reported as associated with time savings are project control, preparation of deliverables, paving, and pipe and drainage construction. (4) Different ranges of cost savings ("less than 10%" and "10% but less than 25%" of project cost) were reported. The main activities reported as associated with cost savings are staking for grading, staking slope, and preparation of survey data deliverables. Other activities reported as associated with cost savings are AMG, staking for paving, staking base, project-control surveying, staking drainage and pipeline, staking curb and gutter, and staking concrete barrier.
Barriers and difficulties	(1) The main barriers or challenges to successful implementation (when digital models are used in construction surveying) that were reported are lack of experience (DOT and contractor) and procedural issues. (2) Other reported barriers or challenges are difficulty of training, cost issues, lack of DOT specifications, inefficient communication among stakeholders, software unable to fulfill certain tasks, and software getting updated frequently. (3) Other barriers and difficulties that were reported include (a) specifications and workflows are under development, and (b) many projects not having 3D models developed in design due to the type of project and cost.
Success factors	The factors that were ranked as most important for successful implementation are cooperation of DOT designers, clear and comprehensive contract specifications, end-user training (DOT), and experience with software (DOT). In addition, half of the respondents reported clear and comprehensive description of workflow and responsibilities, experience with the software (contractor), and cooperation of surveyors. Other reported factors are end-user training (contractor), hardware/software vendor support, and equipment sharing between DOT and contractor.

Table 9 (Continued)

Topic	Responses
Responsibilities	(1) The majority of respondents reported that the contractor is responsible for providing, updating, and revising the digital models used for AMG. (2) The majority of respondents reported that the contractor is responsible for any errors or omissions in the digital models, or any discrepancies between the design files provided by the DOT and the digital models generated by the contractor. (3) Half of the respondents reported that the digital models generated by the contractor are not allowed to be different from the design files provided by the DOT, while 30% of the respondents reported the opposite case.
Electronic data	(1) Types of electronic files provided by DOTs: (a) The majority of respondents reported that cross-section and alignment data files are provided by the DOT. (b) Half of the respondents reported that background graphics files with roadway and drainage features such as centerlines, edges, and hull of ponds are provided by the DOT. (c) Other electronic data that were reported are machine control surface model files, existing and design surface models, and GPS site-calibration data. (2) The most reported time for DOT to provide electronic data to the contractor is at the contractor's request. Other reported times include after the contractor wins the bid, before the preconstruction conference, during the bidding of the project as part the reference information documents, or at advertising prior to bid letting. (3) The majority of respondents reported that the main uses of electronic data are to check quantities, build digital models, survey layout, and acquire accurate information about position, distance, etc. It was reported that the DOT recognizes electronic data as an approach to show the contractor the designer's intent, thus the electronic data are for information purpose only and are not contractual. (4) The majority of respondents reported satisfaction with providing electronic data to the contractor. (5) The main benefits that were reported are time savings, improved project quality, and fast identification of errors. Other reported benefits include more accurate digital models, cost savings, and more accurate bids.
Deliverables	(1) Deliverables: (a) The main deliverables, which should be submitted by the contractor to the DOT, that were reported are as-built construction plan, quality-control (QC) plan, and survey-control report. (b) Other reported deliverables include GPS/AMG work plan, report of post-project benchmarks, and survey notebooks. (2) The main formats of the digital models that were reported are DGN (MicroStation drawing files), LandXML, and TIN (triangulated irregular network). (3) The majority of respondents reported that the GPS/AMG work plan should contain a description of equipment and software, project secondary control, site-calibration procedure, and equipment calibration and maintenance procedure. In addition, half of the respondents reported definition of project boundaries and scope of work to be accomplished using GPS/AMG as part of the GPS/AMG work plan. (4) A few respondents reported that the GPS/AMG work plan is required to be submitted 30 days prior to primary field operation. One respondent reported 5 working days or one week prior to primary field operation.

CHAPTER 4: IDENTIFY POTENTIAL PRACTICES FOR EMPLOYMENT IN ILLINOIS (TASK 3)

The research team identified twelve primary potential practices, with details of how to implement them. The practices are (1) evaluation of construction methods, (2) automated machine guidance (AMG) equipment, (3) AMG work plan, (4) training, (5) digital models, (6) electronic files, (7) project control, (8) accuracy and tolerance, (9) construction spot checks, (10) site calibration and checks, (11) final checks, and (12) staking. Those practices were the basis for developing the written procedures related to the use of modern technologies in construction staking of highway projects (tasks 4, 5, and 6), including the second survey to IDOT employees (task 4). The practices were developed following four key principles:

- The practices cover the core issues of using AMG in construction surveying of highway projects, including evaluation of construction methods, AMG equipment, AMG work plan, training, digital models, electronic files, project control, accuracy and tolerance, construction spot checks, site calibration and checks, final checks, and staking for grading and paving.
- In describing the potential practices, some implementation details were covered (e.g., some roles and responsibilities of the contractor and the Department). Other implementation details were covered in tasks 5 and 6.
- These potential practices shall be read and interpreted together with other relevant documents including but not limited to
    - IDOT's *Survey Manual,* Chapter 3 "GPS"
    - IDOT's *Survey Manual,* Chapter 10 "Construction Surveys"
    - IDOT's *CADD Roadway and Structure Project Deliverables Policy*
    - IDOT's *Standard Specifications for Road and Bridge Construction*
- The practices could be integrated in the project workflow. There are four main phases in a project workflow: pre-bid, bidding, preconstruction, and construction. However, the practices are focused only on the preconstruction and construction phase. As shown in Figure 7, the preconstruction and construction phases are further decomposed into the following subphases:
    - Primary survey control: Provide primary project survey control. The result is provided to the contractor to set additional project control.
    - Preconstruction meeting and agreement on AMG work plan: During the preconstruction phase, the decision has to be made as to what extent (if any) AMG will be used in the project and how AMG will work under proper quality control. The contractor typically submits an AMG work plan. The Department and the contractor then discuss the AMG work plan and any changes needed in the plan.
    - AMG training: Determine the quantity and schedule of training (provided by the contractor) on the utilized AMG system to the personnel specific to the project.

- AMG construction, checking, and inspection: The contractor should refer to the specifications and requirements for AMG construction staking. Some conventional staking might be required by the Department.

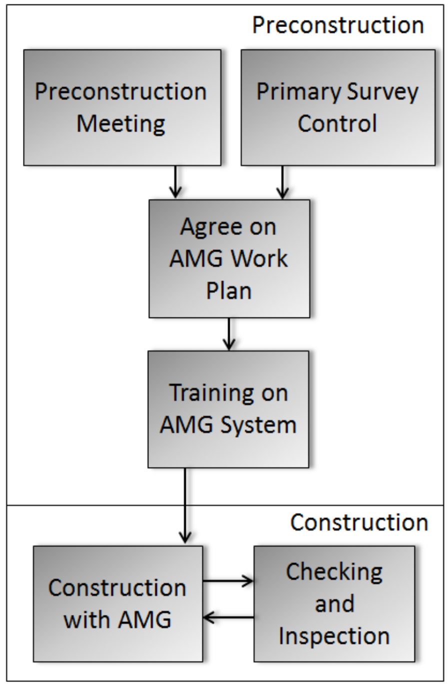


Figure 7. Typical AMG project workflow.

The description of the twelve practices, with the implementation details, is included in Appendix H.

CHAPTER 5: SURVEY/INTERVIEW IDOT STAFF AND ILLINOIS CONTRACTORS ON POTENTIAL PRACTICES FOR EMPLOYMENT IN ILLINOIS (TASK 4)

5.1 SURVEY PURPOSE AND METHODOLOGY

The purpose of the survey was to gather feedback from IDOT staff and Illinois contractors on the potential practices for adopting modern technologies in construction staking of highways in Illinois (identified in task 3). The practices were organized into eleven groups: (1) evaluation of construction methods, (2) automated machine guidance (AMG) equipment, (3) AMG work plan, (4) training, (5) electronic design files, (6) digital models used for AMG, (7) project control, (8) accuracy and tolerance, (9) quality assurance, (10) site calibration and checks, and (11) final checks.

The research team conducted a personal interview survey (also called a face-to-face survey) using a questionnaire. The research team first developed a draft questionnaire including the potential practices (identified in task 3) and a corresponding set of questions to solicit detailed feedback on each of the potential practices. In the September 28, 2016 TRP meeting, the research team discussed the draft questionnaire with the TRP. Based on the discussions during the meeting, the research team revised the questionnaire. Feedback was solicited on different aspects of the practices, including technical content, relevance, suitability, clarity, wording, etc. For example, the wording was discussed to ensure that it reflects the intent of serving as guidelines not specifications. The final questionnaire was then approved by the TRP; and the survey was launched on October 15, 2016.

The target respondents included (1) resident and field engineers, inspectors, and technicians, and surveyors from all nine IDOT districts and (2) contractors from the Associated General Contractors of Illinois and the Illinois Road and Transportation Builders Association. One interview meeting was scheduled in each district, where the meeting was attended by multiple IDOT staff from that district. The date, location, and number of participants for each interview meeting are listed in Table 10. A total of 78 responses were received from IDOT districts, and one response from a contractor.

Table 10. Dates, Locations, and Participants of Interview Meetings with IDOT Districts/Contractors

IDOT District/contractor	Date	Location	Number of respondents
District 1	October 31	Schaumburg	7
District 2	November 15	Dixon	11
District 3	October 28	Ottawa	4
District 4	November 15	Peoria	9
District 5	November 3	Champaign	8
District 6	November 1	Springfield	5
District 7	November 3	Effingham	18
District 8	November 1	Collinsville	8
District 9	November 2	Carbondale	8
K-Five Construction	December 1	Chicago*	1

*The meeting was conducted by phone, not face-to-face.

5.2 QUESTIONNAIRE DESIGN

The questionnaire was composed of twelve sections: (1) respondent information, (2) evaluation of construction methods, (3) equipment, (4) AMG work plan, (5) training, (6) digital models used for AMG, (7) electronic design files, (8) project control, (9) accuracy and tolerance, (10) quality assurance, (11) site calibration and checks, and (12) final checks. Each section in the questionnaire was composed of two parts:

- *The practice part:* This part included the full description of the potential practice. Some words/sentences were underlined to draw the attention of the respondents to particular parts that required extra feedback. Some alternative wording was also included in square brackets. Figure 8a shows an example of the practice part [of section 5 (Training)].
- *The question part:* This part consisted of questions on the respective practice to gather the respondents' feedback. Respondents were requested first to read the practice part and then answer the questions based on their knowledge and experience with the use of AMG. The last question of each section was a comprehensive question asking the respondent whether he/she generally agrees with the content of the section as written. Figure 8b shows an example of the question part [of section 5 (Training)].

The full questionnaire is included in Appendix G.

5. Section 5: Training

1) The Contractor shall provide [the Contractor staff] with training [on the use and operation] of the AMG equipment [prior to the start of any AMG work]. The Contractor shall provide [the Department staff] with training [on the use and operation] of the AMG system [and the use of GPS Rovers or other hand-held devices] [prior to the start of any AMG work]. The Department and the Contractor shall discuss and determine which Contractor staff and Department staff will participate in the training. As part of the staff, the Surveyors (IDOT's Surveyors and Contractor's Surveyors) may participate in the training to get familiar with the Contractor's AMG system or the GPS Rovers used for checking and inspection. The Surveyors can stay involved in the project using AMG by learning the capabilities of the AMG system and Rovers and being available to provide information to new surveyors and equipment operators who have difficulties in using such system or devices.
2) The Contractor shall provide more training upon the request of the Department. The Department shall request more training based on need.
3) The Contractor shall seek technical support from the equipment manufacturer or vendor, as appropriate, if/as necessary. The Department shall encourage the Contractor to seek such technical support, if/as needed.

(a)

Questions: (6)

1) Who shall receive the training?
[District engineer; Surveyors; Other]
2) For each, what is the frequency of training?
[One; At least one; Each month; Other]
3) For each, when shall the training be provided?
[Prior to the start of any AMG work; At the beginning of each month; Other]
4) For each, how many sessions per training?
[One; Two; As specified by the Department; Other]
5) For each, what shall be covered in the training?
[AMG equipment; Digital models; Software; Devices for review such as rovers; Other]
6) Do you agree with roles and responsibilities, types of training, time and frequency of training, and requirements that are described in the "Training" Section?
[1 to 6 scale]

(b)

Figure 8. Example of a section (section 5) from the questionnaire.

Three types of questions were developed: (1) multiple-choice questions, which asked the respondents to select one or more options among a number of options/alternatives; (2) dichotomous questions, in which there were two possible responses (e.g., yes/no); and (3) short-answer questions, which asked the respondents to provide specific information (e.g., specify other characteristics that make projects the best candidates for AMG methods). For multiple-choice questions that required the respondent's rating of agreement level, a six-point Likert scale was used, with 6 being "very agree" and 1 being "very disagree." For most multiple-choice questions, an "other" option—with a blank—was added so that the respondents could provide additional responses/information without being constrained by the response options provided. The respondents were encouraged to answer as many as questions as possible and make comments on the practices or the questions. The face-to-face format helped ensure high engagement in the interview and a high response rate for all questions.

The questions aimed to gather expert feedback on the details of technology implementation, such as responsibilities, submissions, timelines, methods and equipment, work planning, training, use of digital models and electronic files, project control, accuracy and tolerances, quality assurance, site calibration, and checking. The questions also aimed to gather feedback on whether a certain practice is suitable for being included in the *Construction Manual*. The content of each of the twelve sections is summarized as follows:

- Section 1 (Respondent Information) solicited respondent information, including name, agency, job title, role, years of experience, phone, and email.
- Section 2 (Evaluation of Construction Methods) aimed to gather respondent feedback on the evaluation of construction methods, including best-candidate projects for the implementation of AMG, conditions that would limit the use of AMG, and evaluation of the suitability of use of AMG.
- Section 3 (Automated Machine Guidance Equipment) aimed to gather respondent feedback on AMG equipment, including the use of a list of approved AMG equipment, submission of AMG equipment information, provision of AMG equipment, setup of GPS base station, and storage and maintenance of AMG equipment.
- Section 4 (Automated Machine Guidance Work Plan) aimed to gather respondent feedback on the AMG work plan, including the scope and items to be covered in the plan, as well as the review and evaluation of the plan by the Department.
- Section 5 (Training) aimed to gather respondent feedback on training related to the use of AMG, including provision of training to both contractor and Department staff and seeking technical support from the manufacturer. Questions covered issues such as frequency and timing of training, scope of training, and number of training sessions.
- Section 6 (Digital Models Used for AMG) aimed to gather respondent feedback on the use of digital models for AMG, including developing, submitting, updating, and revising the digital models; responsibility for errors or omissions in the models; reviewing and checking the models; and the responsibility for bearing the respective costs.
- Section 7 (Electronic Design Files) aimed to gather respondent feedback on the use of electronic files provided by the Department, including the scope of electronic files provided to the contractor, the timing to provide the files, the use and maintenance of the files, and the notification of errors or discrepancies in the files.
- Section 8 (Project Control) aimed to gather respondent feedback on project control when AMG is used in the project, including setup of control points, deliverables, and responsibility for provision of control points.

- Section 9 (Accuracy and Tolerance) aimed to gather respondent feedback on accuracy and tolerance requirements when AMG is used in the project.
- Section 10 (Quality Assurance) aimed to gather respondent feedback on quality-assurance practices when AMG is used in a project—including responsibility, timing, and methods for conducting spot checks; and provision and review of progress information.
- Section 11 (Site Calibration and Checks) aimed to gather respondent feedback on site calibration and checks when AMG is used in the project, including site-calibration procedures, number of points, and tolerances; and procedures to follow when the site-calibration check does not pass.
- Section 12 (Final Checks) aimed to gather respondent feedback on the final checking procedures when AMG is used, including locations and intervals to set stakes for checking, number of final checks, and checking criteria.

5.3 SURVEY RESULTS

The research team received 78 responses from all nine IDOT districts. The respondents included engineers, surveyors (including survey crew chief), inspectors, supervisors, and technicians. The titles of the respondents included field engineer, engineer technician, civil engineer, construction engineer, resident engineer, construction inspector, supervising field engineer, land surveyor, resident technician, surveyor, acting project-implementation engineer, survey crew chief/data coordinator, and area construction supervisor. The research team also received a response from a contractor who is a member of the Illinois Road and Transportation Builders Association.

5.3.1 General Feedback

Most of the respondents thought that the questionnaire provided rich information about the use of AMG and was comprehensive. The average time needed to finish the whole questionnaire was about 1 hour and 15 minutes. The remainder of this subsection summarizes the respondents' general feedback on (1) the overall content and scope of the practices and the written procedures (in view of its planned inclusion in IDOT's *Construction Manual*), and (2) the wording/writing style of the written procedures. Most of the respondents provided the following feedback:

- All the main practices (i.e., eleven main sections and general content) should be covered in the written procedures that would be included in IDOT's *Construction Manual*. The overall content and scope of the practices and the written procedures were viewed as suitable and relevant.
- Some of the written details provided, such as intervals of stakes and tolerance requirements, are project specific and can be found in IDOT's construction specifications; and therefore these do not need to be repeated in the written procedures.
- The wording/writing style of the practices/procedures should be modified, where/as applicable so that the document is not worded like specifications to the contractor.

Respondents had varied opinions on the following issues:

- Contractor providing AMG equipment such as rovers: Some respondents thought that it is not a good idea that contractors provide rovers because it is difficult to include rovers in pay items. By contrast, other respondents believed that it is a good arrangement that contractors provide rovers and suggested that contractors provide more than one rover (e.g., a rover for the use of the Department independent from the one used by the contractor).
- Whether conventional stakes are needed and how many stakes are needed: Generally, respondents from districts that use AMG less intensively believed that the same number of stakes is needed when using AMG (compared to conventional staking). By contrast, for respondents from districts that commonly use AMG, some believed that only a few stakes are needed; and others believed that no stakes are needed. The contractor respondent also believed that no stakes are needed for the process of AMG checks at the time of construction, as long as the checks and tolerances are met.
- Whether checks are needed and how many checks shall be performed: Some respondents reported that no checks are needed unless there is a problem. By contrast, most respondents reported that checks are needed, with the majority of them agreeing that the Department inspector should conduct such checks rather than the contractor conducting the checks with the Department's staff witnessing.

The detailed respondent feedback and questionnaire responses are summarized in the following subsections.

5.3.2 Evaluation of Construction Methods

The following points summarize the main findings:

- The respondents agreed to include this section in the *Construction Manual.*
- Most of the respondents agreed that the conditions that limit or exclude the use of AMG should be included in the written procedures, but opinions varied slightly.
- Most of the respondents thought that the contractor should submit the notification for use of AMG before or at the preconstruction meeting.

All questions and a summary of their responses are shown below (see Tables 11 to 14).

Question 1: If you suggest other characteristics that make projects the best candidates for AMG methods, please specify.

Table 11. Survey Results—Characteristics Making Projects Best Candidates for AMG Methods

No.	Result
1	Complex project. The more complex the project is, the more beneficial the use of AMG and digital models is.
2	Urban reconstruction and larger reconstruction projects
3	Small earthwork projects
4	Projects with limited site width due to construction staging or physical constraints

Question 2: Do you agree that the conditions that limit or exclude the use of AMG shall be included in the guidance document? Such conditions include but are not limited to

- Widening with narrow strip additions
- Designs, such as overlays, that are not based on an existing digital terrain modeling (DTM). Overlays with new profiles or cross-slope construction benefit from AMG.
- Designs that do not exist in a 3D digital environment (Note that all jobs are capable of being modeled.)
- Structures
- Projects that are under a tree canopy, in narrow canyons, or next to tall buildings that interfere with GNSS signals (Note that robotic total stations or traditional methods are viable solutions.)
- Design difficulties that would prevent the creation of an accurate and complete DTM (If a surface model can be prepared in difficult situations, it saves on rework.)

Table 12. Survey Results—Include Conditions that Limit or Exclude the Use of AMG

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q2	4 (5%)	6 (9%)	5 (6%)	15 (19%)	39 (51%)	8 (10%)	4.34	5	5	1.29	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Question 3: When shall the contractor submit the notification for use of AMG?

Table 13. Survey Results—Time for Contractor to Submit Notification of AMG Use

Response option	Result
After project award	12 (18%)
Before the preconstruction meeting	36 (54%)
Other	At preconstruction meeting: 16 (22%); Prior to use/start of project: 2 (3%); Both options: 2 (3%)

Question 4: Do you agree with the roles and responsibilities, submissions, timeline, evaluation criteria, and requirements that are described in the "Evaluation of Construction Methods" section?

Table 14. Survey Results—Summary Question for Section 2 (Evaluation of Construction Methods)

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q4	0 (0%)	0 (0%)	2 (3%)	16 (22%)	49 (67%)	6 (8%)	4.81	5	5	0.61	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Respondents' comments:

- Whether or not to use AMG should be the contractor's decision/choice.
- The following conditions always limit the use of AMG:
    - Designs, such as overlays, that are not based on an existing digital terrain modeling (DTM). Overlays with new profiles or cross slope-construction benefit from AMG
    - Structures
- The following conditions might or might not limit the use of AMG—it is project specific, and should be assessed case by case:
    - Widening with narrow strip additions
    - Designs that do not exist in 3D digital environments (Note that all jobs are capable of being modeled.)
    - Projects that are under a tree canopy, in narrow canyons, or next to tall buildings that interfere with GNSS signals (Note that robotic total stations or traditional methods are viable solutions.)
    - Design difficulties that would prevent the creation of an accurate and complete DTM (If a surface model can be prepared in difficult situations, it saves rework.)

5.3.3 Automated Machine Guidance Equipment

The following points provide a summary of the main findings:

- The respondents agreed to include this section in the *Construction Manual,* with minor changes.
- Most of the respondents agreed that the AMG equipment information should be included in the AMG work plan.
- Most of the respondents agreed that the AMG equipment information should include a description of the manufacturer, the model used, and the software version. Other information mentioned by the respondents includes accuracy, radio frequency, operation manual, and last calibration date of the equipment.
- Most of the respondents agreed that the Department does not have to provide a list of approved AMG equipment, thereby leaving to the contractor the choice of specific AMG equipment to use.
- The most repeated response option for maintenance frequency was "as needed."

All questions and a summary of their responses are shown below (see Tables 15 to 19).

Question 1: Do you agree that the contractor submits the AMG equipment information as a part of the AMG work plan?

Table 15. Survey Results—Contractor Submits AMG Equipment Information as Part of AMG Work Plan

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q1	0 (0%)	0 (0%)	1 (1%)	6 (8%)	45 (59%)	24 (32%)	5.21	5	5	0.63	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Question 2: What shall the AMG equipment information include?

Table 16. Survey Results—Content of AMG Equipment Information

Response option	Result
A description of the manufacturer	32 (82%)
A description of the model	32 (82%)
A description of the software version	31 (79%)
Other	Accuracy; radio frequency; operating manual; last calibration date of equipment

Question 3: Do you agree that the Department does not need to provide a list of approved AMG equipment?

Table 17. Survey Results—Department Does Not Need to Provide a List of Approved Equipment

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q3	0 (0%)	5 (7%)	11 (15%)	17 (23%)	31 (40%)	11 (15%)	4.43	5	5	1.11	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Question 4: What is the preferred frequency for equipment maintenance?

Table 18. Survey Results—Preferred Frequency for Equipment Maintenance

Response option	Result
At least once at the beginning of each surveying work	7 (13%)
Every 6 months	12 (24%)
Weekly during the survey	5 (7%)
As needed	23 (43%)
Other	As manufacturer requires/recommends and if problem arises; annually; once a month; bimonthly; daily

Question 5: Do you agree with roles and responsibilities, submissions, timeline, equipment operation and maintenance guidelines, and requirements that are described in the "Automated Machine Guidance Equipment" section?

Table 19. Survey Results—Summary Question for Section 3 (Automated Machine Guidance Equipment)

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q5	0 (0%)	0 (0%)	3 (4%)	21 (28%)	48 (63%)	4 (5%)	4.70	5	5	0.63	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Respondents' comments:

- A list of approved AMG equipment would help the engineer be familiar with the equipment from job to job.
- When the contractor provides new equipment, training should be provided "as necessary."
- The Department should have access to the equipment provided by the contractor at all times during the work.
- The Department field staff needs to receive technical support from the contractor.
- On larger projects, two different rovers should be used to check against each other for errors.
- Before the job starts, the contractor can send the Department field staff tutorial videos on how to use the rover.
- Asking the contractor to submit the equipment information 30 days prior to use is too early and might cause contractual problems. Submission 14 days prior to use is suggested.
- Some respondents thought that it is difficult to include rovers in pay items.
- Some respondents believed that it is better that the contractor provides the equipment. In addition, they suggested that
  - The contract should specify that the contractor is required to provide the equipment.
  - The provided equipment must be compatible with the earth software programs to calculate cut and fill used by the district.
  - More than one rover would be better on longer or more complex projects.
  - The equipment should be provided at least 7 days before actual use.

5.3.4 Automated Machine Guidance Work Plan

The following points provide a summary of the main findings:

- The respondents agreed to include this section in the *Construction Manual.*

- The AMG work plan should be submitted, if necessary, to the engineer, survey crew chief, and/or consultant.
- More than half of the respondents selected that the AMG work plan should be submitted "for review"; and more than 40% of the respondents selected "for information" or "for approval." The main reason for not selecting "for approval" was that the AMG work plan will change, so approval is not necessary.
- In addition to the listed items, respondents mentioned other items to be included in the AMG work plan (Please see the detailed results of the second question.).
- The majority of respondents agreed that, if the contractor does not have experience with the use of AMG systems or the experience is not applicable to the specific project, the engineer may ask the contractor to perform a test session.
- Respondents agreeing with this statement also suggested that
    - A technical representative from the contractor should be on hand at the start of the job and/or for the test session.
    - Training for the contractor staff might be needed.
- Respondents disagreeing with the statement suggested that
    - Additional checks at the start-up and for the first portion of the project should be required.
    - If the experience is not applicable, decline the use of AMG for the project.

All questions and a summary of their responses are shown below (see Tables 20 to 25).

Question 1: Regarding the submission of the AMG work plan

1.a Should the AMG work plan be submitted to "the engineer?"

Table 20. Survey Results—Submission of AMG Work Plan

Response option	Result
To engineer	61 (94%)
Other	IDOT surveyor; district survey staff; survey crew chief; consultant. Should not be submitted to the engineer.

1.b Should the AMG work plan be submitted "for information," "for review," or "for approval?"

Table 21. Survey Results—Purpose of AMG Work Plan Submission

Response option	Result
For information	29 (42%)
For review	38 (55%)
For approval	31 (45%)

1.c When shall the contractor submit the AMG work plan?

Table 22. Survey Results—Time to Submit the AMG Work Plan

Response option	Result
Before the preconstruction meeting	20 (29%)
At the preconstruction meeting	36 (52%)
At least 30 days prior to use	20 (29%)
Other	At least 14 days prior to use

Question 2: In addition to the aforementioned items, what else shall the AMG work plan include? If any, please specify.

Table 23. Survey Results—Additional Items to Include in the AMG Work Plan

No.	Result
1	Contractor personnel responsible for AMG
2	Backup plan in case AMG is malfunctioning
3	Personnel to be using AMG equipment on a daily basis
4	Data/models to be entered
5	Radio frequencies to be used
6	Designated contact person with contractor to answer questions or issues during the project
7	Proof that the contractor's specified software is compatible to use with the Department's software. If it is not compatible with the Department's software, provide an alternative.
8	Proposed digital models and control file for QA/QC by Department
9	Tutorial videos
10	Where AMG will be used
11	Software update information

Question 3: Do you agree that if the contractor does not have experience with the use of AMG systems or the experience is not applicable to the specific project, the engineer may ask the contractor to perform a test session?

Table 24. Survey Results—Test Session if Contractor Has No Experience with AMG

Response option	Result
Yes	59 (86%)
No	7 (10%)
Other	Require additional base stations; should apply to all or none; ultimately, contractor's responsibility

Question 4: Do you agree with the roles and responsibilities, submissions, timeline, and requirements that are described in the "AMG Work Plan" section?

Table 25. Survey Results—Summary Question for Section 4 (AMG Work Plan)

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q4	0 (0%)	0 (0%)	3 (4%)	17 (23%)	52 (70%)	2 (3%)	4.72	5	5	0.58	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Respondents' comments:

- If using contractor staking/layout, a district surveyor may not be needed.
- The description of equipment should include a proof that all the latest software updates have been completed.
- The quality-control plan should include daily checks.
- For the contractor's prior experience with using AMG systems, a minimum number of years of recent experience shall be defined, such as the last 3 years.
- The review of the AMG work plan could be conducted during a separate meeting from the preconstruction meeting. In addition to the resident/field engineer and the technicians, a dedicated IDOT construction survey crew or the consultant survey crew should also participate in the meeting.

5.3.5 Training

The following points provide a summary of the main findings:

- The respondents agreed to include this section in the *Construction Manual,* with revisions.
- For the recipients of AMG training, most of the respondents selected "engineer" and/or "surveyor." Other respondents additionally mentioned inspector, on-site Department and contractor construction staff, contractor laborers/workers on the project, and anyone involved with layout.
- For the frequency of training, most of the respondents preferred "as needed" or "initial one and then as needed" rather than a specific number.
- For the time of training, most of the respondents selected "prior to start of any AMG work."
- For the number of training sessions, more than half of the respondents selected "as needed or as specified by the engineer."
- For the training content, all four options (AMG equipment, digital models, software, and rovers) were selected by more than half of the respondents.

All questions and a summary of their responses are shown below (see Tables 26 to 28).

Question 1: Who shall receive the training?

Table 26. Survey Results—Recipients of AMG training

Response option	Result
Engineer	29 (47%)
Surveyor	23 (37%)
Other	Inspector: 12 (19%) On-site Department and contractor construction staff/technicians: 10 (16%) Contractor laborers/workers on the project: (5%) Anyone involved with layout (layout technicians): (3%) All potential users of the equipment: 1 (2%)

Question 2: Details about training.

Table 27. Survey Results—Details about Training

Question	Response option	Responses offered by respondents
What is the frequency of training?	One: 21 (31%) At least one: 19 (28%)	As needed; initial one with optional follow-ups or annual refresher/updating training; yearly basic training and more in-depth training before the project
When shall the training be provided?	Prior to the start of any AMG work: 59 (86%)	As needed; after the preconstruction meeting; at the start of the work
How many sessions per training?	One: 12 (19%) Two: 7 (11%) As specified by engineer or as needed: 42 (66%)	Until the construction staff is trained
What shall be covered in the training?	AMG equipment: 40 (68%) Digital models: 39 (66%) Software: 40 (68%) Devices for review such as rovers: 45 (76%)	As needed; AMG equipment: how to use, where to use, and examples; upload of electronic data; full overview once and specific rover training; QC/QA procedures; AMG equipment for checking and layout

Question 3: Do you agree with roles and responsibilities, types of training, time and frequency of training, and requirements that are described in the "Training" section?

Table 28. Survey Results—Summary Question for Section 5 (Training)

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q3	0 (0%)	1 (1%)	2 (3%)	25 (33%)	43 (58%)	4 (5%)	4.63	5	5	0.69	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Respondents' comments:

- It might be costly if the contractor provides training. In addition, it is not clear how the contractor bids the training.
- Someone properly trained must be available at all times to answer questions from the Department staff.
- Respondents who disagreed that the contractor should provide training thought that the Department would need either a dedicated construction survey crew above and beyond the inspection staff or a survey consultant to deal with GPS issues in AMG projects.

5.3.6 Digital Models

The following points provide a summary of the main findings:

- The respondents agreed to include this section in the *Construction Manual.*
- Most of the respondents agreed that the contractor is responsible for developing, updating, and revising the digital models, and is responsible for any errors or omissions in the digital models. Respondents who disagreed thought that, in the future, the Department would assume those responsibilities. Opinions varied on the contractor's responsibility for errors or discrepancies in the design files provided by the Department.
- Most of the respondents agreed that the contractor should bear the costs associated with the digital models (because currently contractors are responsible for developing and providing the digital models).
- Most of the respondents agreed that the contractor should submit the digital models to the engineer at least 30 days prior to the start of the AMG work. More than half of the respondents thought that the digital models should be submitted "for information."
- Most of the respondents agreed that the contractor should provide the digital model data required by devices used for inspection to the engineer at least 30 days prior to the start of the AMG work.
- Most of the respondents agreed that the contractor should provide the digital models in a specific data format or compatible with the specific software used.

All questions and a summary of their responses are shown below (see Tables 29 to 36).

Question 1: Do you agree that the contractor is responsible for

a. Developing the digital models
b. Updating and revising the digital models
c. Any errors or omissions in the digital models
d. Any errors or discrepancies in the design files or contract documents provided by the Department

e. Bearing all respective costs including but not limited to the cost of developing the digital models, the cost of manipulating the design files provided by the Department, the cost that may be incurred due to the discrepancies between the contractor's digital models and the design files provided by the Department, and the cost of rework or reconstruction that may be incurred due to errors in the application of AMG techniques

Table 29. Survey Results—Responsibilities Related to the Digital Models

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q1.a	1 (2%)	6 (8%)	4 (5%)	8 (11%)	31 (41%)	25 (33%)	4.83	5	5	1.25	Agree
Q1.b	2 (3%)	2 (3%)	3 (4%)	7 (9%)	30 (39%)	30 (42%)	5.04	5	6	1.16	Agree
Q1.c	1 (1%)	3 (5%)	2 (4%)	7 (9%)	27 (36%)	34 (45%)	5.14	5	6	1.11	Agree
Q1.d	7 (9%)	16 (21%)	13 (17%)	6 (8%)	26 (36%)	7 (9%)	3.65	4	5	1.57	Somewhat agree
Q1.e	1 (1%)	2 (3%)	6 (7%)	9 (12%)	33 (46%)	23 (31%)	4.89	5	5	1.10	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Question 2: Do you agree that the contractor shall submit the digital models to the engineer?

Table 30. Survey Results—Submission of Digital Models by the Contractor to the Engineer

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q2	0 (0%)	2 (3%)	2 (3%)	12 (17%)	37 (50%)	20 (27%)	4.97	5	5	0.89	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

If agree (4 to 6 on the scale):

a. Should the digital models be submitted "for information," "for review," "for approval?"

Table 31. Survey Results—Purpose of Digital Model Submission

Response option	Result
For information	38 (55%)
For review	34 (49%)
For approval	20 (29%)

b. When shall the contractor submit the digital models?

Table 32. Survey Results—Time to Submit the Digital Models

Response option	Result
At least 30 days prior to the start of the AMG work	46 (73%)
Other	At the preconstruction meeting; prior to the start of the work, without specific days; 2 weeks; as soon as possible

c. What is the method for the engineer to check the digital models? Specify responses:

- Not checking the digital models
  - The digital models are only for information purpose, and the Department is not responsible for checking the models.
  - Currently unable to check the digital models
  - The engineer should not check the digital models because, if he/she does, then the Department would assume responsibility for errors or omissions in the models.
- Methods used to check the digital models:
  - Check line/grade against plan line/grade.
  - Hand-check selected points.
  - Spot-check in the field: whether the model is compatible with Microstation plans.
  - Verify with cross section 10% of the job.
  - Use profile, station, and cross section to calculate spot checks.
  - Spot-check with rover supplied by contractor.
  - Independent check with Department equipment; independent side-by-side check
  - The dedicated construction survey staff should be responsible for checking; the project engineer does not have the required knowledge.
  - Check with existing terrain elevations; check with tape measure against typical cross sections; and check with the Department design/CADD staff.

Question 3: Do you agree that the contractor shall provide digital model data required by devices used for review or inspection to the engineer?

Table 33. Survey Results—Contractor Providing Digital Model Data for Use in Review or Inspection Equipment

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q3	0 (0%)	2 (3%)	3 (4%)	15 (21%)	42 (57%)	11 (15%)	4.78	5	5	0.85	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

If agree (4 to 6 on the scale), when shall the contractor provide such data?

Table 34. Survey Results—Time to Provide Digital Model Data

Response option	Result
At least 30 days prior to the start of the AMG work	36 (64%)
Other	Prior to the start of the work, without specific days; 2 weeks; as soon as possible

Question 4: Do you agree that the contractor shall provide the digital models in a specific data format or compatible with specific software?

Table 35: Survey Results—Contractor Providing the Digital Models in a Format Compatible with Specific Software

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q4	0 (0%)	5 (7%)	7 (10%)	8 (11%)	39 (54%)	13 (18%)	4.67	5	5	1.09	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

If agree (4 to 6 on the scale), please specify the data format or the software.

Responses:

- Whatever format is compatible with AMG equipment being used
- Whatever software the district is using
- Compatible with Department equipment or supplied computer with software
- Compatible with GeoPAK/trimble (e.g., power Geopak and Trimble Business Center)

Question 5: Do you agree with the roles and responsibilities, submissions, timeline, and requirements that are described in the "Digitals Models" section?

Table 36. Survey Results—Summary Question for Section 6 (Digital Models)

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q5	1 (1%)	1 (1%)	2 (3%)	26 (36%)	39 (54%)	4 (5%)	4.55	5	5	0.81	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Respondents' comments:

- The Department needs to catch up and start to supply plans/models that can be used in AMG equipment.
- Contractor's digital models should be submitted to the engineer upon request; but the information should be reviewed or checked by the dedicated survey staff, or CADD or design staff, if necessary (e.g., when an error is found). The submission is not a must.
- The respondents agreed that currently the contractor is responsible for developing the digital models, whereas in the future the Department will be responsible for developing the digital models. Thus, the Department might also be responsible for the errors or omissions.
- If the contractor chooses to use AMG, then he/she should bear all the costs except those arising from errors in the design files provided by the Department.
- The digital models should not be submitted for approval because if the Department approves it while there are errors, the contractor will assume the Department is responsible for all costs arising from those errors.

5.3.7 Electronic Files

The following points provide a summary of the main findings:

- The respondents agreed to include this section in the *Construction Manual.*
- Opinions varied on the time to provide the electronic files; but the most selected options were "after project award and before the preconstruction meeting," "upon the request of the contractor," and "before bidding."
- Most of the respondents agreed that the Department should provide the electronic files in the native format of the software application by which they were generated and take no responsibilities to convert the file format.
- Most of the respondents disagreed that the Department has no responsibility to provide these electronic files or 3D data used for the AMG system.
- Most of the respondents agreed that the electronic files provided to the contractor are for convenience only, and the Department assumes no responsibility for the sufficiency or accuracy of the electronic files provided. But the opinions varied slightly.

All questions and a summary of their response results are shown below (see Tables 37 to 42).

Question 1: When shall the Department provide the following electronic files?

a) Alignment data
b) Cross sections
c) Background graphics files with roadway and drainage features such as centerlines, edges, and hull of ponds
d) Machine control surface models, or existing and design surface models
e) GPS site-calibration data
f) Project-control information

Table 37. Survey Results—Time to Provide Electronic Files

Response option	Result
Before biding	15 (22%)
During biding	5 (7%)
After project award and before the preconstruction meeting	27 (40%)
After the preconstruction meeting and before any construction work using AMG starts	3 (4%)
Upon the request of the contractor	16 (24%)
Other	Before any construction work; at the preconstruction meeting

Question 2: Do you agree that the Department provides electronic files in the native format of the software application by which they were generated and take no responsibilities to convert the file format?

Table 38. Survey Results—Department Providing Electronic Files in the Native Format

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q2	0 (0%)	0 (0%)	3 (4%)	9 (13%)	34 (48%)	25 (35%)	5.14	5	5	0.79	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Question 3: Do you agree that the Department has no responsibility to provide these electronic files or 3D data used for the AMG system?

Table 39. Survey Results—Department Not Responsible for Providing Electronic Files

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q3	3 (4%)	14 (20%)	19 (28%)	14 (20%)	17 (24%)	3 (4%)	3.54	3	3	1.28	Somewhat disagree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Question 4: Do you agree that the electronic files provided to the contractor are for convenience only and are not part of the contract documents?

Table 40. Survey Results—Electronic Files Are for Convenience Only

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q4	3 (4%)	4 (6%)	10 (14%)	19 (27%)	28 (40%)	6 (9%)	4.19	4	5	1.21	Somewhat agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Question 5: Do you agree that the Department assumes no responsibility for the sufficiency or accuracy of the provided electronic files?

Table 41. Survey Results—Department Not Responsible for Sufficiency/Accuracy of Electronic Files

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q5	2 (3%)	8 (11%)	14 (20%)	15 (21%)	26 (37%)	6 (8%)	4.03	4	5	1.27	Somewhat agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Question 6: Do you agree with the roles and responsibilities, deliverables, and requirements that are described in the "Electronic Files" section?

Table 42. Survey Results—Summary Question for Section 7 (Electronic Files)

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q6	2 (3%)	2 (3%)	6 (9%)	26 (37%)	30 (42%)	4 (6%)	4.31	4	5	1.01	Somewhat agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Respondents' comments:

- About the time to provide electronic files:
  - If the information is given out before bidding, it must be provided to every prospective bidder—along with the letting plans. The electronic files should probably be listed at letting as being available after award.
  - The electronic files should be provided if requested; the contractor should know the condition of the electronic files for bid, because currently there is little consistency.
- The Department should make every effort to provide electronic files. It is very helpful to the resident/field personnel during the project.

- The first point of this practice (about the engineer's developing the survey data) is problematic (and might better be removed).
- It is the contractor's responsibility to verify the elevations and locations of all ties in points to existing pavement or structures and provide verification and any adjustments made to the model.

5.3.8 Project Control

The following points provide a summary of the main findings:

- The respondents agreed to include this section in the *Construction Manual.*
- Most of the respondents agreed that control surveying using GPS method shall comply with IDOT's *Survey Manual,* the chapter on GPS.
- Most of the respondents agreed that the Department is responsible for setting the primary control points and providing the project-control information to the contractor before or at the preconstruction meeting.
- More than half of the respondents agreed that the contractor is responsible for setting the secondary control points and any additional control points; and is also responsible for verifying, maintaining, and documenting all project-control points; but opinions varied slightly.
- More than 40% of the respondents selected "1000 feet" as the interval for secondary control points when GPS-guided machine systems are used.

All questions and a summary of their responses are shown below (see Tables 43 to 48).

Question 1: Do you agree that the control surveying using GPS method shall comply with IDOT's *Survey Manual,* the chapter on GPS?

Table 43. Survey Results—Complying with IDOT's Survey Manual, Chapter on GPS

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q1	0 (0%)	0 (0%)	0 (0%)	11 (15%)	47 (64%)	15 (21%)	5.05	5	5	0.59	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Question 2: Do you agree that the Department is responsible for

a) Setting the primary control points
b) Providing the project-control information to the contractor

Table 44. Survey Results—Department's Responsibilities Related to Primary Control

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q2.a	0 (0%)	2 (3%)	5 (7%)	11 (15%)	42 (57%)	13 (18%)	4.81	5	5	0.90	Agree
Q2.b	1 (1%)	1 (1%)	1 (1%)	4 (5%)	52 (71%)	15 (21%)	5.03	5	5	0.80	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Question 3: When shall the Department provide the project-control information to the contractor?

Table 45. Survey Results—Time to Provide the Project-Control Information to the Contractor

Response option	Result
Before preconstruction meeting	24 (36%)
At the preconstruction meeting	28 (42%)
Other	When requested (8); before the start of the work (e.g., 14 days) (2); after award (2); currently in plans (5); include as a bid document (1); before developing the AMG work plan (contractor needs the information to develop the AMG plan, should be included as part of the AMG plan) (1)

Question 4: Which party shall be responsible for each of the following?

- Setting the secondary control points
- Setting any additional control points
- Verifying, supplementing, and maintaining the project-control points before construction and regularly during construction
- Documenting all project-control points in the project control report

Table 46. Survey Results—Responsibilities Associated with Setting and Maintaining Control Points

Item	Department	Contractor	Both	Project specific
Setting the secondary control points	0 (0%)	54 (74%)	13 (18%)	6 (8%)
Setting any additional control points	1 (1%)	52 (72%)	14 (19%)	6 (8%)
Verifying, supplementing, and maintaining the project-control points before construction and regularly during construction	1 (1%)	49 (68%)	20 (28%)	2 (3%)
Documenting all project-control points in the project control report	3 (4%)	40 (58%)	22 (32%)	4 (6%)

Question 5: What is the interval of secondary control points when a GPS-guided machine system is used?

Table 47. Survey Results—Interval of Secondary Control Points

Response option	Result
Not exceed 2640 feet	6 (11%)
1000 feet	25 (44%)
Other	Based on equipment/manufacturer; as requested; job specific; 500 ft; 250 ft

Question 6: In addition to the information mentioned above, what other deliverables about the control survey shall be provided? Specify. *Responses:* Alignment points and benchmarks; datums.

Question 7: Do you agree with the roles and responsibilities, submissions, timeline, and requirements that are described in the "Project Control" section?

Table 48. Survey Results—Summary Question for Section 8 (Project Control)

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q7	0 (0%)	0 (0%)	2 (3%)	18 (24%)	48 (65%)	6 (8%)	4.78	5	5	0.62	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Respondents' comments:

- The responsibilities associated with setting and maintaining control points are project specific and depend on the contract documents. For example, if it is a new roadway through a rough terrain or large area, it may be beneficial for the contractor to help in setting the primary control points.
- The secondary control points should be determined by the contractor and provided in the AMG plan.
- When the contractor sets the secondary and any additional control points, the Department shall be involved by
    - Checking and verifying those control points
    - Witnessing and helping in setting those control points
    - Setting additional control points if needed
- Verifying, supplementing, maintaining, and documenting the project-control points before construction should be the responsibility of the Department and should be the responsibility of the contractor after construction begins.
- The intervals of control points are project specific and could be determined as recommended by the survey equipment manufacturer.

5.3.9 Accuracy and Tolerance

The respondents agreed to include this section in the *Construction Manual.* A summary of the responses is shown in Table 49.

Question 1: Do you agree with the roles and responsibilities, and the accuracy and tolerance requirements that are described in the "Accuracy and Tolerance" section?

Table 49. Survey Results—Summary Question for Section 9 (Accuracy and Tolerance)

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q1	0 (0%)	0 (0%)	0 (0%)	6 (8%)	46 (60%)	24 (32%)	5.24	5	5	0.58	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Respondents' comments:

- The engineer (or the reader of this written procedures) should refer to the specifications to find the requirements on accuracy and tolerances for different projects.
- One respondent suggested adding a statement of "no pay" if the AMG does not work for layout.

5.3.10 Quality Assurance

The following points provide a summary of the main findings:

- The respondents agreed to include this section in the *Construction Manual.*
- More than half of the respondents agreed that the spot checks should be performed by the engineer.
- Most of the respondents thought that the spot checks could be performed at any time during construction.
- Most of the respondents thought that the spot checks should include checks of machine control results and actual stakes (if any).
- Most of the respondents agreed that the spot checks (and other construction checks) should be conducted using conventional survey methods, independent GPS equipment (such as rovers with project digital models), or a combination of the two approaches.

All questions and a summary of their responses are shown below (see Tables 50 to 54).

Question 1: Who shall perform spot checks?

Table 50. Survey Results—Responsibility to Perform Spot Checks

Response option	Result
Engineer	48 (67%)
Other	Contractor; surveyor; field technicians

Question 2: When shall spot checks be performed?

Table 51. Survey Results—Time to Perform Spot Checks

Response option	Result
Before construction	16 (22%)
At any time during the construction	65 (89%)
Other	Daily; monthly; as needed

Question 3: What are the elements that should be included in a spot check?

Table 52. Survey Results—Contents of Spot Check

Response option	Result
Machine control results	39 (72%)
Surveying calculations	32 (59%)
Field procedures	32 (59%)
Actual staking	42 (78%)
Records and documentation	32 (59%)
Other	Any elements deemed necessary by the engineer

Question 4: Do you agree that the spot checks (and other construction checks) will be conducted using conventional survey methods, independent GPS equipment (such as rovers with project digital models), or a combination of the two approaches?

Table 53. Survey Results—Spot Checks Using Conventional Survey Methods, Independent GPS Equipment, or Both

Response option	Result
Yes	69 (92%)
No	6 (8%)

Question 5: Do you agree with the roles and responsibilities, timeline, and requirements that are described in the "Quality Assurance" section?

Table 54. Survey Results—Summary Question for Section 10 (Quality Assurance)

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q5	0 (0%)	1 (1%)	0 (0%)	18 (24%)	47 (64%)	8 (11%)	4.82	5	5	0.66	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Respondents' comments:

- Most checks are done as constructed—for example, earth grade, subbase grade, edge of pavement layout, sewer layout, etc.
- Spot checks should be performed on a daily basis.
- Spot checks depend on what is being checked—earthwork and portland cement concrete (PCC) or potential vertical rise (PVR) should have different checks.
- The decision to conduct construction checks using conventional survey methods, independent GPS equipment, or a combination of the two approaches depends on accuracy requirements of pay items and should be left to the engineer and the inspector.

5.3.11 Site Calibration and Checks

The following points provide a summary of the main findings:

- The respondents agreed to include this section in the *Construction Manual.*
- More than half of the respondents agreed that three horizontal control points are needed. Opinions on other options varied.
- Most of the respondents agreed that two or more control points are needed to perform the daily site-calibration checks.
- Nearly half of the respondents selected +/- 0.03 ft as horizontal tolerance, and more than half of the respondents selected 0.05 ft or less as vertical tolerance.
- More than half of the respondents agreed that the contractor should submit the daily site-calibration check results to the engineer.

All questions and a summary of their responses are shown below (see Tables 55 to 60).

Question 1: How many control points shall the surveyor use to perform site calibration?

Table 55. Survey Results—Number of Control Points Used for Site Calibration

Response option	Result
Three known horizontal control points for horizontal site calibration	30 (54%)
Two control points per mile along the project area if this results in more control points than the minimum	8 (14%)
Other	Four points surrounding site; five points each project; minimum three horizontal points and one vertical point; depends on project size/scope; depends on survey equipment; three or two points per mile

Question 2: How many control points shall the contractor's surveyor use to perform the daily site-calibration checks?

Table 56. Survey Results—Number of Control Points Used for Site-Calibration Checks

Response option	Result
Two or more	53 (95%)
Other	At least three control points; as needed

Question 3: What are the tolerances for site calibration?

Table 57. Survey results—Tolerances for Site Calibration

Response option	Result
Horizontal tolerance	
+/- 0.03 ft	23 (49%)
0.01 ft or less	14 (30%)
Vertical tolerance	
+/- 0.065 ft	10 (24%)
0.05 ft or less	28 (67%)
Other	0.02 ft or less; 0.02 to 0.03 ft; 0.04 feet; depends on type of job, e.g., dirt or bridge work; equipment specific and based on owner's manual

Question 4: Shall the contractor's surveyor submit the daily site-calibration check results to the engineer?

Table 58. Survey Results—Submission of Site-Calibration Check Results

Response option	Result
Yes	45 (70%)
No	19 (30%)

If yes, who shall review such results?

Table 59. Survey Results—Review of Site-Calibration Check Results

Response option	Result
Survey engineer	31
Other	2 (resident engineer; for information)

Question 5: Do you agree with the roles and responsibilities and the requirements on selection of control points, tolerances, and procedures for site calibration that are described in the "Site Calibration and Check" section?

Table 60. Survey Results—Summary Question for Section 11 (Site Calibration and Check)

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q5	0 (0%)	1 (1%)	3 (4%)	19 (28%)	40 (61%)	4 (6%)	4.64	5	5	0.73	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Respondents' comments:

- The tolerances should depend on the type of work. The mentioned tolerances here would work for rough dirt work. Tighter tolerances will be needed for sub-bases and pavements. Bridge work requires the tightest tolerance—should be +/- 0.01 ft.
- The tolerances also depend on AMG equipment. The mentioned tolerances are OK for GPS equipment but not for total stations.
- Site calibration requires one vertical control point (benchmark) and three horizontal control points instead of four benchmarks (as mentioned in the proposed written procedures). Too many control points might cause the project surface to be tilted.
- The number of control points depends on the project size and scope, and manufacturer requirements.
- The site-calibration results should be submitted for information only, and on a weekly basis, or only if there is a problem. Daily is too often. The calibration check should be done and documented daily by the contractor.
- The resident engineer and inspector should review the site-calibration results; and if a problem is evident, they should contact the Department's surveyor. Approval to continue is required in this case.

5.3.12 Final Check

The following points provide a summary of the main findings:

- The respondents agreed to include this section in the *Construction Manual.*
- Opinions on some items in this section varied.
- Most of the respondents agreed that before the final check, the contractor should perform a quality-control test and the engineer might check the areas that are out of tolerances.
- Most of the respondents agreed that the contractor should perform the final check of construction work, and the engineer may perform or witness the check. But opinions slightly varied.
- Most of the respondents agreed that the contractor should notify the engineer of the final checks 2 days in advance.
- The respondents somewhat agreed that only finish-grade stakes (blue tops) are needed, and no additional centerline stakes, slope stakes, or grade stakes [except at the critical points such as, but not limited to, points of curvature (PCs), points of tangency (PTs), superelevation points] are needed. But opinions varied.
- Most of the respondents reported that the stake intervals are project specific.
- Opinions varied on whether paving stakes are needed at superelevated curve transitions and station equation locations.
- More than half of the respondents agreed with the number and criteria of final checks.

All questions and a summary of their responses are shown below (see Tables 61 to 71).

Question 1: Do you agree that before the final check, the contractor shall perform a quality-control test, and the engineer might check the areas that are out of tolerances?

Table 61. Survey Results—Quality-Control Test by Contractor and Check of Out-of-Tolerance Areas by Engineer

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q1	1 (1%)	0 (0%)	0 (0%)	16 (23%)	46 (66%)	7 (10%)	4.81	5	5	0.72	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Question 2: Do you agree that the contractor shall perform the final check of construction work and the engineer may perform or witness the check?

Table 62. Survey Results—Contractor Performing Final Check with Engineer Witnessing

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q2	1 (1%)	3 (4%)	1 (1%)	17 (26%)	35 (52%)	11 (16%)	4.69	5	5	1.00	Agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Question 3: When shall the contractor notify the engineer of the final checks?

Table 63. Survey Results—Time to Notify the Engineer of the Final Checks

Response option	Result
At least 2 business days before performing the checks	47 (85%)
Other	One day before; one week; 5 days; 10 days; as soon/early as possible

Question 4: Do you agree that only finish-grade stakes (blue tops) are needed and NO additional centerline stakes, slope stakes, or grade stakes, except at the aforementioned critical points, are needed?

Table 64. Survey Results—Types of Stakes Needed

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q4	1 (2%)	9 (15%)	8 (13%)	19 (32%)	21 (35%)	2 (3%)	3.93	4	5	1.17	Somewhat agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

If disagree (1 to 3 on the scale), please specify the staking interval for additional stakes.

Responses:

- 100 ft
- 250 to 500 ft
- Stake intervals are determined by the engineer
- Not needed if check is performed electronic data collector

Question 5: What is the interval for finished subgrade points that are set at points on cross sections on mainline?

Table 65. Survey Results—Interval for Finished Subgrade Points on Mainline

Response option	Result
1000 feet	6 (11%)
500 feet	28 (52%)
Other	Job/project specific; no stakes; 50 ft; 100 ft; 100–200 ft; 250 ft; 1000 ft

Question 6: What is the number of cross sections used to set finished subgrade points on side roads and ramps?

Table 66. Survey Results—Number of Cross Sections to Set Finished Subgrade Points

Response option	Result
At least two	30 (68%)
Other	At least three; project specific; depends on length and typically two; for side road, two are fine—for ramps 500-ft intervals might be needed; none (cross section is not needed anymore)

Question 7: What is the interval for finished subgrade points that are set on curves, transitions, intersections, interchanges, and break points?

Table 67. Survey Results—Interval for Finished Subgrade Points on Curves, Transitions, Intersections, Interchanges, and Break Points

Response option	Result
250 feet	25 (52%)
Other	500 ft; 100 ft; 50 ft for curves; depends on locations but likely 25–50 ft; project dependent

Question 8: Are paving stakes needed only at superelevated curve transitions and station equation locations?

Table 68. Survey Results—Paving Stakes Needed Only at Superelevated Curve Transitions and Station Equation Locations

Response option	Result
Yes	26 (57%)
No	20 (43%)

If no, where shall the paving stakes be set? Specify.

Responses:

- Not needed if the engineer is witnessing the check
- Approaches, bridges, intersections
- Grade changes and supers
- At 100/250/1000-ft intervals
- Not needed if the engineer has electronic data collection equipment
- Various locations, as needed

Question 9: What is the number of final checks?

Table 69. Survey Results—Number of Final Checks

Response option	Result
20 or more randomly selected checks per stage, per project, or per mainline roadway mile, whichever results in the most checks	22 (58%)
Other	20 or more per mile/stage/mainline roadway mile only; as needed or project specific

Question 10: What are the criteria of final check?

Table 70. Survey Results—Criteria of Final Check

Response option	Result
At least four of any five consecutive random checking points are within the tolerance	28 (85%)
Other	80%; 90% within tolerance; 100% in tolerance; at the discretion of the engineer

Question 11: Do you agree with the roles and responsibilities, procedures, timeline, staking specifications, and requirements that are described in the "Final Check" section?

Table 71. Survey Results—Summary Question for Section 12 (Final Check)

Question	Responses[1]						Statistics of results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q11	2 (3%)	3 (5%)	3 (5%)	26 (40%)	25 (39%)	5 (8%)	4.31	4	4	1.06	Somewhat agree

[1] 1 = Very disagree; 2 = Disagree; 3 = Somewhat disagree; 4 = Somewhat agree; 5 = Agree; 6 = Very agree.

[2] Interpretation based on median.

Respondents' comments:

- Final checks
  - Are unnecessary: Respondents from some districts commented that the final check shall be performed *only* when necessary—when some failure or errors are apparent and require corrective action.
  - Could be performed by the contractor staff: Some respondents thought that if the contractor staff performs the final check, the Department construction staff needs to witness.
  - Should be performed by the Department staff: Other respondents thought that the engineer needs to perform the final check.
- Finish-grade stakes
  - Are necessary: The finish-grade stakes are set not for documentation purposes but only to determine that the AMG equipment is working properly.
  - Are unnecessary under certain conditions: If all crews have access to the AMG equipment during their work efforts or at least the engineer is provided with electronic means of checking, the finish-grade stakes are unnecessary.
  - Are generally unnecessary: If the projects are 100% digital, the traditional stakes will be only as requested, otherwise we are paying for both digital models and traditional staking. Thus, traditional staking should be kept to a minimum.
- Stake intervals: The intervals depend on the project specifications and conditions. For example, for finished subgrade staking, the intervals depend on area. For paving staking, the interval could be 25 ft if in a complex area.

CHAPTER 6: DEVELOP DRAFT SUMMARIZED WRITTEN PROCEDURES FOR REVIEW BY TRP (TASK 5)

The research team revised the potential practices based on the results of the survey (task 4) and developed the practices into draft written procedures for the use of modern technologies in construction staking of highway projects, for inclusion in IDOT's *Construction Manual.* This draft was the basis of the complete written procedures (task 6). The draft written procedures were organized into twelve sections: (1) general, (2) evaluation of construction methods, (3) automated machine guidance (AMG) equipment, (4) AMG work plan, (5) training, (6) electronic design files, (7) digital models used for AMG, (8) project control, (9) accuracy and tolerance, (10) site calibration and checks, (11) spot checks, and (12) final checks.

Some of the main issues or decisions (that the engineer and the technicians have to make about the use of AMG, together with the contractor) that were covered (or considered) in the draft written procedures are

- Evaluation of construction methods
  - Is the project a good candidate for use of AMG?
- AMG equipment
  - Should the Department provide a list of approved AMG equipment for the project?
  - Should the contractor provide rover(s) to the Department for the checking/inspection?
  - How should the GPS base stations be set up if GPS is used for AMG?
  - What are the practices that will be used for storing and maintaining the AMG equipment?
- AMG work plan
  - What items should be included in the AMG work plan?
  - What is the process to use for reviewing the AMG work plan, and who will be involved in the review (e.g., the engineer, survey crew chief, and/or the consultant)?
  - Will the engineer use an AMG work plan checklist?
- AMG training
  - Should/will the contractor provide training to the Department construction staff?
  - If yes, who will participate in the training? What is the content and timing of the training, and how many training sessions?
  - If no (or in addition to the contractor's training), will the engineer, technicians, or other staff members participate in training provided by the Department (Central Office or district) or otherwise familiarize themselves with the AMG system and the use of rovers? If yes, who will participate in this kind of training? What is the content, form, and timing of the training?

- Electronic design files
    - What are the Department’s responsibilities associated with electronic design files in the context of AMG?
- Digital models used for AMG
    - What are the contractor’s responsibilities associated with the digital models used for AMG?
    - Will the engineer review the contractor’s digital models used for AMG, and what process will be used for the review?
- Project control
    - Is the Department responsible for the AMG project-control densification?
    - If the Department is responsible for project control, what are the best practices to set the control points?
- Accuracy and tolerance
    - What are the accuracy and tolerance requirements for AMG project?
    - What actions should be taken if the tolerance and accuracy requirements are not met?
- Spot checks
    - Will the engineer and technicians perform spot checks? If so, how will the spot checks be performed, and at which locations?
    - How should the rovers be used in performing the checks?
- Final checks
    - Who performs the final check, the engineer or the contractor?
    - If the engineer performs the final check, how does he/she perform the check?
    - Is staking needed for the final check?

CHAPTER 7: DEVELOP COMPLETE WRITTEN PROCEDURES FOR INCLUSION IN IDOT'S *CONSTRUCTION MANUAL* (TASK 6)

These written procedures for the use of modern technologies for construction staking of highway projects were developed for inclusion in IDOT's *Construction Manual.* The written procedures are organized into twelve sections: (1) general, (2) evaluation of construction methods, (3) automated machine guidance (AMG) equipment, (4) AMG Work Plan, (5) training, (6) electronic design files, (7) digital models used for AMG, (8) project control, (9) accuracy and tolerance, (10) site calibration and checks, (11) spot checks, and (12) final checks.

7.1 GENERAL

AMG systems use positioning techniques such as global positioning system (GPS), robotic total stations, and/or laser scanning to determine the horizontal coordinates and elevation of the equipment and to check the equipment position against a 3D digital model. AMG has the potential to reduce the number of stakes required and increase the efficiency and productivity of the Contractor. As defined by FHWA (2013), AMG "uses enhanced location referencing to provide accurate horizontal and vertical positioning for precise grading, milling, or paving. Bulldozers, graders, milling machines, and paving machines can be programmed to use AMG when performing grading or paving tasks in the field. Moreover, scrapers, excavators, and trenching machines can be equipped with AMG for a wide variety of earthwork (FHWA 2013a, 2)." An AMG equipment/system "references the position of the cutting edges or pavement molds using GPS satellites, robotic total stations, lasers, or combinations of these methods. . . .It calculates the finished-grade for that location using an electronic model of the proposed constructed facility that resides in its onboard computer. . . .Then, it adjusts the cutting edges or pavement molds automatically for small differences in elevation or provides the cut or fill amount via the computer-user interface to the machine operator for large differences in elevation (FHWA 2013a, 2)."

There is a set of decisions that the Engineer and the technicians should consider, together with the Contractor. These decisions are related to the following issues and are discussed in more detail later.

- Evaluation of construction methods
- AMG equipment
- AMG Work Plan
- AMG training
- Electronic design files
- Digital models used for AMG
- Project control
- Accuracy and tolerances
- Site calibration and checks

- Spot checks
- Final checks

When you use this document, keep in mind that

- This document provides guideline practices for the Engineer and technicians to follow in different scenarios related to the use of AMG in construction staking of highway projects.
- This document leaves some decisions to the Engineer and technicians to make (sometimes together with the Contractor).
- This document suggests good relations between the Contractor and the Department construction staff (i.e., the Engineer and technicians), as well as good communication and coordination between the Department construction staff (i.e., the Engineer and technicians) and the survey and design staff.
- This document shall be used in conjunction with IDOT's *Standard Specifications for Road and Bridge Construction (2016),* http://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Construction/Standard-Specifications/Standard%20Specifications%20for%20Road%20and%20Bridge%20Construction%202016.pdf

7.2 EVALUATION OF CONSTRUCTION METHODS

7.2.1 Decision to Use AMG

Not every project is suitable for AMG. AMG is, therefore, not mandatory. The Department encourages the use of AMG if the project is suitable for AMG construction techniques but leaves the decision to use AMG to the Contractor. The Engineer should be aware that the Contractor should notify the Engineer of the intent to use AMG before or at the preconstruction meeting. To evaluate the suitability of adopting such technology in a project, the Contractor could follow AASHTO's criteria (AASHTO 2016), which are defined in AASHTO's *Quick Reference Guide for the Implementation of Automated Machine Guidance System.* The Engineer could participate in the evaluation of the suitability of adopting such technology in a project.

7.2.2 Types of Projects that Are Generally Suitable for the Use of AMG

Generally, based on AASHTO's *Quick Reference Guide for the Implementation of Automated Machine Guidance System,* projects with the following characteristics are the best candidates for this technology (AASHTO 2016):

- Large amounts of earthwork or paving, such as subgrade
- New alignments
- A good global navigation satellite system (GNSS)
- A design based on accurate digital terrain modeling (DTM)

Based on the Department's experience, the following types of projects are also the best candidates for this technology:

- Complex projects
- Projects with flat and long drainage areas
- Urban reconstruction and larger reconstruction projects
- Small earthwork projects
- Projects with limited site width due to construction staging or physical constraints

7.2.3 Types of Projects that Might *Not* be Suitable for the Use of AMG

The following conditions always limit the use of AMG (FHWA 2013a):

- Designs, such as overlays, that are not based on an existing DTM. Overlays with new profiles or cross-slope construction benefit from AMG.
- Structures

The following conditions might or might not limit the use of AMG; it is project specific and should be assessed case by case (FHWA 2013a):

- Widening with narrow strip additions
- Designs that do not exist in a 3D digital environment (Note that all jobs are capable of being modeled.)
- Projects that are under a tree canopy, in narrow canyons, or next to tall buildings that interfere with GNSS signals (Note that robotic total stations or traditional methods are viable solutions.)
- Design difficulties that would prevent the creation of an accurate and complete DTM (If a surface model can be prepared in difficult situations, it saves on rework.)

7.3 AUTOMATED MACHINE GUIDANCE EQUIPMENT

7.3.1 AMG Equipment and Equipment Information

The Engineer should be aware that the Contractor should provide the AMG equipment, in compliance with the contract documents and all applicable standards and specifications. The Engineer should ask the Contractor to submit the equipment information (as part of the AMG Work Plan) before or at the preconstruction meeting and at least 14 days prior to use. It is recommended that the equipment information includes but is not limited to the following: a description of the manufacturer, model, software version, accuracy, radio frequency, and last calibration date of the AMG equipment.

7.3.2 Approved AMG Equipment

In general, the Department does not specify a set of approved AMG equipment; but provisions may be included in some contracts. The equipment information should be requested from the Contractor for review by the Engineer.

7.3.3 Rovers for Inspection

The Contractor may or may not provide rover(s) to the Engineer for inspection purposes. This depends on the contract provisions. If the contract requires the Contractor to provide the rover(s), the contract provisions should specify the number of rovers. In this case, the Engineer must have access to the rover(s) as needed.

Whether GPS rovers are provided by the Contractor or the Department, they should be ready for use prior to the start of the construction work. The technicians familiar with GPS rovers may aid the Engineer—and/or anyone else who is responsible for the inspection—in using the GPS rover. The GPS rover or other handheld devices should be compliant with the contract documents. On large and complex projects, it is suggested to have two independent rovers to check against each other for errors.

7.3.4 Setup of GPS Base Station

When the AMG system is guided by GPS, the Contractor will be in charge of setting up the GPS base station, which is important to the success of the project. The base station should be located at a stable, undisturbed place. The base station should provide radio-signal coverage over the entire area under construction using the GPS-guided machine. If the base station cannot broadcast a signal that covers the entire site, provide adequate repeater radios or other communications. If the base station is to be relocated, document the current location. The Contractor should submit the location of the base station to the Engineer for approval, and should not relocate the base station without the approval of the Engineer. The Engineer should provide such approval in a timely manner (PennDOT 2016).

7.3.5 Storage and Maintenance of AMG Equipment and Rovers

The Contractor is responsible for the storage and maintenance of the AMG equipment and his/her GPS rover(s). In this case, the Engineer and technicians should have access to the equipment provided by the Contractor throughout the work. The Department is responsible for the storage and maintenance of its own GPS rover(s). The GPS equipment should be properly maintained at least once at the beginning of each surveying work, every 6 months, and as needed. The equipment components that should be maintained include but are not limited to tripods, rods, cables, receivers and antennas, and handhelds. Equipment maintenance should include but is not limited to periodic manufacturer maintenance checks, cleaning, and calibration.

7.3.6 References for GPS Equipment Setup, Operation, Maintenance, and Storage

The following is a list of useful references for GPS equipment setup, operation, maintenance, and storage:

- *NGS Guidelines for Single Base Real Time GNSS Positioning* (Henning 2011)
    - Chapter I "Introduction" provides a typical real-time GNSS-positioning checklist. Some of the items in the checklist are dilution of precision (DOP) varieties, multipath, baseline root mean square (RMS), number of satellites, elevation mask, base accuracy—datum level and local level, base security, redundancy, and space weather.
    - Chapter II "Equipment" provides best practices for typical real-time GPS setup.
- *Methods of Practice and Guidelines for Using Survey-Grade Global Navigation Satellite Systems (GNSS) to Establish Vertical Datum in the United States Geological Survey* (USGS 2012), provides detailed introduction to GPS equipment and a checklist for equipment maintenance and quality control/quality assurance (QA/QC) of both real-time GNSS single-base RTK and real-time GNSS single-base RTK network, which is shown in Figure 9.
- *NGS Guidelines for Single Base Real Time GNSS Positioning*, https://www.ngs.noaa.gov/PUBS_LIB/NGSRealTimeUserGuidelines.v2.1.pdf.
- *Methods of Practice and Guidelines for Using Survey-Grade Global Navigation Satellite Systems (GNSS) to Establish Vertical Datum in the United States Geological Survey*, https://pubs.usgs.gov/tm/11d1/tm11-D1.pdf.

Real-time GNSS-single-base RTK	
Equipment	Quality assurance and accessories
Fixed-height GNSS base receiver tripod	Check height with tape, condition not warped or bent, sandbags for stability.
Fixed-height GNSS rover receiver bipod	Check height with tape, condition not warped or bent.
Traditional tripod for GNSS broadcast radio and antenna mast	Tribrach or flat plate for antenna mast; no loose legs.
GNSS broadcast radio antenna	Full-size whip antenna, tribrach or flat plate, cables, range pole.
GNSS broadcast radio battery	Marine (hybrid deep cycle) battery for long occupations, backup battery.
GNSS rover receiver extended range antenna	Full-size whip antenna, mounting brackets, cables, range pole.
GNSS base receiver	Dual frequency required, backup batteries, GPS+GLONASS+Galileo** tracking preferred, latest firmware upgrades, minimize multipath design, operating manual.
GNSS rover receiver	Dual frequency required, backup batteries, GPS+GLONASS+Galileo tracking preferred, latest firmware upgrades, minimize multipath design, operating manual.
Benchmarks	Monumented or non-monumented considerations, anchoring construction materials, datasheets with directions "to-reach" the benchmark location.
Real-time GNSS-networks	
Equipment***	Quality assurance and accessories
Fixed-height GNSS rover receiver bipod	Check height with tape, condition not warped or bent.
GNSS rover receiver	Dual frequency required, backup batteries, GPS+GLONASS+Galileo tracking preferred, latest firmware upgrades, minimize multipath design.
Wireless modem with static internet protocol (IP) address	Assess broadband or cellular coverage area before campaign.
Benchmarks	Monumented or non-monumented considerations, anchoring construction materials, datasheets with directions "to-reach" the benchmark location.

Figure 9. Real-time GNSS single-base RTK checklist (USGS 2012).

7.4 AUTOMATED MACHINE GUIDANCE WORK PLAN

7.4.1 Submission of the Automated Machine Guidance Work Plan

It is recommended that the Contractor develops and submits a comprehensive written AMG Work Plan to the Engineer, for information only, before or at the preconstruction meeting and at least 30 days prior to use. Although the plan is submitted for information only, it is a good practice that the Engineer reviews the information in the AMG Work Plan.

7.4.2 Content of the Automated Machine Guidance Work Plan

The content of AMG Work Plan is project specific. Generally, the AMG Work Plan could include but is not limited to

- Definition of project boundaries and scope of work to be accomplished using the AMG equipment
- Description of the equipment, including but not limited to a description of the manufacturer, model, and software version of the AMG equipment
- Project-control report, including but not limited to all contract control points, coordinates or elevation adopted, office procedures to be used for GPS technology, and the diagram of control points. When a GPS base station is on the site for checking or staking purposes, include the determined coordinates and elevation of the base station and the datum differential from the existing control provided by the Department.
- Detailed site-calibration plan, including but not limited to a map of the control points to be used for site calibration and control points to be used for checking the site calibration, site calibration procedures, frequency of calibration, plan for what information will be documented, and plan for what information to be submitted to the Engineer. The procedures must show a complete record of equipment-check results (Mississippi DOT 2013).
- A quality-control plan, including but not limited to the frequency and type of checks to be performed and procedures to be used for performing the checks. The control plan should show how the Engineer and the Contractor will conduct the initial and daily calibration checks, spot checks, and final-acceptance checks.
- Description of construction checks, including but not limited to the method and frequency of field-verification checks
- Contractor's prior experience within the last 3 years with the use of AMG systems on similar projects (similarity should be assessed by the Engineer). If the Contractor does not have such experience, the Engineer may ask the Contractor to perform a test session or may require additional checks at the beginning of the project. If the AMG is not providing the desired results, the Engineer may suspend the use of AMG for part or all of the project.
- Contractor's primary contact and alternate contact for AMG issues
- Personnel to be using the AMG equipment on a daily basis

7.4.3 Review of the Automated Machine Guidance Work Plan

The Engineer should review and discuss the AMG Work Plan with the Contractor during the preconstruction meeting. If necessary, a separate meeting should be held to review and discuss the AMG Work Plan; and the survey crew chief or consultant should attend the meeting. During the meeting, the Engineer should try to establish a working relationship with the Contractor, including discussing tentative schedules and safety issues related to AMG. It is recommended to conduct at least the following as part of the review:

- Reviewing the AMG equipment information
- Reviewing the project-control report, checking all control points and base-station location, and discussing the needs for additional control points
- Reviewing the site-calibration report and performing checks on site, if/as needed
- Reviewing the equipment calibration and maintenance and providing suggestions based on the knowledge of and experience with GPS
- Reviewing the quality-control plan and discussing the needs for stakes for the checking and inspection of the project

To relieve the Engineer and technicians of potential heavy documentation work, the Engineer and technicians are encouraged to keep an AMG Work Plan Checklist. The Engineer is encouraged to use the checklist to understand and track how the Contractor will implement the AMG system on the project and to request additional information for clarification whenever needed. A sample checklist is shown in the Appendix A (section 7.14).

7.5 TRAINING

7.5.1 Training on AMG Provided to the Department Staff by the Contractor

The Contractor typically provides training to his/her own staff. The Contractor may or may not provide training on AMG to the Department staff. However, if the Contractor provides the rover, the Engineer should request that the Contractor provides the Engineer and inspection staff with training.

- Content of training: The training should cover the use and operation of devices to be used for review of AMG work, such as the use of GPS rovers or other handheld devices.
- Time of training: The initial training should be completed prior to the start of any AMG work.
- Participants of training: The Engineer and the Contractor should discuss and determine which members of the Contractor staff and Department staff, if applicable, will participate in the training.

7.5.2 Training on AMG Provided to the Department Staff by the Department

The Engineer and technicians should familiarize themselves with the AMG system and the use of rovers before they start to use them, especially if the Contractor does not provide the training or the Department uses its own rovers. The Engineer and technicians could also seek help from experienced staff and/or consult relevant web-based training resources (e.g., see 7.5.5 below).

7.5.3 Designated Survey Group or Consultant to Assist with the Use of AMG

It is recommended that the Engineer designates a survey leader to assist with the use of AMG. A designated survey leader can provide information or help to the Engineer, technicians, and any AMG equipment/rover operators who have difficulties in using such system or devices.

7.5.4 Technical Support

The Engineer and technicians could seek technical support if/as needed from the Contractor, who might in turn seek technical support from the equipment manufacturer or vendor as appropriate. The Engineer could ask the Contractor to designate a technical representative from the Contractor (or from the equipment manufacturer or vendor) to be on hand at least at the beginning of the project and to be in contact with the Engineer for issues related to the AMG system throughout the AMG part of project.

7.5.5 Web-based Training Resources

FHWA, together with AASHTO, provides training modules about the use of 3D models and AMG. The link to the training modules is https://www.fhwa.dot.gov/construction/3d/wbt.cfm. This training has four modules; and all of the Department construction staff are encouraged to complete the training, with priority attached to the last module, which is about the applications of 3D-engineered models in highway construction and QA/QC. This module has four lessons:

- Lesson 1: 3D Applications in Highway Construction
- Lesson 2: Constructability Review
- Lesson 3: Automated Machine Guidance (AMG) and Control Systems
- Lesson 4: Quality Assurance in Construction with 3D-Engineered Modeling

7.6 ELECTRONIC DESIGN FILES

7.6.1 Use and Purpose of the Electronic Design Files in the Context of AMG

The Department could provide the available electronic design files (2D or 3D) to the Contractor, which the Contractor may use to generate the digitals models for AMG. The electronic design files provided are for convenience only and are not necessarily part of the contract documents. Note that the Department's practices for the provision of electronic design files are expected to change in the near future.

In general, if the electronic design files are available, it is a good practice to provide such files to the Contractor before the preconstruction meeting or upon the request of the Contractor.

The electronic files may include but are not limited to

- Alignment data
- Cross sections
- Background graphics files with roadway and drainage features such as centerlines, edges, and hull of ponds
- Machine-control surface models, or existing and design surface models
- GPS site-calibration data

- Project-control information

The use of these electronic files to generate the digital models for AMG is at the discretion of the Contractor. These electronic design files provided by the Department will probably be in the native format of the software application by which they were generated, which may be different from the format of the AMG system that the Contractor uses.

7.6.2 Responsibilities Associated with the Use and Provision of the Electronic Design Files in the Context of AMG

The Engineer should be aware that the use of electronic design files provided by the Department does not relieve the Contractor from the responsibility to conduct all necessary investigations of conditions including but not limited to site visits, spot checks, and/or re-computation before bidding or developing the digital models for AMG (IowaDOT 2015).

While preparing the digital models used for AMG (see section 7.7), the Contractor should notify the Engineer of any errors or discrepancies in the electronic design files provided by the Department if such files were provided. In this case, the Engineer should reply to the Contractor within 7 working days of receiving the notification.

7.7 DIGITAL MODELS USED FOR AMG

7.7.1 Developing the Digital Models Used for AMG

The Contractor is typically responsible for developing the digital models used for AMG. The Contractor is responsible for converting the information on the design files (the 2D plans or 3D models) provided by the Department (see section 7.6 for the description of electronic design files provided by the Department) into a format that is compatible with the Contractor's AMG system. The Engineer should ask the Contractor to submit the digital models used for AMG, for information only, at least 14 days prior to the start of the AMG work. The Department should assume no responsibility for any errors or omissions in the developed digital models used for AMG (which is the responsibility of the Contractor).

7.7.2 Updating and Revising the Digital Models Used for AMG

The Contractor is responsible for updating and revising the digital models used for AMG. The Engineer should ask the Contractor to submit the revised or updated digital models (if the digital models get revised or updated) to the Engineer prior to AMG operation in the affected areas. If the revised or updated digital models are not provided in a timely manner, the Engineer may request to postpone the AMG work in the affected areas.

7.7.3 Digital Models as Input to the Devices for Inspection

If any of the devices used for review or inspection by the Engineer requires the digital model data, the Contractor should provide those data to the Engineer prior to the review or inspection, as early as possible. The Engineer should ask for the digital model data if the Contractor does not provide such data on time.

7.7.4 Cost Associated with the Digital Models Used for AMG

The Engineer should be aware that the Contractor is responsible for bearing all costs, including but not limited to, the cost of developing the digital models, the cost of manipulating the design files (2D or 3D) provided by the Department, the cost that may be incurred due to the discrepancies between the Contractor's digital models and the design files provided by the Department, and the cost of rework or reconstruction that may be incurred due to errors in the application of AMG techniques.

7.7.5 Review of the Contractor's Digital Models

The Engineer must review the Contractor's digital models first after receiving the digital models to verify independently that the digital models match the contract documents. The Engineer should *not* provide approval to the Contractor based on this review because the Department does not assume responsibility for errors or omissions in the digital models, and the review process acts only as a necessary QA/QC step. The Engineer could use one or more of the following methods to check the digital models:

- Check line or grade in the digital models against line or grade in the MicroStation plan.
- Spot-check select points using an independent rover from the Department or the Contractor.
- Check with existing terrain elevations.
- Check with tape measure against typical cross sections.
- Ask dedicated construction survey staff to facilitate the checks.
- Forward the digital models to the survey chief or CADD chief for review.

7.8 PROJECT CONTROL

7.8.1 Primary Project Control

Project control is a network of control points whose positions and heights relative to the project datum (*x, y, z* coordinates) are known. The control points include horizontal control points and vertical control points, i.e., benchmarks. The Department is responsible for setting primary control points whether or not AMG is used in the project. This process will be completed by the Department-designated survey crew or consultant.

7.8.2 AMG Control Densification

AMG requires different control points than those needed for projects constructed using conventional methods. In addition to the primary control points established prior to the project by the Department, the surveyor (Contractor's surveyor or Department's surveyor, depending on the responsibility defined in the contract documents, with possible cases presented in Table 72) has to set the secondary/densification control points specified in the plans for grading and preserved for all other project constructions.

Table 72: AMG Project-Control Responsibility (Michigan DOT 2016)

	IDOT Specifications 105.09 survey control points	AMG secondary and additional control points (densification)
Contractor staking (Contractor staking pay item)	Engineer	Contractor
Engineer staking (No contractor staking pay item)	Engineer	Engineer

7.8.3 Project-Control Setup Procedures

The surveyor (Contractor's surveyor or Department's surveyor, depending on the responsibility defined in the contract documents, with possible cases presented in Table 72) may follow the following recommended steps:

- Select points at locations that are likely to survive project construction.
- Place the control stakes along the project corridor with intervals of adjacent points. Set the interval at a maximum of 1000 ft. Additional control points may be determined necessary based on jobsite conditions and terrain, accuracy requirements, AMG equipment, and pay items.
- Establish elevation of secondary control points using different leveling from project vertical control points, forming closed loops.
- Perform an independent traverse check between the secondary control stakes using GPS.
- When a robotic total station is used to guide a paving machine, a denser network of control points of higher vertical accuracy than GNSS-controlled systems is required. Figure 10 shows a diagram of typical control points for a robotic total-station guided paving system. Set additional control points at maximum 500-ft intervals on each side of the pavement. The actual distance may vary by the type of equipment used by the Contractor. The vertical accuracy of the total station could be +/- 0.01 ft.
- Document horizontal and vertical coordinates and station-offset information for each control point.
- Replace any control stakes that are disturbed during project construction, using the recommended steps.
- Add additional control points as required by the Engineer. The Department's surveyor is responsible to update the Contractor with the latest project-control point information.
- For projects whose plans do not show a centerline or other survey control line for the construction of the work (e.g., resurfacing, safety modifications), the surveyor will provide only points marking the beginning and ending of the project.

7.8.4 GPS Control Survey

If GPS is used to set control points, the surveyor shall refer to IDOT's *Survey Manual* (chapter on GPS) for the use of GPS surveying equipment, field procedures, office procedures, and guidelines for post-processed GPS control surveys when performing surveying work using GPS. In this case, the surveyor shall use post-processed fast static and/or real-time GPS methods at accuracy level 3 or 4, according to the *Survey Manual* (IDOT 2015). The link to this manual is http://idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Design-and-Environment/Survey%20Manual.pdf.

7.8.5 Record of Project-Control Points

If the Contractor adds supplemental project-control points, those points should be documented along with other project-control points set by the Department in the project-control report, which is a part of the aforementioned AMG Work Plan. The Engineer should be aware that the Contractor is also responsible for verifying, supplementing, and maintaining the project-control points before construction and regularly during construction. If the project-control points are changed/updated, the Engineer and the Contractor should share the record of coordinates and elevations of the local survey-control calibration points to ensure project consistency.

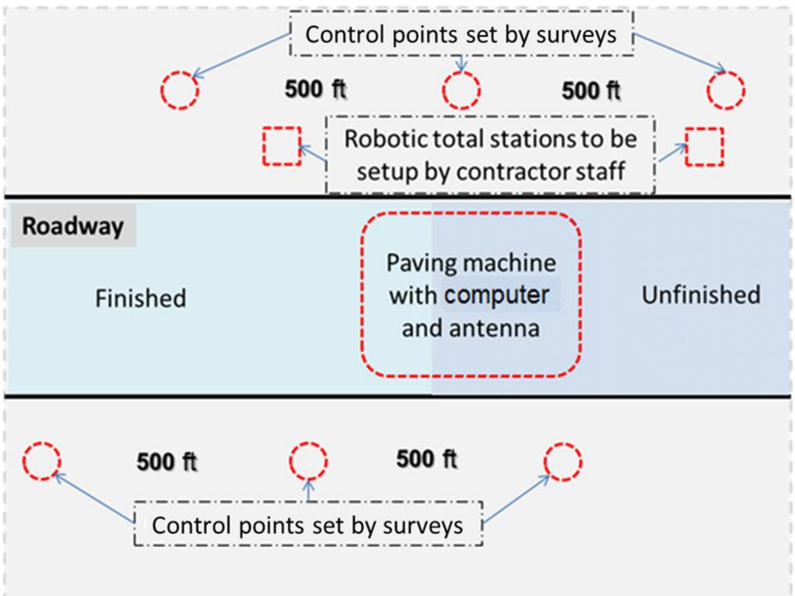


Figure 10. Diagram of control points for robotic total-station guided paving system.

7.9 ACCURACY AND TOLERANCE

7.9.1 Accuracy and Tolerance Requirements for AMG Compared with that for Conventional Staking

The Engineer must understand that at least the same accuracy and tolerance requirements shall be met when AMG is used as when conventional staking is used for grading or paving. In general, the accuracy and tolerances shall be compliant with the contract documents and applicable standards and specifications.

7.9.2 Actions to Take if the Tolerance and Accuracy Requirements Are Not Met

If the tolerance and accuracy requirements are not met, the Engineer may suspend the AMG operation; and the Engineer should discuss this decision with the Contractor and technicians to help the Contractor evaluate and address the AMG operation deficiencies. The Contractor should proceed with AMG only after the approval of the Engineer. Alternatively, the Contractor could proceed with construction using conventional staking and without AMG.

7.10 SITE CALIBRATION AND CHECKS

7.10.1 Site-Calibration Procedures

The surveyor (Contractor's surveyor or Department's surveyor, depending on the responsibility defined in the contract documents) shall use at least three known horizontal control points for horizontal site calibration or two control points per mile along the project area if this results in more control points (WisDOT 2016). The control points selected shall envelope the project area using AMG and be well-distributed within the area. Control points near the corners of the project and approximately midway along its boundaries should be provided. Control points in close proximity to one another should be avoided. Also, long, narrow configurations of control points should be avoided.

The site calibration shall follow IDOT's *Surveying Manual* (chapter on GPS), including but not limited to the following requirements (IDOT 2015):

- A vertical calibration requires a minimum of one NAVD 88 orthometric height benchmark.
- A horizontal calibration requires a minimum of three known control points and one NAVD 88 benchmark.
- The results must be carefully analyzed before being accepted. Residuals exceeding the survey accuracy determined by redundant observations, a scale factor significantly different than 1.0, or excessive slope of the plane may indicate failure of calibration. Additional control points might be added.
- For more information about the specifications and procedures for site calibration, check IDOT's *Survey Manual* (chapter on GPS) (IDOT 2015).

7.10.2 Daily Site-Calibration Check Procedures

The Contractor should perform the daily site-calibration checks, as described in the AMG Work Plan, on two or more control points with the specific tolerances described in the contract documents, IDOT's *Standard Specifications for Road and Bridge Construction,* and IDOT's *Survey Manual* (chapter on GPS). The tolerances will depend on the type of work, for example, +/- 0.03 ft for rough dirt work, and tighter tolerance (less than +/- 0.03 ft) for sub-bases and pavements, and tightest tolerance (less than +/- 0.01 ft) for bridge work.

The type of survey equipment and the methods selected to employ them will affect the level of accuracy attained. Therefore, it is essential to select the proper equipment and apply the correct methods when utilizing them for QA/QC. Table 73 shows some of the equipment and their common accuracies.

Table 73: Equipment and Obtainable Tolerances (Michigan DOT 2016)

Equipment	Horizontal tolerance	Vertical tolerance
GPS rover	0.04 ft	0.07 ft
Total station	0.02 ft	0.02 ft
Laser-augmented GPS	0.04 ft	0.02 ft

The Engineer should ask the Contractor to submit the daily site-calibration check results for information only. If necessary, the Engineer should review these results for extra QA/QC.

If the site-calibration check exceeds the tolerances, the surveyor could follow the following steps (WisDOT 2015):

- Measure the check again at the same independent control points to ensure that there are no problems with the check measurements.
- Perform a second site-calibration check using another independent control point. If the tolerances are not met, then there is a problem with the site calibration.
- Redo the site-calibration measurements and computation procedures to ensure that there is no problem with the initial site-calibration measurements.
- If site-calibration problems persist, consult the vendor or manufacturer manual or seek technical support.
- If the measurements of the second site calibration are in close agreement with that of the initial one, then there is a problem with the control points used in the initial site calibration.
- Perform the site calibration while excluding the control points with the largest horizontal and/or vertical error estimates. Select another control point and document the one with the problem.

7.11 SPOT CHECKS

7.11.1 Performing Spot Checks

The Engineer is responsible for performing continuous and independent QA/QC, including spot checks of the Contractor's machine control results, surveying calculations, field procedures, actual staking (if any), and records and documentation, as necessary.

The Engineer should perform the checks, as needed, before construction and at any time during the construction. The Engineer should perform spot checks on a daily basis if necessary.

The spot checks could be at random locations, at positions deemed by the Engineer as prone to errors or problems, or at set intervals determined by the Engineer or technicians based on project conditions.

The spot checks may be conducted using conventional survey methods, independent GPS equipment, or a combination of the two approaches. If GPS equipment is used in the QA/QC process, the equipment must be independent (i.e., different from the one used by the Contractor for the AMG work). The Contractor's surveyor should assist the Engineer with the inspection of line and grade in areas without conventional staking by using or furnishing the GPS equipment, the project digital models, and survey control points, if/as needed. The Contractor's surveyor should also assist the Engineer with the use of the rover if the Contractor is the party providing the rover. The decision to conduct construction checks using conventional survey methods, independent GPS equipment, or a combination of the two approaches depends on accuracy requirements and pay items, and should be left to the Engineer and technicians.

It is the Inspector's job to review all phases of the work periodically, including various operations being performed by the Contractor, to ensure that his/her instructions are being followed and to keep the Resident well-informed of the progress, problems, and instructions to the Contractor.

7.11.2 No Staking Does Not Mean No Spot Checking

The use of AMG might eliminate the need for some of the Contractor's staking items. The Engineer must understand which staking items are eliminated due to the use of AMG. The Engineer must be also clear that no staking at those positions does *not* mean there is no need for QA/QC by the Engineer at those positions.

7.11.3 Using Rovers for Checking

A rover is a survey tool used to receive signals from satellites and a base station to calculate grade and position. Rovers are primarily used in stake out, the marking of sites for grade alignment, or structural locations. The general procedures for construction stake-out surveys/checks using rovers are (USDA 2015)

1. The RTK base receiver is set over an established benchmark.
2. To stake out coordinates, define a projection and datum transformation.
3. Perform site calibration.
4. Define the point/line/arc/DTM by manually entering the data to the rover, transferring a file from a PC to the rover, or calculating coordinates using a built-in function of the rover.
5. Select the feature to be staked out—points, lines, or arcs.
6. Initialize the survey.
7. Navigate to the point.
8. Stake out the point.
9. Check the point, once set, by measuring the as-staked point (optional).
10. Repeat steps 7 to 9 until all desired points are checked.

7.12 FINAL CHECKS

7.12.1 Quality-Control Test before the Final Checks

The final checking of the grade is an important part of QA/QC. Thus, it is highly needed on most occasions. The Contractor should notify the Engineer of the plan to conduct the final checks at least two business days before performing the checks.

Before performing the final checks, the Engineer may want to direct the Contractor to perform a quality-control test, as stated in the AMG Work Plan, to check randomly selected locations at all hinge points, centerline, edge of lane, and edge of shoulders at all critical locations against plan elevations. The areas that are out of tolerance could be checked additionally by the Engineer before the final checks. The Engineer should direct the Contractor to facilitate these checks by using or furnishing the GPS equipment, the project digital models, and survey-control points, if/as needed. The Engineer should pay attention to the critical points, including the following (WisDOT 2015):

- Beginning and end of the project
- Bridge clearances
- Ramp gore areas
- Above- and belowground utility crossings
- Bridge approaches
- Intersections and side road matches
- Clearances over pipes

7.12.2 Performing the Final Checks

Depending on the pay item, the Engineer may be responsible or not responsible for performing the final checks. The Engineer should perform the final checks and prepare the documentation according to the requirements in section C (“Final Documentation Requirements by Pay Item”) of IDOT’s *Documentation of Contract Quantities,* http://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Construction/Documentation-Guide/Documentation-Guide-FY2017.pdf. For example, if the pay item is pavement, the Engineer is responsible for performing and documenting the depth checks of the work done with AMG (IDOT 2017). The Engineer shall decide how much final check work is to be performed, based on the requirements in IDOT’s *Documentation of Contract Quantities* and based on the project conditions. If the final checks are performed by the Contractor, the Engineer or technicians should be present during the final checks, witness the checks, and make note of each check in the field diary.

7.12.3 The Final Checks Could be Performed With or Without Stakes

If the Contractor chooses AMG, the following types of staking might be eliminated (Michigan DOT 2016):

a) Slope stakes, subgrade stakes, undercut stakes, and clearing stakes

b) Pavement stakes

Before the Contractor eliminates those staking items, the Contractor should describe the AMG operations either to the Engineer or in the AMG Work Plan. If the Contractor is using only GPS machine guidance, then staking items in (a) might be eliminated; but conventional stakes in (b) might still be needed. If the Contractor is performing only stringless paving operations using AMG (e.g., robotic total stations), then staking in (b) and part of the staking in (a) are not needed; but some of the staking in (a) might still be needed.

Staking might be deemed necessary for final checking purposes. The following are examples of possible stakes that might be set (IowaDOT 2015):

- Conventional survey-grade stakes at 500-ft intervals and at critical points such as but not limited to points of curvature (PCs), points of tangency (PTs), superelevation points, and other critical points required for construction of drainage and roadway structures or as requested by the Engineer
- Finished subgrade points on cross sections at 500-ft intervals on the mainline and at least two cross sections on side roads and ramps, and at 250-ft intervals on curves, transitions, intersections, interchanges, and break points. Those points should be established using data other than the machine guidance surface, i.e., digital models, such as plan typicals and cross sections, for use by the Engineer to conduct independent checks.
- Paving stakes with cut or fill to finish pavement elevation at points along superelevated curve transitions and at station equation locations

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7.14 APPENDIX A: THE AMG WORK PLAN CHECKLIST

AMG Work Plan Checklist

Item	Yes	No	Remarks
Is the scope where AMG will be used clearly defined?			
Did the Contractor submit his/her experience with AMG?			
Did the Contractor submit the AMG equipment information?			
Is the project control clearly designed? And what is the interval of control points?			
Did the Contractor address equipment calibration and maintenance?			
Are conventional stakes needed? If so, at which location(s)?			
Did the Contractor submit the site-calibration plan? If so, did you agree on the control points and procedures and frequency of site calibration? If you are uncertain about the site-calibration plan, did you contact the Department or District surveyors?			
Did the Contractor submit the quality-control plan?			
Is there a GPS base station on the site? Will the base station be used for checking or staking purposes? If so, did the Contractor inform you of the position and elevation of the GPS base station? Did he/she provide the datum differential information?			
Did the Contractor agree with you on the frequency and types of checks to be performed?			
Did the Contractor discuss with you the procedures for performing the construction checks?			
Did the Contractor designate a primary contact and a secondary contact for AMG issues? If so, did the Contractor provide their names and phone numbers?			
Did the Contractor inform you of the personnel who will be using the AMG equipment on a daily basis?			
… …			

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APPENDIX B

Questionnaire for Surveying Other State DOTs and Contractors on Current Practices Employed by Other States

Section 1: Respondent Information

Please provide the following information:
Name:
Agency:
Job title:
Years of experience:
Phone:
Email:

Section 2: Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying

1. Based on your agency's experience in the past year, how many highway projects constructed by your agency utilized GPS technology in construction surveying?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All projects)
2. Based on your agency's experience in the past year, how many highway projects regulated by your agency utilized GPS technology in construction surveying?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All projects)
3. If you did NOT answer "All projects" to the previous question, why was GPS technology NOT used during construction surveying?
   [Unawareness of benefits (DOT); Unawareness of benefits (Contractor); Not required by DOT; Lack of specifications by DOT; Procedural issues (DOT); Procedural issues (Contractor); Lack of GPS equipment (DOT); Lack of GPS equipment (Contractor); Lack of end-user technical skills (DOT); Lack of end-user technical skills (Contractor); Cost of acquiring and operating GPS equipment; Inconstant signals; Limited accuracy; Other]
4. Which of the following options best describe the DOT's specifications with respect to the use of GPS technology in construction surveying?
   (Allow unlimited use; Allow limited use; Prohibit use; Mandate use; Are silent)
5. Based on your agency's experience, indicate your level of satisfaction with the use of GPS technology in construction surveying for each of the following activities.
   (Project control surveying; Automated machine guidance; Staking for grading; Staking for paving; Staking structure; Staking drainage and pipeline; Staking slope; Staking base; Staking curb and gutter; Staking concrete barrier; Preparation of surveying data deliverable; Construction staking bid item measurement; Other)
   [1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied]
6. Which of the following benefits did your agency experience when using GPS technology in construction surveying?
   (Decrease crew size; Facilitate measurement of vertical distance; Decrease the duration of surveying; Decrease the cost; Make it possible to work under bad weather conditions; Improve the precision of survey; Reduce staking workload; Other)
7. Based on your agency's experience, indicate the level of significance that the following factors had in contributing to the success of GPS implementation at your agency?
   [Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with GPS technologies (DOT);

Experience with GPS technologies (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]
[1: Very insignificant; 2: Insignificant; 3: Somewhat insignificant; 4: Somewhat significant; 5: Significant; 6: Very significant]

8. Based on your agency's experience, which of the following are difficulties or challenges to the use GPS technology in construction surveying?
   (None; Less trained equipment operators; Inefficient communication between Contractor and DOT; Harsh weather conditions; Interruption due to power failure; Reading and recording wrong antenna height; Unstable GPS signal; All parties need to be on the same site calibration; All parties need to use the same data files; Other)

Section 3: Control Surveying Using GPS Technology and Real Time Kinematic (RTK) Method

Based on your experience in using GPS technology in control surveying and RTK method, please answer the following questions:

1. Who is responsible for performing secondary control surveys for the project?
   (DOT; Contractor)
2. If Automated Machine Guidance (AMG) is used, are additional horizontal and vertical control surveys required?
   (Y/N)
3. Which of the following office procedures are done when conducting RTK control surveying?
   (Check the data collector file for correctness and completeness; Check the base station coordinates and ellipsoid height for correctness; Analyze the GPS site calibration for a high scale factor and high residuals; Compare check shots with the known values; Check all reports for high residuals; Other)
4. Which of the following types of base station networks are utilized by your agency?
   (CORS; OPUS; HARN; VRS; NDGPS; Other)
5. What are the deliverables that are required to be submitted by the Surveyor for a GPS control survey?
   (Project narrative summary; Names of individuals and duties; Coordinates; Coordinate metadata; Project site map; Equipment logs; Calibration report for all points used in the survey; Primary control checks; Post-process report; Weather condition report; GPS raw and solution files; Other)
6. Please provide the link to the manual or document that includes the DOT specifications about GPS RTK survey design, setup, and operation, including:
   Minimum number of horizontal and vertical Real Time Kinematic (RTK) control stations; Horizontal and vertical tolerances; Maximum Position Dilution of Precision (PDOP); Minimum number of satellites observed simultaneously; Maximum epoch interval for data sampling; Minimum number of epochs of collected data for each observation; Minimum time between repeat observations; Maximum difference in horizontal or vertical coordinates of the second occupation from the first occupation; Maximum distance from the base station to the rover units; Minimum satellite mask above the horizon; Geometry of control stations; Minimum level of accuracy of control stations; Whether the base station is occupied by an RTK control station; Whether the base station use a fixed height tripod.
   If the specifications are included in more than one document, please provide the links to ALL documents.
   If a document is not available online, please send a copy of the document to gohary@illinois.edu.

SECTION 4: CONSTRUCTION SURVEYING USING GPS EQUIPMENT

Based on your experience in construction surveying using GPS equipment, please answer the following questions:

1. Where is automated machine guidance (AMG) allowed to be used?
   (Rough grading; Finish grading; Paving; Curb; Pipe and drainage; Structure; Concrete barrier; Resurfacing; Other)
2. Where does the DOT plan to use automated machine guidance (AMG) besides the current use(s)?

(Rough grading; Finish grading; Paving; Curb; Pipe and drainage; Structure; Concrete barrier; Resurfacing; Other)

3. Where does the Contractor plan to use automated machine guidance (AMG) besides the current use(s)?
   (Rough grading; Finish grading; Paving; Curb; Pipe and drainage; Structure; Concrete barrier; Resurfacing; Other)
4. Does the DOT require some conventional staking when conducting construction surveying using GPS equipment?
   (Y/N)
5. If yes to Question 4, indicate your level of agreement with the following statement: The DOT is requiring too much conventional staking, when conducting construction surveying using GPS equipment.
   (1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)
6. Based on your agency's experience in the past year, how many highway projects conducted construction surveying using GPS equipment?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
7. Which of the following benefits did your agency experience when conducting construction surveying using GPS equipment for highway projects?
   (Reduced staking; Stakeless; More efficient processes; Improved accuracy; Less experienced construction staff required; Lower bids from contractors; Safer working environment; Other)
8. Does the DOT provide a list of approved GPS equipment?
   (Y/N)
9. What is the vendor of the GPS equipment that you use?
   (Trimble; Topcon; Other)
10. Do the DOT specifications require that construction surveying using GPS equipment have to achieve the same level of accuracy/tolerance compared with conventional staking?
    (Y/N)
11. What is the specified frequency to maintain the GPS equipment?
    (Not specified; Every six months; At the beginning of each survey; Weekly during the survey; Other)
12. If you answered "Not specified" to Question 11, how frequent do you maintain the GPS equipment?
    (Not regularly; Every six months; At the beginning of each survey; Weekly during the survey; Other)
13. What GPS equipment components are maintained?
    (Tripods; Fixed height tripods; Rods; Cables; Receivers and receiver antennas; Handhelds; Other)
14. What types of GPS equipment checks are specified/required?
    (None; Federal published calibration baseline check by NGS; Zero baseline check of antenna, receiver, and cables according to manufacturer; Primary control check; Other)
15. If you answered "None" to Question 14, what types of GPS equipment checks do you perform?
    (None; Federal published calibration baseline check by NGS; Zero baseline check of antenna, receiver, and cables according to manufacturer; Primary control check; Other)
16. What is the frequency of GPS equipment checks you perform?
    (At beginning and end of survey; Every six months; By request of Engineer or Contractor; Other)
17. Is the Contractor required to provide training on the use of Contractor's GPS system to the Contractor staff?
    (Y/N)
18. If yes to Question 17, what is the specified time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT; Other)
19. If no to Question 17, does the Contractor voluntarily provide training on the use of Contractor's GPS system to the Contractor staff?
    (Y/N)
20. If yes to Question 19, what is the time and frequency of the training?

(One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones as needed; Other)

21. Is the Contractor required to provide training on the use of Contractor's GPS system to DOT staff? (Y/N)
22. If yes to Question 21, what is the specified time and frequency of the training? (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT; Other)
23. If no to Question 21, does Contractor voluntarily provide training on the use of Contractor's GPS system to the DOT staff? (Y/N)
24. If yes to Question 23, what is the time and frequency of the training? (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones as needed; Other)
25. Is the Contactor required to perform daily site calibration checks? (Y/N)
26. If no to question 25, are daily site calibration checks voluntarily performed by the Contractor? (Y/N)
27. What is the horizontal tolerance for daily site calibration checks? (0.10 feet; Other)
28. What is the vertical tolerance for daily site calibration checks? (0.05 feet; Other)
29. Who is performing the spot checks of the control of work? (Contractor; Engineer; Both)
30. Who is responsible to perform the final check? (Contractor, witnessed by Engineer; Engineer; Other)
31. What is the vertical tolerance for the final check? (0.05 feet; 0.10 feet; Other)
32. What is the horizontal tolerance for the final check? (0.04 feet; 0.10 feet; Other)
33. How many consecutive randomly selected checking points should be within the tolerance to ensure conformance to the plan? (Not required; 4 of 5 randomly selected checking points should be within the tolerance; Other)

Section 5: Conventional Staking When Conducting Construction Surveying using GPS Equipment

Based on your experience in using conventional staking when conducting construction surveying using GPS equipment, please answer the following questions about conventional staking specifications/tolerances/accuracies:

1. Does the DOT have specifications for conventional staking when conducting construction surveying using GPS equipment (such as tolerances and stake spacing) written in a construction manual or other guidance documents? (Y/N)
2. Indicate your level of agreement with the following statement: It is necessary to have written specification for conventional staking when conducting construction surveying using GPS equipment (such as tolerances and stake spacing) included in a construction manual or other guidance documents. (1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)
3. Please provide the link to the manual or document that includes the DOT specifications for conventional staking when conducting construction surveying using GPS equipment about the tolerances and stake spacing for subgrade staking, pavement staking, slope staking, and structure layout staking, including: Vertical tolerances; Horizontal tolerances; Maximum spaces or specific

intervals between two stakes; Minimum number of shots needed to verify ground elevation; Where should the shots be taken; Whether the stakes should be set on a line offset from the structure centerline for roadway and substructure units.
If the specifications are included in more than one document, please provide the links to ALL documents.
If a document is not available online, please send a copy of the document to gohary@illinois.edu.

4. Are the staking procedures when conducting construction surveying using GPS equipment written in a construction manual or other guidance documents?
(Y/N)
5. Indicate your level of agreement with the following statement: It is necessary to have written staking procedures when conducting construction surveying using GPS equipment included in a construction manual or other guidance documents?
(1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)
6. Please provide the link to the manual or document that includes the staking procedures when conducting construction surveying using GPS equipment.
If the procedures are included in more than one document, please provide the links to ALL documents.
If a document is not available online, please send a copy of the document to gohary@illinois.edu.
7. Is subgrade staking still required when conducting construction surveying using GPS equipment?
(Y/N)
8. Is pavement staking still required when conducting construction surveying using GPS equipment?
(Y/N)
9. Is slope staking still required when conducting construction surveying using GPS equipment?
(Y/N)
10. Is structure layout staking still required when conducting construction surveying using GPS equipment?
(Y/N)
11. Are electronic devices used to collect and compute positions and distances when staking?
(Y/N)
12. Which document should the Contractor refer to, in order to understand how to operate electronic devices or software used to gather, store, and/or calculate position data?
(Manufacturer's manual; Construction manual; Other)
13. When the slope is not a "catch" and the slope stake is not on a constant cut/fill line, is the cut/fill shown on the stake computed using the digital models and the actual ground elevation with the help of electronic devices?
(Y/N)
14. How is the ground measured?
(At each grade break; Every 25 feet; Other)
15. When is the measurement stopped?
(Until the profile grade line for the station is reached; The difference between the measured ground elevation and the elevation computed is less than the tolerance; Other)
16. If a tolerance is used to determine the stop of the measurement, what is the specified horizontal tolerance?
(0.5 feet; Other)
17. If a tolerance is used to determine the stop of the measurement, what is the specified vertical tolerance?
(0.1 feet; Other)
18. Is the stake/field book automatically generated by the electronic devices?
(Y/N)

Section 6: Digital Models and Electronic Data Exchange Practices

Based on your experience in using digital models and electronic data exchange practices in construction surveying for highway projects, please answer the following questions:

1. Based on your agency's experience in the past year, how many highway construction surveys are using digital models?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
2. Based on your agency's experience in the past year, how many of these highway construction surveys (that are using digital models) are using the following software for creating and updating the digital models?
   [AutoCAD Civil 3D; AutoCAD Map 3D; Autodesk Navisworks Simulate; Bentley ConstrucSim; MicroStation; GEOPAK; InRoads; Trimble Business Center; Other]
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
3. Indicate your level of satisfaction with the use of the following software in supporting construction surveying.
   [AutoCAD Civil 3D; AutoCAD Map 3D; Autodesk Navisworks Simulate; Bentley ConstrucSim; MicroStation; GEOPAK; InRoads; Other]
   (1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied)
4. Which of the following benefits are involved with the use of digital models in construction surveying for highway projects?
   (Simulate and visualize the project more accurately; More quickly perform quantity takeoffs; Deliver models of higher quality to Contractor for automated machine guidance; Combine multiple types of data such as CAD and geospatial data; Standardize the as-built data collection process; Improve access to highway project information; Facilitate information exchange among stakeholders; Streamline different phases such as design, construction, operation, and maintenance; Decrease the risk of redoing; Improve bid accuracy; Other)
5. How does the use of digital models affect the project time?
   (Does not have any effect on project time; Saves less than 25% of project time; Saves over 25% of project time but less than 50% of project time; Saves over 50% of project time; Add project time; Does not save or add time, but spends more time on earlier stages and less on later stages; Does not save or add time, but spends less time on earlier stages and more on later stages; Other)
6. If time savings are reported, which of the activities are associated with the most time saving?
   (Project control; Grading; Paving; Earthwork and excavation; Curb and gutter construction; Pipe and drainage construction; Structure construction; Site calibration and check; Preparation of deliverable; Other)
7. How does the use of digital models affect the project cost?
   (Does not have any effect on project cost; Saves less than 10% of project cost; Saves over 10% of project time but less than 25% of project cost; Saves over 25% of project cost; Adds project cost; Does not save or add cost, but spend more on earlier stages and less on later stages; Does not save or add cost, but spend less on earlier stages and more on later stages; Other)
8. If cost savings are reported, which of the activities are associated with the most cost saving?
   (Project control surveying; Automated machine guidance; Staking for grading; Staking for paving; Staking structure; Staking drainage and pipeline; Staking slope; Staking base; Staking curb and gutter; Staking concrete barrier; Preparation of surveying data deliverables; Construction staking bid item measurement; Other)
9. If digital models are used in construction surveys, which of the following are barriers or challenges to successful implementation?
   (Training is difficult; Software get updated frequently; Software cannot fulfill certain tasks; Inefficient communication among stakeholders; DOT lack of experience; Contractor lack of experience; DOT lack of specifications; Procedural issues; Cost issues; Other)
10. If digital models are NOT used in construction surveys, what are the reasons why they are not used

or what are the barriers to implementation?
(Training is difficult; Software get updated frequently; Software cannot fulfil certain tasks; Upfront cost of software and hardware is high; Cost of implementation is high; Lack of specifications; Reluctance to learn new technology; Unawareness of benefits of new technology; Legal concerns about sharing data; Other)

11. In construction projects using digital models, which of the following factors contribute to the success of implementation of the mentioned software?
[Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive contract specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with the software (DOT); Experience with the software (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]
12. Who is responsible for providing the digital models used for AMG?
(DOT; Contractor)
13. Who is responsible for updating and revising the digital models used for AMG?
(DOT; Contractor)
14. Who is responsible for any errors or omissions in the digital models used for AMG?
(DOT; Contractor)
15. Are the digital models generated by the Contractor allowed to be different from the design files provided by the DOT?
(Y/N)
16. Who is responsible for any discrepancies between the design files provided by DOT and the 3D models generated by the Contractor?
(DOT; Contractor)
17. What electronic data are provided by the DOT to the Contractor?
(Cross section; Machine control surface model files; Alignment data files; Background graphics file with roadway and drainage features such as centerlines, edges and hull of ponds; Other)
18. When are the electronic data provided to the Contractor?
(After the Contractor wins the bid; Before the preconstruction conference; After the preconstruction conference; At request by the Contractor; Other)
19. Indicate your level of satisfaction with providing electronic data to the Contractor during construction.
(1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied)
20. What are the main uses of existing electronic data provided by the DOT?
(Check quantities; Build digital model; Layout survey; Exchanging information with DOT personnel; Acquire accurate information about position, distance, etc.; Other)
21. What are the additional electronic files that should be provided by the DOT if NOT provided now?
(Cross section; Machine control surface model files; Alignment data files; Background graphics file with roadway and drainage features such as centerlines, edges and hull of ponds; Other)
22. Which of the following benefits are involved with providing electronic data to the Contractor?
(Cost savings; Time savings; Improved project quality; More accurate bids; Fast identification of errors; More accurate digital models; Other)
23. How do additional electronic data affect the workload of the DOT?
(No effect; Decreases the workload; Increases less than 25% of the workload; Increases about or over 25% of the workload; Especially increases the workload during preparation of data provided to Contractor; Especially increases the workload during construction stage due to additional quality control; Other)
24. What are the specified deliverables that should be submitted by the Contractor to the DOT?
(GPS/AMG work plan; Survey control report; Quality control (QC) plan; Report of post project benchmarks; As-built construction plan; Survey notebooks; Other)
25. What is the specified format of the digital models?

[ASCII; LandXML; ALG (InRoads geometry); CSV (Comma-separated values); DC (Data Collector file used in Trimble Survey Controller); DGN (MicroStation drawing files); DWG (Native format of AutoCAD); DXF (Data exchange file); DTM (Digital terrain model); GPK (GEOPAK coordinate geometry file); IRD (InRoads roadway definition file); TIN (Triangulated Irregular Network); SHP (Shapefile spatial data format); Other]

26. What should the GPS/AMG work plan contain?
    (Description of equipment and software; Contractor's experience; Definition of project boundaries and scope of work to be accomplished using GPS/AMG; Project secondary control; Site calibration procedure; Equipment calibration and maintenance procedure; Other)
27. What is the specified time at which the GPS/AMG work plan should be submitted?
    (5 working days or one week prior to primary field operation; 5 working days or one week prior to preconstruction conference; 30 days prior to primary field operation; Other)

<u>Section 7: Laser Scanning</u>

Based on your experience in using <u>laser scanning</u>, please answer the following questions:

1. Based on your agency's experience in the past year, how many highway construction surveys are using laser scanning?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
2. Is laser scanning used for construction staking of highway projects?
   (Y/N)
3. Which of the following applications of laser scanning in highway projects have you used? Indicate your level of satisfaction for each one used.
   (Digital terrain modeling; Automated machine control; Post-construction quality control; Quantities; Pavement analysis scans; Roadway/pavement topographic surveys; Structure and bridge clearance surveys; As-built surveys; Corridor planning survey; Earthwork surveys; Urban mapping and modeling)
   [1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied]
4. If laser scanning is used in construction surveys, what are the benefits to the project?
   (Provides dense point cloud data in a short time; Provides reusable data; Makes it possible for surveyors to be at a safe distance from traffic; Facilitates survey about inaccessible area and vegetated area; Saves time and cost for example when generating digital terrain model from the point cloud data; Other)
5. If laser scanning is not used in construction surveys, what are the barriers or challenges to the implementation?
   [Cost and budget; Unawareness of benefits; End-user technical skill (DOT); End-user technical skill (Contractor); Lack of specification; Lack of laser scanning equipment (DOT); Lack of laser scanning equipment (Contractor); DOT procedural issues; Requiring supplemented measurement such as total station and GPS survey; Requiring post-processing; Requiring significant data storage; Other]
6. In construction projects using laser scanning, which of the following factors contribute to the success of implementation of laser scanning?
   [Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive contract specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with laser scanning (DOT); Experience with laser scanning (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]

APPENDIX C

Questionnaire for Surveying Contractors on Current Practices Employed about Adapting Construction Staking to Modern Technologies

The questionnaire consists of **seven** sections and has **92** questions. It will take you about **50 minutes** to complete all the questions.
If you **do not know** the answer to a question, please respond *Do not know* instead of randomly providing an answer.
If you choose *Other*, please provide **you own answer** to the question.

Section 1: Respondent Information
Please provide the following information:
Name:
Agency:
Job title:
Years of experience:
Phone:
Email:

Section 2: Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying

1. Based on your agency's experience in the past year, how many highway projects constructed by your agency utilized GPS technology in construction surveying?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All projects)
2. If you did NOT answer "All projects" to the previous question, why was GPS technology NOT used during construction surveying?
   [Unawareness of benefits (DOT); Unawareness of benefits (Contractor); Not required by DOT; Lack of specifications by DOT; Procedural issues (DOT); Procedural issues (Contractor); Lack of GPS equipment (DOT); Lack of GPS equipment (Contractor); Lack of end-user technical skills (DOT); Lack of end-user technical skills (Contractor); Cost of acquiring and operating GPS equipment; Inconstant signals; Limited accuracy; Other]
3. Which of the following options best describe the DOT's specifications with respect to the use of GPS technology in construction surveying?
   (Allow unlimited use; Allow limited use; Prohibit use; Mandate use; Are silent)
4. Based on your agency's experience, indicate your level of satisfaction with the use of GPS technology in construction surveying for each of the following activities.
   (Project control surveying; Automated machine guidance; Staking for grading; Staking for paving; Staking structure; Staking drainage and pipeline; Staking slope; Staking base; Staking curb and gutter; Staking concrete barrier; Preparation of surveying data deliverable; Construction staking bid item measurement; Other)
   [1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied]
5. Which of the following benefits did your agency experience when using GPS technology in construction surveying?
   (Decrease crew size; Facilitate measurement of vertical distance; Decrease the duration of surveying; Decrease the cost; Make it possible to work under bad weather conditions; Improve the precision of survey; Reduce staking workload; Other)
6. Based on your agency's experience, indicate the level of significance that the following factors had in contributing to the success of GPS implementation at your agency?

[Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with GPS technologies (DOT); Experience with GPS technologies (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]
[1: Very insignificant; 2: Insignificant; 3: Somewhat insignificant; 4: Somewhat significant; 5: Significant; 6: Very significant]

7. Based on your agency's experience, which of the following are difficulties or challenges to the use GPS technology in construction surveying?
(None; Less trained equipment operators; Inefficient communication between Contractor and DOT; Harsh weather conditions; Interruption due to power failure; Reading and recording wrong antenna height; Unstable GPS signal; All parties need to be on the same site calibration; All parties need to use the same data files; Other)

Section 3: Control Surveying Using GPS Technology and Real Time Kinematic (RTK) Method

Based on your experience in using GPS technology in control surveying and RTK method, please answer the following questions:

1. Who is responsible for performing secondary control surveys for the project?
(DOT; Contractor)
2. If Automated Machine Guidance (AMG) is used, are additional horizontal and vertical control surveys required?
(Y/N)
3. Which of the following office procedures are done when conducting RTK control surveying?
(Check the data collector file for correctness and completeness; Check the base station coordinates and ellipsoid height for correctness; Analyze the GPS site calibration for a high scale factor and high residuals; Compare check shots with the known values; Check all reports for high residuals; Other)
4. Which of the following types of base station networks are utilized by your agency?
(CORS; OPUS; HARN; VRS; NDGPS; Other)
5. What are the required deliverables that should be submitted by the Surveyor for a GPS control survey?
(Project narrative summary; Names of individuals and duties; Coordinates; Coordinate metadata; Project site map; Equipment logs; Calibration report for all points used in the survey; Primary control checks; Post-process report; Weather condition report; GPS raw and solution files; Other)

SECTION 4: CONSTRUCTION SURVEYING USING GPS EQUIPMENT

Based on your experience in construction surveying using GPS equipment, please answer the following questions:

1. Where is automated machine guidance (AMG) allowed to be used?
(Rough grading; Finish grading; Paving; Curb; Pipe and drainage; Structure; Concrete barrier; Resurfacing; Other)
2. Where does the Contractor plan to use automated machine guidance (AMG) besides the current use(s)?
(Rough grading; Finish grading; Paving; Curb; Pipe and drainage; Structure; Concrete barrier; Resurfacing; Other)
3. Does the DOT require some conventional staking when conducting construction surveying using GPS equipment?
(Y/N)
4. If yes to Question 4, indicate your level of agreement with the following statement: The DOT is requiring too much conventional staking, when conducting construction surveying using GPS equipment.
(1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)

5. Based on your agency's experience in the past year, how many highway projects conducted construction surveying using GPS equipment?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
6. Which of the following benefits did your agency experience when conducting construction surveying using GPS equipment for highway projects?
   (Reduced staking; Stakeless; More efficient processes; Improved accuracy; Less experienced construction staff required; Lower bids from contractors; Safer working environment; Other)
7. Does the DOT provide an approved list of GPS equipment?
   (Y/N)
8. What is the vendor of the GPS equipment that you use?
   (Trimble; Topcon; Other)
9. Do the DOT specifications require that construction surveying using GPS equipment have to achieve the same level of accuracy/tolerance compared with conventional staking?
   (Y/N)
10. What is the specified frequency to maintain the GPS equipment?
    (Not specified; Every six months; At the beginning of each survey; Weekly during the survey; Other)
11. If you answered "Not specified" to Question 10, how frequent do you maintain the GPS equipment?
    (Not regularly; Every six months; At the beginning of each survey; Weekly during the survey; Other)
12. What GPS equipment components are maintained?
    (Tripods; Fixed height tripods; Rods; Cables; Receivers and receiver antennas; Handhelds; Other)
13. What types of GPS equipment checks are specified/required?
    (None; Federal published calibration baseline check by NGS; Zero baseline check of antenna, receiver, and cables according to manufacturer; Primary control check; Other)
14. If you answered "None" to Question 13, what types of GPS equipment checks do you perform?
    (None; Federal published calibration baseline check by NGS; Zero baseline check of antenna, receiver, and cables according to manufacturer; Primary control check; Other)
15. What is the frequency of GPS equipment checks you perform?
    (At beginning and end of survey; Every six months; By request of Engineer or Contractor; Other)
16. Is the Contractor required to provide training on the use of Contractor's GPS system to the Contractor staff?
    (Y/N)
17. If yes to Question 16, what is the specified time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT; Other)
18. If no to Question 16, does Contractor voluntarily provide training on the use of Contractor's GPS system to the Contractor staff?
    (Y/N)
19. If yes to Question 18, what is the time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones as needed; Other)
20. Is the Contractor required to provide training on the use of Contractor's GPS system to DOT staff?
    (Y/N)
21. If yes to Question 20, what is the specified time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT; Other)
22. If no to Question 20, does Contractor voluntarily provide training on the use of Contractor's GPS system to the DOT staff?
    (Y/N)
23. If yes to Question 22, what is the time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones as needed; Other)

24. Is the Contactor required to perform daily site calibration checks?
    (Y/N)
25. If no to question 24, are daily site calibration checks voluntarily performed by the Contractor?
    (Y/N)
26. What is the horizontal tolerance for daily site calibration checks?
    (0.10 feet; Other)
27. What is the vertical tolerance for daily site calibration checks?
    (0.05 feet; Other)
28. Who is performing the spot checks of the control of work?
    (Contractor; Engineer; Both)
29. Who is responsible to perform the final check?
    (Contractor, witnessed by Engineer; Engineer; Other)
30. What is the vertical tolerance for the final check?
    (0.05 feet; 0.10 feet; Other)
31. What is the horizontal tolerance for the final check?
    (0.04 feet; 0.10 feet; Other)
32. How many consecutive randomly selected checking points should be within the tolerance to ensure conformance to the plan?
    (Not required; 4 of 5 randomly selected checking points should be within the tolerance; Other)

Section 5: Conventional Staking When Conducting Construction Surveying using GPS Equipment

Based on your experience in using conventional staking when conducting construction surveying using GPS equipment, please answer the following questions about conventional staking specifications/tolerances/accuracies:

1. Does the DOT have specifications for conventional staking when conducting construction surveying using GPS equipment (such as tolerances and stake spacing) written in a construction manual or other guidance documents?
   (Y/N)
2. Indicate your level of agreement with the following statement: It is necessary to have written specification for conventional staking when conducting construction surveying using GPS equipment (such as tolerances and stake spacing) included in a construction manual or other guidance documents.
   (1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)
3. Are the staking procedures when conducting construction surveying using GPS equipment written in a construction manual or other guidance documents?
   (Y/N)
4. Indicate your level of agreement with the following statement: It is necessary to have written staking procedures when conducting construction surveying using GPS equipment included in a construction manual or other guidance documents?
   (1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)
5. Is subgrade staking still required when conducting construction surveying using GPS equipment?
   (Y/N)
6. Is pavement staking still required when conducting construction surveying using GPS equipment?
   (Y/N)
7. Is slope staking still required when conducting construction surveying using GPS equipment?
   (Y/N)
8. Is structure layout staking still required when conducting construction surveying using GPS equipment?
   (Y/N)
9. Are electronic devices used to collect and compute positions and distances when staking?

(Y/N)

10. Which document should the Contractor refer to, in order to understand how to operate electronic devices or software used to gather, store, and/or calculate position data?
    (Manufacturer's manual; Construction manual; Other)
11. When the slope is not a "catch" and the slope stake is not on a constant cut/fill line, is the cut/fill shown on the stake computed using the digital models and the actual ground elevation with the help of electronic devices?
    (Y/N)
12. How is the ground measured?
    (At each grade break; Every 25 feet; Other)
13. When is the measurement stopped?
    (Until the profile grade line for the station is reached; The difference between the measured ground elevation and the elevation computed is less than the tolerance; Other)
14. If a tolerance is used to determine the stop of the measurement, what is the specified horizontal tolerance?
    (0.5 feet; Other)
15. If a tolerance is used to determine the stop of the measurement, what is the specified vertical tolerance?
    (0.1 feet; Other)
16. Is the stake/field book automatically generated by the electronic devices?
    (Y/N)

Section 6: Digital Models and Electronic Data Exchange Practices

Based on your experience in using digital models and electronic data exchange practices in construction surveying for highway projects, please answer the following questions:

1. Based on your agency's experience in the past year, how many highway construction surveys are using digital models?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
2. Based on your agency's experience in the past year, how many of these highway construction surveys (that are using digital models) are using the following software for creating and updating the digital models?
   [AutoCAD Civil 3D; AutoCAD Map 3D; Autodesk Navisworks Simulate; Bentley ConstrucSim; MicroStation; GEOPAK; InRoads; Trimble Business Center; Other]
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
3. Indicate your level of satisfaction with the use of the following software in supporting construction surveying.
   [AutoCAD Civil 3D; AutoCAD Map 3D; Autodesk Navisworks Simulate; Bentley ConstrucSim; MicroStation; GEOPAK; InRoads; Other]
   (1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied)
4. Which of the following benefits are involved with the use of digital models in construction surveying for highway projects?
   (Simulate and visualize the project more accurately; More quickly perform quantity takeoffs; Deliver models of higher quality to Contractor for automated machine guidance; Combine multiple types of data such as CAD and geospatial data; Standardize the as-built data collection process; Improve access to highway project information; Facilitate information exchange among stakeholders; Streamline different phases such as design, construction, operation, and maintenance; Decrease the risk of redoing; Improve bid accuracy; Other)
5. How does the use of digital models affect the project time?
   (Does not have any effect on project time; Saves less than 25% of project time; Saves over 25% of project time but less than 50% of project time; Saves over 50% of project time; Add project time;

Does not save or add time, but spends more time on earlier stages and less on later stages; Does not save or add time, but spends less time on earlier stages and more on later stages; Other)

6. If time savings are reported, which of the activities are associated with the most time saving? (Project control; Grading; Paving; Earthwork and excavation; Curb and gutter construction; Pipe and drainage construction; Structure construction; Site calibration and check; Preparation of deliverable; Other)
7. How does the use of digital models affect the project cost? (Does not have any effect on project cost; Saves less than 10% of project cost; Saves over 10% of project time but less than 25% of project cost; Saves over 25% of project cost; Adds project cost; Does not save or add cost, but spend more on earlier stages and less on later stages; Does not save or add cost, but spend less on earlier stages and more on later stages; Other)
8. If cost savings are reported, which of the activities are associated with the most cost saving? (Project control surveying; Automated machine guidance; Staking for grading; Staking for paving; Staking structure; Staking drainage and pipeline; Staking slope; Staking base; Staking curb and gutter; Staking concrete barrier; Preparation of surveying data deliverables; Construction staking bid item measurement; Other)
9. If digital models are used in construction surveys, which of the following are barriers or challenges to successful implementation? (Training is difficult; Software get updated frequently; Software cannot fulfill certain tasks; Inefficient communication among stakeholders; DOT lack of experience; Contractor lack of experience; DOT lack of specifications; Procedural issues; Cost issues; Other)
10. If digital models are NOT used in construction surveys, what are the reasons why they are not used or what are the barriers to implementation? (Training is difficult; Software get updated frequently; Software cannot fulfil certain tasks; Upfront cost of software and hardware is high; Cost of implementation is high; Lack of specifications; Reluctance to learn new technology; Unawareness of benefits of new technology; Legal concerns about sharing data; Other)
11. In construction projects using digital models, which of the following factors contribute to the success of implementation of the mentioned software? [Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive contract specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with the software (DOT); Experience with the software (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]
12. Who is responsible for providing the digital models used for AMG? (DOT; Contractor)
13. Who is responsible for updating and revising the digital models used for AMG? (DOT; Contractor)
14. Who is responsible for any errors or omissions in the digital models used for AMG? (DOT; Contractor)
15. Are the digital models generated by the Contractor allowed to be different from the design files provided by the DOT? (Y/N)
16. Who is responsible for any discrepancies between the design files provided by DOT and the 3D models generated by the Contractor? (DOT; Contractor)
17. What electronic data are provided by the DOT to the Contractor? (Cross section; Machine control surface model files; Alignment data files; Background graphics file with roadway and drainage features such as centerlines, edges and hull of ponds; Other)
18. When are the electronic data provided to the Contractor? (After the Contractor wins the bid; Before the preconstruction conference; After the preconstruction

conference; At request by the Contractor; Other)

19. Indicate your level of satisfaction with providing electronic data to the Contractor during construction. (1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied)
20. What are the main uses of existing electronic data provided by the DOT? (Check quantities; Build digital model; Layout survey; Exchanging information with DOT personnel; Acquire accurate information about position, distance, etc.; Other)
21. What are the additional electronic files that should be provided by the DOT if NOT provided now? (Cross section; Machine control surface model files; Alignment data files; Background graphics file with roadway and drainage features such as centerlines, edges and hull of ponds; Other)
22. Which of the following benefits are involved with providing electronic data to the Contractor? (Cost savings; Time savings; Improved project quality; More accurate bids; Fast identification of errors; More accurate digital models; Other)
23. What are the specified deliverables that should be submitted by the Contractor to the DOT? (GPS/AMG work plan; Survey control report; Quality control (QC) plan; Report of post project benchmarks; As-built construction plan; Survey notebooks; Other)
24. What is the specified format of the digital models? [ASCII; LandXML; ALG (InRoads geometry); CSV (Comma-separated values); DC (Data Collector file used in Trimble Survey Controller); DGN (MicroStation drawing files); DWG (Native format of AutoCAD); DXF (Data exchange file); DTM (Digital terrain model); GPK (GEOPAK coordinate geometry file); IRD (InRoads roadway definition file); TIN (Triangulated Irregular Network); SHP (Shapefile spatial data format); Other]
25. What should the GPS/AMG work plan contain? (Description of equipment and software; Contractor's experience; Definition of project boundaries and scope of work to be accomplished using GPS/AMG; Project secondary control; Site calibration procedure; Equipment calibration and maintenance procedure; Other)
26. What is the specified time at which the GPS/AMG work plan should be submitted? (5 working days or one week prior to primary field operation; 5 working days or one week prior to preconstruction conference; 30 days prior to primary field operation; Other)

<u>Section 7: Laser Scanning</u>

Based on your experience in using <u>laser scanning</u>, please answer the following questions:

1. Based on your agency's experience in the past year, how many highway construction surveys are using laser scanning?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
2. Is laser scanning used for construction staking of highway projects?
   (Y/N)
3. Which of the following applications of laser scanning in highway projects have you used? Indicate your level of satisfaction for each one used.
   (Digital terrain modeling; Automated machine control; Post-construction quality control; Quantities; Pavement analysis scans; Roadway/pavement topographic surveys; Structure and bridge clearance surveys; As-built surveys; Corridor planning survey; Earthwork surveys; Urban mapping and modeling)
   [1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied]
4. If laser scanning is used in construction surveys, what are the benefits to the project?
   (Provides dense point cloud data in a short time; Provides reusable data; Makes it possible for surveyors to be at a safe distance from traffic; Facilitates survey about inaccessible area and vegetated area; Saves time and cost for example when generating digital terrain model from the point cloud data; Other)
5. If laser scanning is not used in construction surveys, what are the barriers or challenges to the

implementation?
[Cost and budget; Unawareness of benefits; End-user technical skill (DOT); End-user technical skill (Contractor); Lack of specification; Lack of laser scanning equipment (DOT); Lack of laser scanning equipment (Contractor); DOT procedural issues; Requiring supplemented measurement such as total station and GPS survey; Requiring post-processing; Requiring significant data storage; Other]

6. In construction projects using laser scanning, which of the following factors contribute to the success of implementation of laser scanning?
   [Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive contract specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with laser scanning (DOT); Experience with laser scanning (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]

APPENDIX D

Questionnaire for Surveying Construction Staff in State Department of Transportation on Current Practices Employed about Adapting Construction Staking to Modern Technologies

The form consists of **four** sections and has **57** questions. It will take you about **30 minutes** to complete all the questions.
If you **do not know** the answer to a question, please respond *Do not know* instead of randomly providing an answer.
If you choose *Other*, please provide **you own answer** to the question.

Section 1: Respondent Information
Please provide the following information:
Name:
Agency:
Job title:
Years of experience:
Phone:
Email:

Section 2: Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying

1. Based on your agency's experience in the past year, how many highway projects regulated by your agency utilized GPS technology in construction surveying?
(None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All projects)
2. If you did NOT answer "All projects" to the previous question, why was GPS technology NOT used during construction surveying?
[Unawareness of benefits (DOT); Unawareness of benefits (Contractor); Not required by DOT; Lack of specifications by DOT; Procedural issues (DOT); Procedural issues (Contractor); Lack of GPS equipment (DOT); Lack of GPS equipment (Contractor); Lack of end-user technical skills (DOT); Lack of end-user technical skills (Contractor); Cost of acquiring and operating GPS equipment; Inconstant signals; Limited accuracy; Other]
3. Which of the following options best describe the DOT's specifications with respect to the use of GPS technology in construction surveying?
(Allow unlimited use; Allow limited use; Prohibit use; Mandate use; Are silent)
4. Based on your agency's experience, indicate your level of satisfaction with the use of GPS technology in construction surveying for each of the following activities.
(Project control surveying; Automated machine guidance; Staking for grading; Staking for paving; Staking structure; Staking drainage and pipeline; Staking slope; Staking base; Staking curb and gutter; Staking concrete barrier; Preparation of surveying data deliverable; Construction staking bid item measurement; Other)
[1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied]
5. Which of the following benefits did your agency experience when using GPS technology in construction surveying?
(Decrease crew size; Facilitate measurement of vertical distance; Decrease the duration of

surveying; Decrease the cost; Make it possible to work under bad weather conditions; Improve the precision of survey; Reduce staking workload; Other)

6. Based on your agency's experience, indicate the level of significance that the following factors had in contributing to the success of GPS implementation at your agency?
   [Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with GPS technologies (DOT); Experience with GPS technologies (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]
   [1: Very insignificant; 2: Insignificant; 3: Somewhat insignificant; 4: Somewhat significant; 5: Significant; 6: Very significant]
7. Based on your agency's experience, which of the following are difficulties or challenges to the use GPS technology in construction surveying?
   (None; Less trained equipment operators; Inefficient communication between Contractor and DOT; Harsh weather conditions; Interruption due to power failure; Reading and recording wrong antenna height; Unstable GPS signal; All parties need to be on the same site calibration; All parties need to use the same data files; Other)

SECTION 3: CONSTRUCTION SURVEYING USING GPS EQUIPMENT

Based on your experience in construction surveying using GPS equipment, please answer the following questions:

1. Where is automated machine guidance (AMG) allowed to be used?
   (Rough grading; Finish grading; Paving; Curb; Pipe and drainage; Structure; Concrete barrier; Resurfacing; Other)
2. Where does the DOT plan to use automated machine guidance (AMG) besides the current use(s)?
   (Rough grading; Finish grading; Paving; Curb; Pipe and drainage; Structure; Concrete barrier; Resurfacing; Other)
3. Does the DOT require some conventional staking when conducting construction surveying using GPS equipment?
   (Y/N)
4. If yes to Question 3, indicate your level of agreement with the following statement: The DOT is requiring too much conventional staking, when conducting construction surveying using GPS equipment.
   (1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)
5. Based on your agency's experience in the past year, how many highway projects conducted construction surveying using GPS equipment?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
6. Which of the following benefits did your agency experience when conducting construction surveying using GPS equipment for highway projects?
   (Reduced staking; Stakeless; More efficient processes; Improved accuracy; Less experienced construction staff required; Lower bids from contractors; Safer working environment; Other)
7. Does the DOT provide a list of approved GPS equipment?
   (Y/N)
8. What is the vendor of the GPS equipment that you use?
   (Trimble; Topcon; Other)
9. Do the DOT specifications require that construction surveying using GPS equipment have to achieve the same level of accuracy/tolerance compared with conventional staking?
   (Y/N)
10. What is the specified frequency to maintain the GPS equipment?
   (Not specified; Every six months; At the beginning of each survey; Weekly during the survey; Other)
11. If you answered "Not specified" to Question 11, how frequent do you maintain the GPS equipment?

(Not regularly; Every six months; At the beginning of each survey; Weekly during the survey; Other)
12. What GPS equipment components are maintained?
(Tripods; Fixed height tripods; Rods; Cables; Receivers and receiver antennas; Handhelds; Other)
13. What types of GPS equipment checks are specified/required?
(None; Federal published calibration baseline check by NGS; Zero baseline check of antenna, receiver, and cables according to manufacturer; Primary control check; Other)
14. If you answered “None” to Question 13, what types of GPS equipment checks do you perform?
(None; Federal published calibration baseline check by NGS; Zero baseline check of antenna, receiver, and cables according to manufacturer; Primary control check; Other)
15. What is the frequency of GPS equipment checks you perform?
(At beginning and end of survey; Every six months; By request of Engineer or Contractor; Other)
16. Is the Contractor required to provide training on the use of Contractor’s GPS system to the Contractor staff?
(Y/N)
17. If yes to Question 16, what is the specified time and frequency of the training?
(One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT; Other)
18. If no to Question 16, does Contractor voluntarily provide training on the use of Contractor’s GPS system to the Contractor staff?
(Y/N)
19. If yes to Question 18, what is the time and frequency of the training?
(One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones as needed; Other)
20. Is the Contractor required to provide training on the use of Contractor’s GPS system to DOT staff?
(Y/N)
21. If yes to Question 20, what is the specified time and frequency of the training?
(One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT; Other)
22. If no to Question 20, does Contractor voluntarily provide training on the use of Contractor’s GPS system to the DOT staff?
(Y/N)
23. If yes to Question 22, what is the time and frequency of the training?
(One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones as needed; Other)
24. Is the Contactor required to perform daily site calibration checks?
(Y/N)
25. If no to question 24, are daily site calibration checks voluntarily performed by the Contractor?
(Y/N)
26. What is the horizontal tolerance for daily site calibration checks?
(0.10 feet; Other)
27. What is the vertical tolerance for daily site calibration checks?
(0.05 feet; Other)
28. Who is performing the spot checks of the control of work?
(Contractor; Engineer; Both)
29. Who is responsible to perform the final check?
(Contractor, witnessed by Engineer; Engineer; Other)
30. What is the vertical tolerance for the final check?
(0.05 feet; 0.10 feet; Other)
31. What is the horizontal tolerance for the final check?
(0.04 feet; 0.10 feet; Other)
32. How many consecutive randomly selected checking points should be within the tolerance to ensure

conformance to the plan?
(Not required; 4 of 5 randomly selected checking points should be within the tolerance; Other)

Section 4: Conventional Staking When Conducting Construction Surveying using GPS Equipment

Based on your experience in using conventional staking when conducting construction surveying using GPS equipment, please answer the following questions about conventional staking specifications/tolerances/accuracies:

1. Does the DOT have specifications for conventional staking when conducting construction surveying using GPS equipment (such as tolerances and stake spacing) written in a construction manual or other guidance documents?
(Y/N)
2. Indicate your level of agreement with the following statement: It is necessary to have written specification for conventional staking when conducting construction surveying using GPS equipment (such as tolerances and stake spacing) included in a construction manual or other guidance documents.
(1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)
3. Please provide the link to the manual or document that includes the DOT specifications for conventional staking when conducting construction surveying using GPS equipment about the tolerances and stake spacing for subgrade staking, pavement staking, slope staking, and structure layout staking, including: Vertical tolerances; Horizontal tolerances; Maximum spaces or specific intervals between two stakes; Minimum number of shots needed to verify ground elevation; Where should the shots be taken; Whether the stakes should be set on a line offset from the structure centerline for roadway and substructure units.
If the specifications are included in more than one document, please provide the links to ALL documents.
If a document is not available online, please send a copy of the document to gohary@illinois.edu.
4. Are the staking procedures when conducting construction surveying using GPS equipment written in a construction manual or other guidance documents?
(Y/N)
5. Indicate your level of agreement with the following statement: It is necessary to have written staking procedures when conducting construction surveying using GPS equipment included in a construction manual or other guidance documents?
(1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)
6. Please provide the link to the manual or document that includes the staking procedures when conducting construction surveying using GPS equipment.
If the procedures are included in more than one document, please provide the links to ALL documents.
If a document is not available online, please send a copy of the document to gohary@illinois.edu.
7. Is subgrade staking still required when conducting construction surveying using GPS equipment?
(Y/N)
8. Is pavement staking still required when conducting construction surveying using GPS equipment?
(Y/N)
9. Is slope staking still required when conducting construction surveying using GPS equipment?
(Y/N)
10. Is structure layout staking still required when conducting construction surveying using GPS equipment?
(Y/N)
11. Are electronic devices used to collect and compute positions and distances when staking?
(Y/N)
12. Which document should the Contractor refer to, in order to understand how to operate electronic

devices or software used to gather, store, and/or calculate position data?
(Manufacturer's manual; Construction manual; Other)

13. When the slope is not a "catch" and the slope stake is not on a constant cut/fill line, is the cut/fill shown on the stake computed using the digital models and the actual ground elevation with the help of electronic devices?
(Y/N)
14. How is the ground measured?
(At each grade break; Every 25 feet; Other)
15. When is the measurement stopped?
(Until the profile grade line for the station is reached; The difference between the measured ground elevation and the elevation computed is less than the tolerance; Other)
16. If a tolerance is used to determine the stop of the measurement, what is the specified horizontal tolerance?
(0.5 feet; Other)
17. If a tolerance is used to determine the stop of the measurement, what is the specified vertical tolerance?
(0.1 feet; Other)
18. Is the stake/field book automatically generated by the electronic devices?
(Y/N)

APPENDIX E

Questionnaire for Surveying Design Staff in State Department of Transportation on Current Practices Employed about Adapting Construction Staking to Modern Technologies

The form consists of **three** sections and has **34** questions. It will take you about **20 minutes** to complete all the questions.
If you **do not know** the answer to a question, please respond *Do not know* instead of randomly providing an answer.
If you choose *Other*, please provide **you own answer** to the question.

Section 1: Respondent Information
Please provide the following information:
Name:
Agency:
Job title:
Years of experience:
Phone:
Email:

Section 2: Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying

1. Based on your agency's experience in the past year, how many highway projects regulated by your agency utilized GPS technology in construction surveying?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All projects)
2. If you did NOT answer "All projects" to the previous question, why was GPS technology NOT used during construction surveying?
   [Unawareness of benefits (DOT); Unawareness of benefits (Contractor); Not required by DOT; Lack of specifications by DOT; Procedural issues (DOT); Procedural issues (Contractor); Lack of GPS equipment (DOT); Lack of GPS equipment (Contractor); Lack of end-user technical skills (DOT); Lack of end-user technical skills (Contractor); Cost of acquiring and operating GPS equipment; Inconstant signals; Limited accuracy; Other]
3. Which of the following options best describe the DOT's specifications with respect to the use of GPS technology in construction surveying?
   (Allow unlimited use; Allow limited use; Prohibit use; Mandate use; Are silent)
4. Based on your agency's experience, indicate your level of satisfaction with the use of GPS technology in construction surveying for each of the following activities.
   (Project control surveying; Automated machine guidance; Staking for grading; Staking for paving; Staking structure; Staking drainage and pipeline; Staking slope; Staking base; Staking curb and gutter; Staking concrete barrier; Preparation of surveying data deliverable; Construction staking bid item measurement; Other)
   [1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied]
5. Which of the following benefits did your agency experience when using GPS technology in construction surveying?
   (Decrease crew size; Facilitate measurement of vertical distance; Decrease the duration of surveying; Decrease the cost; Make it possible to work under bad weather conditions; Improve the precision of survey; Reduce staking workload; Other)
6. Based on your agency's experience, indicate the level of significance that the following factors had

in contributing to the success of GPS implementation at your agency?
[Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with GPS technologies (DOT); Experience with GPS technologies (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]
[1: Very insignificant; 2: Insignificant; 3: Somewhat insignificant; 4: Somewhat significant; 5: Significant; 6: Very significant]

7. Based on your agency's experience, which of the following are difficulties or challenges to the use GPS technology in construction surveying?
(None; Less trained equipment operators; Inefficient communication between Contractor and DOT; Harsh weather conditions; Interruption due to power failure; Reading and recording wrong antenna height; Unstable GPS signal; All parties need to be on the same site calibration; All parties need to use the same data files; Other)

Section 3: Digital Models and Electronic Data Exchange Practices

Based on your experience in using digital models and electronic data exchange practices in construction surveying for highway projects, please answer the following questions:

1. Based on your agency's experience in the past year, how many highway construction surveys are using digital models?
(None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
2. Based on your agency's experience in the past year, how many of these highway construction surveys (that are using digital models) are using the following software for creating and updating the digital models?
[AutoCAD Civil 3D; AutoCAD Map 3D; Autodesk Navisworks Simulate; Bentley ConstrucSim; MicroStation; GEOPAK; InRoads; Trimble Business Center; Other]
(None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
3. Indicate your level of satisfaction with the use of the following software in supporting construction surveying.
[AutoCAD Civil 3D; AutoCAD Map 3D; Autodesk Navisworks Simulate; Bentley ConstrucSim; MicroStation; GEOPAK; InRoads; Other]
(1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied)
4. Which of the following benefits are involved with the use of digital models in construction surveying for highway projects?
(Simulate and visualize the project more accurately; More quickly perform quantity takeoffs; Deliver models of higher quality to Contractor for automated machine guidance; Combine multiple types of data such as CAD and geospatial data; Standardize the as-built data collection process; Improve access to highway project information; Facilitate information exchange among stakeholders; Streamline different phases such as design, construction, operation, and maintenance; Decrease the risk of redoing; Improve bid accuracy; Other)
5. How does the use of digital models affect the project time?
(Does not have any effect on project time; Saves less than 25% of project time; Saves over 25% of project time but less than 50% of project time; Saves over 50% of project time; Add project time; Does not save or add time, but spends more time on earlier stages and less on later stages; Does not save or add time, but spends less time on earlier stages and more on later stages; Other)
6. If time savings are reported, which of the activities are associated with the most time saving?
(Project control; Grading; Paving; Earthwork and excavation; Curb and gutter construction; Pipe and drainage construction; Structure construction; Site calibration and check; Preparation of deliverable; Other)
7. How does the use of digital models affect the project cost?

(Does not have any effect on project cost; Saves less than 10% of project cost; Saves over 10% of project time but less than 25% of project cost; Saves over 25% of project cost; Adds project cost; Does not save or add cost, but spend more on earlier stages and less on later stages; Does not save or add cost, but spend less on earlier stages and more on later stages; Other)

8. If cost savings are reported, which of the activities are associated with the most cost saving?
   (Project control surveying; Automated machine guidance; Staking for grading; Staking for paving; Staking structure; Staking drainage and pipeline; Staking slope; Staking base; Staking curb and gutter; Staking concrete barrier; Preparation of surveying data deliverables; Construction staking bid item measurement; Other)
9. If digital models are used in construction surveys, which of the following are barriers or challenges to successful implementation?
   (Training is difficult; Software get updated frequently; Software cannot fulfill certain tasks; Inefficient communication among stakeholders; DOT lack of experience; Contractor lack of experience; DOT lack of specifications; Procedural issues; Cost issues; Other)
10. If digital models are NOT used in construction surveys, what are the reasons why they are not used or what are the barriers to implementation?
    (Training is difficult; Software get updated frequently; Software cannot fulfil certain tasks; Upfront cost of software and hardware is high; Cost of implementation is high; Lack of specifications; Reluctance to learn new technology; Unawareness of benefits of new technology; Legal concerns about sharing data; Other)
11. In construction projects using digital models, which of the following factors contribute to the success of implementation of the mentioned software?
    [Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive contract specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with the software (DOT); Experience with the software (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]
12. Who is responsible for providing the digital models used for AMG?
    (DOT; Contractor)
13. Who is responsible for updating and revising the digital models used for AMG?
    (DOT; Contractor)
14. Who is responsible for any errors or omissions in the digital models used for AMG?
    (DOT; Contractor)
15. Are the digital models generated by the Contractor allowed to be different from the design files provided by the DOT?
    (Y/N)
16. Who is responsible for any discrepancies between the design files provided by DOT and the 3D models generated by the Contractor?
    (DOT; Contractor)
17. What electronic data are provided by the DOT to the Contractor?
    (Cross section; Machine control surface model files; Alignment data files; Background graphics file with roadway and drainage features such as centerlines, edges and hull of ponds; Other)
18. When are the electronic data provided to the Contractor?
    (After the Contractor wins the bid; Before the preconstruction conference; After the preconstruction conference; At request by the Contractor; Other)
19. Indicate your level of satisfaction with providing electronic data to the Contractor during construction.
    (1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied)
20. What are the main uses of existing electronic data provided by the DOT?
    (Check quantities; Build digital model; Layout survey; Exchanging information with DOT personnel; Acquire accurate information about position, distance, etc.; Other)

21. What are the additional electronic files that should be provided by the DOT if NOT provided now?
    (Cross section; Machine control surface model files; Alignment data files; Background graphics file with roadway and drainage features such as centerlines, edges and hull of ponds; Other)
22. Which of the following benefits are involved with providing electronic data to the Contractor?
    (Cost savings; Time savings; Improved project quality; More accurate bids; Fast identification of errors; More accurate digital models; Other)
23. How do additional electronic data affect the workload of the DOT?
    (No effect; Decreases the workload; Increases less than 25% of the workload; Increases about or over 25% of the workload; Especially increases the workload during preparation of data provided to Contractor; Especially increases the workload during construction stage due to additional quality control; Other)
24. What are the specified deliverables that should be submitted by the Contractor to the DOT?
    (GPS/AMG work plan; Survey control report; Quality control (QC) plan; Report of post project benchmarks; As-built construction plan; Survey notebooks; Other)
25. What is the specified format of the digital models?
    [ASCII; LandXML; ALG (InRoads geometry); CSV (Comma-separated values); DC (Data Collector file used in Trimble Survey Controller); DGN (MicroStation drawing files); DWG (Native format of AutoCAD); DXF (Data exchange file); DTM (Digital terrain model); GPK (GEOPAK coordinate geometry file); IRD (InRoads roadway definition file); TIN (Triangulated Irregular Network); SHP (Shapefile spatial data format); Other]
26. What should the GPS/AMG work plan contain?
    (Description of equipment and software; Contractor's experience; Definition of project boundaries and scope of work to be accomplished using GPS/AMG; Project secondary control; Site calibration procedure; Equipment calibration and maintenance procedure; Other)
27. What is the specified time at which the GPS/AMG work plan should be submitted?
    (5 working days or one week prior to primary field operation; 5 working days or one week prior to preconstruction conference; 30 days prior to primary field operation; Other)

APPENDIX F

Questionnaire for Surveying Survey Staff in State Department of Transportation on Current Practices Employed about Adapting Construction Staking to Modern Technologies

The form consists of **four** sections and has **16** questions. It will take you about **10 minutes** to complete all the questions.
If you **do not know** the answer to a question, please respond *Do not know* instead of randomly providing an answer.
If you choose *Other*, please provide **you own answer** to the question.

Section 1: Respondent Information
Please provide the following information:
Name:
Agency:
Job title:
Years of experience:
Phone:
Email:

Section 2: Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying

1. Based on your agency's experience in the past year, how many highway projects regulated by your agency utilized GPS technology in construction surveying?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All projects)
2. If you did NOT answer "All projects" to the previous question, why was GPS technology NOT used during construction surveying?
   [Unawareness of benefits (DOT); Unawareness of benefits (Contractor); Not required by DOT; Lack of specifications by DOT; Procedural issues (DOT); Procedural issues (Contractor); Lack of GPS equipment (DOT); Lack of GPS equipment (Contractor); Lack of end-user technical skills (DOT); Lack of end-user technical skills (Contractor); Cost of acquiring and operating GPS equipment; Inconstant signals; Limited accuracy; Other]
3. Which of the following options best describe the DOT's specifications with respect to the use of GPS technology in construction surveying?
   (Allow unlimited use; Allow limited use; Prohibit use; Mandate use; Are silent)
4. Based on your agency's experience, indicate your level of satisfaction with the use of GPS technology in construction surveying for each of the following activities.
   (Project control surveying; Automated machine guidance; Staking for grading; Staking for paving; Staking structure; Staking drainage and pipeline; Staking slope; Staking base; Staking curb and gutter; Staking concrete barrier; Preparation of surveying data deliverable; Construction staking bid item measurement; Other)
   [1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied]
5. Which of the following benefits did your agency experience when using GPS technology in construction surveying?
   (Decrease crew size; Facilitate measurement of vertical distance; Decrease the duration of surveying; Decrease the cost; Make it possible to work under bad weather conditions; Improve the precision of survey; Reduce staking workload; Other)
6. Based on your agency's experience, indicate the level of significance that the following factors had

in contributing to the success of GPS implementation at your agency?
[Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with GPS technologies (DOT); Experience with GPS technologies (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]
[1: Very insignificant; 2: Insignificant; 3: Somewhat insignificant; 4: Somewhat significant; 5: Significant; 6: Very significant]

7. Based on your agency's experience, which of the following are difficulties or challenges to the use GPS technology in construction surveying?
   (None; Less trained equipment operators; Inefficient communication between Contractor and DOT; Harsh weather conditions; Interruption due to power failure; Reading and recording wrong antenna height; Unstable GPS signal; All parties need to be on the same site calibration; All parties need to use the same data files; Other)

Section 3: Control Surveying Using GPS Technology and Real Time Kinematic (RTK) Method

Based on your experience in using GPS technology in control surveying and RTK method, please answer the following questions:

1. Who is responsible for performing secondary control surveys for the project?
   (DOT; Contractor)
2. If Automated Machine Guidance (AMG) is used, are additional horizontal and vertical control surveys required?
   (Y/N)
3. Which of the following office procedures are done when conducting RTK control surveying?
   (Check the data collector file for correctness and completeness; Check the base station coordinates and ellipsoid height for correctness; Analyze the GPS site calibration for a high scale factor and high residuals; Compare check shots with the known values; Check all reports for high residuals; Other)
4. Which of the following types of base station networks are utilized by your agency?
   (CORS; OPUS; HARN; VRS; NDGPS; Other)
5. What are the required deliverables that should be submitted by the Surveyor for a GPS control survey?
   (Project narrative summary; Names of individuals and duties; Coordinates; Coordinate metadata; Project site map; Equipment logs; Calibration report for all points used in the survey; Primary control checks; Post-process report; Weather condition report; GPS raw and solution files; Other)
6. Please provide the link to the manual or document that includes the DOT specifications about GPS RTK survey design, setup, and operation, including:
   Minimum number of horizontal and vertical Real Time Kinematic (RTK) control stations; Horizontal and vertical tolerances; Maximum Position Dilution of Precision (PDOP); Minimum number of satellites observed simultaneously; Maximum epoch interval for data sampling; Minimum number of epochs of collected data for each observation; Minimum time between repeat observations; Maximum difference in horizontal or vertical coordinates of the second occupation from the first occupation; Maximum distance from the base station to the rover units; Minimum satellite mask above the horizon; Geometry of control stations; Minimum level of accuracy of control stations; Whether the base station is occupied by an RTK control station; Whether the base station use a fixed height tripod.
   If the specifications are included in more than one document, please provide the links to ALL documents.
   If a document is not available online, please send a copy of the document to gohary@illinois.edu.

SECTION 4: CONSTRUCTION SURVEYING USING GPS EQUIPMENT

Based on your experience in construction surveying using GPS equipment, please answer the following questions:

1. What types of GPS equipment checks are specified/required?
   (None; Federal published calibration baseline check by NGS; Zero baseline check of antenna, receiver, and cables according to manufacturer; Primary control check; Other)
2. If you answered "None" to Question 1, what types of GPS equipment checks do you perform?
   (None; Federal published calibration baseline check by NGS; Zero baseline check of antenna, receiver, and cables according to manufacturer; Primary control check; Other)
3. What is the frequency of GPS equipment checks you perform?
   (At beginning and end of survey; Every six months; By request of Engineer or Contractor; Other)

APPENDIX G

Questionnaire for Surveying/Interviewing IDOT Staff and Illinois Contractors on Potential Practices for Employment in Illinois

1. Section 1: Respondent Information

Please provide the following information:
Name:
Agency:
Job title:
Years of experience:
Phone:
Email:

The questionnaire has three types of questions:
1) Multiple choice questions: please select one or more options among a number of options/alternatives. If you select "Other", please specify your option. If the options are 1 to 6 scale, 1 to 6 represent very disagree, disagree, somewhat disagree, somewhat agree, agree, and very agree, respectively.
2) Yes/no questions: please select yes or no.
3) Short answer questions: please specify your answer.

2. Section 2: Evaluation of Construction Methods

1) Automated Machine Guidance (AMG) systems use positioning techniques such as GPS, robotic total stations, and/or laser scanning to determine the horizontal coordinates and elevation of the equipment and check the equipment position against a 3D digital model. AMG has the potential to reduce the number of stakes required and increase the efficiency and productivity of the Contractor. Construction surveying can be performed using conventional methods, AMG, or a combination of the two approaches. Not every project is suitable for AMG. AMG is, therefore, not mandatory.
2) The Department will allow the use of AMG if the project is suitable for AMG construction techniques. The machines can be guided by a GPS system, or a robotic total station system. The Contractor shall notify [the Engineer] of the intent to use AMG [after project award, before the preconstruction meeting]. To evaluate the suitability of adopting such technology in a project, [the Department] could follow AASHTO's criteria, which is defined in AASHTO's Quick Reference Guide for the Implementation of Automated Machine Guidance System. Generally, projects with the following characteristics will be the best candidates for this technology:
   a) large amounts of earthwork or paving,
   b) new alignments,
   c) a good Global Navigation Satellite System (GNSS),
   d) a design based on an accurate Digital Terrain Modeling (DTM).

Questions: (4)

1) If you suggest other characteristics that make projects the best candidates for AMG methods, please specify.

2) Do you agree that the conditions that limit or exclude the use of AMG shall be included in the guidance document? Such conditions include, but are not limited to
   - Widening with narrow strip additions
   - Designs, such as overlays, that are not based on an existing (Digital Terrain Modeling) DTM. Overlays with new profiles or cross slope construction benefit from AMG
   - Designs that do not exist in a 3D digital environment (note that all jobs are capable of being modeled)
   - Structures
   - Projects that are under a tree canopy, in narrow canyons, or next to tall buildings that interfere with GNSS signals (note that robotic total stations or traditional methods are viable solutions)
   - Design difficulties that would prevent the creation of an accurate and complete DTM (if a surface model can be prepared in difficult situations, it saves on rework)

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

3) When shall the Contractor submit the notification for use of AMG?
   [After project award; Before the preconstruction meeting; Other________]

4) Do you agree with the roles and responsibilities, submissions, timeline, evaluation criteria, and requirements that are described in the “Evaluation of Construction Methods” Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

3. Section 3: Automated Machine Guidance Equipment

1) The Contractor shall provide all AMG equipment. For the use of AMG equipment, the Contractor shall comply with the Contract Documents and all applicable standards and specifications. The Department is not required to provide a list of approved AMG equipment. The Contractor shall submit the equipment information (as part of the Automated Machine Guidance Work Plan) to [the Engineer], [before or at the preconstruction meeting and at least 30 days prior to use]. The equipment information shall include, but not limited to, the following: [a description of the manufacturer, model, and software version of the AMG equipment].
2) The Contractor shall provide [at least one] GPS Rover to [the Engineer] for the review of the work, as needed. The GPS Rover should be ready for use prior to the start of the construction work. IDOT's Surveyors familiar with GPS Rovers may aid the Engineer in using the GPS Rover for the review of the work. The GPS Rover or other handheld devices shall be compliant with the Contract Documents and any applicable standards and specifications.
3) When the AMG system is guided by GPS, [the Surveyor (Contractor's Surveyor or IDOT's Surveyor, depending on the responsibility defined in the Contract Documents)] will be in charge of setting up the GPS base station, which is important to the success of the project. The Surveyor shall locate the base station at [a stable, undisturbed place]. The base station should provide radio signal coverage [over the entire area constructed using the GPS-guided machine]. If the base station cannot broadcast a signal that covers the entire site, provide adequate repeater radios or other communications. If the base station is to be relocated, document the current location. The Contractor shall submit the location of the base station to [the Engineer] [for approval]. The Contractor shall not relocate the base station without [the approval] of [the Engineer].
4) The Contractor is responsible for the storage and maintenance of the AMG equipment and all GPS Rovers. The GPS equipment shall be properly maintained [at least once at the beginning of each surveying work; every six months; weekly during the survey; as needed]. Equipment components to be maintained shall include, but not limited to: [tripods, rods, cables, receivers and antennas, and handhelds]. Equipment maintenance shall include, but not limited to: [periodic manufacturer maintenance checks, cleaning, and calibration].

Questions: (5)

1) Do you agree that the Contractor submits the AMG equipment information as a part of the AMG work plan?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

If you disagree, when shall the Contractor submit the information?
[Before the preconstruction meeting; At the preconstruction meeting; At least 30 days prior to use; Other____________________________]

2) What shall the AMG equipment information include?
[A description of the manufacturer; A description of the model; A description of the software version; Other____________________________]

3) Do you agree that the Department does not provide a list of approved AMG equipment?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

If you disagree, when shall the Department provide that list?
[The Department will provide a general list that is applicable to all projects using AMG and update the list if/when needed; The Department will provide a specific list that is applicable to this particular project right after evaluating the suitability of AMG use for the project; Other____________________]

4) What is the preferred frequency for equipment maintenance?
[At least once at the beginning of each surveying work; Every six months; Weekly during the survey; As needed; Other____________________]

5) Do you agree with roles and responsibilities, submissions, timeline, equipment operation and maintenance guidelines, and requirements that are described in the "Automated Machine Guidance Equipment" Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

4. Section 4: Automated Machine Guidance Work Plan

1) The Contractor shall submit a comprehensive written Automated Machine Guidance Work Plan to [the Engineer] [for review; for approval] [before or at the preconstruction meeting and at least 30 days prior to use]. The Automated Machine Guidance Work Plan shall include, but not limited to:
   a) Definition of project boundaries and scope of work to be accomplished using the AMG equipment.
   b) Description of the equipment including, but not limited to, a description of [the manufacturer, model, and software version of the AMG equipment].
   c) Project control report including, but not limited to, [all contract control points, coordinates or elevation adopted, office procedures used for GPS technology, and the diagram of control points]. When a GPS base station is on the site for checking or staking purposes, include the determined coordinate and elevation of the base station and the datum differential from the existing control provided by the Department.
   d) Detailed site calibration procedure including, but no limited to, [map of the control points used for site calibration and control points used to check the site calibration, site calibration procedure, frequency of calibration, plan for what information will be documented, and plan for what information will be submitted to the Engineer]. The procedure must show a complete record of equipment check results.
   e) AMG equipment calibration plan including, but not limited to, [equipment to be calibrated, the frequency of calibration, the location and time of calibration, and the status of each calibrated equipment].
   f) AMG equipment maintenance plan including, but not limited to, [frequency of maintenance, components to be maintained, and procedure for maintenance].
   g) A quality control plan including, but not limited to, [frequency and type of checks to be performed, and procedures used to perform the checks]. The control plan must show how the Engineer and the Contractor conduct the initial and daily calibration checks, spot checks, and final acceptance check.
   h) Description of construction checks including, but not limited to, [method and frequency of field verification checks].
   i) Contractor's prior experience with the use of AMG systems.
   j) Contractor's primary contact and alternate contact for AMG issues.
2) [IDOT's Surveyor] shall participate in the preconstruction meeting. During the meeting, [IDOT's Surveyor] shall establish a working relationship with the Engineer and the Contractor, including discussing tentative schedules and safety issues. [IDOT's Surveyor] shall also discuss the Automated Machine Guidance Work Plan with the Engineer and the Contractor, and shall review and evaluate the Automated Machine Guidance Work Plan by:
   a) Reviewing the equipment information.
   b) Reviewing the project control report, checking all control points and base station location, and discussing the needs for additional control points.
   c) Reviewing the site calibration report and performing checks on site, if/as needed. If the report is rejected, IDOT's Surveyor shall inform the Engineer and the Contractor and provide aid to resolve any problems.
   d) Reviewing the equipment calibration and maintenance and providing suggestions based on knowledge of and experience with GPS.
   e) Reviewing the quality control plan and discussing the needs of stakes for the checking and inspection of the project.

Questions: (5)

1. Regarding the submitting of the AMG work plan
   a. Should the AMG work plan be submitted to "the Engineer"?
      [Engineer; Other____________________________]

b. Should the AMG work plan be submitted “for information”, “for review”, or “for approval”?
[For information; For review; For approval; Other____________]

c. When shall the Contractor submit the AMG work plan?
[Before the preconstruction meeting; At the preconstruction meeting; At least 30 days prior to use; Other______________________]

2. In addition to the aforementioned items, what else shall the AMG work plan include? If any, please specify.

3. In addition to the aforementioned items, what else shall IDOT’s Surveyor conduct in order to review and evaluate the AMG work plan? If any, please specify.

4. Do you agree that if the Contractor does not have experience with the use of AMG systems or the experience is not applicable to the specific project, the Engineer may ask the Contractor to perform a test session?
[Y/N]

5. Do you agree with the roles and responsibilities, submissions, timeline, and requirements that are described in the “AMG Work Plan” Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

5. Section 5: Training

1) The Contractor shall provide [the Contractor staff] with training [on the use and operation] of the AMG equipment [prior to the start of any AMG work]. The Contractor shall provide [the Department staff] with training [on the use and operation] of the AMG system [and the use of GPS Rovers or other handheld devices] [prior to the start of any AMG work]. The Engineer and the Contractor shall discuss and determine which Contractor staff and Department staff will participate in the training. As part of the staff, the Surveyors (IDOT's Surveyors and Contractor's Surveyors) may participate in the training to get familiar with the Contractor's AMG system or the GPS Rovers used for checking and inspection. The Surveyors can stay involved in the project using AMG by learning the capabilities of the AMG system and Rovers and being available to provide information to new surveyors and equipment operators who have difficulties in using such system or devices.
2) The Contractor shall provide more training upon the request of the Engineer. The Engineer shall request more training based on need.
3) The Contractor shall seek technical support from the equipment manufacturer or vendor, as appropriate, if/as necessary. The Engineer shall encourage the Contractor to seek such technical support, if/as needed.

Questions: (3)

1. Who shall receive the training?
   [Engineer; Surveyors; Other_______________________]

2. Details about the training.

Question	Engineer	Surveyor	Other
a) What is the frequency of training? [One; At least one; Each month; Other_________________]			
b) When shall the training be provided? [Prior to the start of any AMG work; At the beginning of each month; Other_____]			
c) How many sessions per training? [One; Two; As specified by the Engineer; Other_________________]			
d) What shall be covered in the training? [AMG equipment; Digital models; Software; Devices for review such as rovers; Other_________________]			

3. Do you agree with roles and responsibilities, types of training, time and frequency of training, and requirements that are described in the "Training" Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

6. Section 6: Digital Models

1) The Contractor is responsible for developing the digital models used for AMG. The Contractor is responsible for converting the information on [the plans and/or the design files] provided by the Department into a format compatible with the Contractor's AMG system. The Contractor shall submit the digital models used for AMG to [the Engineer] [for review; for information; for approval] [at least 30 days] prior to the start of the AMG work. The [Engineer] shall reply to the Contractor within [7;14] business days of receiving the submission.
2) The Contractor shall notify the Engineer of any errors or discrepancies in the [design files] or Contract Documents provided by the Department. The [Engineer] shall reply to the Contractor within [7;14] business days of receiving the notification.
3) The Contractor is responsible for updating and revising the digital models. The Contractor shall submit the revised or updated digital models to the Engineer [at least 2 business days prior to AMG operation in the affected areas]. If the revised or updated digital models are not provided in time, the Engineer [may request conventional staking in the affected area].
4) The Contactor is responsible for any errors or omissions in the digital models used for AMG.
5) If any of the devices used for review or inspection by the Engineer requires the digital model data, the Contractor is responsible for providing those data to [the Engineer] [prior to the review or inspection].
6) The Contractor shall bear all costs including, but not limited to, [the cost of developing the digital models, the cost of manipulating the design files provided by the Department, the cost that may be incurred due to the discrepancies between the Contractor's digital models and the design files provided by the Department, and the cost of rework or reconstruction that may be incurred due to errors in the application of AMG techniques].

Questions: (5)

1. Do you agree that Contractor is responsible for
   a. Developing the digital models

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

   b. Updating and revising the digital models

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

   c. Any errors or omissions in the digital models

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

   d. Any errors or discrepancies in the design files or Contract Documents provided by the Department

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

   e. Bearing all respective costs, including, but not limited to, the cost of developing the digital models, the cost of manipulating the design files provided by the Department, the cost that may be incurred due to the discrepancies between the Contractor's digital models and the design files provided by the Department, and the cost of rework or reconstruction that may be incurred due to errors in the application of AMG techniques

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

2. Do you agree that the Contractor shall submit the digital models to the Engineer?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

If agree (4-6 on the scale):

a. Should the digital models be submitted “for information”, “for review”, or “for approval”?
[For information; For review; For approval; Other____________]
b. When shall the Contractor submit the digital models?
[At least 30 days prior to the start of the AMG work; Other_________]
c. What is the method for the Engineer to check the digital models?

3. Do you agree that the Contractor shall provide digital model data required by devices used for review or inspection to the Engineer?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

If agree (4-6 on the scale), when shall the Contractor provide such data?
[At least 30 days prior to the start of the AMG work; Other__________]

4. Do you agree that the Contractor shall provide the digital models in a specific data format or compatible with specific software?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

If agree (4-6 on the scale), please specify the data format or the software.

5. Do you agree with the roles and responsibilities, submissions, timeline, and requirements that are described in the “Digitals Models” Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

7. Section 7: Electronic Files

1) In preparing the electronic files by the Department, [IDOT's Surveyor] shall provide [the Engineer] with the 3D data of the existing ground surface, and shall review the electronic files and survey data developed by [the Engineer].
2) The Department shall provide available electronic files to the Contractor. These electronic files will be [in the native format of the software application by which they were generated], which may be different from the format of the systems the Contractor uses. The use of these electronic files to [generate 3D data and/or digital models for AMG] is at the discretion of the Contractor. The Department has no responsibility to provide these electronic files [or 3D data] used for the AMG system, but is encouraged to do so if available. The electronic files may include:
    a) Alignment data.
    b) Cross sections.
    c) Background graphics files with roadway and drainage features such as centerlines, edges, and hull of ponds.
    d) Machine control surface model, or existing and design surface models.
    e) GPS site calibration data.
    f) Project control information.
3) Electronic files will be provided to the Contractor, [if available], [upon the request of the Contractor]. The Department shall provide available information within [5; 7] business days of receiving the request.
4) The electronic files are provided to the Contractor for [convenience only], and are not part of the Contract Documents. The Department assumes no responsibility [for the sufficiency or accuracy of the provided electronic files]. The Contractor is responsible for conducting all necessary investigations of conditions including, but not limited to, [site visits, spot checks, and/or re-computation before bidding or developing the digital models for AMG].
5) The Department shall maintain copies of the electronic files provided to the Contractor using the Department's designated file management system or other method to ensure that both parties utilize the same data to establish locations and measure quantities.
6) The Contractor shall notify [the Engineer] of any errors or discrepancies in the electronic files provided by the Department. The [Engineer] shall reply to the Contractor within [7;14] business days of receiving the notification.

Questions: (7)

1. When shall the Department provide the following electronic files?
    a) Alignment data.
    b) Cross sections.
    c) Background graphics files with roadway and drainage features such as centerlines, edges, and hull of ponds.
    d) Machine control surface model, or existing and design surface models.
    e) GPS site-calibration data.
    f) Project-control information.

    [Before biding; During biding; After project award and before the preconstruction meeting; After the preconstruction meeting and before any construction work using AMG starts; Upon the request of the Contractor; Other_________]
2. Do you agree that the Department provides electronic files in the native format of the software application by which they were generated and take no responsibilities to convert the file format?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

3. In addition to the electronic files mentioned in Item 1, what other electronic files shall be provided by the Department and when shall the Department provide such electronic files, if any?

[Before biding; During biding; After project award and before preconstruction meeting; After preconstruction meeting and before any construction work using AMG starts; Upon the request of the Contractor; Other____________]

4. Do you agree that the Department has no responsibility to provide these electronic files or 3D data used for the AMG system?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

5. Do you agree that the electronic files provided to the Contractor are for convenience only, and are not part of the contract documents?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

6. Do you agree that the Department assumes no responsibility for the sufficiency or accuracy of the provided electronic files?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

7. Do you agree with the roles and responsibilities, deliverables, and requirements that are described in the “Electronic Files” Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

8. Section 8: Project Control

1) AMG requires different control points than needed for projects constructed using conventional methods. In addition to the primary control points established prior to the project by the Department, [the Surveyor (Contractor's Surveyor or IDOT's Surveyor, depending on the responsibility defined in the Contract Documents)] has to set the secondary control points specified in the plans for grading and preserved for all other project constructions. The Surveyor may follow the following recommended steps:
   a) Select points at locations that are likely to survive project construction.
   b) Place the control stakes along the project corridor with intervals of adjacent points that shall not exceed [2640 feet; 1000 feet].
   c) Establish elevation of secondary control points using different leveling from project vertical control points, forming closed loops.
   d) Perform an independent traverse check between the secondary control stakes using GPS.
   e) When a robotic total station is used to guide a paving machine, a more dense network of control points of higher vertical accuracy than GNSS controlled systems is required. Figure 1 shows a diagram of typical control points for a robotic total station guided paving system. Set additional control points at maximum [500 feet] intervals on each side of pavement. The actual distance may vary by the type of equipment used by the Contractor. The vertical accuracy of the total station shall be of +/- 0.01 ft.
   f) Document horizontal and vertical coordinates and station offset information for each control point.
   g) Replace any control stakes that are disturbed during project construction using the recommended steps.
   h) Add additional control points as required by the Engineer. IDOT's Surveyor is responsible to update the Contractor with the latest project control point information.
   i) For projects where the plans do not show a centerline or other survey control line for construction of the work (e.g., resurfacing, safety modifications, etc.) the surveyor will provide only points marking the beginning and ending of the project.
2) The Surveyor shall refer to IDOT's Survey Manual (Chapter on GPS) for the use of GPS surveying equipment, field procedures, office procedures, and guidelines for Post-Processed GPS control surveys when performing surveying work using GPS. If GPS is used to set control points, the Surveyor shall use Post-Processed Fast Static and/or Real-Time GPS methods at accuracy levels 3 or 4 according to the Survey Manual. The deliverables of control survey include, but are not limited to:
   a) Coordinates.
   b) Primary control check.
   c) GPS raw and solution files.
   d) Coordinate metadata.
   e) Project site map.
   f) Project narrative summary.
   g) Post-process report.
   h) Equipment logs.
   i) Names of individuals and duties.
3) If the Contractor adds supplemental project control points, those points shall be documented along with other project control points set by the Department in the project control report, which is a part of the aforementioned Automated Machine Guidance Work Plan. The Contractor is also responsible for verifying, supplementing, and maintaining the project control points before construction and regularly during construction.
4) The Department shall provide the Contractor with the latest control points. Provide the Engineer and the Contractor with coordinates and elevation for the local survey control calibration points to ensure

project consistency.

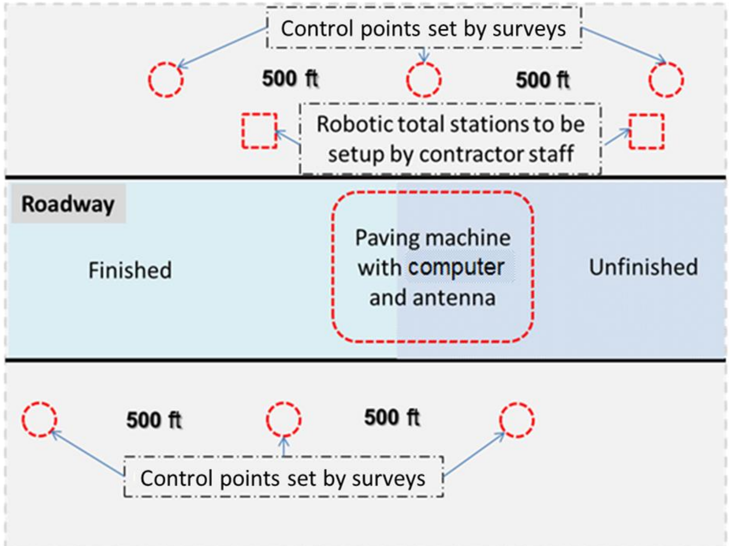

Figure 1: Diagram of typical control points for robotic total station guided paving system

Questions: (7)

1. Do you agree that the control surveying using GPS method shall comply with IDOT's *Survey Manual*, the chapter on GPS?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

2. Do you agree that the Department is responsible for
   a) Setting the primary control monuments

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

   b) Providing the project-control information to the Contractor

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

3. When shall the Department provide the project-control information to the Contractor?
   [Before preconstruction meeting; At the preconstruction meeting; Other________________________________]

4. Which party shall be responsible for each of the following?
   a) Setting the secondary control points?
      [Department; Contractor; Both; Project specific]
   b) Setting any additional control points?
      [Department; Contractor; Both; Project specific]
   c) Verifying, supplementing, and maintaining the project control points before construction and regularly during construction
      [Department; Contractor; Both; Project specific]
   d) Documenting all project control points in the project control report

[Department; Contractor; Both; Project specific]

5. What is the interval of secondary control points when GPS-guided machine system is used? [Not exceed 2640 feet; 1000 feet; Other__________________]

6. In addition to the information mentioned above, what other deliverables about the control survey shall be provided?

7. Do you agree with the roles and responsibilities, submissions, timeline, and requirements that are described in the "Project Control" Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

9. Section 9: Accuracy and Tolerance

1) The Engineer should be clear that the same accuracy and tolerance requirements shall be met when AMG is used as when conventional staking is used for grading or paving.
2) The accuracy and tolerance shall be compliant with the Contract Documents and [applicable standards and specifications] such as IDOT Standard Specifications for Road and Bridge Construction.
3) If the tolerance and accuracy are not met, the Engineer may suspend the AMG operation and the Contractor shall discuss with the Engineer and the Surveyor to evaluate and address the AMG operation deficiencies. The Contractor shall proceed with AMG only after the approval of the Engineer. Alternatively, the Contractor shall proceed with construction using conventional staking and without AMG.

Questions: (1)

1. Do you agree with the roles and responsibilities and the accuracy and tolerance requirements that are described in the “Accuracy and Tolerance” Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

10. Section 10: Quality Assurance

1) [The Engineer] shall perform spot checks of the Contractor's [machine control results, surveying calculations, field procedures, actual staking, and records and documentation], [as necessary].
2) The Engineer shall perform the checks, as needed, [before construction and at any time during the construction]. The Contractor shall facilitate the spot checks.
3) The spot checks may be conducted using conventional survey methods, or independent GPS equipment, or a combination of the two approaches. The Contractor's Surveyor shall assist the Engineer with the inspection of line and grade in areas without conventional staking by using or furnishing the GPS equipment, Rovers, the project digital models, and survey control points, if/as needed.
4) The Contractor's Surveyor shall report the progress to the [Engineer] to assist with the evaluation of the work completed by AMG methods. When conventional staking is used, the stakes act as a ready source of progress information for the [Engineer]. AMG eliminates most of the stakes and, in some cases, the machine operator may have access to the progress information in the AMG system and send the information to the Contractor or the [Engineer]; otherwise the Contractor's Surveyor may have to periodically collect and develop progress information such as cut/fill maps and report them to the [Engineer]. The [Engineer] shall review the progress reports in a timely manner. [The Engineer may request additional information from the Contractor, or notify the Contractor if there is any discrepancy between the actual progress and the reported progress].

Questions: (5)

1. Who shall perform spot checks?
   [Engineer; Other____________________________]

2. When shall spot checks be performed?
   [Before construction; At any time during the construction; Other_______]

3. What are the elements that should be included in a spot check?
   [Machine control results; Surveying calculations; Field procedures; Actual staking; Records and documentation; Other___________________]

4. Do you agree that the spot checks (and other construction checks) will be conducted using conventional survey methods, or independent GPS equipment (such as rovers with project digital models), or a combination of the two approaches?
   [Y/N]

5. Do you agree with the roles and responsibilities, timeline, and requirements that are described in the "Construction Spot Checks" Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

11. Section 11: Site Calibration and Checks

1) The [Surveyor (Contractor's Surveyor or IDOT's Surveyor, depending on the responsibility defined in the Contract Documents)] shall use at least [three known horizontal control points for horizontal site calibration or two control points per mile along the project area if this results in more control points]. The control points selected shall [envelope the project area using AMG and be well-distributed within the area].
2) The Contractor shall perform daily site calibration checks as described in the Automated Machine Guidance Work Plan on [two or more] control points with a horizontal tolerance of [+/- 0.03 foot; 0.01 foot or less] and a vertical tolerance of [+/- 0.065 foot; 0.05 foot or less].
3) The site calibration shall follow IDOT's Survey Manual (Chapter on GPS) including, but not limited to, the following requirements:
   a) A vertical calibration requires a minimum of four NAVD 88 orthometric height benchmarks
   b) A horizontal calibration requires a minimum of three know control points and one NAVD 88 benchmark
   c) The results must be carefully analyzed before accepting. Residuals exceeding the survey accuracy determined by redundant observations, a scale factor significantly different than 1.0, or excessive slope of the plane may indicate failure of calibration. Additional control points might be added

   The Contractor shall check the manual for more information about the specifications and procedures for site calibration.
4) If the site calibration check exceeds the tolerance, the Surveyor may follow the following steps:
   a) Measure the check again at the same control points to ensure that there are no problems with the check measurement.
   b) Perform a second site calibration check using another independent control point. If the tolerances are not met, then there is a problem with the site calibration. Redo the site calibration.
   c) If the measurement of the second site calibration approximates that of the first one, then there is a problem with the control points. Select another control point and document the one with problem.

Questions: (5)

1. How many control points shall the Surveyor use to perform site calibration?
   [Three known horizontal control points for horizontal site calibration; Two control points per mile along the project area if this results in more control points than the minimum;
   Other______________________________]

2. How many control points shall the Contractor's Surveyor use to perform the daily site-calibration checks?
   [Two or more; Other___________________________]

3. What are the tolerances for site calibration?
   Horizontal: [+/- 0.03 foot; 0.01 foot or less; Other______________]
   Vertical: [+/- 0.065 foot; 0.05 foot or less; Other________________]

4. Shall the Contractor's Surveyor submit the daily site-calibration check results to the Engineer?
   [Y/N]
   If yes, who shall review such results?
   [Survey Engineer; Other_________________________]

5. Do you agree with the roles and responsibilities and the requirements on selection of control points, tolerances, and procedures for site calibration that are described in the "Site Calibration and Checks" Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

12. Section 12: Final Checks

1) Before the final check, the Contractor shall perform a quality control test, as stated in the Automated Machine Guidance Work Plan, in order to check [randomly selected locations] [at all hinge points, centerline, edge of lane and edge of shoulders at all critical locations, and against plan elevations]. The areas that are out of tolerances might be checked additionally by the Engineer before the final check. The Contractor's Surveyor shall assist the Engineer with these checks by using or furnishing the GPS equipment, Rovers, the project digital models, and survey control points, if/as needed.
2) The Contractor shall perform the final check of construction work. [The Engineer] may [either perform or witness] the check. If [Engineer] performs the check, the [Surveyor (IDOT's Surveyor or Contractor's Surveyor)] shall set stakes and assist him/her to perform such checks. Otherwise, the Contractor shall notify the Engineer at least [2 business days] before performing the checks, so the Engineer [can observe the process].
3) The Surveyor should provide/set
    a) conventional survey grade stakes at [500 feet] intervals and at critical points such as, but not limited to, PC's, PT's, super elevation points, and other critical points required for construction of drainage and roadway structures or as requested by the Engineer.
    b) finished subgrade points on cross sections at [500 feet] intervals on mainline and at least two cross sections on side roads and ramps, and at [250 feet] intervals on curves, transitions, intersections, interchanges, and break points. Those points should be established using data other than the machine guidance surface, i.e., digital models, such as plan typicals and cross sections, for use by [the Engineer] to conduct independent checks.
    c) paving stakes with cut or fill to finish pavement elevation at points along superelevated curve transitions and at station equation locations.
4) The final check is conducted at random locations at the finished subgrade points. The Contractor or the Engineer shall perform [20 or more randomly selected checks per stage, per project, or per mainline roadway mile, whichever results in the most checks].
5) If [at least four of any five consecutive random checking points are within the tolerance], the grade passes this check. If more than [one of any five consecutive random checking points] is out of tolerance (i.e., differs from the design by more than the vertical tolerance), the grade does not pass this check and the Contractor shall correct the grade.

Questions: (11)

1. Do you agree that before the final check, the Contractor shall perform a quality-control test and the Engineer might check the areas that are out of tolerances?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

2. Do you agree that the Contractor shall perform the final check of construction work and the Engineer may perform or witness the check?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

3. When shall the Contractor notify the Engineer of the final checks?
[At least 2 business days before performing the checks; Other__________]

4. Do you agree that only finish-grade stakes (blue tops) are needed and NO additional centerline stakes, slope stakes, or grade stakes, except at the aforementioned critical points, are needed?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

If disagree (1-3 on the scale), please specify the staking interval for additional stakes.

5. What is the interval for finished subgrade points that are set at points on cross sections on mainline?
[1000 feet; 500 feet; Other________________________]

6. What is the number of cross sections used to set finished subgrade points on side roads and ramps?
[At least two; Other___________________________]

7. What is the interval for finished subgrade points that are set on curves, transitions, intersections, interchanges, and break points?
[250 feet; Other____________________________]

8. Are the paving stakes needed only at superelevated curve transitions and station equation locations?
[Y/N]
If no, where shall the paving stakes be set?

9. What is the number of final checks?
[20 or more randomly selected checks per stage, per project, or per mainline roadway mile, whichever results in the most checks; Other__________]

10. What are the criteria of final check?
[At least four of any five consecutive random checking points are within the tolerance; Other____________________________]

11. Do you agree with the roles and responsibilities, procedures, timeline, staking specifications and requirements that are described in the "Final Check" Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

APPENDIX H

Interim Reports

ICT Project R27-163

Adapting Construction Staking and Inspection to Modern Technology

Internal Interim Report #1

Submitted by: (Include Name and Address of Organization)	**Department of Civil and Environmental Engineering** **University of Illinois at Urbana-Champaign** 205 N. Mathews Ave. Urbana, IL 61801
Proposed Investigator(s):	**Nora El-Gohary**, Assistant Professor **Khaled El-Rayes**, Professor **Liang Y. Liu**, Associate Professor **Mani Golparvar-Fard**, Assistant Professor **Ruichuan Zhang**, Graduate Student
Corresponding Investigator Name:	Nora El-Gohary
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Corresponding Investigator Email:	gohary@illinois.edu
For Period:	August 16, 2015-February 15, 2016
Status:	

1 INTRODUCTION

1.1 Project Motivation

The Illinois Department of Transportation (IDOT) has no written specifications, guidelines, or policies for the use of 3D computer-aided design and drafting (CADD) models, information models for highways [known as civil information models (CIM)], global positioning system (GPS), or other modern technologies that have developed over the past 10 years for highway construction. Such technologies could support various construction processes (e.g., staking, inspection) and could offer major opportunities for quality improvements, cost savings, and expediting project delivery. Many contractors also request the project CADD files for positioning devices used on their construction equipment for grading and paving. However, IDOT's policies and guidelines (e.g., IDOT's Construction Manual) do not address this practice and are out of date with modern technologies. As such, IDOT needs to develop written procedures for the use of these modern technologies in construction staking and inspection of highway projects for inclusion in IDOT's Construction Manual.

1.2 Project Objectives

The main goal of this research project is to develop written procedures for the use of modern technologies (such as GPS, CADD models, and civil information models) in construction staking of highway projects in the State of Illinois for inclusion in IDOT's Construction Manual, which would enable the employment of these technologies in Illinois, and in turn offer major opportunities for quality improvements, cost savings, and expediting project delivery.

To accomplish this critical goal, the research objectives of this project are:

(1) Provide a comprehensive literature review of the use of modern technologies by industry and other state DOTs, relevant construction manuals by other state DOTs that cover the use of these modern technologies (e.g., WisDOT's 2014 Construction and Material Manual), relevant state and federal regulations, guidelines, and protocols/policies on the use of these technologies, and relevant research studies on the use of these technologies. The scope will focus on technologies that could support construction staking of highway projects such as GPS, CADD models, and civil information models.
(2) Conduct a survey to gather information from state DOTs and contractors on current practices employed by other states that successfully adopted these technologies for construction of highways.
(3) Identify a set of potential practices for employment in the State of Illinois, based on the literature review and the survey results (i.e., based on the results of Objectives 1 and 2).
(4) Conduct a survey to gather feedback from IDOT staff and Illinois contractors on the potential success and suitability of these potential practices in the State of Illinois.
(5) Develop recommendations for IDOT's written procedures for the use of these technologies in construction staking of highway projects to be included in the IDOT's Construction Manual, based on the data collected and the survey results (i.e., based on the results of Objectives 3 and 4). This written procedures are intended to support construction staking processes when a contractor employs such technologies.

1.3 Project Tasks and Deliverables

The proposed methodology breaks down the research work into six primary tasks that will lead to four project deliverables, as shown in Figure 1.

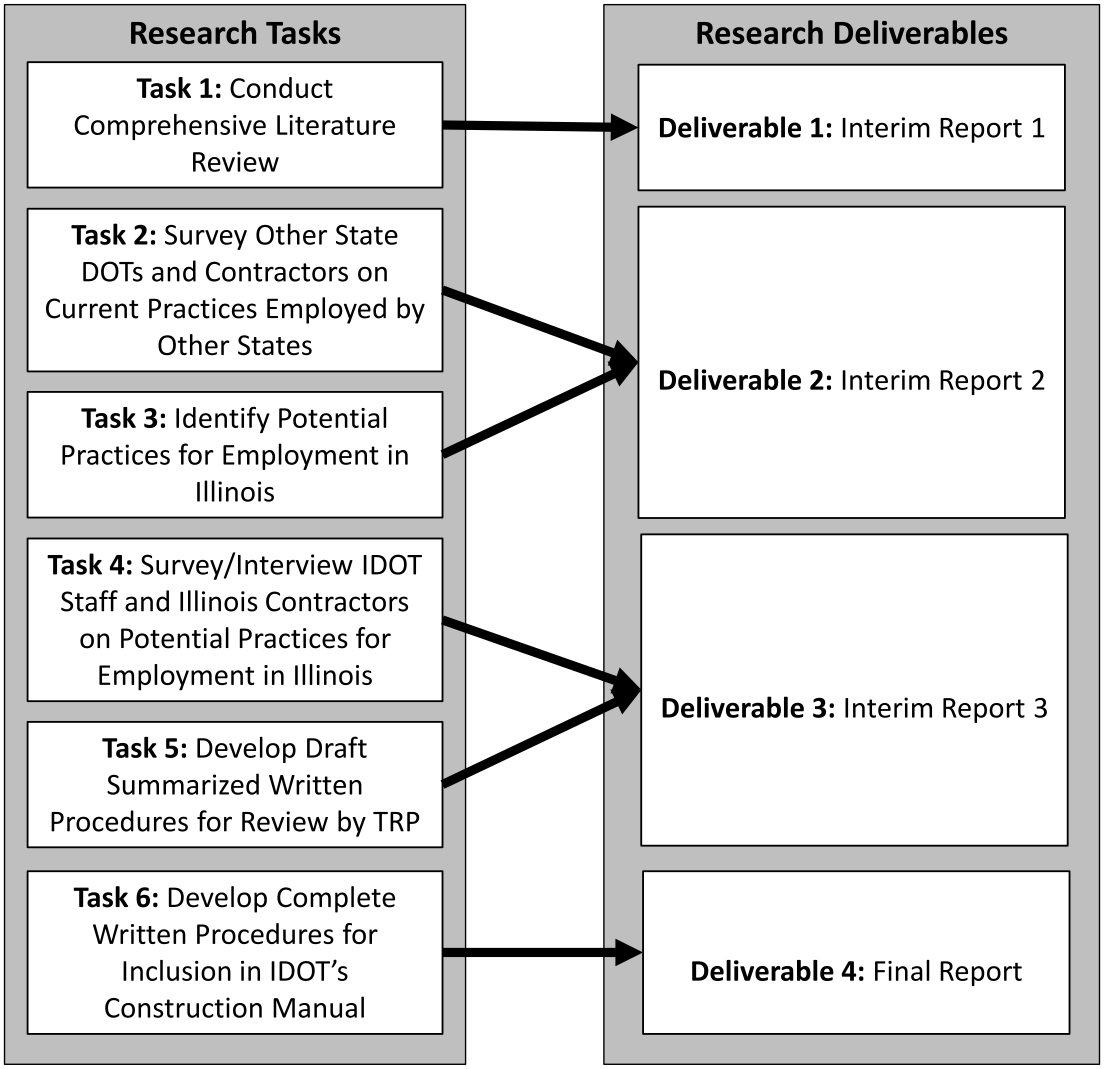

Figure 1: Proposed research methodology

1.4 Scope and Organization of this Report

This interim report intends to summarize the outcomes of Task 1 (Literature Review). Task 1 started on August 16, 2015 and was completed on February 15, 2016. Task 1 focused on conducting a comprehensive literature review to gather and analyze the most current resource materials, regulations, guidelines, protocols/policies, and best practices on the use of modern technologies by state DOTs and contractors in construction staking of highway projects, including a review of: (1) relevant state DOT construction manuals that cover the use of these modern technologies in construction staking, (2) relevant regulations, guidelines, and protocols/policies/strategies by other state DOTs on the use of these modern technologies, (3) relevant federal regulations, guidelines, and protocols/policies/strategies on the use of these technologies, and (4) relevant research studies on the use of these technologies. The scope focused on technologies that could support construction staking of highway projects such as GPS, CADD models, and civil information models. The scope focuses on current practices employed by other states that successfully adopted these technologies.

2 LITERATURE REVIEW (TASK 1)

2.1 Current IDOT Construction and Survey Manuals

2.1.1 IDOT Construction Manual

2.1.1.1 Purpose and Organization of Current Construction Manual

The construction manual is not a collection of specifications or policies, but rather a guidance document to the field personnel. The manual aims to suggest uniform procedures for field personnel to take when conducting highway construction field work (IDOT, 2005).

This literature review focused on the "Survey Section" of the manual, with special focus on the items that would be still relevant/useful when modern technologies are employed for surveying.

2.1.1.2 Summary of Survey Section

The survey section suggests procedures for surveyors to take to improve the quality of highway construction surveying and fulfill the Contractor's needs. The section also provides many examples to help calculate the distances.

Care of Department Owned Property

This subsection emphasizes the importance of protecting the property of the Department, including vehicles, surveying, and laboratory equipment. Examples of the suggested actions include:

- "Handle the instruments carefully and cushion them against vibration and shock." (IDOT, 2005)
- "When taking the instruments out of their carrying case, handle them firmly until secured onto the tripod." (IDOT, 2005)
- "Clean the lenses only as specified in the owner's manual." (IDOT, 2005)

Field Notes

This subsection emphasizes that field notes should follow uniform practices and conform as a minimum to the following general requirements: neatness, legibility, clarity, completeness, permanence, accuracy, and self-checking. The field notes are part of the permanent records of the Department. The manual also provides examples of field notes in the documentation section. The following is an example of the description of these requirements:

- "Accuracy. Record exactly what was done at the time it was done rather than depending on memory at a later time. Never erase. If an item is incorrectly entered, draw a line through the item and insert the corrected value immediately above. When it is necessary to add data to notes previously prepared, the additional item should be dated and initialed. Always enter notes directly into the record." (IDOT, 2005)

Setting and Recording Layout Stakes

This subsection suggests several actions for surveyors to take to better stakeout the highway project. Examples of these actions include (IDOT, 2005):

- Get timely feedback from the Contractor about possible errors to eliminate further effect of a wrongly placed stake and maintain accuracy as specified.

- Determine which parts of the project to be staked first, agree with the Contractor upon the desired lines and grades, and plan the work schedule so that sufficient stakes are always available.
- Check grade elevations, curve data, etc. with the plan to reduce the possibility of error.
- Keep clear and complete field records so that any stakes can be replaced with minimum effort.
- Prepare all field data (e.g., necessary grades, sketches, tie points, benchmarks, etc.) in advance.

The rest of the "Survey" Section is same as the "Construction Surveys" Chapter in IDOT's Survey Manual, which is summarized in section 2.1.2.

2.1.2 Construction Surveys Chapter in IDOT's Survey Manual

Chapter ten, the "Construction Surveys" Chapter, is adapted from the IDOT's Construction Manual and consists of three subsections: pre-construction, construction, and post-construction. The chapter requires the survey crew to meet the State's obligations when setting stakes and preparing information for the construction project.

2.1.2.1 Pre-Construction

Surveyors should check and study the project plans and provisions, and report to the project engineer, who is chosen before the pre-construction conference (IDOT, 2015).

2.1.2.2 Construction

The following points provide a brief summary of the guidelines during the construction phase (IDOT, 2015):

- Regular communications should be established among the surveyor, the project engineer, the inspector, and the Contractor. Before the project is started, a conference is held between the Contractor and the engineering personnel of the Department. This conference is focused on schedule and sequence of operations. During the project, the surveyor should maintain a good relationship with the Contractor and the foremen.
- To set layout stakes, surveyors should pay attention to accuracy, service to the Contractor, establishing a survey line, and work checking. Surveyors should also prepare the field book and other necessary data in advance. This subsection is similar to the "Survey" Section in the Construction Manual.
- The manual then introduces detailed steps for staking curves, setting stakes for bridges, setting stakes for borrow pits and cross sections, and setting stakes for grading using traditional methods. There is no procedures mentioned for staking using modern methods or technologies.
- The manual then provides requirements on layout of entrance culverts, across-road culverts, and pavement. Details about setting grade stakes and stringlines when automatic grade equipment is used are also provided.
- Finally, the manual emphasizes the use of computers to conduct field control, field quantities computation, and quality control.

2.1.2.3 Post-Construction

This section includes post-construction guidelines, including final measurements, which determine the final pay quantities and monumentation for final alignment, right-of-way, bench marks, and traverse stations (IDOT, 2015).

2.1.3 Potential Improvements

Because total stations and GPS equipment are now widely used in highway construction surveying, it is necessary to incorporate the use of such advanced equipment in the "Survey" Section. Examples of potential changes to the manual, proposed by the research team, include:

- Adding guidance on the checking and calibration, maintenance, and training needed for the advanced equipment.
- Updating the requirements on field notes, because a lot of the relevant data will be captured and stored electronically.
- Updating the requirements on deliverables, because the types of deliverables will change depending on the type of technology used.
- If GPS equipment are used, the need for manual calculation could be eliminated or reduced.
- If GPS equipment are used, new relevant procedures should be added, such as GPS surveying planning, equipment checking and calibration, field equipment operation, and data processing.
- If automated machine grading is used, the Contractor needs to develop and submit the digital terrain model.

2.2 GPS Surveying

2.2.1 Scope and Method of the Literature Review

2.2.1.1 Relevant State DOT Manuals

Potentially relevant manuals by all 50 state DOTs were reviewed, including construction manuals and survey manuals. Based on their level of detail, the manuals were classified into three groups for further investigation:

- Level 1: the investigated technology does not appear in the manual.
- Level 2: the manual has an introduction or specification for the technology.
- Level 3: the manual has detailed user guidance for the technology.

The criteria for classification included:

- How many times the technology (e.g., GPS) is mentioned in the manual,
- How many times the technology is specifically mentioned in the context of construction surveying/staking, not only other types of surveying, and
- How many different aspects about the use of the technology (e.g., definition and principles, equipment and personnel, field and office procedure, specifications and deliverables) are included in the manuals.

Table 1 summarizes the content of the documents and shows their classifications.

Table 1: Summary of relevant manuals for GPS surveying

State	Manual	Reference	Introduction of GPS/GNSS	Equipment operation/ maintenance	Field and office procedures	Deliverables	Planning	Specifications and tolerances	Specific to construction surveying	Level of detail*
Arizona	Manual for Field Surveys	Arizona DOT, 2010	√		√					2
Arkansas	Requirements and Procedures for Control, Design, and Land Survey	Arkansas DOT, 2013		√	√					2
California	Survey Manual	Caltrans, 2012	√	√	√	√	√	√		3
Colorado	Survey Manual	Colorado DOT, 2008	√	√	√	√	√	√	√	3
Georgia	Automated Survey Manual	Georgia DOT, 2015	√		√		√	√		3
Kansas	Construction Manual	Kansas DOT, 2014		√		√			√	3
Michigan	Design and Survey Manual	Michigan DOT, 2015	√	√	√					2
Minnesota	Survey and Mapping Manual	Minnesota DOT, 2007	√		√					2
Mississippi	Survey Manual	Mississippi DOT, 2008		√	√					2
Montana	Survey Manual	Montana DOT, 2005			√		√	√		2
Nevada	Construction Survey Manual	Nevada DOT, 2012	√		√					2
North Carolina	Location and Surveys Manual	North Carolina DOT, 2010			√		√			2
North Dakota	Training Manual for GPS Operations	North Dakota DOT, 2008	√	√	√					2
Oregon	Construction Survey Manual for Contractor	Oregon DOT, 2014		√	√					2
Pennsylvania	Surveying and Mapping Manual	PennDOT, 2010		√	√	√	√			3
South Dakota	Survey Manual	South Dakota DOT, 2015			√					2
Tennessee	Survey Manual	TDOT, 2011			√					2
Texas	Survey Manual	TxDOT, 2011			√	√	√	√		3
Utah	Survey and Geomatics Standards	UDOT, 2015			√		√	√		2
Virginia	Survey Manual	VDOT, 2015	√		√	√		√		3
Washington	Survey Manual	Washington DOT, 2005	√	√	√			√		2
Wisconsin	Construction and Material Manual	WisDOT, 2015		√		√	√		√	3
Wyoming	Construction Manual	Wyoming DOT, 2012	√		√	√	√		√	2

* All manuals classified as Level 1 are not shown in this table.

2.2.1.2 Other Relevant Documents

Other relevant documents were collected from the website of each state DOT. These documents can be classified into four groups:

1) Work guidance documents: guidance documents providing detailed job requirements, such as the responsibility of personnel, specific software and hardware to be used in the work, and format of the deliverables. Example of these documents include: Guideline and Summary of Requirements for Montana DOT Surveying (Montana DOT, 2015).
2) Special provisions: provisions for the use of GPS techniques in a unique event or a certain situation. Example of these documents include: Special Provision for Construction Surveying by the Contractor (Minnesota DOT, 2015), Survey Control of Grading by GPS Methods for Pilot Projects (Colorado DOT, 2008).
3) Strategic plans and protocols: plans or the use of GPS in highway construction surveying. Example of these documents include: Development of GPS Survey Data Management Protocols/Policy (Alaska DOT, 2010).
4) Studies about the use of GPS surveying in highway construction.

Table 2 shows the list of the reviewed documents.

Table 2: Other documents relevant to GPS surveying

Type of document	Name of document
Work guidance document	Guideline and Summary of Requirements for Montana DOT Surveying (Montana DOT, 2015)
Special provisions	Special Provision for Construction Surveying by the Contractor (Minnesota DOT, 2015)
	Revision of Section 625 Survey Control of Grading by GPS or RTS Method (Colorado DOT, 2008)
Strategic plan and protocol	Development of GPS Survey Data Management Protocols/Policy (Alaska DOT, 2010)
Studies about the use of GPS surveying in highway construction	An Investigation of the Use of Global Position System (GPS) Technology and Its Augmentations within State and Local Transportation Departments (FHWA, 2000)
	GPS in Construction Staking (WisDOT, 2006)
	Emerging Technologies for Construction Delivery, Project 20-5 (Topic 37-06) (NCHRP, 2007)
	Memorandum, Design-Bid-Build Best Value Procurement Under Special Experimental Project No. 14 (SEP-14), http://www.fhwa.dot.gov/construction/contracts/sep14ny150818.pdf (FHWA, 2015)

2.2.2 Description of Technology

2.2.2.1 Introduction of GNSS and GPS

The global navigation satellite system (GNSS) is a network of satellites that generate signals sent to ground receivers for calculation of global position. The global positioning system (GPS), a type of GNSS, is the satellite navigation system developed, owned, and operated specifically by the U.S. Department of Defense. GPS is based on a constellation of 24 satellites that transmit signals continuously. Users can receive signals from the satellites through the use of specific receivers to calculate the user position, time, and velocity. The GPS signal is available free of charge worldwide (FHWA, 2015).

Many transportation applications including those used in highway construction projects require higher accuracy than can be provided by basic GPS that is used in everyday life. One type of GPS called Differential GPS (DGPS) is used to augment accuracy. DGPS is based on the location of GPS reference station which is surveyed geodetically. The reference station receives GPS signals in real-time and compares the ranging information to the ranges expected to be observed at the fixed location. The difference between the observed and expected ranges is used to compute the differential correction which is in turn sent to GPS users (FHWA, 2015).

GPS augmentation techniques like DGPS can be classified into two groups: real-time and post-processing. Real-time augmentation means that the differential correction is received by GPS users at the time of data collection. The users have full knowledge of the whole augmentation process, which is performed within the receiver hardware. Post-process augmentation means that the GPS data is collected in the field and stored in electronic format, which is then sent to the office with specific software application and access to Continuously Operating Reference Stations (CORS) and processed by computers. Generally post-process augmentation can achieve higher accuracy up to centimeter level (NGS, 2015). Figure 2 shows a snapshot of CORS.

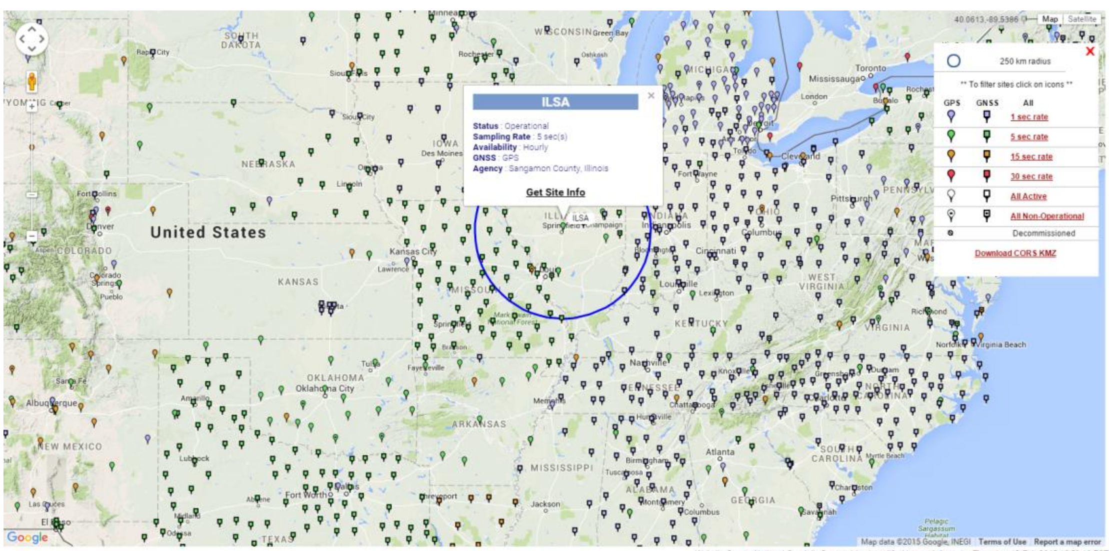

Figure 2: CORS National Geodetic Survey (NGS, 2015)

2.2.2.2 Types of GPS Surveying Methods

GPS surveying methods vary in terms of the type of equipment used, length of observation times, and the accuracy to be achieved or required. The most commonly used GPS survey methods include autonomous GPS surveying, (fast) static GPS surveying, and kinematic GPS surveying (Caltrans, 2012).

Autonomous GPS Surveys

Autonomous GPS surveys allow positions to be immediately determined without using post processing or differential corrections. Low-end handheld GPS receivers may be used to find monuments or rough positions within about 30 feet. Only the lowest level of accuracy can be achieved via autonomous GPS surveys (Caltrans, 2012).

Static GPS Surveys

Static GPS surveys relieve some systematic errors compared with autonomous GPS surveys to achieve high-accuracy positioning. Static procedures are used to produce baselines between stationary GPS units by recording data over a long period of time during which the satellite geometry changes (Caltrans, 2012).

Long observations establishing long baselines for the purpose of determining survey grade coordinates for project control or intermediate points for extending the National Spatial Reference System (NSRS). The data from these observations are post-processed in a network which is adjusted using a least squares method (Caltrans, 2012).

Fast Static GPS Surveys

Fast-static GPS surveys are similar to static GPS surveys, except that shorter observation periods (approximately 5 to 10 minutes) are required. Fast-static GPS survey procedures require more advanced equipment and data reduction techniques than what are required by static GPS methods. Typically, the fast-static GPS method should not be used for corridor control or other surveys requiring high horizontal accuracy due to the low accuracy level they are able to achieve (Caltrans, 2012).

Real Time Kinematic (RTK)

Kinematic GPS surveys are widely used in highway construction staking. Kinematic GPS surveys are performed with a data transfer link between two reference GPS units, which can be either a base station or a rover unit. As a type of kinematic GPS surveys, RTK is performed with a network consisting of several Continuous Geodetic Positioning Stations (CGPS), which are reference GPS units constructed permanently, a central computer system, and a data transfer link between CGPS, and the rover. As shown in Figure 3, the CGPS send measurement data to the central computer system, which processes the data and monitors the CGPS network (Caltrans, 2012).

Typically, RTK is used for topographic surveys, staking out, and other applications, where radial baselines are acceptable. Accuracies of about 2cm (0.79 in) in horizontal and 3cm (1.18 in) in vertical are achievable at distances of up to about 10km/6mi. Accuracy drops off quickly at longer distances because of atmospheric errors. Moreover, the communication link between the base station and rover unit will prevent working at these distances. Observation times can be as short as 5 seconds (Caltrans, 2012).

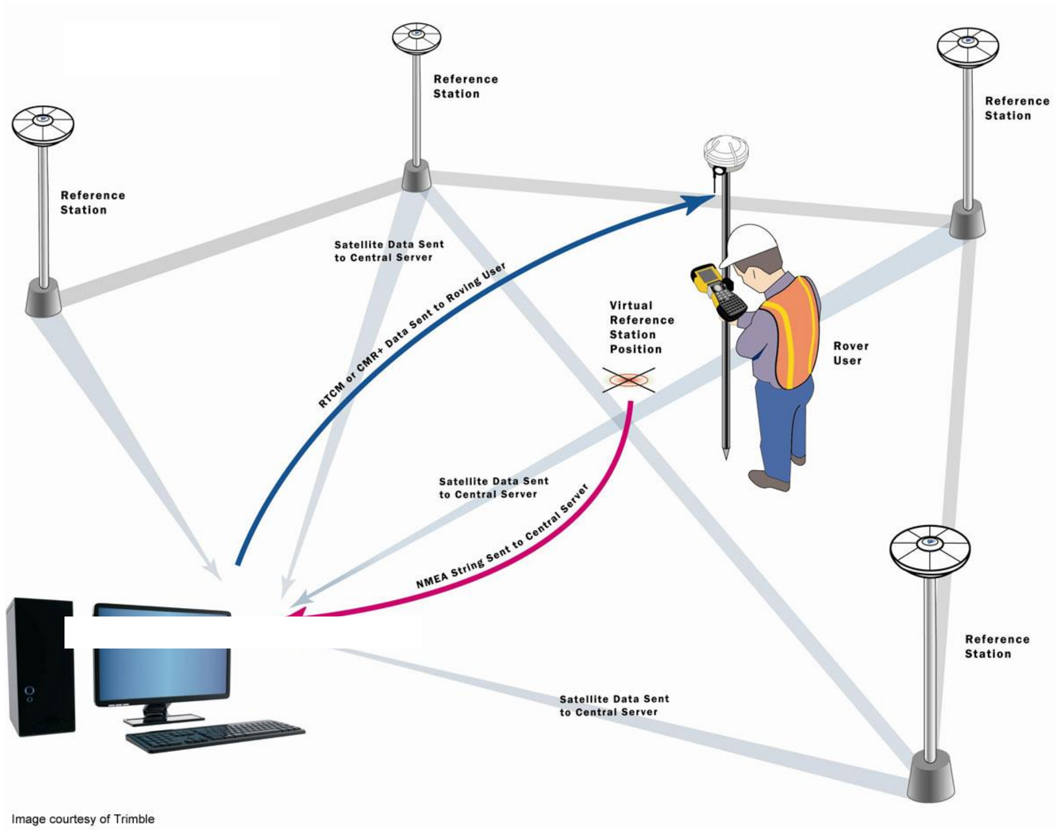

Figure 3: Kinematic method (Image Courtesy: Trimble)

Post Process Kinematic (PPK)

PPK surveys are similar to an RTK survey except that the equipment is not able to process the baselines in real time; rather, the data are post-processed after collected from the base stations. Similarly, PPK uses two or more receivers. At least one receiver remains stationary at project control monument, which usually is a reference or base station. Other receivers (i.e., rovers) are moved from one position to another, collecting position data (Caltrans, 2012).

2.2.2.3 Coordinate and Information Source

The following coordinate systems are used as control points for surveying (TxDOT, 2011):

1) The National Spatial Reference System (NSRS) and the Continuously Operating Reference Stations (CORS): According to TxDOT's survey manual, the reference system for horizontal control in the United States is the North American Datum of 1983 (NAD 83). The reference system for vertical control is the North American Vertical Datum of 1988 (NAVD 88). Surveys are referenced to these datums through measurements to control points of the NSRS.
2) The Cooperative CORS Stations: The Cooperative CORS are different from the National CORS in that the former are based on public data from site operators, whereas the latter are based on data from NGS. If surveyors plan to use these stations, they must be familiar with the Cooperative CORS stations in the local area of the survey project.
3) The Federal Base Network stations (FBN) or the Cooperative Base Network stations (CBN): High Accuracy Reference Network (HARN) is made up of these stations which have been observed using GPS methods. The stations have been either used previously in the

adjustment of federal monuments surveyed using conventional methods as reference stations, or newly placed monuments.

4) The Online Positioning User Service (OPUS): As the latest modification to NGS' Geodetic Tool Kit, OPUS facilitates the submission, analysis, and feedback of field data by admitting users to submit their GPS data files, which are in the Receiver Independent Exchange (RINEX) format, to NGS, where the data will be processed and a position is calculated using NGS computers and software.

2.2.2.4 Equipment Components and Personnel

A typical GPS equipment consists of receiver, antenna, tripod, and tribrach. RTK method may also require a rover.

Receiver

First-order, second-order, and third-order post processed GPS surveys require GPS receivers to be able to record data. When performing specific types of GPS surveys (i.e., static, fast-static, and kinematic), receivers and software shall be suitable for the survey method as specified by the manufacturer. Dual frequency receivers shall be used for observing baselines over 9 miles in length. During periods of intense solar activity, dual frequency receivers shall be used for observing baselines over 6 miles in length (CDOT, 2008). An example of a receiver from Trimble is shown in Figure 4.

Antennas

The requirements on antennas include (CDOT, 2008):

- For a project, all antennas used should be identical.
- For vertical control surveys, identical antennas shall be used unless software is available to accommodate the use of different antennas.
- For first-order and second-order horizontal surveys, antennas with a ground plane attached shall be used, and the antennas shall be mounted on a tripod or a stable supporting tower. In these cases, where tripods and towers are used, optical plummets or collimators are required to ensure accurate centering over marks.
- For third-order or better vertical surveys, fixed height tripods are required. Poles such as range poles and stakeout poles shall only be used for third-order horizontal and general-order surveys.

An example of antenna from Trimble is shown in Figure 4.

Figure 4: Left: Receiver Right: Antenna (Image Courtesy: Trimble)

GPS-RTK Rover Rod

A fixed height rover rod should be used and it should be the same height as the other fixed height tripods on the project. The height is usually set as 2 meters. Before and after each project the level bubble should be checked (CDOT, 2008).

Tripods

The tripods are to facilitate precise offset measurements between the mark datum point and the antenna reference point. Fixed-height rods or fixed height tripods are preferred and required for certain surveys where antenna centering and height measurement errors are less (Caltrans, 2012). All tripods should be examined for stability before use, ensuring that hinges, clamps, and feet are secure. Test the fixed-height tripods for stability, plumb alignment, and height verification at the start and end of each project (CDOT, 2008).

Tribrachs

Tribrachs and rod levels should be calibrated before use on each project and should be checked at the end of the project. Professional Tribrach calibration, usually scheduled once a year with regular use, is conducted to maintain the accuracy (CDOT, 2008).

Personnel

All field personnel should be trained before the project starts. Field personnel often work alone and must be prepared to make on-the-spot decisions regarding mark identification and stability, equipment use and troubleshooting, and antenna setup. Office personnel should be familiar with geodetic concepts and least squares adjustments. Personnel should participate in any available certification and training activities (CDOT, 2008).

For example, in Texas (TxDOT, 2011), a boundary control survey project performed for TxDOT will be in charge by a Texas Registered Professional Land Surveyor. Personnel requirements for various types of surveys may vary from one TxDOT district to another. The use of certified survey technicians is encouraged for any types of surveys to improve the efficiency of operations (TxDOT, 2011).

2.2.2.5 Factors Affecting Accuracy

The accuracy of a GPS survey generally depends on the following factors, which are complex and interactive (TxDOT, 2011):

1) Survey method or observation technique used (e.g., static GPS survey requires higher accuracy while kinematic GPS survey requires lower accuracy),
2) Quantity and quality of data to be acquired,
3) GPS signal strength and continuity, which could be affected by weather conditions,
4) Station site stability, obstructions, and multipath,
5) Network design, which could be affected by weather conditions and satellite geometry, and
6) Processing methods used.

2.2.2.6 Types and Sources of Error

Errors in GPS surveys could be classified into three types (TxDOT, 2011; ADOT, 2010): multipath errors, equipment errors, and human errors.

Multipath Errors

Multipath errors arise when a GPS signal reaches the receiver's antenna by two or more different paths, which usually happens when one path is bounced or reflected off from a surface and generates a new path (TxDOT, 2011).

Sources of multipath include barriers such as mountains, towers, buildings, signs, fences, airport antenna systems and vehicles, and reflective surfaces such as bodies of water, snow and ground surface, etc. (TxDOT, 2011).

The effect of multipath can be reduced by (TxDOT, 2011):

1) Avoiding setting GPS equipment in areas with multipath or in the case of kinematic surveys, move the base to a different primary control monument.
2) Collecting data for longer periods of time.
3) Collecting data with multiple sessions with substantially different GPS constellations.

Equipment Errors

Equipment errors include reference position errors associated with coordinate, monument stability and crustal motion, antenna position errors happening during equipment setup, phase center variation and offsets, timing error due to satellite or receiver clock errors, and computing errors happening during processing and modeling data. Equipment errors can be relieved by checking and calibrating equipment regularly or when needed (ADOT, 2010).

Human Errors

Human errors are field or office blunders caused by surveyors or other project participants. The effect of human errors can be controlled or eliminated through QA/QC and training before the start of the surveying (ADOT, 2010).

2.2.3 Benefits of GPS Surveying

GPS could benefit surveyors in four primary ways (NCHRP, 2007):

1) GPS surveying helps decrease the crew size. Before the use of GPS equipment in surveying, survey crews often consisted of several members because surveyors had to cover distances to set control points and baselines for surveying. While a survey crew that uses GPS equipment usually has one or two surveyors. Surveyors can measure horizontal

distances and get position information by operating the GPS equipment. Over the last decade, Caltrans saw a drop of percentage of field survey staff to capital outlay support workload from 7.5% to 5.5% with a promotion of use of modern technologies such as GPS.
2) GPS surveying facilitates measurement of 3D coordinates. The integration of total station and GPS provides a reliable method to measure vertical distances in 3D coordinates easily.
3) GPS surveying helps decrease the duration of highway construction projects.
4) GPS surveying helps decrease the cost of highway construction projects, because of the smaller survey crew sizes and the shorter surveying duration.

The Indiana DOT collected response from one Tennessee Contractor about the benefits of GPS-guided machines in construction surveying, as summarized in Table 3. The results of an interview with Kiewit Southern and New York State DOT that shows the benefits from using GPS-guided machines are summarized in Table 4. (Indiana DOT, 2009)

Table 3: Benefits of GPS-guided machines used in surveying reported by one Tennessee Contractor (Indiana DOT, 2009)

New method	Traditional method	Estimated savings
Grade checking	Manual method	Up to 66% of time
Reduction or elimination of stakes	Using stakes	Up to 85% of time
Uninterrupted earth moving under any weather conditions	Daytime/fine weather operation only	30% to 50% of time
RTK supported robotic stakeout	Traditional stakeout	More than 100% in speed and 66% in staffing

Table 4: Benefits of new methods supported by 3D models and GPS used in surveying reported by Kiewit Southern and New York State DOT (Indiana DOT, 2009)

Source	Project description	Estimated savings
Kiewit Southern	12.5 mile widening of I-95; 75% of machines equipped 3D machine controller	8-month project schedule reduction
New York State DOT	8 projects during summer of 2007	Productivity increases by 40%-50% for placement, grading, and removal of granular materials

2.2.4 Barriers that Could Affect the Use of GPS Surveying

Based on the NCHRP report, there are six main possible barriers that could limit the use of GPS surveying by state agencies (NCHRP, 2007):

1) Lack of specifications of GPS surveying.
2) Lack of GPS equipment.
3) Lack of knowledge of how to use GPS equipment and awareness of benefits provided by GPS to the construction project
4) Lack of skilled users.
5) Limited budget.
6) Agency procedural issues.

Besides, the nature of GPS also brings barriers to the use of it in several conditions as reported by state DOTs, including (WisDOT, 2006):

1) Plants or structures block satellite signals.
2) Change of satellite geometry might affect the accuracy of GPS equipment.
3) Change of vertical measure leads to change of horizontal measure. So errors in measuring antenna heights could also lead to errors in horizontal distances.
4) GPS is unable to measure elevation directly without a geoid model. So GPS is not allowed for vertical control by state DOTs.
5) Signals are not constant. The loss in signals makes it difficult to use GPS for fine grading which requires higher accuracy.

2.2.5 Extent of Use of GPS in Construction Surveying

Many state DOTs have already been utilizing GPS technology for years, while others are in the process of evaluating it for their specific application requirements. Some of the emerging applications include but are not limited to: traffic emergency system, highway inventory, automatic vehicle location for public transit, navigation snowplows, land-use planning, tracking hazardous material, and mapping pavement condition data. GPS has already been used for highway construction surveying for more than a decade in most states. The details of the use of GPS in construction surveying are covered in the remainder of this section.

One of the earlier studies on the use of GPS for surface transportation was conducted in 2000 by the Federal Highway Administration (FHWA). FHWA conducted an investigation on the applications of GPS technology and its augmentation for surface transportation, especially by highway departments on the State and local government level (FHWA, 2000). Table 5 provides some examples on the use of GPS in highway construction surveying in a number of states, and the associated benefits, based on the results of that investigation.

Table 5: Use of GPS in highway construction surveying based on a FHWA study (FHWA, 2000)

State	GPS network construction	GPS in highway construction surveying
Alabama	A statewide GPS network was completed in 1995 with a total of 3,176 sites.	One survey crew specializing in GPS surveys for project location sets survey control for individual projects using static method.
Arkansas	In 1996, high-precision reference points were established to be part of High-Accuracy Reference Network (HARN) and Federal Baseline Network (FBLN).	One crew operates static GPS units to set control on construction jobs. Two crews operate real-time kinematic (RTK) GPS units for small roadway and design survey jobs.
Colorado	Create 1:500,000 densification of HARN throughout the state.	Use GPS equipment to set control. Savings in manpower are reported.
Connecticut	Plan to set up eight new GPS base stations.	A saving of $30,000 to $50,000 per project with higher accuracy for control when using GPS is reported. Also GPS allows the completion of a project at least 3 months ahead of schedule.
Florida	Plan to build a network of approximately 75 stations.	Both post-process and real-time methods are used in surveying.

Other states such as Kansas, Maine, Maryland, Michigan, Minnesota, Montana, Nevada, New York, North Dakota, Oregon, South Dakota, Tennessee, Texas, Utah, Vermont, Virginia, Washington, and Wisconsin also reported the use of GPS in surveying for highway projects.

WisDOT's report titled "GPS in Construction Staking", which was published in 2006, summarizes the use of GPS in construction staking in several states including: Wyoming, Minnesota, Maine, Oregon, New York, and Washington. It is reported that GPS has been used in survey staking since 2003, when Minnesota and Maine had contractors use GPS to guide graders working on highway beds (WisDOT, 2006). It is also reported that some state DOTs hesitate to develop GPS-related specifications and policies and rely on contractors to meet standards and come up with solutions. This shifts the responsibility and risk to the contractors and manufacturers from the public sector. Table 6 summarizes the results of the report.

Table 6: Use of GPS in highway construction surveying (WisDOT, 2006)

State	Use	Implementation	Barriers
Wyoming	Rough grading and survey staking; no vertical control.	Specifications have not been changed due to the use of GPS.	1) Vertical control is not yet sophisticated. 2) Multiple sources of error. 3) Signal variability.
Minnesota	Staking: GPS is used to lay out the highway course and grading height.	Specifications remain the same; implementation is left to contractors.	Loss in signal happens daily.
Maine	Rough grading: GPS is used to align grading equipment and for rough grade elevation. Staking: to direct grading paths and heights.	Specifications remain the same.	Cannot be used for fine grading and paving although contractors are interested in such uses.
Oregon	Staking and bulk excavation, or rough grading.	Standards have been revised for GPS use.	Accuracy is not guaranteed.

FHWA's memorandum of March, 2015 about the implementation of Section 1517 of the 2012 Moving Ahead for Progress in the 21st Century Act (MAP-21) Mapping summarized the results of a survey conducted by FHWA on the State Transportation Agencies (STAs) in each of the 50 states, the District of Columbia, and Puerto Rico. The purpose of the survey was to investigate the surveying and mapping services provided by STAs and encourage the use of private sector sources for surveying and mapping for federal-aid projects. The results showed that (FHWA, 2015):

- "34 of the 52 STAs utilize private sector sources for more than 50 percent of their projects." (FHWA, 2015)
- "38 STAs indicated that they were moving toward a greater use of private sector forces for mapping and photogrammetric services. 10 STAs plan to maintain their current mix of in-house and private sector sources." (FHWA, 2015)

- “30 STAs indicated that their State has a standard operating procedure that establishes surveying standards and specifications on when is it considered practicable to contract surveying and mapping work to private sector sources. Additionally, the survey indicated that STAs consider aerial mapping and LiDAR to be the most practicable service to be accomplished by the private sector.” (FHWA, 2015)

Table 7 lists the number of STAs that provide in-house services for each surveying and mapping service.

Table 7: In-house services provided by STAs (FHWA, 2015)

Service	Number of STAs providing the service in house
Aerial photography	14
Aerial digital data collection	8
Airborne GPS services	5
Boundary (cadastral) surveying	40
Cartographic services	27
Charting	2
Digitizing	18
Engineering surveying	40
GIS consulting and implementation	23
GPS surveying	42
Geodetic surveying	38
Hydrography	15
Image processing	17
Orthophoto production (digital and conventional)	26
Photogrammetric mapping	27
Photo processing	9
Planimetric mapping	32
Remote sensing	11
Right-of-way surveying	42
Terrestrial or close range photogrammetry	5
Topographic mapping	40
Scanning	26

2.2.6 Procedures for GPS Surveying

Many state DOTs provide detailed guidance on performing GPS surveying. For example, in the Construction Manual of Nevada (Nevada 2012), contents about planning, site choosing, preparing the data collector, setting up a base station, starting a Trimble base receiver, performing calibrations, and conducting field observations are provided in detail.

This section aims to summarize the general field and office procedures of a GPS survey. Figure 5 shows the whole process of a GPS survey.

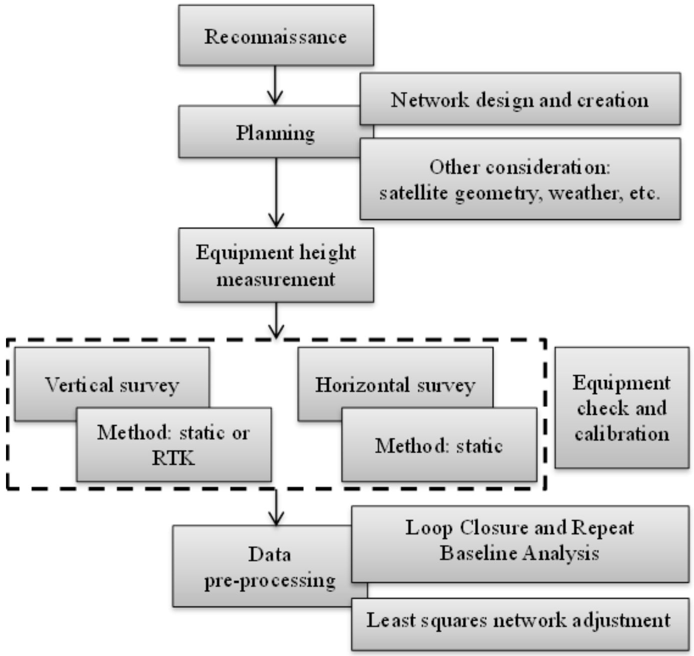

Figure 5: General procedures of a GPS survey

2.2.6.1 Reconnaissance

Field reconnaissance is necessary for an efficient and effective survey. Generally, reconnaissance includes, but is not limited to: station setting or recovery, checks for potential error source, and development of a comprehensive observation schedule with responsibilities clarified for each participant (Caltrans, 2012).

2.2.6.2 Planning

During planning, a good station site is selected to design and create a network, and a GPS survey plan is developed for reviewing and to guide the following procedures. The main components of planning are explained in more detail in Section 2.2.7.

2.2.6.3 Antenna Height Measurement

Antenna height measurement determines the distance from the phase center of the GPS antenna to the survey monument mark. Since GPS surveys are three-dimensional, the result of height measurement will directly influence the outcome of the survey. Blunders in antenna height measurements are a common source of error in GPS surveys. Figure 6 shows all types of distances required to compute different types of heights. “H” stands for the length of fixed height tripod rods, “C+H” stands for the length of adjustable height rods, and they are different from “S” which should not be used as height (ADOT, 2010).

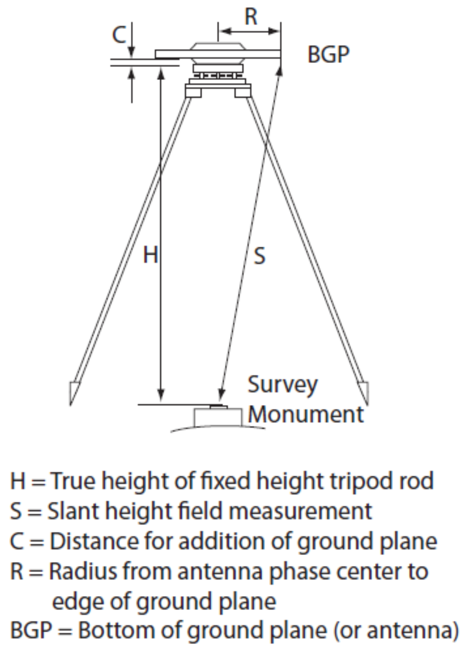

Figure 6: Antenna height (ADOT, 2010)

ADOT (ADOT, 2010) defines three types of antenna height measurements:

1) Fixed height tripod rods: To be used for static, fast static, RTK, and PPK surveys. For static and fast static surveys, an adjustable height tripod is preferred (ADOT, 2010).
2) Adjustable height tripods: To be used for static, fast static, RTK, and PPK surveys (ADOT, 2010).
3) Adjustable height rods: To be used only for RTK and PPK surveys (ADOT, 2010).

ADOT also provides detailed measurement procedures and requirements on documentation and records on height measurements in the "Development of GPS Survey Data Management Protocols/Policy" (2010).

2.2.6.4 Vertical and Horizontal Procedures

Most DOTs define various classes of vertical and horizontal surveys with different levels of accuracy. Different classes of surveys are used in different occasions for different purposes. For example, ADOT and CDOT define two classes of vertical surveys: (1) Class A primary vertical surveys, and (2) Class B secondary vertical surveys. Caltrans defines four orders of vertical/horizontal surveys: first-order, second-order, third-order, and general-order (ADOT, 2010; CDOT, 2008).

The following examples of classes of surveys and their descriptions are from ADOT (ADOT, 2010).

1) "Class A primary surveys include HARN densification and primary project control networked into the HARN and/or using the NGS CORS data or OPUS utility": ADOT requires not using GPS methods to measure heights for elevation in ADOT Class A primary vertical survey or primary control monument that requires accurate elevations. Any ADOT Class A Primary vertical survey or any static or fast static survey requires post-processing data: a minimal constrained adjustment shall be performed. Once an acceptable accuracy is achieved using the minimal constrained adjustment, a surface model based on current data is imported to the software to compute separations. Finally a fully-constrained adjustment is performed.

Repeat this process until all differential leveled vertical control marks have been incorporated into the survey and are held fixed (ADOT, 2010; CDOT, 2008).

2) "Class B secondary surveys include project control densification networked into the primary control. This would apply to most road and airport control surveys": ADOT requires that no ADOT Class B Primary vertical survey or primary control monument that requires accurate elevations using height measured by GPS methods, unless approved by the region right-of-way engineering supervisor or their designated representative. And for survey monuments that require accurate elevations beyond the GPS equipment manufacturer's stated vertical accuracy tolerance, 100% of all GPS-derived elevations must be verified or supplemented with elevations by a more accurate survey method (e.g., differential leveled elevations and trigonometric elevations) (ADOT, 2010; CDOT, 2008).

Similarly, ADOT and CDOT define two classes of horizontal surveys: (1) Class A primary horizontal surveys, and (2) Class B horizontal surveys. Both Class A primary horizontal surveys and Class B horizontal surveys requires static or fast static methods and RTK or PPK methods are not allowed (ADOT, 2010; CDOT, 2008).

Besides Class A and B surveys, ADOT also defines Class C Topo Modeling Survey System (TMOSS) or topographic surveys (ADOT, 2010), which are used to acquire DTM data for design purposes. Table 8 summarizes classes of surveys defined by different state DOTs.

Table 8: Classes of surveys and typical applications

State	Classes of survey	Typical application
Alaska	Class A Primary	Primary control
	Class B Secondary	Second control
	Class C Topological Modeling	Topo Modeling Survey System (TMOSS) points
Arkansas	Second-order, Class II	Horizontal control
	Third-order	Vertical control
California	Third-order Real Time Kinematic (RTK)	1) Supplemental control for construction surveys 2) Construction survey set-up points
	General-Order RTK	Construction surveys excluding major structure points and finish grade stakes
Colorado	Class A Primary	Primary control
	Class B Secondary	Second control
	Class C Topological Modeling	TMOSS points
Georgia	Second order	Horizontal control
	Third order	Vertical control
Mississippi	Third order	Project control
North Dakota	Third-order RTK	1) Supplemental control for construction surveys 2) Construction survey set-up points
	General-order RTK	Construction surveys excluding major structure points and finish grade stakes
Texas	Level 2	1) Primary project control 2) Control for airborne GPS for photogrammetry or LiDAR
	Level 3	1) Local control 2) Boundary corners
	Level 4	1) Topography 2) Stakeout

2.2.6.5 Post Processing Data

Caltrans (Caltrans, 2012) requires that raw GPS observation data shall be collected and post processed for results and analysis. Post-processing software shall be capable of producing relative-position coordinates and corresponding statistics which can be used in a 3D least squares network adjustment. The software shall also allow analysis of loop closures and repeat baseline observations. RTK GPS Surveys utilizes the CORS, with data processed by the central computer system. Thus, it is not necessary to post process GPS data if RTK is used.

Loop Closure and Repeat Baseline Analysis

Loop closures and differences in repeat baselines are computed to check for human errors and to obtain initial estimates of the internal consistency of the GPS network. Tabulate and include loop closures and differences in repeat baselines in the project documentation. Failure of a baseline in a loop closure does not automatically mean that the baseline in question should be rejected, but is an indication that a portion of the network requires additional analysis (Caltrans, 2012).

Least Squares Network Adjustment

Two types of adjustments could be performed, as suggested by Caltrans: (1) an unconstrained (free) adjustment, which is performed after human errors are removed from the network to verify the baselines of the network; and (2) a constrained network adjustment, which is performed after a satisfactory standard deviation of unit weight (a network reference factor) is achieved using realistic a priori error estimates. The constrained network adjustment fixes the coordinates of the known reference stations, thereby adjusting the network to the datum and epoch of the reference stations. A consistent control reference network (datum) and epoch shall be used for the constrained adjustment (Caltrans, 2012).

Table 9 summarizes the GPS data post processing practices suggested by state DOTs for GPS surveys that require post-processing to ensure accuracy.

Table 9: GPS data post processing

State	Suggested post processing
Michigan	1) Differencing. 2) Baseline resolution. 3) Network adjustment.
Mississippi	Least squares network adjustment using software approved by MDOT.
Montana	1) Baseline processing. 2) Network adjustment.
North Dakota	GPS observation data simultaneously collected by several receivers is returned to the office for differential correction processing and adjustment.
North Carolina	1) Loop closure and repeat baseline analysis 2) Least squares network adjustment
South Dakota	1) After the observation session has been completed, the received GPS signals from both receivers are then processed to compute 3D vector distance which is used to further compute and adjust coordinates. 2) User should consult manufacturer's operation manual.
Tennessee	1) Conduct network adjustment. 2) Compute coordinate and orthometric heights using NGS's geoid model. 3) Compute average datum adjustment factor using the coordinates.
Texas	Least squares adjustment or other multiple baseline statistical analysis capable of producing a weighted mean average of multiple observations.

2.2.7 Planning

Planning is an important step before any field and office work is carried out in a survey. Planning is basically about designing a competent and effective network for the survey project, considering satellite geometry and weather conditions. A survey work plan shall be developed no later than the first meeting to guide the project.

2.2.7.1 Network Components

A network consists of a set of baselines between network points [i.e., reference (control) stations]. The following introduction of the network components is from Caltrans survey manual (Caltrans, 2012):

1) Baselines: Baselines are developed by processing data collected simultaneously by GPS units at each end of a line (Caltrans, 2012).
2) Loops: A loop is defined as a series of at least three independent and connecting baselines, which start and end at the same station. Each loop shall have at least one baseline in common with another loop. Each loop shall contain baselines collected from a minimum of two sessions (Caltrans, 2012).
3) Networks: Networks shall only contain closed loops. Each station in a network shall be connected with at least two different independent baselines. Avoid connecting stations to a network by multiple baselines to only one other network station (Caltrans, 2012).
4) Redundancy: Sufficient redundancy has to be created when designing first-order, second-order, and third-order GPS control networks to detect and isolate errors. Redundancy of network design is achieved by (Caltrans, 2012):
    a) Connecting each network station with at least two independent baselines,
    b) Including closed loops only, and
    c) Repeating baseline measurements.
5) Reference (Controlling) Stations: State DOTs have special requirements for the selection of reference stations. For example, TxDOT (TxDOT, 2011) requires all of the control stations selected for reference points must have positions known on the NAD 83 datum. The particular adjustment recommended is the 2003 CORS Adjustment denoted as NAD 83.

Further information about the reference stations designated by state DOTs is summarized in Table 10.

Table 10: Reference stations

State	Reference stations
Alaska	Referenced and tied into HARN as defined by the NGS National Spatial Reference System (NSRS)
Arkansas	1) Vertical datum: North America Vertical Datum of 1988 (NAVD 88) 2) Horizontal datum: Arkansas State Plane Coordinate System reference to the North America Datum of 1983 (NAD 83)
California	1) All reference stations are on the NAD83 datum 2) All included in, or adjusted to, the California High Precision Geodetic Network (HPGN)
Colorado	North American Vertical Datum of 1988 control monument
Montana	1) NAD 83 with CORS is preferred for horizontal control 2) NAVD88 is preferred for vertical control
North Carolina	1) The reference stations should all be included in, or adjusted to, the High Accuracy Reference Network (HARN) with coordinate values that are current and meet reference network accuracy standards 2) Horizontal datum for the HARN network is NAD83 3) Vertical datum: NAVD88
Pennsylvania	NAD83 (2007)
Texas	1) Horizontal datum: NAD83 (2007) 2) Vertical datum: NAVD 88

2.2.7.2 Network Design

TxDOT suggests the following steps to design and create a network when using static or fast static methods (TxDOT, 2011):

1) Roughly locate both new points and existing control on a map showing roads to use in moving the observers around the project.
2) During field reconnaissance flag and mark points for easy identification by all personnel.
3) For each session draw independent baselines intended for observation on a map. Move through the project until all points have been included.
4) From an almanac of satellite orbits choose appropriate times for observations to avoid consider space weather – unusually poor conditions caused by solar storms and magnetic disturbances can cause many hours of unusable data.
5) When possible, separate redundant observations by 24 hours to consider different atmospheric conditions and then a several hour shift to take advantage of a slightly different satellite constellation.
6) Observing the above suggestions, plan your repeated occupations and observations. Make a schedule understandable to all personnel doing the fieldwork.

2.2.7.3 Satellite Geometry

Good satellite geometry increases the accuracy of GPS survey. CDOT (CDOT, 2008) suggests that the following factors should be considered when planning a GPS survey:

1) Number of satellites available: A minimum of four satellites are required to survey with GPS. A minimum of five satellites are recommended.
2) Minimum elevation angle above the horizon (elevation mask): CDOT recommends an elevation mask setting of 15 degrees for all GPS surveys.

3) Obstructions limiting satellite visibility: The ideal satellite geometry is one which has the visible satellites distributed throughout the sky.
4) Dilution of precision: Satellite geometry is expressed as a numeric value known as Dilution of Precision (DOP). Good satellite geometry will have small DOP values while poor satellite geometry will have large DOP values. As a guideline DOP values of six or lower are recommend for CDOT GPS surveys.

2.2.7.4 Weather Conditions

CDOT (CDOT, 2008), Caltrans (Caltrans, 2012), Nevada DOT (Nevada DOT, 2012), North Carolina DOT (NCDOT, 2010) and North Dakota DOT (NDDOT, 2008) suggest that the following weather conditions should be considered when planning a GPS survey:

1) GPS Observations should never be conducted during an electrical storm.
2) Significant changes in weather or unusual weather conditions should be noted either in the field notes, data collector, or receiver.
3) Horizontal and vertical GPS observations can at times be affected by severe snow, hail, and rain storms. High accurate GPS surveys should not be conducted during these periods.
4) Sunspots or magnetic storms can affect GPS observations. It is suggested to avoid GPS surveying during these periods.

Moreover, CDOT (CDOT, 2008) provides a five-digit weather code to summarize the weather conditions and whether GPS survey should be performed or not.

Nevada DOT (NDDOT, 2008), Caltrans (Caltrans, 2012), and South Carolina DOT suggest that horizontal GPS surveys should generally be avoided during periods of significant weather changes mentioned above, and that vertical GPS surveys should not be attempted during these conditions.

2.2.8 Equipment Maintenance, Checking, and Calibration

Some state DOTs define different types/levels of checking and calibration of GPS survey equipment. For example, ADOT accepts four types of checking and calibration: equipment maintenance, federal published calibration baseline check, existing ADOT project control check, and Zero baseline check.

2.2.8.1 Equipment Maintenance

Some state DOTs suggest regular maintenance and list necessary maintenance that should be performed. For example, ADOT suggests that at the beginning of any survey and once every six months thereafter, all survey equipment needed to perform the survey shall be checked and adjusted by the professional land surveyor in charge of the survey or under their direct supervision. During the survey, all equipment should be checked when needed. Some of the suggested regular checks and adjustments include (ADOT, 2010):

- Tripods: nuts and bolts are tight; no legs are loose or broken; tripod head is tight, flat, and not damaged.
- Fixed height tripods: level bubbles are in adjustment; rod is not bent or damaged; height of rod is correct; legs are secure.
- Rods: level bubbles are in adjustment; rod is not bent or damaged; height of rod is correct; and adjustable rod height clamps are secure.
- Tribrachs: optical plummets are in adjustment; level bubble is in adjustment; no loose legs; no loose or missing screws; bottom head is flat and not damaged.

- Collimators: level bubbles are in adjustment; top and bottom heads are both flat with no damage.
- Cables: the cables are not cut, broken, pinched or damaged
- Receivers: there are no cracks or visible damage on the receivers.
- Receiver antennas: if equipped with a ground plane, the plane shall not be bent or warped, and have no cracks or visible damage. Ground planes should produce a plane that when leveled varies no more than +/– 0.003 meters (0.12 inches) when measured at three notches approximately 120 degrees apart. Ground planes that are warped more than +/– 0.003 meters (0.12 inches) shall not be used for any ADOT GPS surveys.

2.2.8.2 Federal Published Calibration Baseline Check by NGS

NGS provides specifications for surveyors on how to calibrate and check errors in electronic distance measuring instruments including GPS equipment for static, fast static, RTK, and PPK methods. The basic procedures for static and fast static methods can be elucidated as (ADOT, 2010):

- A minimum of two receivers are set up on any two calibrated baseline marks.
- A survey is performed with simultaneous observations collected at each baseline mark with the same equipment configurations and methods.
- The receivers are moved and set up on each calibrated baseline mark so that each published baseline length is observed at least twice.
- The data is exported and processed with the same procedures and settings that will be used for the survey.
- The baseline lengths and vertical differences are computed and compared with the published data. And for the equipment to be adjusted, the final baseline lengths and vertical differences shall meet or exceed the manufacturer's ratings for the equipment.

The procedure for baseline check of GPS equipment in RTK mode is similar except that several receivers are replaced by one base receiver and one rover receiver (ADOT, 2010):

- The base receiver is set up on any one of the calibrated baseline marks.
- The rover receiver collects data at each calibrated baseline mark with the same equipment configuration and methods that will be used for performing the survey.
- After the rover has collected data at each calibrated baseline mark, the base receiver is moved and set up on each calibrated baseline mark and the rover again collects data at each calibrated mark.

2.2.8.3 Primary Control Check Published by state DOTs

State DOTs such as ADOT also provides specifications on GPS equipment checking when performing RTK or PPK methods. The idea is that existing ADOT primary control monuments shall be checked to ensure that the data being collected meets or exceeds the minimum horizontal and vertical accuracy tolerances as required for the survey. This type of checking acts as a quality control procedure during the survey and is not to be used as a substitute of a calibrated baseline check (ADOT, 2010):

2.2.8.4 Zero Baseline Check

The zero baseline check is an optional equipment check which is performed to check the GPS antenna phase center and for noise carried through the GPS antennas and cables. All receivers, antennas, and cables that will be used while performing the survey should be checked.

Publications on the procedures for this type of check are available from various manufacturers such as Trimble and Leica (ADOT, 2010).

Summaries of equipment maintenance and equipment checking and calibration required/mentioned by state DOTs are shown in Table 11 and Table 12, respectively.

Table 11: GPS equipment maintenance requirements

State DOT	Equipment maintenance	Frequency	Who is responsible
ADOT	Required	At beginning of survey or every 6 months	Contractor/surveyor
Caltrans	Required	At beginning and end of survey, and weekly during the survey	Contractor/surveyor
CDOT	Required	At beginning of survey or every 6 months	Contractor/surveyor
NDDOT	Required	At beginning of survey or every 6 months	Contractor/surveyor

Table 12: GPS equipment checking and calibration requirements

State DOT	NGS Calibration Baseline Check	Primary Control Check	Zero Baseline Check
ADOT	Mentioned*	Required	Mentioned
CDOT	Mentioned	Required	Mentioned
KDOT	Mentioned		
NDDOT	Mentioned	Required	Mentioned

*Mentioned means this type of check is mentioned in the document, but not stated if required or optional.

2.2.9 Specifications and Tolerances for GPS surveying

State DOTs define different levels of accuracies for GPS surveys and some states provide tolerances of accuracy and specifications for field and office procedures. Table 13 shows the specifications and tolerances when performing general-order horizontal and vertical GPS surveys required by Caltrans in the survey manual (Caltrans, 2012). Note that general-order specifications and tolerances are acceptable for construction staking, and the corresponding method is Kinematic survey.

Table 13: Specifications for general-order GPS surveys from Caltrans (Caltrans, 2012)

Specification	Kinematic
Minimum number of reference stations to control the project	3 third-order or better
Minimum number of check stations	2
Maximum distance between the survey project boundary and the network reference control stations	6 miles
Maximum Positional Dilution of Precision (PDOP) during station occupation	5
Minimum observation time on station	5 epochs
Minimum number of satellites observed simultaneously at all stations	5 (100% of time)
Maximum epoch interval for data sampling	1-15 seconds
Minimum satellite mask angle above the horizon	10 degrees

Table 14 shows the specifications and tolerances when performing third-order horizontal GPS surveys required by Caltrans in the survey manual (Caltrans, 2012). Note that third-order specifications and tolerances are acceptable for construction survey setup points for radial stakeout, controlling stakes for major structures, and supplemental control for engineering and construction surveys. The corresponding methods could be static, fast-static, or kinematic survey.

Table 14: Specifications for third-order GPS surveys from Caltrans (Caltrans, 2012)

Specification	Static	Fast-static	Kinematic
General			
Minimum number of reference stations to control the project	3 third-order or better	3 third-order or better	3 third-order or better
Maximum distance between the survey project boundary and network control stations	30 miles	30 miles	30 miles
Location of reference network control (relative to center of project); minimum number of "quadrants," not less than	2	2	2
Minimum percentage of all baselines contained in a loop	50%	50%	50%
Direct connection between survey stations which are less than 20 percent of the distance between those stations traced along existing or new connections	No	No	No
Minimum percentage of repeat independent baselines	5%	5%	5%
Percent of stations occupied 2 or more times	75%	75%	100%
Direct connection between intervisible azimuth pairs	No	No	No
Field			
Maximum PDOP during station occupation	5 (75% of time)	5	5
Minimum observation time on station	30 mins	5 mins	5 Epochs
Minimum number of satellites observed simultaneously at all stations	4 (75% of time)	5	5 (100% of time)
Maximum epoch interval for data sampling	15 secs	10 secs	1-15 secs
Minimum time between repeat station observations	20 mins	20 mins	20 mins
Antenna height measurements in feet and meters at beginning and end of each session	Yes	Yes	Yes
Minimum satellite mask angle above the horizon	10 degrees	10 degrees	10 degrees

Table 15 shows specifications and tolerances when performing third-order RTK GPS surveys required by state DOTs in the survey manual.

Table 15: Specifications for third-order RTK GPS surveys

Specification	Caltrans	UDOT	NDDOT
Field			
Geometry of RTK control stations	Surround and enclose the RTK project		
Minimum accuracy of RTK control stations	Third-order	Third-order	
Minimum number of horizontal RTK control stations for horizontal RTK surveys	4	3	
Minimum number of vertical RTK control stations for vertical RTK surveys	5		
Base station occupies an RTK control station	Recommended		
Base station uses a fixed height tripod	Yes		Yes
Percent of data collected with a valid checked initialization	100%		
Maximum PDOP during station observation	5	5	6
Minimum number of satellites observed simultaneously	5	5	4 (5 recommended)
Maximum epoch interval for data sampling	5 seconds	1-15 second	1 second
Minimum time between repeat station observations		45 minutes	
Minimum satellite mask above the horizon	15 degrees	10 degrees	15 degrees
Maximum RMS during a station observation	70 millicycles		
Minimum number of epochs of collected data for each observation	30	30	
Horizontal precision of the measurement data for each observation	Less than or equal to 0.03 feet		
Vertical precision of the measurement data for each observation	Less than or equal to 0.05 feet		
Maximum residual of the horizontal coordinates for the horizontal RTK control stations in the GPS calibration	0.07 feet		
Maximum residual of the height for the vertical RTK control stations included in the GPS calibration	0.10 feet		
Maximum distance from the base station to the rover unit(s)	6 miles		
Percent of new stations occupied 2 or more times	100%		
Percent of second occupations having a different base station	100%		
Maximum difference in horizontal coordinates of the second occupation from the first occupation	0.07 feet		
Maximum difference in height of the second occupation from the first occupation	0.13 feet		
Establish stations to be used as conventional survey control in groups of 3	Yes		
Office			
Check the data collector file for correctness and completeness	Yes		
Check the base station WGS84 coordinates and ellipsoid height for correctness	Yes		
Analyze the GPS site calibration for a high scale factor and high residuals	Yes		
Compare check shots with the known values	Yes		
Check all reports for high residuals	Yes		

Table 16 shows specifications and tolerances when performing general-order RTK GPS surveys required by state DOTs in the survey manual.

Table 16: Specifications for genera-order RTK GPS surveys

Specification	Caltrans	UDOT
Field		
Geometry of RTK control stations	Surround and enclose the RTK project	
Minimum accuracy of RTK control stations	Third-order	Third-order
Minimum number of horizontal RTK control stations for horizontal RTK surveys	3	3
Minimum number of vertical RTK control stations for horizontal RTK surveys	4	
Minimum number of check stations		2
Maximum distance between the survey project boundary and the network reference control stations		6 miles
Base station occupied an RTK control station	Recommended	
Base station uses a fixed height tripod	Recommended	
Percent of data collected with a valid checked initialization	100%	
Maximum PDOP during station observation	6	5
Minimum number of satellites observed simultaneously	5	
Maximum epoch interval for data sampling	5 seconds	1 second
Minimum satellite mask above the horizon	13 degrees	10 degrees
Maximum RMS during station observation	70 millicycles	
Horizontal precision of the measurement data for each observation	Less than or equal to 0.05 feet	
Vertical precision of the measurement data for each observation	Less than or equal to 0.07 feet	
Office		
Check the data collector file for correctness and completeness	Yes	
Check the base station WGS84 coordinates and ellipsoid height for correctness	Yes	
Analyze the RTK site calibration for a high scale factor and high residuals	Yes	
Compare check shots with the known values	Yes	
Check all reports for high residuals	Yes	

Specifications of GPS-guided AMG project are summarized in Table 17, which is adapted from the table in WisDOT's study in 2007 (Vonderohe, 2007).

Table 17: Specifications of GPS-guided AMG project

Specification	Iowa	Kansas	Maryland	Minnesota	Mississippi	New York	Wisconsin	Pennsylvania
Use of AMG	Grading	Grading	Subgrade staking	Grading	Grading	Excavation, fill, material placement, and grading	Subgrade	Subgrade
Can be combined with conventional method?	Yes			Yes	Yes		Yes	Yes
Guidance equipment		GPS	GPS and robotic total station	GPS and robotic total station		GPS, robotic total station, other demonstrably reliable new technologies	GPS	
Approved equipment list	Allows any equipment			Yes, but Contractor may request others	Allows any equipment			
Contractor provides rover to Engineer?	Yes	Yes	Yes		Yes			Yes
Who provides primary control	DOT Engineer		DOT Engineer					DOT Engineer
Who provides project control	Contractor		Contractor			Contractor		Contractor
Accuracy same as conventional grading?	Yes	Yes			Yes			Yes

Training is required by most DOTs. A Contractor who plans to use AMG in the project must provide training to the representatives of the Department. Table 18 summarizes state DOTs' requirements on training.

Table 18: State DOTs' requirements on training

State	Training to representatives of DOT	Time	Duration
Kansas	Required	Prior to any use of GPS equipment	Minimum of 8 hours
Iowa	Required		8 hours
Maryland	Required		8 hours
Mississippi	Required		
Pennsylvania	Required	1) Provide the first session within 1 week of delivery of the unit(s) to the site. 2) Provide the second session upon the request of the DOT.	Two sessions, each is of more than 8 hours length, and an additional 8 hour minimum session during each additional contract year.

Checking is conducted at different stages in project using AMG and often is conducted by different parties. Table 19 summarizes state DOTs' requirements on checking when AMG is adopted.

Table 19: Construction checks required by state DOTs for AMG projects

State	Spot check	Daily check of Equipment	Final check of grading
Kansas	Performed by Representative of DOT.		Performed by Engineer
Iowa	Performed by Representative of DOT.	Performed by Contractor	
Mississippi	Performed by Engineer of DOT, assisted by the Contractor's personnel.		
Pennsylvania	Performed by Representative of DOT.	Performed by Contractor	1) Performed by Contractor and witnessed by Representative. 2) Performed at all hinge points and/or centerline, edge of lane, and edge of shoulders on the cross section at random locations every 500 feet.
Wisconsin	Performed periodically by the Department.	1) Performed by Contractor Performed at individual control points not used in the initial site calibration. 2) Horizontal tolerance is 0.10 feet or less. 3) Vertical tolerance is 0.05 feet or less.	1) Performed by Contractor and witnessed by Representative. 2) Performed at randomly selected points on cross sections located at stations evenly divisible by 100. 3) Performed at least 20 times per stage, per project, or per mainline roadway mile whichever results in the most tests.

Specifications of stakes when grading with AMG and without AMG are listed in Table 20.

Table 20: Specifications of staking in construction survey with and without AMG

State	With AMG	Without AMG
Kansas	1) Provide centerline stakes, slope stakes, and grade stakes from the beginning through the end of the project, at 500-foot intervals on straight runs, and at 250-foot intervals on curves, transitions, intersections, interchanges and break points. 2) Finish staking or blue top staking is required.	
Iowa	1) Establish elevation of secondary control points using differential leveling from project benchmarks, forming closed loops. 2) Set hubs at top of finished subgrade at hinge points on cross section at 1000 foot intervals on mainline and at least two cross sections on side roads and ramps. Establish these hubs, using means other than the machine guidance surface for use by Engineer to check accuracy of construction. 3) Provide grade stakes at critical transition points such as, but not limited to, point of curvature (PC's), point of tangency (PT's), super elevation points, and other critical points required for construction of drainage and roadway structures.	1) Set slope stakes at 100 foot intervals, or less if needed, for embankment and excavation work including roadway, channel changes, and borrow areas. Interpolations may be necessary to match cross-sections. Set stakes at toe of fore-slope or top of back-slope, or both. Mark slope stakes with a flat and lath. Clearly mark flat with station location, distance, slope, and cut or fill information. 2) Set grade check stakes at 100 foot intervals for bottoms of subgrade treatments. Set stakes on centerline for two-lane roads and in median for four-lane roads. Mark grade check stakes with a lath. Clearly mark lath with station location and cut or fill information. 3) Set finish grade stakes (blue tops) at 100 foot intervals, or less if needed. Set blue tops at each shoulder line and each point where there is a change in cross slope.
Mississippi	1) Set grade stakes using conventional methods at the top of finished sub-grade and base course at all hinge points on the typical sections at 1000-foot maximum intervals on mainline, critical points such as, but not limited to PC's, PT's, beginning and ending super elevation transition sections, middle of curve, and at least two locations on each of the side roads and ramps, and at the beginning and end of each cross slope transition where AMG is used. 2) The Contractor shall set slope stakes and centerline stationing every 500 feet and at the beginning and end of spirals and curves.	
Pennsylvania	At a minimum, set grade points at right angles to the centerline on tangents and radial offsets on curves at 500 foot intervals the entire length of mainline. In addition, set a minimum of two grade points on each ramp, on each intersecting roadway, and on projects less than 1,000 feet in length.	Where the finished grade is 5 feet or more vertically above or below existing grade, place an offset grade point with a guard stake at right angles to the centerline or base line controlling the grade point(s), or at 90 degrees from the tangent to the curve, at each 100-foot station. Offset grade points from the intersection of the cross section template and original ground.

Note that the use of any modern technologies does not change the staking tolerance and the same tolerances have to be achieved as when conventional methods are used. Staking tolerances are summarized in Table 21. Blanks mean tolerances are not found in the manual, but can exist in other regulatory documents.

Table 21: Staking tolerances

State	Clearing	Slope staking	Finish staking	Critical bridge member staking	Pavement and drainage stakes	Project control points
Kansas		0.1 ft	Horizontal: 0.05 ft Vertical: 0.01 ft	Horizontal: 0.02 ft Vertical: 0.01 ft		0.05 ft
Wisconsin		0.05 ft				0.02 ft
Michigan	Horizontal: 0.1 ft	Horizontal: 0.1 ft Vertical: 0.03 ft		0.01 ft	0.01 ft	0.02 ft
Colorado		Horizontal: 0.098 ft Vertical: 0.1 ft		0.01 ft		
Wyoming		Horizontal: 0.3 ft Vertical: 0.1 ft		Horizontal: 0.05 Vertical: 0.02 ft	(Pavement hub line) 0.05 ft	
Caltrans		Cut/fill within 1 ft: 1)Stationing: 1 ft 2)Offset distance: 0.1 ft 3)Elevation: 0.1 ft Otherwise: 1)Stationing: 1 ft 2)Offset distance: 0.2 ft 3)Elevation: 0.2 ft		Horizontal: 0.03 Vertical: 0.02 ft	(Drainage) Horizontal: 0.03 ft Vertical: 0.02 ft	

The use of any modern technologies also does not change the nature and purpose of staking, so staking procedures are generally unchanged. In Table 22, slope staking procedures using stake book and electronic data are compared (Wyoming DOT, 2012).

Table 22: Slope staking procedures

Stake book	Electronic data
1) Measure the actual ground elevation and offset in the slope stake book.	1) Measure the actual ground elevation at the design slope stake location indicated by 3D points or the road model in electronic device.
2) If the difference between the actual ground elevation and design elevation is less than the tolerance, the slope is a “catch”: a) Place the stake at the offset shown in the slope stake book. b) The cut/fill shown on the stake is as shown in the slope stake book. c) Use the design slope when writing the stake. d) In the slope stake book, document that the stake was set with no changes.	2) If the difference between the actual ground elevation and design elevation is less than the tolerance, the slope is a “catch”: a) Place the stake at the design slope stake location. b) The cut/fill shown on the stake is computed by using the road model. c) Use the design slope when writing the stake. d) The as-staked information shall be recorded in the electronic data collector.
3) If the difference between the actual ground elevation and design elevation is greater than or equal the tolerance, the slope is not a “catch”: a) Place the slope stake. If the slope stake is on a constant cut/fill line, place it at the offset shown in the slope stake book. Otherwise, move the slope stake to the point where the design slope intersects the actual ground. b) The cut/fill shown on the stake is computed using the actual ground elevation. c)) If the slope stake is on a constant cut/fill line, compute the new slope to be written on the stake. Otherwise, use the design slope. d) If the difference measured earlier between the actual ground elevation and the design elevation at the design slope stake point was greater than 0.5 ft: measure the actual ground elevation of the terrain points on each side of the slope stake. If the difference between the actual ground elevation and the design elevation for both the terrain points is not greater than 0.5 ft, no recross of the station is necessary. Otherwise recross the station from the new slope stake location to the profile grade line. e) Document the changes made to the slope stake information on the slope stake, and also any recross information in the stake book	3) If the difference between the actual ground elevation and design elevation is greater than or equal the tolerance, the slope is not a “catch”: a) Place the slope stake. If the slope stake is on a constant cut/fill line, place it at the design slope stake location. Otherwise, move the slope stake to the point where the design slope intersects the actual ground. b) The cut/fill shown on the stake is computed using the road model and the actual ground elevation. Starting at the as-staked slope stake location, measure the ground at each grade break or every 25 ft (10 m), whichever is less. Continue moving to the next break point and measuring, until the profile grade line for the station is reached, or the difference between the measured ground elevation and the elevation derived from the original ground terrain model is less than or equal to 0.5 ft (15.2 cm). c) The as-staked and any recross information shall be recorded in the electronic data collector

2.2.10 Deliverables

The requirements for the deliverables by two state DOTs are listed as examples: PennDOT and ADOT.

Deliverables Required by PennDOT (PennDOT, 2010)

PennDOT has requirements on both format and content of the deliverables of GPS surveys. The required deliverables include:

1) One hard copy of the entire survey report.
2) Two hard copies of the overall site map.
3) Two digital CD's of the entire survey report with the following specifications:
    a) Survey report in MS WORD (or compatible format).
    b) Existing control in MS WORD (or compatible format).
    c) Project coordinates in MS WORD and ASCII (or compatible format).
    d) Record of Control Sheets in MS WORD (or compatible format).
    e) GPS raw and solution files in Trimble or RINEX.
    f) Overall site map in MicroStation (or compatible format).

Also, Penn DOT requires a list of deliverables for the survey network, when GPS differential leveling methods are used. The deliverables include: narrative description of the project, discussion of the observation plan, data processing description, etc.

Deliverables Required by ADOT (ADOT, 2010)

ADOT requires a control diagram for Class A Primary and Class B secondary surveys and projects reports for all types of surveys. The projects reports include all project, alignment, monumentation, control, or calibration reports generated from the survey procedures. The survey reports for RTK and PPK surveys which are used for construction staking mush include the following items:

1) Project report (narrative summary),
2) Names of individuals and their duties,
3) Project sketch or map showing project location,
4) Equipment logs stating manufacturer, model, serial numbers, and equipment settings,
5) RTK calibration narrative required elements,
6) Calibration report for all points used in the calibration, rotation, scale factor, horizontal and vertical residuals, and geoid model,
7) Primary control checks immediately after first initialization, during roving while initialized, and before ending the initialization session,
8) Post-processed report for any points located with PPK,
9) Space weather report, and
10) Project coordinates report.

A summary of deliverables for GPS surveying required by different state DOTs is shown in Table 23.

Table 23: Deliverables for RTK GPS surveying

State	Project report (narrative summary)	Project coordinates	Coordinate metadata	Project site map	Names of individuals and duties	Equipment logs	Equipment checks calibration	Calibration report	Control monuments checks	GPS raw and solution files	Post-processed report for PPK	As-built construction plan and survey notebooks
PennDOT	√	√		√					√			
ADOT	√	√		√	√	√	√	√	√	√	√	
CDOT							√		√			
KDOT									√			√
TxDOT	√	√	√	√					√	√		
WisDOT	√			√								

2.3 CADD and CIM

2.3.1 Scope and Method of the Literature Review

To gain a comprehensive understanding of the use of CADD and CIM in highway construction staking, the following relevant documents have been reviewed:

1) Relevant manuals from state DOTs, including construction manuals, surveying and mapping manuals, CADD manuals, and CIM manuals. For those manuals, the research team mainly focused on the existing policies, standards, and procedures for the use of CADD and CIM models in highway surveying, the software used, and the required deliverables.
2) Relevant introductory webpages of CADD and CIM software products. From those webpages, the research team summarized how the CADD or CIM is used in construction surveying, what are the benefits and barriers of using CADD or CIM, and the availability and popularity of those software products to users.
3) Relevant research about the use of CADD and CIM in highway construction surveying. From those research reports, the research identified the potential successful procedure for the use of CADD and CIM in highway surveying.

The reviewed literatures are listed in Table 24.

The remaining part of this section is arranged as follows:

1) Description of CADD and CIM, benefit and barrier of using CADD and CIM, and how CADD and CIM are used in automated machine guidance (AMG) and in construction surveying.
2) Summary of 3D model development and electronic data exchange practices and requirements in DOTs especially when AMG is used in construction surveying.
3) Summary of procedures and policies in DOTs for the use of AMG in construction surveying, especially when contractor staking is adopted.

It is noted that the literature review indicates that a number of terms are used interchangeably, all meaning CADD or CIM: Virtual design and construction (VDC), computer aided design and drafting (CADD), 3D models, electronic engineered data (EED), and civil information modeling (CIM). An example is: "Virtual Design and Construction (VDC) is a term used almost interchangeably with CIM although it is actually a generic terminology for a model-based computer-supported project delivery process" (Indiana DOT, 2009).

This review is focused on the development and exchange of 3D models, CIM models, and other EED for both the Department and the Contractor during the whole construction surveying process.

Table 24: Literatures reviewed for Section 2.3 CADD and CIM

Reference	Name of the literature
Kansas DOT, 2015	Construction Manual, Section 802, "Contractor Construction Staking of the Standard Specifications"
Hannon and Sulbaran, 2010	MDOT Implementation Plan for Global Positioning Systems (GPS) Technology in Planning, Design, and Construction Delivery
The city of Portland, Oregon, 2014	CAD Standards and Guidelines
IDOT, 2014	CADD Roadway and Structure Project Deliverables Policy
Hovey and Lubliner, 2012	KDOT's Evaluation of Sharing Electronic Data with Contractors and GPS Construction Procedures
Richins et al., 2010	UDOT's Construction Machine Control Guidance Implementation Strategy
Autodesk®, 2015	Autodesk® BIM Solutions for Roads and Highways http://static-dc.autodesk.net/content/dam/autodesk/www/industries/civil-infrastructure/road-highway-design-infrastructure/Docs/autodesk_roadsandhighways_us_final.pdf
TOPCON, 2015	LN-100 3D Layout Navigator https://www.topconpositioning.com/sites/default/files/product_files/ln-100_broch_7010_2153_reva_utr_sm.pdf
FHWA, 2013	The Interoperability of Computer-Aided Design and Geographic Information Systems in Transportation - Case Studies of Select Transportation Agencies
WisDOT, 2009	Status and Plans For Implementing 3D Technologies for Design and Construction in WisDOT
Indiana DOT, 2009	Practices for Seamless Transmission of Design Data from Design Phase to Construction Equipment Operation – A Synthesis Study
Yan and Damian, 2008	Benefits and Barriers of Building Information Modeling
PennDOT, 2016	Publication 408/2016 Specifications
Vonderohe, 2007	Implementation of GPS Controlled Highway Construction Equipment
Mississippi DOT, 2013	Special Provision No. 907-699-5 Construction Stakes
Minnesota DOT, 2007	Best Practices – Machine Control Evaluation
Caltrans, 2014	Advanced Modeling Techniques for Enhanced Constructability Review, Phase II: A Survey of State Practice and Related Research
Iowa DOT, 2015	Standard Specification for Highway and Bridge Construction Section 2526
WisDOT, 2016	Standard Specifications Section 650
FHWA, 2016	FHWA-HRT-16-002 Leveraging A Data-Rich World

2.3.2 Description of the Technology

2.3.2.1 CADD in Highway Construction Staking

Computer aided design and drafting (CADD) is the use of computer technology for design and design documentation (Autodesk®, 2015).

CADD can be used during the highway's entire life-cycle, including planning, design, surveying, construction, operation, maintenance, and planning (FHWA, 2013). This literature review focuses on the use of CADD in staking of highway projects.

During the design phase, a CADD model of the highway is developed based on the data from the surveying. During the construction phase, staking is performed based on the data in the CADD model provided to the Contractor. In the highway's life-cycle, CADD could be used in the following ways (FHWA, 2013):

1) CADD software can be used to build models using data obtained from handheld devices, total stations, GPS receivers, cameras, and laser scanners. So CADD software is applicable in different surveying situations.
2) CADD allows user to create drawings with details that are precise enough to use for design, planning, and construction of buildings, roads, and bridges, consuming less time with less error.
3) CADD is also frequently used as a site-specific mapping tool, employed by surveyors and engineers to capture ground-level data. Since drawing lines and polygons with precise measurements is one of CADD's strengths, property delineation, detailed elevation mapping, and site planning are all important uses of the tool.

2.3.2.2 CIM in Highway Construction Staking

Civil information modeling (CIM) is an intelligent model-based process that provides insight to facilitate the planning, design, construction, and management of a civil infrastructure project (FHWA, 2016). During construction staking, digital points are added in the office to the CIM model and can be sent directly to a total station equipment on site. Once receiving the points and coordinates, the equipment is able to stakeout points automatically, thereby eliminating the need to generate stakeout points from 2D CAD or paper drawings (TOPCON, 2015). This process allows a more efficient and accurate way to link the office to the site, and meanwhile get feedback from the site to the office through verification of the as-built.

An example is the CIM solution for construction layout by TOPCON. Three devices are used: LN-100 Layout Navigator, MAGNET Field Layout, and TESLA (TOPCON, 2015), as shown in Figure 7. The typical operational procedures are summarized as follows:

1) Take a prism and MAGNET Field Layout within the layout zone of the project and precise horizontal and vertical data can be generated automatically.
2) MAGNET Field allows surveyors to perform construction stakeout, land surveying, and road layout using total stations, layout tools, auto levels, and GPS equipment. The survey data can be shared with the whole crew faster.
3) The LN-100 can automatically level and when connected to the wireless field controller (i.e., TESLA), the surveyor can use job point schedule or CADD drawing to select positions to layout.

Figure 7: Left: A surveyor with TESLA Right: LN-100 Layout Navigator (Image Courtesy: TOPCON)

2.3.3 Benefits of CADD and CIM in Construction Staking

CADD is an important tool for construction projects. The benefits of using CADD in highway construction staking include (FHWA, 2013):

1) CADD replaces the manually drawn drawings of the past with models visualized on computer. With fewer human errors, the drawings are more accurate and precise and are easier to check.
2) The automation tools provided in CADD software make it possible to create drawings conveniently.
3) Drawings and design can be easily maintained, saved, and sent across to Contractor who performs construction staking.
4) CADD, when integrated with other software can model the facility in more complex ways (i.e. modeling the point clouds, raster imagery, reality meshes, etc.) and reflect project changes. Thus, CADD is used to create DTM which is an important reference for construction surveying.

As stated in FHWA's publication (FHWA, 2016), CIM can improve the consistency and efficiency of highway projects, and thus improve productivity and result in time and cost savings by:

1) Improving access to highway project information
2) Facilitating information exchange among stakeholders (e.g., designers, planners, surveyors, and construction personnel)
3) Enabling the project to streamline project design, construction, operation, and maintenance

Also, to promote the use of CIM in highway projects, the publication mentioned future practices of incorporating schedule and cost information into 3D models, using as-built data, and using post-construction survey data. The benefits of these practices include (FHWA, 2016):

1) Enable the stakeholder to visualize phases of project by 4D modeling, which integrates schedule with 3D models, to better manage the construction site and conflicts.
2) Enable the stakeholder to better control and estimate cost by adding fifth dimension to the models.
3) Enable the stakeholder to have access to a living record of the highway project throughout the life cycle by incorporating data comprehensively and immediately.

The benefits of implementing CIM in highway construction staking include (Autodesk®, 2015):

1) Making changes in design easier and faster, and making it convenient to exchange ideas about design and surveying.
2) Simulating and visualizing the project (e.g., terrain and construction site) to support decision making in surveying.
3) Saving time and material by quickly integrating data for performing quantity takeoffs and using automated machine guidance.
4) Creating design deliverables directly and quickly from the information model. Deliverables include not only 2D construction documentation, but also the model itself and all the rich information it contains, which can be leveraged for quantity take-off, construction sequencing, construction stake-out, as-built comparisons, and operation and maintenance.
5) CIM makes it possible to perform automated, model-based, and GPS-guided grading and eliminate the necessity to stake and the delays during undesired weather conditions such as fog and dust.

The study of Caltrans (Caltrans, 2014) collected responses from several state DOTs about the use of 3D modeling in highway construction. While none of the respondents were able to quantify the benefits, their comments helped to identify four types of benefits:

1) Time savings. Though a modeler without experience may spend longer time to get familiar with 3D when first transitioning from 2D, overall time saving during preconstruction stage is reported (Caltrans, 2014):
    a) Kentucky DOT: was not adding time; spent more time in earlier stages, and less time later.
    b) Wisconsin DOT: reported 3D modeling does not increase workload and can decrease risk of redoing
2) Cost savings. Although where cost savings is most significant is not clear, it is accepted that 3D modeling can reduce costs by helping identifying errors earlier (Caltrans, 2014):
    a) Iowa DOT: reported greater cost savings in construction stage than in design stage, by exempting Contractor from paying consultants to create 3D models from 2D designs, and by saving money through using AMG for grading and paving.
    b) Wisconsin DOT: reported greater cost savings through using 3D modeling for general, drainage, structural and feature design than using 3D modeling during earthwork and excavation.
3) Quality benefits. With the use of 3D models by DOTs, the quality of design and construction can be improved (Caltrans, 2014):
    a) Iowa DOT: reported that design intent is clearer in 3D than 2D.
    b) Wisconsin DOT: reported that 3D models add more details which contribute to higher quality design.
    c) Several DOTs: reported that if DOT did not provide 3D models to Contractors who used AMG in construction, Contractors tend to employ consultants to prepare 3D models for AMG and thus rely on the consultant’s interpretation of 2D designs, which may bring blunts and ambiguities.

In terms of providing more EED to the Contractor, KDOT reported 6 main benefits based on contractors’ feedback (Hovey and Lubliner, 2012):

1) Cost savings
2) Time savings
3) Improved product quality
4) More accurate bids

5) Quicker identification of errors
6) More accurate 3D models

2.3.4 Barriers to Implementation of CIM in Construction Staking

Despite the potential of CIM, some barriers to implementing CIM has been reported in the literature (Yan and Damian, 2008):

1) The lack of CIM expertise impedes using CIM in some construction projects. Consultants and contractors sometimes are reluctant to learn a relatively new technology.
2) The upfront cost of hardware, software, training, and implementation can be high. Government agencies are uncertain about the quality of the project using CIM and whether it is necessary to use CIM in average infrastructure projects, and contractors do not want to take the risk of not gaining profit with this cost.
3) Different parties have to be involved in the CIM model to either provide input, or revise it, or make use of the output. The person acting as a CIM manager must be able to control the workflow in a competent way.

The study of Caltrans also reported several barriers to the use of 3D modeling reflected by state DOTs (Caltrans, 2014):

1) Training issues: DOTs reported that software get updated frequently, and thus modeling training could be difficult.
2) Software issues: Sometimes software cannot fulfill certain tasks and state DOTs have to modify modeling software to meet local needs.
3) Network issues: In remote areas, data cannot be shared with outside collaborators through Internet access due to ineffective network.
4) Resistance to change: All respondents reported resistance to change as a significant barrier. Lack of knowledge or awareness of the importance of 3D modeling prevents agency staff from taking new practices.
5) Legal issues: Kentucky DOT reported that consultants are concerned about issues related with sharing data, such as signing and sealing digital documents.

2.3.5 Extent of Use of CADD and CIM in Construction Staking

A study was conducted by KDOT (Hovey and Lubliner, 2012) that provides a summary of contractors' preference of CAD files. Generally, the contractors believed that the release of CADD files would result in time and cost savings and improved accuracy in both bid preparation and construction. The results of the study are summarized in Table 25.

Table 25: Feedback from contractors in KDOT's survey (2012) on the use of 3D and electronic data

Item related to use of 3D and EED	Feedback from contractors
Use of existing electronic deliverables	1) Check quantities 2) Build 3D model 3) Layout survey 4) Exchange information 5) Acquire more accurate information
Additional EED preferred by contractors	1) Plan view 2) Cross-sections 3) Existing survey data 4) Profile view
Preferred format for additional files	1) AutoCAD 2) Microstation 3) Pro
3D model preference	Half of the surveyed contractors prefer creating 3D model by themselves; while the others prefer the 3D model provided by DOT

WisDOT collected information about the use of 3D models in AMG in highway construction surveying from seven state DOTs as shown in Table 26.

Table 26: Use of 3D models in AMG in seven state DOTs (WisDOT, 2009)

State DOT	Progress on using 3D models to facilitate AMG
Florida	Rewrote the design standards to create 3D model for AMG
Georgia	1) Modified staking specifications. 2) Developed specifications for AMG with fine graders for base course placement.
Michigan	AMG pilot program and a related "design deliverable enhancement" project, which made EED such as CADD drawings or survey files available through the e-Proposal website to Contractor as non-contractual items prior to bidding, were launched.
Minnesota	1) Released AMG specifications in 2006, which required DOT to develop 3D models. But 3D models are not part of the contract documents. 2) Reported barriers: legal issues, changing technology with its continual upgrades and learning curves, agency culture, and time and cost to implement.
Missouri	DOT developed Digital Terrain Model (DTM) but did not guarantee the conformance of the DTMs to the project plan.
New York	Worked toward 3D models for AMG and automated stakeout and inspection.
North Carolina	Questioned the return-on-investment of the 3D models adopted by designer and hesitated to provide 3D models to Contractor.

In the recent publication of FHWA (FHWA, 2016), several facts about the promotion of CIM in the transportation sector, in the past five years, were listed:

1) A joint technology committee that included members from the American Association of State Highway and Transportation Officials, the Associated General Contractors of America, and the American Road & Transportation Builders Association identified several technologies that might help to accelerate highway construction in 2010. The trend of highway construction is toward all-digital practices, and automated machinery and civil information modeling are recognized by the committee as most recommended technologies. The committee and FHWA initiated Every Day Counts (EDC) whose goal is to "develop guidance on 3D modeling capabilities and practices for the transportation sector" (FHWA, 2016).
2) The U.S. Domestic Scan Program (NCHRP Project 20-68A) has been launched, whose goal is to facilitate information sharing and technology exchange among state DOTs and other transportation agencies. CIM is one of the innovations covered by the program (FHWA, 2016).
3) NCHRP Project 10-96, titled "Guide for Civil Integrated Management in Departments of Transportation", has been developing guidance for state DOTs to use digital information in project delivery and asset management in the operation stage (FHWA, 2016).
4) FHWA encouraged a transition from traditional CADD, which generates 2D paper plan and design, to 3D modeling to facilitate project delivery and improve quality and safety on the construction site (FHWA, 2016).
5) During 2013, the number of state DOTs using 3D models increased from 9 to 24. FHWA's Office of Federal Lands Highway also started to use the 3D technology. Four of the 24 state DOTs now use 3D models in highway construction as a standard practice. A few state DOTs also explored application of 3D models to bridge design and construction beyond the excavation and pavement where 3D models have already been standard and regular (FHWA, 2016).

2.3.6 Electronic Data Development and Exchange Practices for Construction Surveying

2.3.6.1 Model Development

An important procedure for 3D model development is to download and merge survey data into civil design software. After the base mapping data of the roads has been gathered through surveying, the data need to be imported to a comprehensive 3D model for use by the design team.

Some of the sources of the data may include (UDOT, 2015):

1) TPS/GPS survey data, which usually can be exported directly in a format acceptable by most CADD software. Post-processing may be required according to instruction provided by the surveying equipment manufacturer.
2) In case laser scanning is used (see Section 2.4), terrestrial/aerial/mobile LiDAR data, which usually are in the form of a point cloud and needs to be filtered to get rid of noise before use.
3) In case photogrammetry is used (outside the scope of this report), photogrammetry data.

2.3.6.2 Electronic Data Exchange

The modeling tools used, as reported by state DOTs (Caltrans, 2014), are summarized in Table 27. The file types used, reported in the same study (Caltrans, 2014), are summarized in Table 28.

Table 27: Modeling tools used by state DOTs

Product	Vendor	State
Civil 3D	Autodesk	Florida, Wisconsin
GEOPAK	Bentley	Florida, Iowa, Missouri, North Carolina
InRoads	Bentley	Kentucky, New York, Pennsylvania
MicroStation	Bentley	Florida, Iowa, Missouri, New York, Pennsylvania

Table 28: File types used

File type	Description
ALG	InRoads geometry file
AMG	Automated machine guidance; links design software with construction equipment to direct the equipment's operation
CSV	Comma separated values file
DC	Data Collector file format used in Trimble Survey Controller
DGN	MicroStation drawing files
DTM	Digital terrain model or surface model
DWG	Native file format of AutoCAD
DXF	Data exchange file, a file format used to transfer 2-D and 3-D information
GPK	GEOPAK coordinate geometry database file
IRD	InRoads roadway definition file
LandXML	ASCII format based on XML used to specify civil engineering and surveying data
TIN	Triangulated Irregular Network

After development by the design team, the 3D model and other useful files, such as 1D, 2D project coordinates and project alignment information, can be provided to the Contractor for various uses in construction, such as stakeout, rough grading, and Portland cement concrete paving.

When requested by either the Project or Construction Manager, the following items that represent the final design approved for construction shall be prepared [Bureau of Environmental Services (BES), the city of Portland, 2014]:

1) Proposed Design CADD file (XREF drawing, which is an external reference to another AutoCAD drawing file).
2) ASCII file containing coordinates of center of proposed manholes, angle points, and any other significant points needed for construction staking.

According to the guidelines used by BES of Portland, when these items are provided to Contractor, these files should be delivered with the following words displayed (BES, the city of Portland, 2014):

"Owner is providing Contractor the attached documents, dated {**date**} as prepared by {**designer/consultant name**}, for reference purposes only and without any warranty as to their accuracy or completeness. By accepting these documents, Contractor agrees to hold Owner harmless for any errors contained therein. Contractor should contact Owner before relying on these documents in order to obtain corrected or updated versions."

If required, alignment report files, cross section report files, and earthwork computation files are released to contractors (KDOT, 2015). Those electronic deliverables are provided to contractors before bidding:

1) The alignment files describe the existing and proposed horizontal alignments and propose vertical alignments (KDOT, 2015).
2) The cross section report files give the station, offset, and elevation of each break point for the existing ground and proposed templates for all cross sections. The report files are generated from the electronic design files, typically using GEOPAK Software. (KDOT, 2015)
3) The earthwork files provide the cut and fill quantities at cross sections along with the end area calculations (KDOT, 2015).

The alignment files and cross section report are useful to create 3D models. While KDOT has already planned to directly provide CADD files to contractors because CADD files allow contractor to immediately incorporate plan changes through e-mail rather than paper plan process, and to create value engineering proposals using established plan data.

2.3.6.3 <u>Electronic Data Provided by DOTs</u>

As mentioned at the beginning of the section, contractors prefer to obtain 3D models directly from the DOT for the purpose of AMG, while most DOTs are still unable to provide the desired 3D models. Table 29 summaries 2D/3D documents provided by the Department to the Contractor, and Table 30 summarizes the details of electronic data provided by DOTs to Contractor if contractor staking is adopted (WisDOT, 2007).

Table 29: 2D/3D files provided by state DOTs to Contractors before AMG

State DOTs	2D Project Plans (Electronic)	2D Project Plans (Paper)	Cross Sections	3D Design files
Florida	√		√	
Georgia	√		√	
Michigan		√		
Minnesota	√		√	
Missouri	√		√	√
New York		√		
North Carolina	√		√	

Table 30: Documents provided by state DOTs to Contractor

State DOTs	Contents
Iowa	1) CADD files: CADD cross section; right of way; topography; 3D design break line files in an industry standard format, such as GEOPAK and MicroStation 2) Machine Control Surface Model files: a) ASCII format b) LandXML format c) Trimble Terramodel format 3) Alignment data files: a) ASCII format b) LandXML format c) Trimble Terramodel format
Minnesota	1) Background graphics file with centerlines, edges of pavement, and hull of ponds, wetlands, sensitive areas. 2) 3D files of proposed finish grade
Pennsylvania	CADD files including: 1) Files representing the design surfaces 2) Files containing all horizontal and vertical alignment information 3) Documentation file describing all of the profiles 4) Primary design file 5) Cross section files
Utah	1) 3D model of finished roadway surface 2) LandXML files 3) .dxf background file 4) Other documents including: a) Roadway features such as profile grade line, axis of rotation, edge of pavement, curb and gutter features, sidewalks, walls, slope break lines, etc. b) Drainage features such as ditches, ponds, swells, etc. c) Utility features 5) Survey specifications which have been modified for the use of GPS-guided grading, e.g., setting additional control points, modifying the construction staking tolerance, etc.
Wisconsin	Contractor staking packet, which contains survey information, design data files, and documents to be used by the contractor

2.3.6.4 Deliverables Submitted by Contractor

Table 31 summarizes the deliverables required by DOTs and when the submissions should be made.

Table 31: Deliverables required by DOTs

State DOTs	Deliverable	Time
Iowa	A work plan that contains: 1) Equipment type. 2) Control software manufacturer and version. 3) Proposed location of local GPS base station for broadcasting differential correction data to rover units. 4) Proposed locations where AMG will be used. Provide notice at least 30 days prior to changes to proposed AMG locations that will require additional construction staking by Contracting Authority.	At least one week prior to preconstruction conference, submit to Engineer
Minnesota	A work plan that contains: 1) A description of the manufacturer, model, and software version of the AMG equipment. 2) Contractor's experience in the use of AMG. 3) A single onsite staff person as the primary contact for AMG issue. 4) A definition of the project boundaries and scope of work to be accomplished with the AMG system. 5) A description of how the project proposed secondary control(s) is to be established, including a list and map detailing control points enveloping the site. 6) A description of site calibration procedures. 7) A description of the Contractor's quality control procedures for checking mechanical calibration and maintenance of equipment. 8) Contractor's contingency plan in the event of failure/outage of the AMG system. 9) A schedule of Digital Terrain Models (DTM).	At least 30 days prior to use
Pennsylvania	A survey control report that contains: 1) All contract control shown in the contract documents. 2) Adjustment method used to balance or adjust the control. 3) Control network diagram. 4) Horizontal and vertical datum used.	Upon completion of initial survey reconnaissance control verification and 5 working days before the scheduled beginning of primary field operations
	A quality control (QC) plan that: 1) Demonstrates that the equipment meets the performance requirements within the DOT’s tolerance. 2) Provides a methodology for Representative to make checks for location, grade, flowline, and position.	At least 5 business days before the preconstruction conference
	Electronic construction data for the machine-controlled data surface model (DTM) compatible with MicroStation	
Wisconsin	A work plan that discusses how AMG will be integrated into other technologies employed on the project, and: 1) Designate which portions of the contract will be done using AMG and which portions will be done using conventional base staking. 2) Describe the manufacturer, model, and software version of the GPS equipment. 3) Provide information on the qualifications of contractor staff, including formal training and field experience. 4) Describe how project control is to be established, including a list and map showing control points enveloping the site. 5) Describe site calibration procedures, including a map of the control points used for site calibration and control points used to check the site calibration. Describe the site calibration and checking frequency and documentation. 6) Describe the contractor's quality control procedures.	Before the preconstruction conference
	All survey notebooks and disks of project information/data.	Upon project completion

2.3.7 Practices of Automated Machine Guidance (AMG)

Applying GPS machine control requires a 3D surface model. Software such as Field General Construction Layout Software can generate construction staking data and export 3D models, as shown in Figure 8, to Leica, Sokkia, Topcon, or Trimble machine control systems.

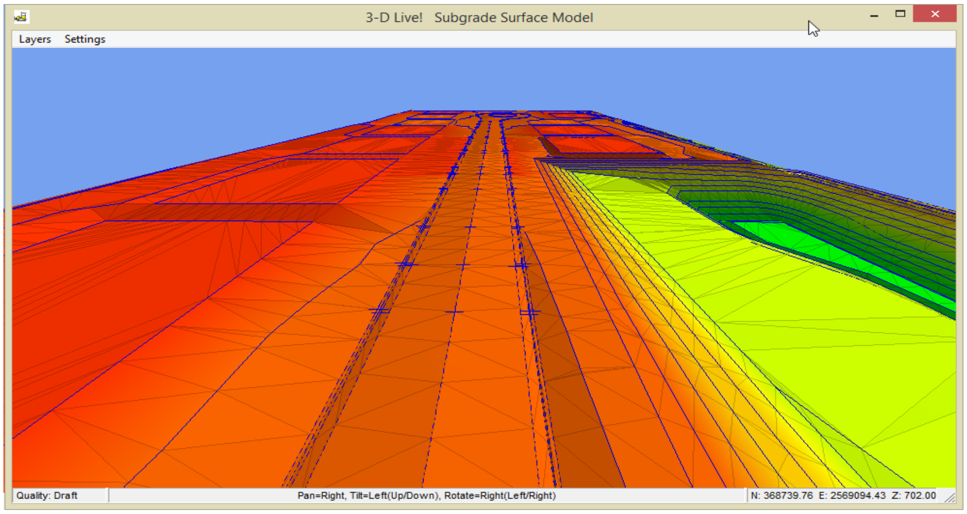

Figure 8: Surface model used by AMG (Image Courtesy: InSite)

Figure 9 shows the general process for AMG. Here, Electronic Engineered Data (EED), is defined as all the data required to create a Digital Terrain Model, or a 3D representation (e.g., surface model) of what is to be constructed. EED may include all types of capital project related engineering data which is used for defining, developing, designing, documenting, spatially locating, constructing, and historical recording, including documents and publications, geospatial data, and graphical information (Hannon and Sulbaran, 2010).

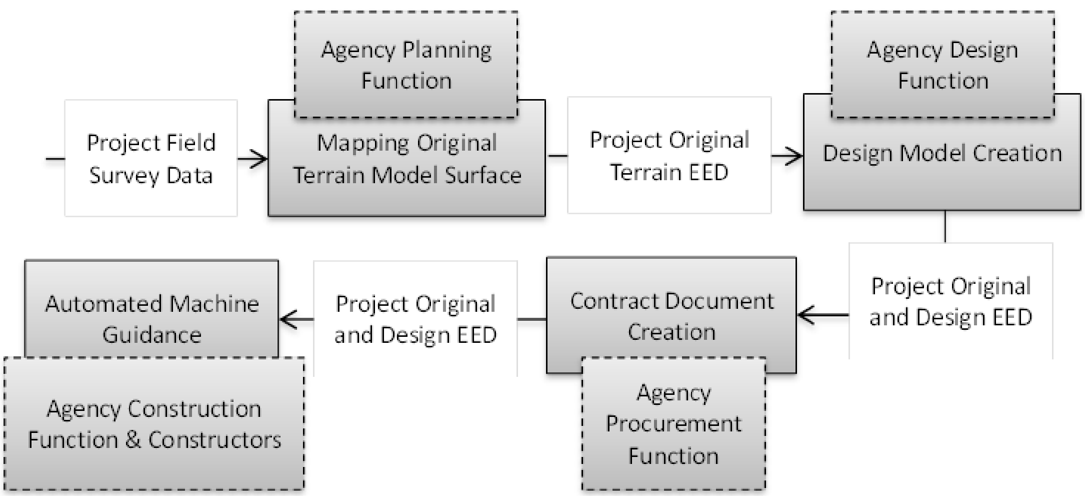

Figure 9: General AMG procedure

The current trend is to replace the traditional method of AMG using the new method. Traditionally, the 3D models are generated from 2D design products provided to the Contractor, and the 2D design products are often generated from 3D design data files owned by the Department. This process is time-consuming, costly, and prone to error. Now, contractors demand 3D models prior to construction as a part of the contract documents (WisDOT, 2007). A comparison of the traditional method versus the desired method is shown in Figure 10.

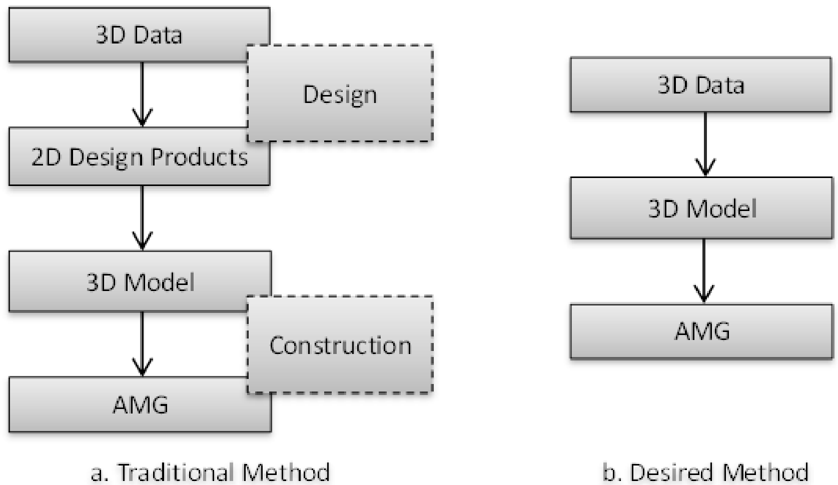

Figure 10: Comparison of the traditional and desired methods of AMG

In this subsection, practices or recommendations on automated machine guidance (e.g., GPS guided grading) by the following state DOTs are presented and discussed: MDOT (Hannon and Sulbaran, 2010), WisDOT (WisDOT, 2015), and UDOT (Richins et al., 2010).

<u>MDOT AMG Procedures</u>

Figure 11 shows the AMG procedures proposed in the MDOT Draft Special Provision. The whole process consists of 12 steps (S), each is related to certain functions and associated with certain participants.

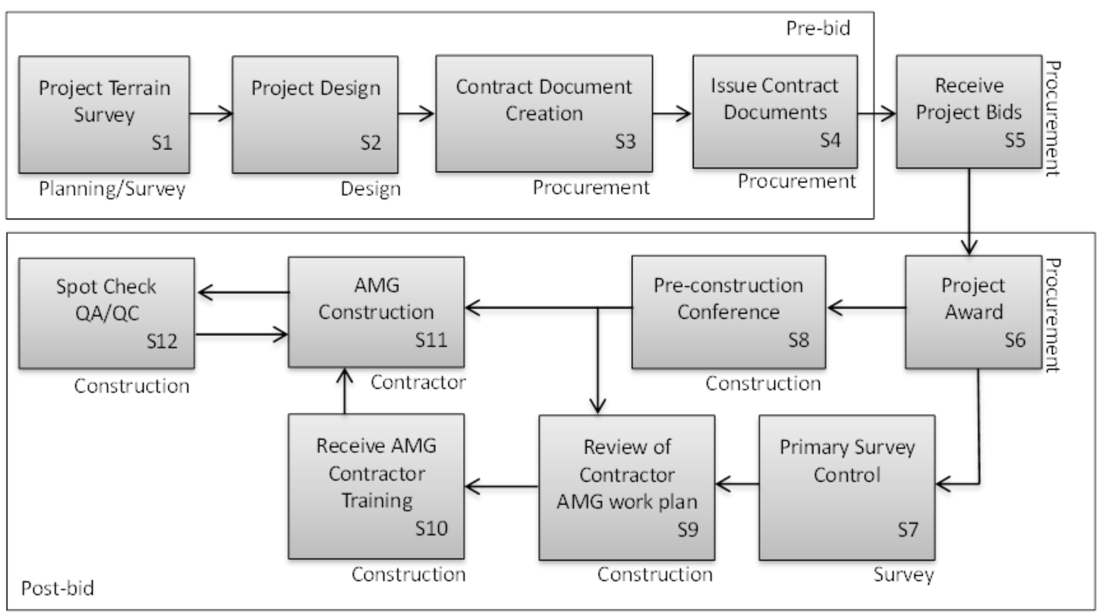

Figure 11: MDOT's AMG procedures (Hannon and Sulbaran, 2010)

1) Project terrain survey: collect and document original ground surface information and data, including location, traffic, environmental, and survey data. The data is collected using aerial or ground surveys, supported by CORS and RTK GPS (Hannon and Sulbaran, 2010).
2) Project design: develop the construction plan, possible alternatives, and drawings with specifications, and involves design engineers (Hannon and Sulbaran, 2010).
3) Contract document creation and issuance (Hannon and Sulbaran, 2010).
4) Receiving bids and project award (Hannon and Sulbaran, 2010).
5) Primary survey control: provide primary project survey control (i.e., 3D coordinates referenced to Mississippi State Plane Coordinate System and based on NGRS). The result is provided to the Contractor to set secondary survey control (Hannon and Sulbaran, 2010).
6) Pre-construction conference: contractor shall deliver an AMG Work Plan at the meeting before kick-off of the project. The plan then will be reviewed by the agency engineers for conformance to the special provision, and any changes or alterations to the AMG plan and system. The work plan shall at least include the following items (Hannon and Sulbaran, 2010):
    a) Detailed specifications of the AMG system components
    b) Information revealing the contractor’s personnel who will implement the AMG system, and their level of experience and competency
    c) The scope of the project work which will be affected by the adoption of AMG
    d) How the secondary survey control will be carried out
    e) Quality control calibration procedures and frequency for the equipment in AMG system
    f) Proposed documentation for the AMG work
    g) Methodology and frequency of field verification spot checks and how the information will be conveyed to the agency
    h) Contingency plans in case that AMG system fails
    i) How the DTM is shared with the agency for feedback

7) Receive AMG training: determine the quantity and schedule of training on the utilized AMG system of agency personnel specific to the project, provided by the Contractor (Hannon and Sulbaran, 2010).
8) AMG Construction and QA/QC: performance specification for AMG construction shall be followed by the Contractor. Some conventional grade stakes are required. And the DTM and AMG system shall use the Mississippi State Plane Coordinates, not the localized coordinates. QA/QC procedures shall be clarified in the Contractor’s AMG Work Plan (Hannon and Sulbaran, 2010).

UDOT’s Policy on AMG

According to UDOT’s Machine Control Guidance Final Report, the Designer should prepare complete and accurate 3D models of the highway project when the Contractor plans to use GPS guided grading. The 3D model is provided to the Contractor and used to compare with the 3D model developed by Contractor. The whole workflow of AMG is shown in Figure 12.

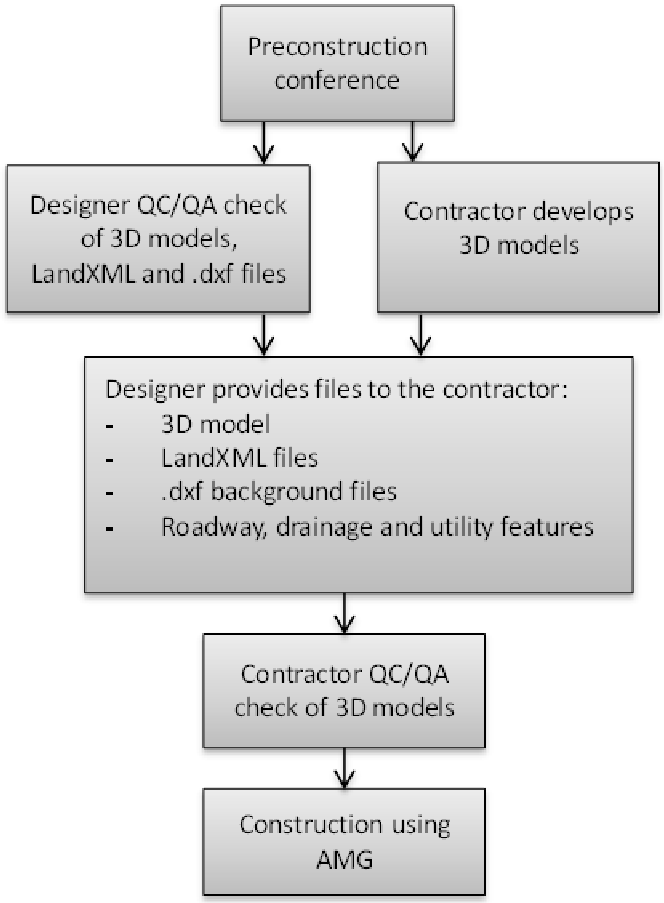

Figure 12: UDOT's AMG procedures

1) Contractor shall discuss and coordinate the following items/issues with the Engineer before the survey work begins at the preconstruction conference (Richins et al., 2010):
   a) Required submittals
   b) Survey and staking methods
   c) Stake markings
   d) Grade control
   e) Referencing
   f) Structure control
   g) Any other procedures and control necessary for the work
   h) Documentation procedures
2) All the following items should be clarified before AMG to reach an agreement on the use of GPS guided grading and reduce inconsistence during the project (Richins et al., 2010):
   a) 3D model to be used
   b) Control to be used
   c) Whether to use a lump sum; if not, how the quantities are to be calculated
   d) The amount of survey control
3) Generally, the design files, which are usually in MicroStation or InRoad format, are converted to a format that the equipment can read. A preferred format is LandXML. The LandXML files are inputs to the GPS guided grading equipment and software. Also, the design linework files should be exported to a .dxf file format to be used in background maps and linework for 3D models (Richins et al., 2010).

4) Moreover, the 3D model and all other files required for GPS guided grading should be independently viewed by a third party other than the designer to check the accuracy and completeness (Richins et al., 2010).
    a) Design: it is required that the designer shall provide a report documenting a full quality control and quality assurance (QC/QA) check of the 3D models with the LandXML and .dxf files. The QC/QA check shall be completed prior to advertising the project. This includes verifying the horizontal and vertical accuracy of the points and lines in the models.
    b) Construction: it is required that the contractor is responsible to perform a full QC/QA check of the 3D models to be used for AMG. A report documenting the QC/QA process shall be provided to the UDOT Engineer prior to using the models in construction.
5) Establish construction survey points, elevations, and grades as necessary to control layout and complete the work. Verify all control surveying and staking meets specified tolerances before beginning work (Richins et al., 2010).
6) Calculate all grades, elevations, offsets, and alignment data necessary for staking or setting items of work. Obtain approval from the Engineer for alternate methods of establishing grade control with wire lines, computer, or laser controlled grading or other suitable methods (Richins et al., 2010).

WisDOT's Policy on AMG

According to WisDOT, staking may be one of the items discussed at the pre-construction conference. A contractor staking packet will be made available at the pre-construction conference to facilitate staking operations.

The Contractor Staking Packet consists of the folder (legal size brown expanding wallet) prepared by the Design Engineer. The packet contains survey information, Design Data Files, and documents to be used by the contractor. This list provides categories of digital data, submittal requirements, data formats, the person responsible for survey data and links to FDM procedures and WisDOT forms to use (WisDOT, 2015).

The Contractor must develop and maintain the design model for use with the GPS machine guidance equipment, based on the initial survey information provided in the contractor staking packet (WisDOT, 2015).

The Contractor is responsible for ensuring that the model agrees with the contract plans. If a plan error is discovered, the Contractor must notify the Engineer. The Department will make necessary plan revisions and updates to the existing surface DTM, but the Contractor is still responsible for updating the model and sending the revised version back to the Department in LandXML or other engineer-approved format (WisDOT, 2015).

The Engineer should review the Contractor's proposed model and perform spot checks by projecting known points generated from the plan cross sections onto the proposed model, and generate an error report. The Engineer is responsible for maintaining an archive of DTM revisions and dates. The digital terrain model (DTM) serves as the base for the 3D design model. It is a 3D representation of the surface of the ground in a given area. The archive should include the DTM files and the time period for which each was active on the project (WisDOT, 2015).

2.3.8 Specifications of Automated Machine Guidance (AMG)

AMG specifications of eight state DOTs are summarized in Table 32. This table is adapted from the table in WisDOT's study in 2007 (Vonderohe, 2007).

Table 32: AMG specifications

Specification	Iowa	Kansas	Maryland	Minnesota	Mississippi	New York	Wisconsin	Pennsylvania
Who develops 3D model?	DOT	Contractor	Contractor	DOT		DOT		DOT and Contractor
3D model can be revised				DOT has 3 days to make correction		Revision based on supplemental survey and agreed upon by all parties		
Provide updated 3D model for as-build	Yes					Yes		
Contractor checks 3D model	Yes							
Accuracy same as conventional grading?	Yes	Yes			Yes			Yes

2.3.9 Existing IDOT Policies about CADD and CIM

The purpose of CADD Roadway and Structure Project Deliverables Policy is to guarantee that IDOT will receive CADD drawings for a given project that are in a standard and consistent format that IDOT staff are accustomed to working with and can manage. Based on the policies, IDOT (IDOT, 2014) will require CADD highway project data placed in a "Strip Map" format as surveyed on the Illinois state plane coordinate system with horizontal and vertical control elements in a design database.

To achieve this goal, IDOT requires using MicroStation and GEOPAK project files, for final plan submittal.

All files necessary to recreate the design contract plans in their entirety shall be included in the submittal, including (IDOT, 2014):

1) GEOPAK files shall include all files generated by GEOPAK Road and GEOPAK Survey.
2) A "Project Content File" (a Microsoft compatible document or spreadsheet listing each file submitted with the description of file content (sheet number, area and stationing if applicable) and any references associated to design files shall also be included with the above mentioned files at final submittal and each review submittal as required by the IDOT Project Engineer.
3) In addition to MicroStation and GEOPAK files, 11" x 17" PDFs of the contract plan sheets are also required.

The CADD policies are about using CADD in the design phase, not the construction phase. Though the policy itself provides detailed guidance on how to prepare the CADD deliverables for project design, it does not show what electronic files are to be provided to contractors, how contractors can make use of the CADD models, and how to integrate the results of construction staking with the 3D models (IDOT, 2014).

2.4 Laser Scanning

2.4.1 Scope and Method of the Literature Review

Basically, three different types of LiDAR are used in highway surveying: airborne LiDAR, Mobile Terrestrial LiDAR, and Static Terrestrial LiDAR (3D Scanning). Because this literature review is not intended to focus on the LiDAR, this report does not provide details on the three different types of LiDAR; rather, it provides a general introduction of the LiDAR technology, the technical and managerial process to use LiDAR for highway construction staking, and the required deliverables by some DOTs, neglecting the differences among the three types of LiDAR.

To achieve this goal, the research team focused on the following literature:

1) Research on evaluation or assessment of laser scanning or LiDAR funded by state DOTs
2) Requirements on Laser scanning or LiDAR surveying published by state DOTs

The literature reviewed is listed in Table 33.

Table 33: Literature reviewed for Section 2.4 (laser scanning)

Reference	Name of document
Helmer, 2003	Advanced Surveying and Mapping Technologies: Systems Overview and Applications
Hiremagalur et al., 2007	Creating Standards and Specifications for the Use of Laser Scanning in Caltrans Projects
Vincent and Ecker, 2010	Light Detection and Ranging (LiDAR) Technology Evaluation, funded by Missouri Department of Transportation
Gräfe, 2008	Kinematic 3D Laser Scanning for Road or Railway Construction Surveys
Young, 2013	Assessing LiDAR Elevation Data for KDOT Applications
Olsen et al., 2013	NCHRP 15-44 Guidelines for the Use of Mobile LiDAR in Transportation Applications
Nayegandhi, 2007	LiDAR Technology Overview
Caltrans, 2011	Chapter 15 Terrestrial Laser Scanning Specifications, Survey manual,

2.4.2 Description of the Technology

Laser scanning equipment emits a laser signal that can be detected when returning from reflective surfaces. The distance from the laser scanning equipment to the reflected surface can be calculated from the time needed for the laser signal to travel. And the laser signal is rapid to capture thousands of points of the reflected surface in seconds. Each point's 3D coordinates relative to the equipment axis are recorded with an attribute indicating the returning signal's intensity (NCHRP, 2013).

One type of laser scanning technique commonly used in construction is called Light Detection and Ranging (LiDAR). The LiDAR equipment illuminates the target with a laser, captures and analyzes the reflected light, and computes and documents the 3D coordinates. It is usually used to create digital terrain models (DTM) and digital elevation models (DEM). LiDAR differs from photogrammetry in that photogrammetry uses natural light while LiDAR emit a laser beam (NCHRP, 2013).

The intensity with the 3D coordinates data provided by LiDAR can be used to further generate a black and white-like image as shown in Figure 13. Those results are stored in a point cloud database that can be accessed and utilized on computers. The users can visualize and analyze those results in a way similar to 3D models in CADD software (NCHRP, 2013).

Mobile terrestrial LiDAR vehicles usually mount a group of equipment consisting of a laser scanner, a GPS sensor, an inertial measurement unit, distance measurement indicators, and digital cameras. The point data gathered via the mobile terrestrial LiDAR can be corrected for the pitch, roll, and yaw of the vehicle as it moves through the corridor (NCHRP, 2013).

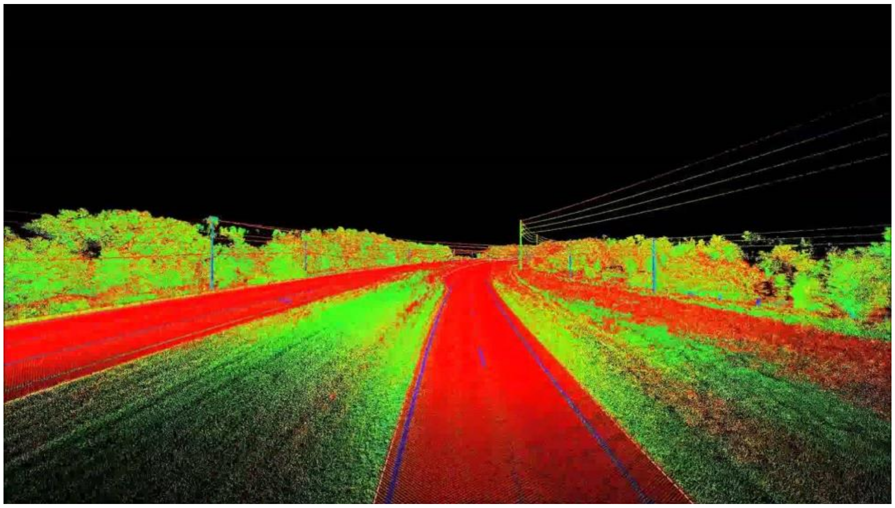

Figure 13: Mobile LiDAR highway corridor – SR54, Pasco County, FL (Image Courtesy: Leica)

Laser scanning is used in two types of surveys (Caltrans, 2012):

1) Hard surface topographic surveys, including:
    a) Pavement analysis scans
    b) Roadway/pavement topographic surveys
    c) Structures and bridge clearance surveys
    d) Engineering topographic surveys
    e) As-built surveys
2) Earthwork and lower-accuracy topographic surveys:
    a) Corridor study and planning surveys
    b) Asset inventory and management surveys
    c) Sight distance analysis surveys
    d) Earthwork surveys such as stockpiles, borrow pits, and landslides
    e) Urban mapping and modeling

2.4.3 Benefits of Laser Scanning in Construction Surveying

The benefits of using laser scanning for highway construction surveying include (Young, 2013):

1) Provide dense point cloud data. Thousands of data points can be captured in seconds.
2) Provide reusable data. The point cloud data could be used for other purposes in future work. For example, point cloud data collected to determine pavement thickness could be used to analyze line-of-sight conditions for accident.
3) Make it possible for surveyors to conduct the survey at a safe distance from the traffic.

4) Make it possible for surveyors to conduct the survey for inaccessible areas such as property where the agency is not permitted to enter.
5) Make it possible for surveyors to conduct the survey on vegetated areas.
6) Map long, narrow features and small objects ideally. Such features include highway, rail corridors, and power lines.
7) Save time and cost. The acquisition of point cloud is rapid even for large areas. And the process to generate DTMs from point clouds is highly automatic thus requires less time and human effort.

2.4.4 Sources of Error

Errors of LiDAR are generated from three main sources (Nayegandhi, 2007):

1) Laser ranging: Laser manufacturers suggest that the laser ranging has an accuracy level of 1-5 cm (0.39-1.97 in). This is due to the nature of laser pulses: after they are transmitted and received, phenomenon such as leading edge discrimination, separability of targets in range, and range walk may cause loss of accuracy.
2) GPS positioning: Horizontal positioning has error up to 1 meter (16.4 ft), and vertical error is much higher in sloping terrains. GPS error contributes the most to the total error.
3) Aircraft attitude positioning: If properly calibrated, the aircraft attitude positioning may have horizontal error about 10-50 cm (0.33-1.64 ft), and vertical error less than 5 cm (1.97 in).

2.4.5 Barriers to Implementation of Laser Scanning in Construction Surveying

Some of the barriers to using laser scanning for highway construction surveying include (Young, 2013):

1) Could involve multiple errors: Each step in the LiDAR survey processes can lead to human or instrument errors and due to the fact that new laser scanning technology keeps updating, less surveyors are able to manage the whole LiDAR survey process.
2) Requires supplemented measurement: LiDAR surveying should be conducted together with other ground-based conventional methods such as total station and RTK GPS method in order to achieve better measurements. LiDAR cannot act as the only source of elevation data.
3) Requires post-processing: Though less intensive than post-processing of photogrammetry data, the post-processing of LiDAR data is still necessary and costly.
4) Requires significant data storage: LiDAR surveys generate millions of points that must be documented and stored for future analysis. Both raw and final point clouds should be stored and archived in a format that will be accessible for decades.
5) Generate high entry cost. The cost of LiDAR equipment is higher than other commonly-used highway surveying equipment. LiDAR surveying also requires specialists or training, which adds further to the cost.

Challenges indicated by state DOTs in NCHRP’s report when using mobile LiDAR include (Olsen et al., 2013):

1) Software interoperability and data exchange,
2) Dataset size and complexity,
3) Needed technical expertise, and
4) Cost.

For many state DOTs, the cost is the most significant challenge to use mobile LiDAR. Thus evidence and education about a cost-benefit analysis on mobile LiDAR is required (Olsen et al., 2013).

In addition, state DOTs care most about the following issues when developing guidance for the use of LiDAR (Olsen et al., 2013):

1) Accuracy,
2) QA/QC procedures,
3) Software interoperability and integration, and
4) Data management and exchange.

2.4.6 Extend of Use of LiDAR in Construction

NCHRP's study in 2013 (Olsen et al., 2013) showed that about 70% of the state DOTs had experience with static laser scanning in one project in the preceding year. Most DOTs reported that mobile LiDAR has been investigated to some degree and may be put into use in the future. Also, 50% of the state ODTs reported to have experience with mobile LiDAR. Their experience with LiDAR mainly focuses on application in mapping and surveying, and DTM.

LiDARs with different levels of accuracy (1 = High, 2 = Medium, 3 = Low) and different levels of point density (A = Coarse, B = Intermediate, C = Fine) are suggested for different applications as shown in Table 34 (Olsen et al., 2013).

Table 34: Application of LiDAR with suggested level of accuracy and point cloud density (Olsen et al., 2013)

Accuracy / Density	High (1) <0.05 m (<0.16 ft)	Medium (2) 0.05 to 0.20 m (0.16 to 0.66 ft)	Low (3) >0.20 m (>0.66 ft)
Fine (C) >100 pts/m^2 >9 pts/ft^2	1) Surveying and mapping 2) Digital Terrain Modeling 3) Construction automated machine control 4) CAD models 5) CIM 6) Post-construction quality control 7) As-built documentation		Roadway condition assessment
Intermediate (B) 30 to 100 pts/m^2 3 to 9 pts/ft^2	Landslide assessment	1) General mapping 2) Driver assistance 3) Automated extraction of signs and other features	1) Asset management 2) Inventory mapping
Coarse (A) <30 pts/m^2 <3 pts/ft^2	Quantities (e.g., earthwork)		

2.4.7 Procedures for Laser Scanning for Construction Surveying

This section first provides an overview of the general process of using LiDAR in surveying projects. The section then presents MoDOT's specifications on the LiDAR survey procedures (Vincent and Ecker 2010) as an example to elucidate LiDAR implementation details in practice. Leica's static and airborne LiDARs are shown in Figure 14.

2.4.7.1 General Process

Figure 14: Left: Leica ALS70-HP High-Pulse-Rate Airborne LIDAR

Right: Tripod-based terrestrial HD LiDAR scanning (Image Courtesy: Leica)

The general process of LiDAR surveying consists of 5 steps (Caltrans, 2011):

1) Pre-planning: before laser scanning is carried out, a pre-planning meeting should be conducted to discuss the following topics (Caltrans, 2011):
   a) Measurement objects
   b) Security and access constraints
   c) Mobilization
   d) Control network details
2) Project control establishment and target placement: two types of points are set up, i.e. control points which are used to control the point cloud adjustment, and validation points which are used to check the point cloud adjustment. Best results are typically obtained when the targeted control stations are positioned horizontally throughout the scanning evenly (Caltrans, 2011).
3) Equipment setup and calibration: when a known control point is being used, ensure the instrument is right over the point and measure and record the height of instrument and height of targets at the beginning of each setup. Equipment height, plummet position, and target height should be checked at the end of each setup (Caltrans, 2011).
4) Creating redundancy: LiDAR data should be collected in a way that there is a 5% to 15% overlapping in terms of scan distance from one scan to the next adjacent scan. The Figure 15 shows overlapping among three scans (Caltrans, 2011).
5) Quality management (QA/QC): develop the QA/QC report, including control points, comparison of elevation data from overlapping scans, comparison of point cloud data and control points, comparison of adjusted point cloud data and redundant validation points (Caltrans, 2011).

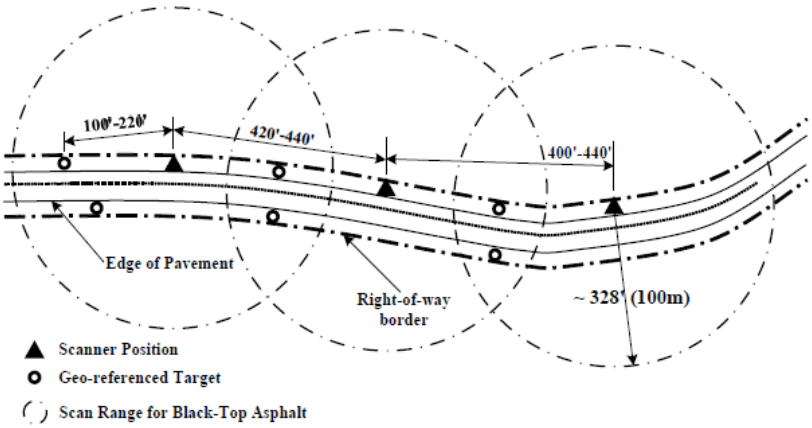

Figure 15: Suggested survey layout for a typical 2- or 4- lane Caltrans highway (Hiremagalur, 2007)

2.4.7.2 Example of DOT Requirements

MoDOT has the following requirements on the procedure of using LiDAR in highway surveying (Vincent and Ecker, 2010).

1) Beginning the work: the work shall begin after MoDOT notification and the ground is not obscured by snow, haze, smoke, dust, or cloud (when using airborne LiDAR) (Vincent and Ecker, 2010).
2) Flight planning: if airborne LiDAR is used, flights planning shall follow the recommendation by MoDOT (Vincent and Ecker, 2010):
   a) For planimetric coverage, flight corridors shall include all features affecting design and right of way takings, and remain within the area where horizontal controls have been established.
   b) For terrain coverage, flight corridors shall be within the area that needs earthwork computations. Generally, this area is within the limits of proposed right of way and must be within the area where horizontal and vertical controls have been established.
   c) LiDAR and aerial mapping data shall be provided to MoDOT with conventional survey data.
3) Developing LiDAR sensor calibration reports: the Consultant shall provide the calibration report developed according to the specifications, and/or the manufacturer's recommended equivalent procedure. Moreover, if the LiDAR sensor is distributed, repaired, or modified after the award of the contract, a new calibration report shall be provided to reflect the changes (Vincent and Ecker, 2010).
4) Quality control and checks: quality control shall be performed by Central Office survey staff (Vincent and Ecker, 2010).
   a) The staff will take check shots along the main alignment of the project at least every 200 ft. and alternate shots every 400 ft. each side of the main alignment.
   b) The staff will take check shots along curb lines, bridge rails, retaining walls and other features with elevation differences.
5) Post-processing LiDAR data: MoDOT defines three types of data: Type A roadway and pavement scan data, Type B urban corridor and earthwork scan data, and Type C rural corridor and earthwork scan data. Different types of data shall be processed using different methods (Vincent and Ecker, 2010).

The procedures/workflow for using LiDAR in surveying suggested by Caltrans (Caltrans, 2011), MoDOT (Vincent and Ecker, 2010), and NCHRP (Olsen et al., 2013) are summarized in Table 35.

Table 35: Procedures/workflow for using LiDAR in surveying

Source	Procedures/workflow
Caltrans	1) Pre-planning 2) Project control establishment and target placement 3) Equipment setup and calibration 4) Creating redundancy 5) Quality management (QA/QC) 6) Deliverables and documentation
MoDOT	1) Beginning the work 2) Flight planning (if airborne LiDAR is used) 3) Developing LiDAR sensor calibration reports 4) Quality control and checks 5) Post-processing LiDAR data
NCHRP	1) Planning a) Quality management plan b) Determine location of interest c) Coordinate between Contractor with Department d) Consider weather/environment conditions e) Develop the path for vehicle f) Preliminary site survey 2) Data acquisition a) Verify system calibration b) Set and acquire control and validation points c) Get scan data or imagery data from sensors 3) Post processing a) Clean and filter data b) Build surface model c) Extract features/line d) Quality control 4) Computations and analysis (e.g., cut/fill estimation) 5) Packaging and delivery

2.4.8 Current IDOT's Use of LiDAR and Relevant Requirements

IDOT's requirements on the use of LiDAR in topological surveying are summarized below: (IDOT, 2015)

1) Calibrate the equipment and develop a Calibration Report, which includes a list of the equipment, the calibration parameters, method used, and estimated accuracies.
2) Set control and validation points. Control points and validation points shall be on each side of the scan trajectory and be spaced less than 1500 and 500 feet respectively.
3) Develop a Safety Plan which includes site conditions, time of work, equipment, and procedures to minimize unsafe conditions for traffic and workers.

4) Overlap the point clouds from adjacent runs by 20%. Point cloud density shall exceed the minimum requirement.
5) Process data. Multiple methods (and terms) are used by vendors to correct or adjust the point cloud to better fit the control or transformation points. The most common and preferred method is the adjustment of the raw navigation trajectory of the vehicle. This is performed post-processing where the observed transformation points are input and the trajectory of the vehicle reprocessed or adjusted to best fit the points. The second method is a rigid body translation of the point cloud to fit the control points.

2.4.9 Deliverables

In this section, the LiDAR deliverables required by two state DOTs are presented as examples: MoDOT (Vincent and Ecker 2010) and Caltrans (Caltrans, 2012).

<u>Deliverables defined by MoDOT</u>

MoDOT defined the following deliverables for laser scanning surveying (Vincent and Ecker 2010):

1) Three ASCII coordinate (point cloud) files: primary control file, the geodetic control file, and check shots file.
2) MoDOT survey report: It shall include copies of all inter-visible control survey pair station descriptions along with all benchmark descriptions and field ties. A sketch of each point shall be provided showing the relative location of field ties to the point being referenced.
3) An orthomosaic captured simultaneously with LiDAR or separate aerial sensor.
4) LiDAR data, including: record return, intensity, GPS time, etc., together with a report about LiDAR processing, a report about vertical accuracy, and a shape file.
5) MicroStation and GEOPAK files: a 3D MicroStation file of all the topographic and survey data collected manually, GEOPAK Digital Terrain Models (.tin) for the entire project, and GEOPAK Coordinate Database (.gpk) containing the data imported for the project.

<u>Deliverables and documentations required by Caltrans</u>

Caltrans published specifications on both deliverables and documentations for laser scanning surveying, as follows:

1) Deliverables (Caltrans, 2011)
    a) 3D coordinates files in ASCII, CSV, XML, or LAS format
    b) Point clouds data
    c) Caltrans Roadway design and drafting software files
    d) Digital photo panorama/mosaic files
    e) Survey narrative report documenting the general information of the survey (e.g., name and identification, datum, epoch and units, personnel, equipment and surveying methods, etc.)
    f) QA/QC files
    g) Geospatial metadata files
2) Documentation (Caltrans, 2011)
    a) Control lineage or pedigree, including primary and project control held or established, traverse points, scanner occupied and targeted control points, validation points, and adjustment report for control.
    b) Registration reports, including results of target and cloud to cloud registration, QA/QC reports, and results of finished products to validation points.

An example of point cloud data with the 3D model generated from the data is shown in Figure 16.

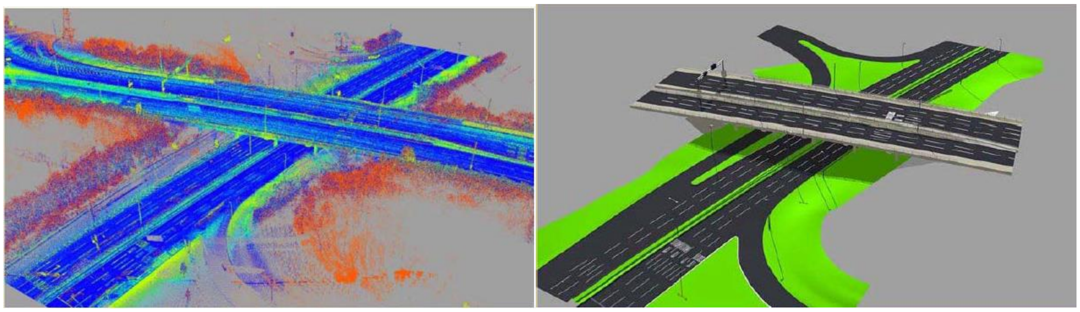

Figure 16: Left: Point cloud data Right: CADD model converted from the point cloud data (Image Courtesy: ASPRS)

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ICT Project R27-163

Adapting Construction Staking and Inspection to Modern Technology

Internal Interim Report #2 (DRAFT)

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For Period:	February 16, 2016-August 31, 2016
Status:	**DRAFT**

1 INTRODUCTION

1.1 Project Motivation

The Illinois Department of Transportation (IDOT) has no written specifications, guidelines, or policies for the use of 3D computer-aided design and drafting (CADD) models, information models for highways [known as civil information models (CIM)], global positioning system (GPS), or other modern technologies that have developed over the past 10 years for highway construction. Such technologies could support various construction processes (e.g., staking, inspection) and could offer major opportunities for quality improvements, cost savings, and expediting project delivery. Many contractors also request the project CADD files for positioning devices used on their construction equipment for grading and paving. However, IDOT's policies and guidelines (e.g., IDOT’s Construction Manual) do not address this practice and are out of date with modern technologies. As such, IDOT needs to develop written procedures for the use of these modern technologies in construction staking and inspection of highway projects for inclusion in IDOT’s Construction Manual.

1.2 Project Objectives

The main goal of this research project is to develop written procedures for the use of modern technologies (such as GPS, CADD models, and civil information models) in construction staking of highway projects in the State of Illinois for inclusion in IDOT’s Construction Manual, which would enable the employment of these technologies in Illinois, and in turn offer major opportunities for quality improvements, cost savings, and expediting project delivery.

To accomplish this critical goal, the research objectives of this project are:

1) Provide a comprehensive literature review of the use of modern technologies by industry and other state DOTs, relevant construction manuals by other state DOTs that cover the use of these modern technologies (e.g., WisDOT’s 2014 Construction and Material Manual), relevant state and federal regulations, guidelines, and protocols/policies on the use of these technologies, and relevant research studies on the use of these technologies. The scope will focus on technologies that could support construction staking of highway projects such as GPS, CADD models, and civil information models.
2) Conduct a survey to gather information from state DOTs and contractors on current practices employed by other states that successfully adopted these technologies for construction of highways.
3) Identify a set of potential practices for employment in the State of Illinois, based on the literature review and the survey results (i.e., based on the results of Objectives 1 and 2).

4) Conduct a survey to gather feedback from IDOT staff and Illinois contractors on the potential success and suitability of these potential practices in the State of Illinois.
5) Develop recommendations for IDOT's written procedures for the use of these technologies in construction staking of highway projects to be included in the IDOT's Construction Manual, based on the data collected and the survey results (i.e., based on the results of Objectives 3 and 4). This written procedures are intended to support construction staking processes when a contractor employs such technologies.

1.3 Project Tasks and Deliverables

The proposed methodology breaks down the research work into six primary tasks that will lead to four project deliverables, as shown in Figure 1.

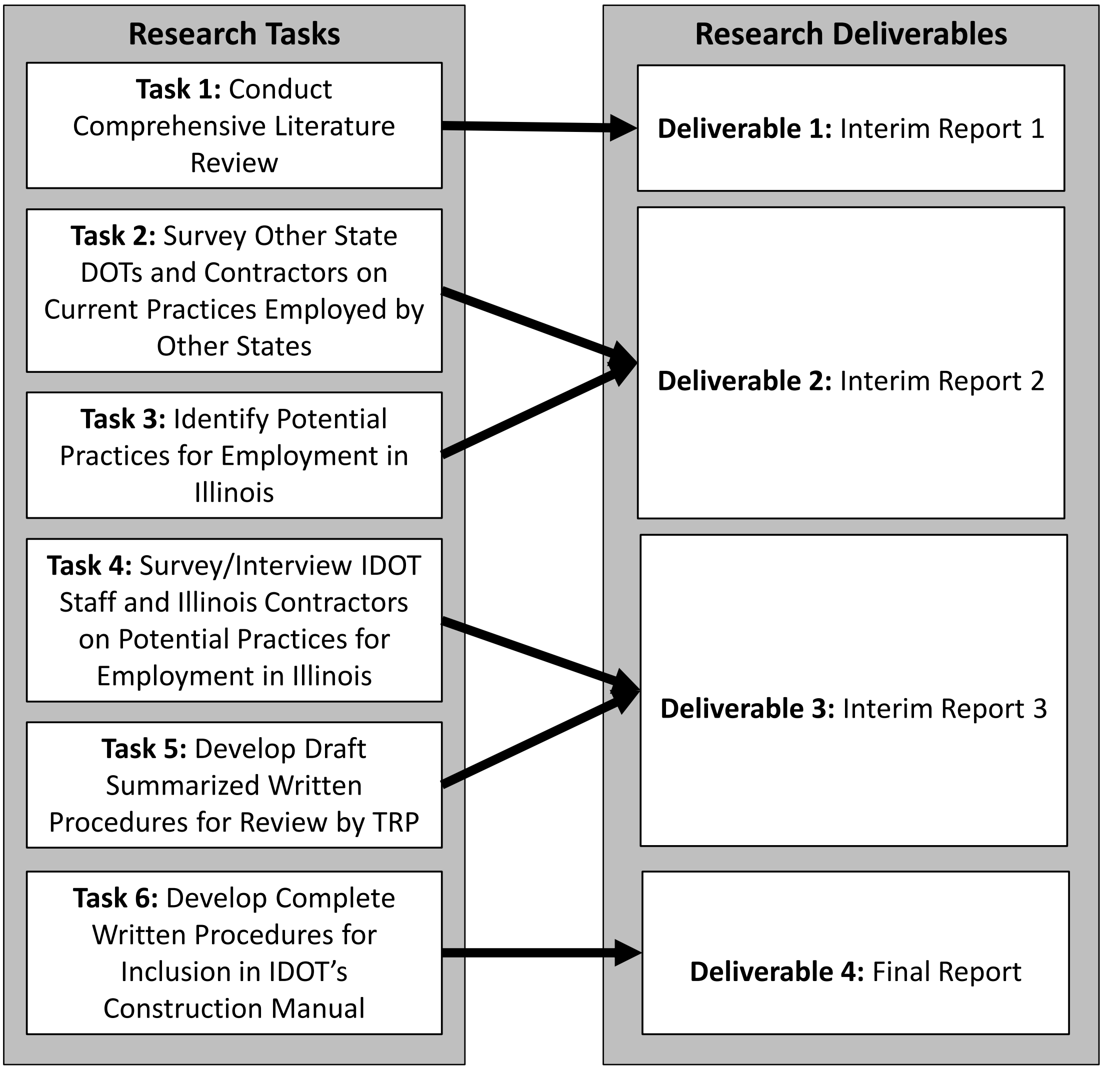


Figure 1: Proposed Research Methodology

1.4 Scope and Organization of this Report

This interim report intends to summarize the outcomes of Task 2 (Survey Other State DOTs and Contractors on Current Practices Employed by Other States) and Task 3 (Identify Potential Practices for Employment in Illinois). Task 2 started on March 01, 2016 and was completed on July 31, 2016. Task 3 started on July 01, 2016 and was completed on August 31, 2016. Task 2 focused on conducting a survey to gather information from other state DOTs and contractors on current practices employed by other states that successfully adopted modern technologies (GPS, CADD, Civil Information Models) for construction of highways. In Task 3, the research team identified the potential practices for employment in Illinois (by IDOT and Illinois contractors) based on the analysis of the results of the literature review and the survey. The research team also incorporated the identified practices into a project workflow. This task will be the basis for developing the written procedures related to the use of modern technologies for construction staking of highway projects to be included in the IDOT's Construction Manual (Tasks 4, 5, and 6).

2 TASK 2: SURVEY OTHER STATE DOTS AND CONTRACTORS ON CURRENT PRACTICES EMPLOYED BY OTHER STATES

2.1 Survey Purpose and Methodology

The purpose of the survey was to gather information from other state DOTs and contractors on current practices employed by other states that successfully adopted modern technologies for construction staking of highways, including information on: (1) extent of use of the technologies by the state DOT and construction contractors, (2) practices for successful implementation, (3) barriers to implementation, and (4) relevant written procedures/documents followed by each state DOT (e.g., the state DOT's Construction Manual).

The research team conducted the survey using a set of online questionnaires. The research team first developed a list of potential questions based on the results of the literature review (Task 1). The questions were then organized into five sections based on content (as described in Section 2.2). Four questionnaires were then developed – one questionnaire for each of the following target groups: (1) state DOT construction staff, (2) state DOT design staff, (3) state DOT surveying staff, and (4) state contractors. Each questionnaire included only the questions that were relevant to the respective target group. The online questionnaires were developed using Google Forms. In the March 30, 2016 TRP meeting, the research team discussed the draft questionnaires with the TRP. Based on the comments/discussions during the meeting, the research team revised the questionnaires. After the questionnaires were approved by the TRP, the research team conducted a pilot survey to test the effectiveness of the questionnaires. Three respondents, from IDOT District 9, participated in the pilot survey. Feedback was solicited on different aspects of the questionnaire, such as question wording, response options and evaluation scale, and clarity of instructions to respondents. The questionnaires were then revised based on the feedback. For example, a ”do not know” option was added for each multiple choice question. The final questionnaires were then approved by the TRP and the survey was launched on June 06, 2016. The target respondents included: (1) members of the AASHTO Subcommittee on Construction, and (2) district engineers and contractors referred by the members. The survey was conducted online. The survey invitation emails were sent to members of AASHTO Subcommittee on Construction by the TRP Chair, Tim Kell, on June 06, 2016. The original survey deadline was July 15, 2016. The research team received 33 responses by that date. Accordingly, the research team and the TRP Chair decided to extend the deadline to July 31, 2016, with an aim to increase the response rate. Three (3) additional responses were received during the extension period. The research team considered extending the deadline for a second time, but with the low response rate during the 2-week extension, the team decided to proceed with the survey result analysis. A total of 36 responses were, thus, received.

2.2 Questionnaire Design

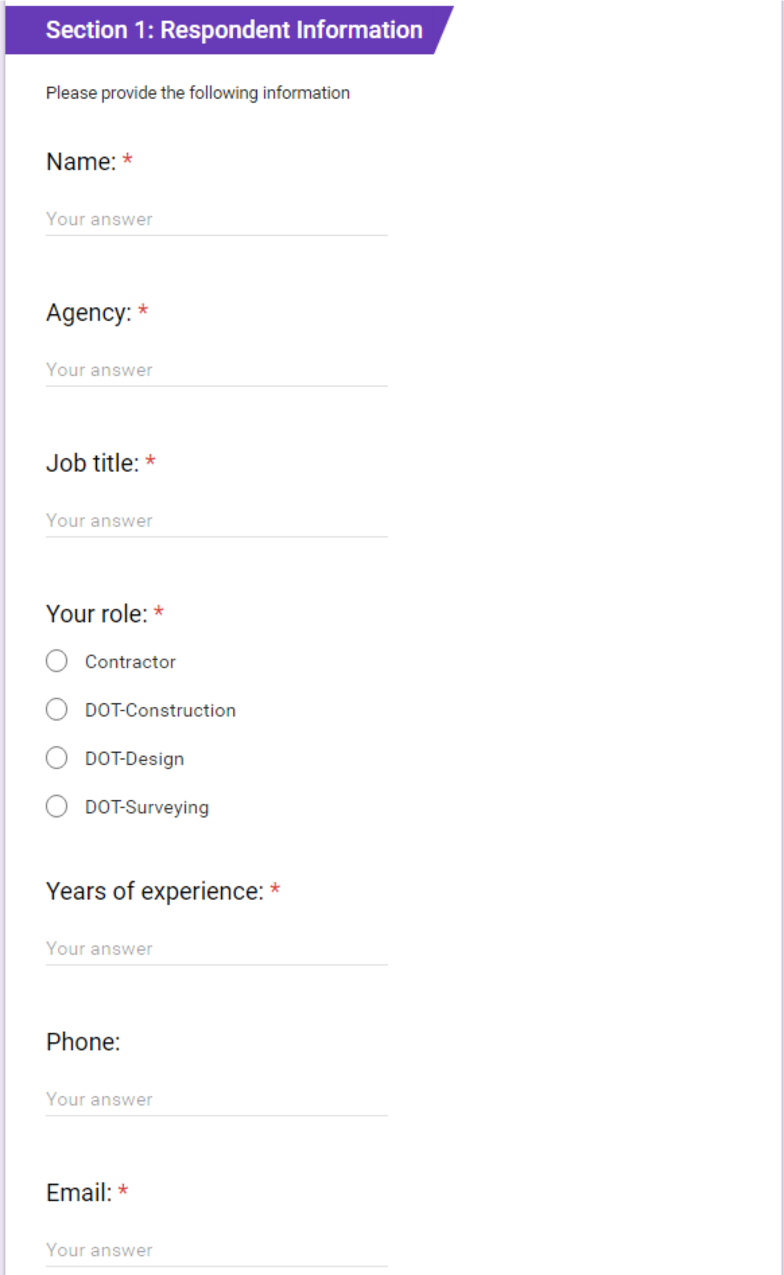
The questionnaires were composed of seven sections: (1) respondent information, (2) extent of use, satisfaction, benefits, success factors, and barriers of/with GPS technology in construction surveying, (3) control surveying using GPS technology and Real Time Kinematic (RTK) method, (4) construction surveying using GPS equipment, (5) conventional staking when conducting construction surveying using GPS equipment, (6) digital models and electronic data exchange practices, and (7) laser scanning. Section 7 is not presented for the respondents provided no answers.

The sections were assembled, forming the four questionnaires. As mentioned in Section 2.1, four questionnaires were developed – one questionnaire for each target respondent group. The complete set of questions are included in Appendix A, while the four questionnaires are included in Appendices B to E. The following shows the relevancy of sections to the four questionnaires/groups:

1) Questionnaire sent to DOT construction staff: Section 2, Section 4, and Section 5.
2) Questionnaire sent to DOT design staff: Section 2 and Section 6.
3) Questionnaire sent to DOT surveying staff: Section 2 and Section 3, and part of Section 4.
4) Questionnaire sent to contractors: all of the seven sections.

Three types of questions were developed: (1) multiple choice questions, which ask the respondents to select one or more options among a number of options/alternatives, (2) dichotomous questions, where there are two possible responses (e.g., yes/no), and (3) short answer questions, which ask the respondents to provide a specific information (e.g., link to a document). For multiple choice questions that require respondent's rating (e.g., rating of satisfaction level), a six-point Likert scale was used, with 6 being the most favorable (e.g., very satisfied) and 1 being the least favorable (e.g., "very dissatisfied"). For each question, a "do not know" option was added so that the respondents do not to answer a question randomly when they have no information/knowledge about the answer. For most multiple choice questions, an "other" option was added – with a blank – so that the respondents can provide additional responses/information, without being limited by the response options provided. Within one section, all questions were required. But, respondents were able to skip a whole section.

Section 1 solicited respondent information, including name, agency, job title, role, years of experience, phone, and email. Figure 2 shows a snapshot of Section 1.



Section 1: Respondent Information

Please provide the following information

Name: *

Your answer

Agency: *

Your answer

Job title: *

Your answer

Your role: *

- Contractor
- DOT-Construction
- DOT-Design
- DOT-Surveying

Years of experience: *

Your answer

Phone:

Your answer

Email: *

Your answer

Figure 2: Questionnaire – Snapshot of Section 1 (Respondent Information)

Section 2 (Respondent Information) aimed at gathering respondent feedback on the extent of use, satisfaction, benefits, success factors, and barriers associated with the use of GPS technology in construction surveying. A multiple choice question format was used to capture the responses (with some questions using a six-point Likert scale, as mentioned above). Figure 3 shows an example of the questions that were included in Section 2. All questions in Section 2, except Question 1 (which is relevant to contractors only), were included in the questionnaires sent to DOT construction staff, DOT design staff, and DOT surveying staff. All questions in Section 2, except Question 2 (which is relevant to DOT staff only), were included in the questionnaire sent to contractors. The complete set of questions is included in Appendix A, while the four questionnaires are included in Appendices B to E.

1. Based on your agency's experience in the past year, how many highway projects regulated by your agency utilized GPS technology in construction surveying? *

- ◯ None
- ◯ Less than 25%
- ◯ 25% to 50%
- ◯ 50% to 75%
- ◯ More than 75%
- ◯ All projects
- ◯ Do not know

Figure 3: Questionnaire – An Example Question in Section 2 (Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying)

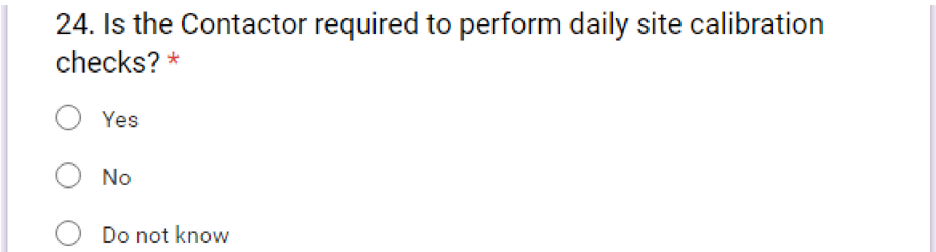
Section 3 [Control Surveying Using GPS Technology and Real Time Kinematic (RTK) Method] aimed at gathering respondent feedback on control surveying using GPS technology and Real Time Kinematic (RTK) method. The questions covered the following aspects: responsibility for performing secondary control surveys, use of additional control surveys if AMG is used, office procedures, types of base station networks utilized, and deliverables. Respondents were also requested to provide the link(s) to the manual(s) or document(s) that includes the DOT's respective specifications. Multiple-choice, dichotomous, and short-answer question formats were used to capture the responses, depending on the type of feedback needed. For example, for Question 6 a short-answer format was used, where the respondents were asked to provide the link(s) to the manual(s) or document(s) that includes the DOT's respective specifications of GPS surveying. Figure 4 shows an example of the questions that were included in Section 3. All questions in Section 3 were included in questionnaire sent to DOT survey staff. All questions in Section 3, except Question 6, were included in questionnaire sent to contractors. The complete set of questions are included in Appendix A, while the four questionnaires are included in Appendices B to E.

3. If Automated Machine Guidance (AMG) is used, are additional horizontal and vertical control surveys required?

- ◯ Yes
- ◯ No

Figure 4: Questionnaire – An Example Question in Section 3 [Control Surveying Using GPS Technology and Real Time Kinematic (RTK) Method]

Section 4 (Construction Surveying using GPS Equipment) aimed at gathering respondent feedback on construction surveying when AMG, specifically GPS-guided machine, is used. The questions covered the following aspects: the use of AMG, use of conventional staking along with AMG, use of GPS equipment list, GPS equipment vendors, specifications, tolerances, GPS equipment maintenance, calibration, spot checks, final checks, and training. Similar to previous sections, multiple-choice and dichotomous question formats were used, depending on the type of feedback needed. Figure 5 shows an example of the questions that were included in Section 4. All questions in Section 4 except Question 2 (which is relevant to DOT staff only), were included in the questionnaire sent to contractors. All questions in Section 4, except Question 3 (which is relevant to contractors only), were included in the questionnaire sent to DOT construction staff. The questionnaire sent to DOT surveying staff included only three questions (Questions 14 to 16). The complete set of questions are included in Appendix A, while the four questionnaires are included in Appendices B to E.


24. Is the Contactor required to perform daily site calibration checks? *

- Yes
- No
- Do not know

Figure 5: Questionnaire – An Example Question in the Section 4 (Construction Surveying Using GPS Equipment)

Section 5 (Conventional Staking When Conducting Construction Surveying Using GPS Equipment) aimed at gathering respondent feedback on conventional construction staking when AMG, specifically GPS-guided machines, is used. The questions covered the following aspects: conventional construction staking procedures and specifications, the degree that conventional staking is needed when AMG is used, how electronic devices are used to facilitate staking, and the references that are used for staking procedure and specifications such as tolerances and spacing. Similar to previous sections, multiple-choice, dichotomous, and short-answer question formats were used, depending on the type of feedback needed. For example, the respondents were asked to select the option that corresponds to the current type of specifications for construction staking. The respondents were also asked whether conventional staking is still utilized when AMG is used for construction work. In some questions a six-point Likert scale was used to measure level of agreement with certain statements (e.g., see Figure 6). The respondents were also asked to provide the link(s) to the manual(s) or document(s) that includes the DOT's respective staking specifications and procedures. Figure 6 shows an example of the questions that were included in Section 5. All questions in Section 5 were included in questionnaire sent to DOT construction staff. All questions in Section 5, except Questions 3 and 6, were included in questionnaire sent to contractors. The complete set of questions are included in Appendix A, while the four questionnaires are included in Appendices B to E.

2. Indicate your level of agreement with the following statement: It is necessary to have written specification for AMG (such as tolerances and stake spacing) included in a construction manual or other guidance documents. *

- 1: Very disagree
- 2: Disagree
- 3: Somewhat disagree
- 4: Somewhat agree
- 5: Agree
- 6: Very agree
- Do not know

Figure 6: Questionnaire – An Example Question in the Section 5 (Conventional Staking When Conducting Construction Surveying Using GPS Equipment)

Section 6 (Digital Models and Electronic Data Exchange Practices) aimed at gathering respondent feedback on digital models and electronic data exchange practices in construction surveying. The questions covered the following aspects: the use of digital models and associated practices and specifications, satisfaction, benefits and barriers, success factors, impact of digital models on project time and cost, responsibilities regarding digital models when AMG is used, electronic data provided by the DOT, and deliverables submitted by the contractor. The respondents were asked to select the option that best answers the question or the options that are true based on their experience with digital models and electronic data in highway construction projects. In some questions a six-point Likert scale was used to measure level of satisfaction with the use of certain CADD software and electronic data to support construction surveying, with 1 the least agreed and 6 the most agreed. Figure 7 shows an example of the questions that were included in Section 6. All questions in Section 6 were included in the questionnaire sent to DOT design staff. All questions in Section 6, except the Question 23, were included in questionnaire sent to contractors.

13. Who is responsible for updating and revising the digital models used for AMG? *

- DOT
- Contractor
- Do not know

Figure 7: Questionnaire – An Example Question in the Section 6 (Digital Models and Electronic Data Exchange Practices)

2.3 Survey Results

2.3.1 Distribution of Responses

The research team received 36 responses from 20 states, including Illinois. Among all the responses, 14 are from DOT construction staff, 6 are from DOT design staff, 10 are from DOT surveying staff, and 6 are from contractors. Among these 36 responses, 5 are not complete, (i.e., those respondents only provided answers to certain sections, but not all sections, in the questionnaire they received. Please note that respondents were allowed to skip sections, but for a section they chose to answer they had to respond to all questions).

Table 1: Distribution of responses by state and agency

State	Contractor	DOT-Construction	DOT-Design	DOT-Survey	Total
Illinois	1	2	1	2	6
Florida	4			1	5
Michigan			2	3	5
Colorado		1	1	1	3
Massachusetts				1	1
Arizona				1	1
Arkansas		1			1
California		1			1
Connecticut			1		1
Indiana	1				1
Kentucky		1			1
New Hampshire		1			1
New Jersey		1			1
North Carolina		1			1
Oregon		2			2
Pennsylvania				1	1
South Carolina		1			1
Virginia			1		1
West Virginia		1			1
Wyoming		1			1
Total	6	14	6	10	36

2.3.2 Respondent Information

Table 2 summarizes the information of all 36 respondents, from the 20 different states.

Table 2: Summary of respondent information

Name	Agency	Job title
DOT-Construction		
Bill Zdankiewicz	Illinois DOT District 9 Construction	Senior Resident Engineer
Ben Hill	Illinois DOT District 9 Construction	Super badass engineer tech L3
Andy Long*	Wyoming DOT	State Construction Engineer
Wei Johnson	South Carolina DOT	Engineer
Andrew Alvarado*	Caltrans	Chief, Office of Contract Administration and Risk Management
Chris Pucci	Oregon DOT	Construction Automation Surveyor
Al Balluch**	NJDOT	Manager
Kevin Ryburn	Colorado DOT	Construction Area Engineer
Dwayne	Arkansas DOT	Staff Construction Engineer
Phillip Johnson	NCDOT	Roadway Estimate and Claims Engineer
Ryan Griffith	Kentucky Transportation Cabinet	Director-Division of Construction
J. Darby Clayton	WVDOT	Regional Construction Engineer
Theodore Kitsis	NHDOT	State Construction Engineer
Christopher Harris	Oregon DOT	Construction Automation Engineer
DOT-Design		
Kevin Kelley	Illinois DOT – District 9	CADD Technician
Jack Rick	Michigan DOT	University Region Design Engineer
Jackie Pethers	Michigan DOT	Design Engineer
Sahar Alola	Colorado DOT	CADD Manager
Adam Wilkerson	Virginia DOT	Roadway Design Section Manager
Greg Sardinskas	Connecticut DOT	Senior Transportation Engineer
DOT-Surveying		
Jim Cox - Surveying	Illinois DOT – District 8 - Surveying	Resident Technician IV
Scott A. Zacharias	Illinois DOT - District 9 - Division of Highways	Chief of Surveys
John P. Lobbestael	Michigan DOT	Supervising (Chief) Land Surveyor
Jeff Bartlett	Surveying Solutions, Inc.	Principal/Project Surveyor

Table 2 (Cont'd): Summary of respondent information

Name	Agency	Job title
Brian Bartlett*	Surveying Solutions Inc.	Project Surveyor
Clifton Clark	Arizona DOT	Chief Surveyor
Daniel Smith	CDOT	Land Survey Coordinator
Ernie	D.A.B. Consructors, Inc	Party Chief
Stephen Michael Moore	PennDOT Photogrammetry & Surveys Section	Photogrammetry Manager (Geodetic Surveys Manager)
John S. Anthony, PLS	MassDOT	State Survey Engineer
Contractor		
Joe Lenzini	E. T. Simonds Construction Company	Operations Manager
William Gelner	D.A.B. Constructors, Inc.	Project Manager
Paul Suellentrop*	OHL/Community Asphalt	VP/Miami Operations
Bob Schafer*	Florida DOT	President
Chuck McIntosh	Superior Construction, SE	Survey Manager
Pat McGriff	The Lane Construction Corporation	Pursuit Manager

* Did not respond to the last section in the corresponding questionnaire

** Reported no experience with GPS in highway construction projects

2.3.3 Survey Results and Analysis

This section of the report provides a summary of the survey results and analysis.

2.3.3.1 Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying

This section of the survey collected respondent feedback on the extent of use, satisfaction, benefits, success factors, and barriers associated with the use of GPS technology in construction surveying. Table 3 provides a summary of the main findings. All questions and a summary of their response results are shown below (see Table 4-Table 11).

Table 3: Summary of survey results of Section 2 (Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying)

	Responses
Use of GPS technology	1) Only one respondent reported not using GPS technology during the past year and over 40% of all respondents reported the use by more than 75% of the projects. 2) Users are satisfied with the use of GPS technology in highway construction works, except for structure work. 3) Other than the listed uses of GPS technology, the technology is also used for as-built work.
Barriers	1) The top-ranked reported barrier is GPS not being required by the DOT. For example, MDOT CPM jobs (mill/fill paving) do not require positioning. 2) The second-ranked reported barrier is cost of acquiring and operating GPS equipment. 3) Limited accuracy, lack of GPS equipment (DOT), lack of GPS equipment (contractor), lack of specifications by the DOT, lack of end-user technical skills (DOT), and lack of end-user technical skills (contractor) were also highly reported as barriers. 4) As reported, sometimes GPS is not the most appropriate method for the item being built. This reflects the drawback of the technology itself.
Benefits	1) The main benefits that were reported are: decrease in crew size, decrease in duration of surveying, decrease in staking workload, and decrease in cost. 2) Other reported benefits include: save time by eliminating multiple instrument set-ups, no line-of-sight issues, and never have to worry about horizontal control getting destroyed.
Factors for successful implementation	1) The factors that were ranked as important for successful implementation are: cooperation of surveyors, cooperation of DOT designers, experience with GPS technologies(Contractor), clear and comprehensive description of workflow and responsibilities, clear and comprehensive specifications, experience with GPS technologies(DOT), hardware/software vendor support, end-user training (Contractor), and end-user training (DOT). 2) Additional reported factors include FHWA awareness and support through Every Day Count (EDC) Rounds 2 and 3, which was rated as somewhat important.

Table 3 (Cont'd): Summary of survey results of Section 2 (Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying)

	Responses
Challenges and difficulties	1) The challenges that were ranked the highest are: less trained equipment operators, all parties need to be on the same site calibration, all parties need to use the same data files. 2) Other challenges that were reported include: unstable GPS signal, inefficient communication between contractor and DOT, reading and recording wrong antenna height, harsh weather, and interruption due to power failure. 3) Additional reported difficulties include not matching existing control when trying to calibrate the site.

1. Based on your agency's experience in the past year, how many highway projects constructed by your agency utilized GPS technology in construction surveying?

Table 4: Survey results – Use of GPS technology in construction surveying (contractor)

	Contractor
None	0
Less than 25%	0
25% to 50%	2 (33%)
50% to 75%	0
More than 75%	1 (17%)
All	3 (50%)
Do not know	0

2. Based on your agency's experience in the past year, how many highway projects regulated by your agency utilized GPS technology in construction surveying?

Table 5: Survey results – Use of GPS technology in construction surveying (DOT)

	DOT-Construction	DOT-Design	DOT-Surveying	Total
None	1 (7%)	0	0	1 (3%)
Less than 25%	3 (21%)	1 (17%)	1 (10%)	5 (17%)
25% to 50%	1 (7%)	0	1 (10%)	2 (7%)
50% to 75%	2 (14%)	0	2 (20%)	4 (13%)
More than 75%	5 (36%)	2 (33%)	1 (10%)	8 (26%)
All	2 (14%)	0	3 (30%)	5 (17%)
Do not know	0	3 (50%)	2 (20%)	5 (17%)

3. If you did NOT answer "All projects" to the previous question, why was GPS technology NOT used during construction surveying?

Table 6: Survey results – Reasons for not using GPS technology

	DOT-Construction	DOT-Design	DOT-Surveying	Contractor	Total
Unawareness of benefits (DOT)	1 (8%)	0	2 (29%)	0	3 (12%)
Unawareness of benefits (Contractor)	2 (17%)	0	1 (14%)	0	3 (12%)
Not required by DOT	6 (50%)	0	4 (57%)	2 (67%)	12 (48%)
Lack of specifications by DOT	4 (33%)	0	0	2 (67%)	6 (24%)
Procedural issues	0	0	0	0	0
Lack of GPS equipment (DOT)	4 (33%)	1 (17%)	2 (29%)	0 (0%)	7 (28%)
Lack of GPS equipment (Contractor)	3 (25%)	0	2 (29%)	1 (33%)	6 (24%)
Lack of end-user technical skills (DOT)	3 (25%)	1 (17%)	2 (29%)	0	6 (24%)
Lack of end-user technical skills (Contractor)	1 (8%)	0	3 (43%)	1 (33%)	5 (20%)
Cost of acquiring and operating GPS equipment	5 (42%)	3 (50%)	2 (29%)	0	10 (40%)
Inconstant signals	1 (8%)	1 (17%)	2 (29%)	1 (33%)	5 (20%)
Limited accuracy	2 (17%)	0	3 (43%)	2 (67%)	7 (28%)
Do not know	1 (8%)	2 (33%)	0	0	3 (12%)
Other	3 (25%)	2 (33%)	2 (29%)	2 (67%)	9 (36%)

4. Which of the following options best describes the DOT's specifications with respect to the use of GPS technology in construction surveying?

Table 7: Survey results – DOT's policy on use of GPS technology

	DOT-Construction	DOT-Design	DOT-Surveying	Contractor	Total
Allow unlimited use	8 (57%)	1 (17%)	2 (20%)	1 (17%)	12 (33%)
Allow limited use	3 (21%)	3 (50%)	6 (60%)	1 (17%)	13 (36%)
Prohibit use	0	0	0	0	0
Mandate use	0	0	0	0	0
Are silent	2 (14%)	0	0	3 (50%)	5 (14%)
Do not know	1 (7%)	2 (33%)	2 (20%)	1 (17%)	6 (17%)

5. Based on your agency's experience, indicate your level of satisfaction with the use of GPS technology in construction surveying for each of the following activities

Table 8: Survey results – Level of satisfaction with the use of GPS technology*

	1: Very dissatisfied	2: Dissatisfied	3: Somewhat dissatisfied	4: Somewhat satisfied	5: Satisfied	6: Very satisfied	Do not know
Project control surveying	1 (3%)	1 (3%)	2 (6%)	5 (14%)	11 (30%)	13 (36%)	3 (8%)
Automated machine guidance	1 (3%)	0	3 (8%)	4 (11%)	6 (17%)	15 (42%)	7 (19%)
Staking for grading	1 (3%)	1 (3%)	0	9 (25%)	9 (25%)	11 (30%)	5 (14%)
Staking for paving	1 (3%)	4 (11%)	3 (8%)	7 (19%)	6 (17%)	8 (22%)	7 (19%)
Staking structure	4 (11%)	3 (8%)	6 (17%)	7 (19%)	4 (11%)	7 (19%)	5 (14%)
Staking drainage and pipeline	1 (3%)	2 (6%)	3 (8%)	8 (22%)	6 (17%)	12 (33%)	4 (11%)
Staking slope	1 (3%)	0	0	6 (17%)	8 (22%)	16 (44%)	5 (14%)
Staking base	1 (3%)	1 (3%)	2 (6%)	5 (14%)	10 (28%)	11 (31%)	6 (17%)
Staking curb and gutter	1 (3%)	5 (14%)	6 (17%)	4 (11%)	7 (19%)	10 (28%)	3 (8%)
Staking concrete barrier	1 (3%)	2 (6%)	2 (6%)	7 (19%)	8 (22%)	10 (28%)	6 (17%)
Preparation of surveying data deliverable	1 (3%)	2 (6%)	2 (6%)	7 (19%)	7 (19%)	11 (31%)	6 (17%)
Construction staking bid item measurement	1 (3%)	2 (6%)	4 (11%)	6 (17%)	4 (11%)	8 (22%)	11 (31%)

*The percentages in a certain row may not sum up to 100% due to rounding.

6. Which of the following benefits did your agency experience when using GPS technology in construction surveying?

Table 9: Survey results – Benefits of GPS technology

	DOT-Construction	DOT-Design	DOT-Surveying	Contractor	Total
Decrease crew size	12 (86%)	4 (67%)	7 (70%)	6 (100%)	29 (81%)
Facilitate measurement of vertical distance	3 (21%)	1 (17%)	3 (30%)	3 (50%)	10 (28%)
Decrease the duration of surveying	11 (79%)	4 (67%)	7 (70%)	5 (83%)	27 (75%)
Decrease the cost	7 (50%)	1 (17%)	7 (70%)	4 (67%)	19 (53%)
Make it possible to work under bad weather conditions	0	1 (17%)	1 (10%)	0	2 (6%)
Improve the precision of survey	1 (7%)	2 (33%)	3 (30%)	1 (17%)	7 (19%)
Reduce staking workload	9 (64%)	3 (50%)	6 (60%)	5 (83%)	23 (64%)
Do not know	0	2 (33%)	1 (10%)	0	3 (8%)
Other	1 (7%)	0	1 (10%)	0	2 (6%)

7. Based on your agency's experience, indicate the level of significance that the following factors had in contributing to the success of GPS implementation at your agency?

Table 10: Survey results – Factors contributing to successful use of GPS technology*

	1: Very insignificant	2: Insignificant	3: Somewhat insignificant	4: Somewhat significant	5: Significant	5: Very significant	Do not know
Cooperation of surveyors	2 (6%)	0	2 (6%)	4 (11%)	8 (22%)	17 (47%)	3 (8%)
Cooperation of DOT designers	1 (3%)	3 (8%)	5 (14%)	10 (28%)	7 (19%)	8 (22%)	2 (6%)
Clear and comprehensive specifications	1 (3%)	3 (8%)	4 (11%)	8 (22%)	5 (14%)	8 (22%)	7 (19%)
End-user training (DOT)	3 (8%)	4 (11%)	3 (8%)	7 (19%)	6 (17%)	7 (19%)	6 (17%)
End-user training (Contractor)	2 (6%)	1 (3%)	5 (14%)	5 (14%)	9 (25%)	6 (17%)	8 (22%)
Equipment sharing between DOT and contractor	8 (22%)	8 (22%)	5 (14%)	4 (11%)	2 (6%)	1 (3%)	8 (22%)
Hardware/software vendor support	2 (6%)	2 (6%)	5 (14%)	4 (11%)	7 (19%)	10 (28%)	6 (17%)
Experience with GPS technologies(DOT)	3 (8%)	1 (3%)	6 (17%)	2 (6%)	8 (22%)	11 (31%)	5 (14%)
Experience with GPS technologies(Contractor)	2 (6%)	1 (3%)	2 (6%)	4 (11%)	5 (14%)	15 (42%)	4 (11%)
Clear and comprehensive description of workflow and responsibilities	3 (8%)	0	4 (11%)	8 (22%)	10 (28%)	5 (14%)	6 (17%)

*The percentages in a certain row may not sum up to 100% due to rounding.

8. Based on your agency's experience, which of the following are difficulties or challenges to the use GPS technology in construction surveying?

Table 11: Survey results – Difficulties and challenges to the use of GPS technology

	DOT-Construction	DOT-Design	DOT-Surveying	Contractor	Total
None	1 (7%)	0	0	0	1 (3%)
Less trained equipment operators	4 (29%)	1 (17%)	7 (70%)	1 (17%)	13 (36%)
Inefficient communication between Contractor and DOT	3 (21%)	0	3 (30%)	2 (33%)	8 (22%)
Harsh weather conditions	1 (7%)	0	3 (30%)	1 (17%)	5 (14%)
Interruption due to power failure	0	0	2 (20%)	1 (17%)	3 (8%)
Reading and recording wrong antenna height	2 (14%)	1 (17%)	1 (10%)	1 (17%)	5 (14%)
Unstable GPS signal	3 (21%)	1 (17%)	3 (30%)	4 (67%)	11 (31%)
All parties need to be on the same site calibration	5 (36%)	2 (33%)	3 (30%)	3 (50%)	13 (36%)
All parties need to use the same data files	5 (36%)	1 (17%)	4 (40%)	3 (50%)	13 (36%)
Do not know	1 (7%)	2 (33%)	1 (10%)	0	4 (11%)
Other	4 (29%)	1 (17%)	2 (20%)	3 (50%)	10 (28%)

2.3.3.2 Control Surveying Using GPS Technology and Real Time Kinematic (RTK) Method

This section of the survey collected respondent feedback on control surveying using GPS technology and Real Time Kinematic (RTK) method. Table 12 provides a summary of the main findings. All questions and a summary of their response results are shown below (see Table 13-Table 17).

Table 12: Summary of survey results of Section 3 (Control Surveying Using GPS Technology and Real Time Kinematic Method)

	Responses
Secondary control surveys	The majority of respondents reported that the contractor is responsible for performing secondary control surveys. It was also reported that either the DOT or the contractor could be responsible for performing secondary control surveys, which is project specific and depends on the pay item.
Additional control surveys	When AMG is used, the majority of respondents reported that additional horizontal and vertical control surveys are required.
Office procedures	1) The majority of respondents reported that the following office procedures are done: compare check shots with the known values, check the base station coordinates and ellipsoid height for correctness, analyze the GPS site calibration for a high scale factor and high residuals, and check the data collector file for correctness and completeness. 2) Other reported procedures include check all reports for high residuals.
Deliverables	1) The majority of respondents reported that the following deliverables are required to be submitted by the Surveyors for a GPS control survey: coordinates, primary control checks, GPS raw and solution files, coordinate metadata, project site map, and project narrative summary. 2) Other reported deliverables include: post-process report, equipment logs, names of individuals and duties, calibration report for all points used in the survey, weather condition report, and Project Control Diagram (PCD).
GPS survey specifications, including deliverables, base station network, accuracy, and tolerances	The specifications for GPS control survey is included in survey manual of most DOTs (e.g. Illinois DOT's Survey Manual). Only one respondent reported that no one monitors the GPS surveying work.

1. Who is responsible for performing secondary control surveys for the project?

Table 13: Survey results – Responsibility for project secondary control surveys

	DOT-Surveying	Contractor	Total
DOT	3 (33%)	0	3 (23%)
Contractor	4 (45%)	3 (75%)	7 (54%)
Do not know	0	1 (25%)	1 (8%)
Other	2 (22%)	0	2 (15%)

2. If Automated Machine Guidance (AMG) is used, are additional horizontal and vertical control surveys required?

Table 14: Survey Results – Additional project control surveys required when AMG is used

	DOT-Surveying	Contractor	Total
Yes	5 (56%)	2 (50%)	7 (54%)
No	1 (11%)	1 (25%)	2 (15%)
Do not know	3 (33%)	1 (25%)	4 (31%)

3. Which of the following office procedures are done when conducting RTK control surveying?

Table 15: Survey results – Office procedures for RTK surveying*

	DOT-Surveying	Contractor	Total
Check the data collector file for correctness and completeness	6 (67%)	1 (25%)	7 (54%)
Check the base station coordinates and ellipsoid height for correctness	6 (67%)	2 (50%)	8 (62%)
Analyze the GPS site calibration for a high scale factor and high residuals	6 (67%)	2 (50%)	8 (62%)
Compare check shots with the known values	8 (89%)	3 (75%)	11 (85%)
Check all reports for high residuals	3 (33%)	1 (25%)	4 (31%)
Do not know	0	1 (25%)	1 (8%)
Other	1 (11%)	0	1 (8%)

*Colorado DOT does not use RTK for control surveys, instead, static or fast static GPS procedures are used and surveyors run level loops for elevations.

4. Which of the following types of base station networks are utilized by your agency?

Table 16: Survey results – Types of base station networks utilized

	DOT-Surveying	Contractor	Total
CORS	7 (78%)	1 (25%)	8 (62%)
OPUS	4 (44%)	0	4 (31%)
HARN	4 (44%)	0	4 (31%)
VRS	4 (44%)	0	4 (31%)
NDGPS	2 (22%)	0	2 (15%)
Do not know	1 (11%)	3 (75%)	4 (31%)
Other	0	0	0

5. What are the deliverables that are required to be submitted by the Surveyor for a GPS control survey?

Table 17: Survey results – Required deliverables for GPS control survey

	DOT-Surveying	Contractor	Total
Project narrative summary	7 (78%)	1 (25%)	8 (62%)
Names of individuals and duties	3 (33%)	2 (50%)	5 (38%)
Coordinates	8 (89%)	3 (75%)	11 (85%)
Coordinate metadata	6 (67%)	2 (50%)	8 (62%)
Project site map	5 (56%)	3 (75%)	8 (62%)
Equipment logs	4 (44%)	1 (25%)	5 (38%)
Calibration report for all points used in the survey	3 (33%)	1 (25%)	4 (31%)
Primary control checks	7 (78%)	3 (75%)	10 (77%)
Post-process report	5 (56%)	1 (25%)	6 (46%)
Weather condition report	2 (22%)	2 (50%)	4 (31%)
GPS raw and solution files	6 (67%)	3 (75%)	9 (69%)
Do not know	1 (11%)	1 (25%)	2 (15%)
Other	1 (11%)	0	1 (8%)

6. Please provide the link to the manual or document that includes the DOT specifications about GPS RTK survey design, setup, and operation.

The following six relevant documents that include the DOT specifications about GPS RTK survey design, setup, and operation were reported:

- Illinois DOT Survey manual http://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Design-and-Environment/Survey%20Manual.pdf
- Arizona DOT Manual for Field Surveys http://azdot.gov/docs/business/manual-for-field-surveys.pdf?sfvrsn=0

- Colorado DOT Survey Manual https://www.codot.gov/business/manuals/survey
- Pennsylvania DOT Publication 408/2016 Specifications http://www.dot.state.pa.us/public/PubsForms/Publications/Pub_408/408_2016/408_2016_1/408_2016_1.pdf
- Massachusetts DOT MACORS Real-Time Network http://macors.massdot.state.ma.us/spiderweb/frmIndex.aspx
- Michigan DOT Survey Standards of Practices http://mdotwiki.state.mi.us/design/index.php/Chapter_1_-_Survey_Standards_Introduction

2.3.3.3 Construction Surveying Using GPS Equipment

This section of the survey collected respondent feedback on construction surveying when AMG, specifically GPS-guided machine, is used. Table 18 provides a summary of the main findings. All questions and a summary of their response results are shown below (see Table 19-Table 49).

Table 18: Summary of survey results of Section 4 [Construction Surveying When Automated Machine Guidance (AMG) Is Used]

	Responses
Use of AMG	1) More than 73% of the respondents reported that AMG is used in 50% of the projects or more. 2) Responses show that AMG is allowed to be used in grading, paving, and other highway construction work requiring excavation. However, it was reported by one DOT that they still do not have experience with AMG. 3) It was also reported that: a) the Contractor decides where to use the technology and DOT will work with them. b) AMG is used for compaction on soils and pavement. c) a decision would have to be made when approached with AMG for each type of construction.
Conventional staking	1) Most of the respondents reported that the DOT is requiring conventional staking when AMG is used. 2) There was a split opinion about the extent of use/requirement of conventional staking when AMG is used: 54% of the respondents agreed or somewhat agreed that the DOT is requiring too much traditional staking when AMG is used, whereas 46% of the respondents very disagreed, disagreed, or somewhat disagreed with this statement.
Equipment	1) All respondents (17 out of 18, with 1 not knowing) reported that no list of approved GPS equipment is provided by the DOT. 2) Responses show that the most commonly-used vendors of AMG equipment are Trimble, Topcon, and Leica. 3) The majority of respondents reported that there is no specified frequency for equipment maintenance, with only one reporting weekly maintenance requirement during the survey. Among those who reported no specified frequency, 33% maintain equipment irregularly and 17% maintain equipment at the beginning of each survey. 4) The majority of contractors reported that all GPS equipment components are maintained. Respondents reported that periodic manufacturer maintenance checks, cleaning, and calibration are performed.
Checking	1) The primary control check was the top-reported check, among both the checks that are specified/required by the DOT and those that are voluntarily performed.

Table 18 (Cont'd): Summary of survey results of Section 4 [Construction Surveying When Automated Machine Guidance (AMG) Is Used]

Checking	2) More than one-third of the respondents (including half the surveyed contractors and half the surveyed DOT surveying staff) reported that they perform GPS equipment checks at the beginning and end of each survey. Some respondents (including 40% of the surveyed DOT surveying staff) reported that they perform GPS equipment checks every six months and others (10% of the surveyed contractors) reported that they perform the checks by request of the engineer or contractor. 3) All contractors reported that they perform daily site calibration checks, even if not be required by the DOT (about half of the responses indicated that daily site calibration checks are not required by the DOT). One respondent reported that the horizontal tolerance is 0.03 foot and vertical tolerance is 0.065. 4) All contractors reported that the contractor conducts the spot checks, while DOT construction staff reported that both the contractor and the engineer conduct the spot checks. 5) Contractors reported that contractor conducts the final check, while DOT construction staff reported that either Contractor (witnessed by the engineer) or engineer conducts the final check. One respondent reported that the DOT has the final decision about final acceptance check. About 30% of the respondents reported that the vertical tolerance is 0.05 foot and horizontal tolerance is 0.04 foot. The majority of the rest of the respondents were not clear about the tolerances, or reported that tolerance depends on pay item and varies on material.
Training	1) The majority of respondents reported that training on the use of GPS system to both contractor and DOT staff is not required, but contractors provide training to contractor staff voluntarily. 2) When training to contractor staff is required, all respondents reported that multiple trainings are provided by the contractor, with the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT. 3) When training to DOT staff is required, all respondents reported that one training is provided by the contractor, prior to beginning the use of the GPS equipment.
Tolerances and specifications	The majority of respondents reported that the DOT specifications require that construction surveying/staking using GPS equipment has to achieve the same level of accuracy/tolerance compared with conventional staking.

1. Where is automated machine guidance (AMG) allowed to be used?

Table 19: Survey results – Where is AMG allowed to be used

	DOT-Construction	Contractor	Total
Rough grading	11 (79%)	4 (100%)	15 (83%)
Finish grading	12 (86%)	4 (100%)	16 (89%)
Paving	8 (57%)	4 (100%)	12 (67%)
Curb	8 (57%)	3 (75%)	11 (61%)
Pipe and drainage	6 (43%)	3 (75%)	11 (61%)
Structure	3 (21%)	3 (75%)	9 (50%)
Concrete barrier	6 (43%)	3 (75%)	6 (33%)
Resurfacing	7 (50%)	3 (75%)	9 (50%)
Other	2 (14%)	0	7 (39%)

2. Where does the DOT plan to use AMG besides the current use(s)?

Table 20: Survey results – Where does the DOT plan to use AMG

	DOT-Construction
Rough grading	3 (21%)
Finish grading	3 (21%)
Paving	3 (21%)
Curb	2 (14%)
Pipe and drainage	3 (21%)
Structure	3 (21%)
Concrete barrier	1 (7%)
Resurfacing	1 (7%)
Do not know	4 (29%)
Other	4 (29%)

3. Where does the Contractor plan to use AMG besides the current use(s)?

Table 21: Survey results – Where does the Contractor plan to use AMG

	Contractor
Rough grading	1 (25%)
Finish grading	1 (25%)
Paving	0
Curb	0
Pipe and drainage	2 (50%)
Structure	1 (25%)
Concrete barrier	0
Resurfacing	1 (25%)
Do not know	1 (25%)
Other	1 (25%)

4. Does the DOT require conventional staking, when conducting construction surveying using GPS equipment?

Table 22: Survey results – Conventional staking required when conducting construction surveying using GPS equipment

	DOT-Construction	Contractor	Total
Yes	10 (71%)	3 (75%)	13 (72%)
No	1 (8%)	1 (25%)	2 (11%)
Do not know	3 (21%)	0	3 (17%)

5. If yes to Question 4, indicate your level of agreement with the following statement: The DOT is requiring too much traditional staking, when conducting construction surveying using GPS equipment.

Table 23: Survey Results – Opinion on conventional staking (required too much) when conducting construction surveying using GPS equipment

	DOT-Construction	Contractor	Total
1: Very disagree	1 (10%)	0 (0%)	1 (8%)
2: Disagree	3 (30%)	0 (0%)	3 (23%)
3: Somewhat disagree	1 (10%)	1 (25%)	2 (15%)
4: Somewhat agree	4 (40%)	0	4 (31%)
5: Agree	1 (10%)	2 (50%)	3 (23%)
6: Very agree	0	0	0

6. Based on your agency's experience in the past year, how many highway construction surveys are using AMG?

Table 24: Survey results – Extent of use of AMG in the past year*

	DOT-Construction	Contractor	Total
None	0	0	0
Less than 25%	3 (21%)	0	3 (17%)
25% to 50%	1 (7%)	0	1 (6%)
50% to 75%	4 (29%)	1 (25%)	5 (28%)
More than 75%	3 (21%)	2 (50%)	5 (28%)
All	2 (14%)	1 (25%)	3 (17%)
Do not know	1 (7%)	0	1 (6%)

*The percentages in a certain column may not sum up to 100% due to rounding.

7. Which of the following benefits did your agency experience when conducting construction surveying using GPS equipment for highway projects?

Table 25: Survey results – Benefits of using GPS equipment in construction surveying

	DOT-Construction	Contractor	Total
Reduced staking	10 (71%)	3 (75%)	13 (72%)
Stakeless	6 (43%)	3 (75%)	9 (50%)
More efficient processes	12 (86%)	3 (75%)	15 (83%)
Improved accuracy	6 (43%)	2 (50%)	8 (44%)
Less experienced staff required	3 (21%)	0	3 (17%)
Lower bids from contractors	6 (43%)	1 (25%)	7 (39%)
Safer working environment	6 (43%)	3 (75%)	9 (50%)
Other	1 (7%)	3 (75%)	4 (22%)

8. Does the DOT provide a list of approved GPS equipment?

Table 26: Survey results – Does the DOT provide a list of approved GPS equipment

	DOT-Construction	Contractor	Total
Yes	0	0	0
No	13 (93%)	4 (100%)	17 (94%)
Do not know	1 (7%)	0	1 (6%)

9. What is the vendor the GPS equipment that you use?

Table 27: Survey results – Vendor of GPS equipment

	DOT-Construction	Contractor	Total
Trimble	6 (43%)	1 (25%)	7 (39%)
Topcon	1 (7%)	2 (50%)	3 (17%)
Do not know	2 (14%)	0	2 (11%)
Other	5 (36%)	1 (25%)	6 (33%)

10. Do the DOT specifications require that construction surveying/staking using GPS equipment have to achieve the same level of accuracy/tolerance compared with conventional staking?

Table 28: Survey results – Level of accuracy/tolerance when GPS is used (same compared to conventional staking)

	DOT-Construction	Contractor	Total
Yes	10 (71%)	3 (75%)	13 (72%)
No	2 (14%)	0	2 (11%)
Do not know	2 (14%)	1 (25%)	3 (17%)

11. What is the specified frequency to maintain the GPS equipment?

Table 29: Survey results – Specified frequency of equipment maintenance*

	DOT-Construction	Contractor	Total
Not specified	8 (57%)	4 (100%)	12 (67%)
Every six months	0	0	0
At the beginning of each survey	0	0	0 (0%)
Weekly during the survey	1 (7%)	0	1 (6%)
Do not know	4 (29%)	0	4 (22%)
Other	1 (7%)	0	1 (6%)

*The percentages in a certain column may not sum up to 100% due to rounding.

12. If you answered "Not specified" to Question 11, how frequent do you maintain the GPS equipment?

Table 30: Survey results – Actual frequency of equipment maintenance when not specified

	DOT-Construction	Contractor	Total
Not regularly	4 (50%)	0	4 (33%)
Every six months	0	0	0
At the beginning of each survey	0	2 (50%)	2 (17%)
Weekly during the survey	0	0	0
Do not know	2 (25%)	1 (25%)	3 (25%)
Other	2 (25%)	1 (25%)	3 (25%)

13. What GPS equipment components are maintained?

Table 31: Survey results – Equipment components that are maintained

	DOT-Construction	Contractor
Tripods	1 (7%)	3 (75%)
Fixed height tripods	2 (14%)	2 (50%)
Rods	4 (29%)	2 (50%)
Cables	1 (7%)	3 (75%)
Receivers and receiver antennas	4 (29%)	3 (75%)
Handhelds	2 (14%)	4 (100%)
Do not know	6 (43%)	0
Other	3 (21%)	0

14. What types of GPS equipment checks are specified/required?

Table 32: Survey results – Specified/required equipment checks

	DOT-Construction	DOT-Surveying	Contractor	Total
None	2 (14%)	4 (40%)	1 (25%)	7 (25%)
Federal published calibration baseline check by NGS	1 (7%)	3 (30%)	0	4 (14%)
Zero baseline check of antenna, receiver, and cables according to manufacturer	0 (0%)	1 (10%)	0	1 (4%)
Primary control check	5 (36%)	4 (40%)	1 (25%)	10 (36%)
Do not know	4 (29%)	1 (10%)	2 (50%)	7 (25%)
Other	2 (14%)	1 (10%)	0	3 (11%)

15. If you answered "None" to Question 14, what types of GPS equipment checks do you perform?

Table 33: Survey results – Performed equipment checks when not specified

	DOT-Construction	DOT-Surveying	Contractor	Total
None	1 (50%)	1 (25%)	0	2 (29%)
Federal published calibration baseline check by NGS	0	1 (25%)	0	1 (14%)
Zero baseline check of antenna, receiver, and cables according to manufacturer	0	0	0	0
Primary control check	1 (50%)	1 (25%)	1 (100%)	3 (43%)
Do not know	0	1 (25%)	0	1 (14%)
Other	0	0	0	0

16. What is the frequency of the GPS equipment checks you perform?

Table 34: Survey results – Actual frequency of equipment checks

	DOT-Construction	DOT-Surveying	Contractor	Total
At beginning and end of survey	3 (21%)	5 (50%)	2 (50%)	10 (36%)
Every six months	1 (7%)	4 (40%)	0	5 (18%)
By request of Engineer or Contractor	0	1 (10%)	0	1 (4%)
Do not know	7 (50%)	0	1 (25%)	8 (29%)
Other	3 (21%)	2 (20%)	1 (25%)	6 (21%)

17. Is the Contractor required to provide training on the use of Contractor's GPS system to the Contractor staff?

Table 35: Survey results – Contractor required to provide training to Contractor staff

	DOT-Construction	Contractor	Total
Yes	1 (8%)	1 (25%)	2 (11%)
No	10 (71%)	3 (75%)	13 (72%)
Do not know	3 (21%)	0	3 (17%)

18. If yes to Question 17, what is the specified time and frequency of the training?

Table 36: Survey results – Time and frequency of training to contractor staff when required

	DOT-Construction	Contractor	Total
One training, prior to beginning the use of the GPS equipment	0	0	0
Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT	1 (100%)	1 (100%)	2 (100%)
other	0	0	0

19. If no to Question 17, does the Contractor voluntarily provide training on the use of Contractor's GPS system to the Contractor staff?

Table 37: Survey results – Voluntary training provided to contractor staff

	DOT-Construction	Contractor	Total
Yes	4 (40%)	3 (100%)	7 (54%)
No	3 (30%)	0	3 (23%)
Do not know	3 (30%)	0	3 (23%)

20. If yes to Question 19, what is the time and frequency of the training?

Table 38: Survey results – Time and frequency of training to contractor staff when voluntarily provided

	DOT-Construction	Contractor	Total
One training, prior to beginning the use of the GPS equipment	1 (25%)	0	1 (14%)
Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT	1 (25%)	2 (67%)	3 (43%)
Do not know	2 (50%)	1 (33%)	3 (43%)

21. Is the Contractor required to provide training on the use of Contractor's GPS system to the DOT staff?

Table 39: Survey results – Contractor required to provide training to DOT staff

	DOT-Construction	Contractor	Total
Yes	2 (14%)	0	2 (11%)
No	9 (64%)	4 (100%)	13 (72%)
Do not know	3 (22%)	0	3 (17%)

22. If yes to Question 21, what is the specified time and frequency of the training?

Table 40: Survey results – Time and frequency of training by contractor to DOT staff when required

	DOT-Construction	Contractor	Total
One training, prior to beginning the use of the GPS equipment	2 (100%)	0	2 (100%)
Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT	0	0	0
Other	0	0	0

23. If no to Question 21, does Contractor voluntarily provide training on the use of Contractor's GPS system to the DOT staff?

Table 41: Survey results – Voluntary training provided by contractor to DOT staff

	DOT-Construction	Contractor	Total
Yes	1 (11%)	2 (50%)	3 (23%)
No	7 (78%)	2 (50%)	9 (69%)
Do not know	1 (11%)	0	1 (8%)

24. If yes to Question 23, what is the time and frequency of the training?

Table 42: Survey results – Time and frequency of training by contractor to DOT staff when voluntarily provided

	DOT-Construction	Contractor	Total
One training, prior to beginning the use of the GPS equipment	1 (100%)	0	1 (33%)
Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT	0	1 (50%)	1 (33%)
Other	0	1 (50%)	1 (33%)

25. Is the Contactor required to perform daily site calibration checks?

Table 43: Survey results – Required daily site calibration checks

	DOT-Construction	Contractor	Total
Yes	3 (21%)	1 (25%)	4 (22%)
No	5 (36%)	3 (75%)	8 (44%)
Do not know	6 (43%)	0	6 (35%)

26. If no to Question 25, are daily site calibration checks voluntarily performed by the Contractor?

Table 44: Survey results – Voluntary daily site calibration checks

	DOT-Construction	Contractor	Total
Yes	1 (20%)	3 (100%)	4 (50%)
No	1 (20%)	0	1 (12%)
Do not know	3 (60%)	0	3 (38%)

27. What is the horizontal tolerance for daily site calibration checks?

Only two respondents provided answer to this question. The answers are as follows:

a) Daily site calibration checks are performed on two or more control points with the horizontal tolerance of +/- 0.03 ft.

b) +/- 0.033ft

28. What is the vertical tolerance for daily site calibration checks?

Only one respondent provided answer to this question. The answer is +/- 0.065 ft.

29. Who is conducting the spot checks?

Table 45: Survey results – Party conducting spot checks

	DOT-Construction	Contractor	Total
Contractor	2 (14%)	4 (100%)	6 (33%)
Engineer	2 (14%)	0	2 (11%)
Both	6 (43%)	0	6 (33%)
Do not know	4 (29%)	0	4 (23%)

30. Who is responsible to perform the final check?

Table 46: Survey results – Party responsible for performing the final check

	DOT-Construction	Contractor	Total
Contractor, witnessed by Engineer	3 (21%)	3 (75%)	6 (33%)
Engineer	4 (29%)	0	4 (22%)
Do not know	4 (29%)	1 (25%)	5 (28%)
Other	3 (21%)	0	3 (17%)

31. Vertical tolerance for the final check

Table 47: Survey results – Vertical tolerance of the final check

	DOT-Construction	Contractor	Total
0.05 foot	3 (21%)	2 (50%)	5 (28%)
0.1 foot	1 (7%)	0	1 (6%)
Do not know	5 (36%)	2 (50%)	7 (38%)
Other	5 (36%)	0	5 (28%)

32. Horizontal tolerance for the final check

Table 48: Survey results – Horizontal tolerance of the final check

	DOT-Construction	Contractor	Total
0.04 foot	4 (29%)	2 (50%)	6 (33%)
0.1 foot	1 (7%)	0	1 (6%)
Do not know	5 (35%)	2 (50%)	7 (38%)
Other	4 (29%)	0	4 (23%)

33. How many consecutive randomly selected checking points should be within the tolerance to ensure conformance to the plan?

Table 49: Survey results – Number of randomly selected checking points

	DOT-Construction	Contractor	Total
Not required	5 (36%)	1 (25%)	6 (33%)
4 of 5 randomly selected checking points should be within the tolerance	2 (14%)	1 (25%)	3 (17%)
Do not know	5 (36%)	2 (50%)	7 (39%)
Other	2 (14%)	0	2 (11%)

2.3.3.4 Conventional Staking When Automated Machine Guidance (AMG) Is Used

This section of the survey collected respondent feedback on conventional staking when AMG is used. Table 50 provides a summary of the main findings. All questions and a summary of their response results are shown below (see Table 51-Table 64).

Table 50: Summary of survey results of Section 5 [Conventional Staking When Automated Machine Guidance (AMG) Is Used]

	Responses
Staking specifications	The majority of the respondents reported that the DOT has no written specifications for conventional staking when conducting construction surveying using GPS equipment, and agreed that it is necessary to have such written specifications. The reported documents that include such specifications are listed below, with links (see Question 3).
Staking procedures	About half of the respondents reported that there is no written staking procedures when conducting construction surveying using GPS equipment, and the majority agreed that it is necessary to have such written procedures. The reported documents that include such procedures are listed below, with links (see Question 6).
Staking required or not	About half of respondents reported that subgrade, pavement, and slope staking are still required by the DOT when conducting construction surveying using GPS equipment, while most of the others reported an opposite case. The majority of respondents reported that structure layout staking is still required by the DOT.
Electronic devices used in staking	1) The majority of respondents reported that electronic devices are used to collect and compute positions and distances when staking, and that to understand how to operate electronic devices or software, they refer to the manufacturer's manual. A few respondents reported the construction manual and the company guidance as references. 2) The majority of respondents reported that electronic devices with digital models and the actual ground elevation are used to compute and show the cut/fill of slope. 3) The most reported approach to measure the ground is at each grade break. Some respondents reported that ground measurement intervals vary and are as needed. One respondent reported except at grade breaks, the ground is measured at random points too. Some respondents reported that the measurement should not stop until the profile grade line for the station is reached and others reported that the measurement should stop when the difference between the measured ground elevation and the elevation computed is less than the tolerance.

1. Does the DOT have specifications for conventional staking when conducting construction surveying using GPS equipment (such as tolerances and stake spacing) written in a construction manual or other guidance documents?

Table 51: Survey results – Specifications for conventional staking when GPS guided machines are used

	DOT-Construction	Contractor	Total
Yes	5 (45%)	0	5 (33%)
No	6 (55%)	3 (75%)	9 (60%)
Do not know	0	1 (25%)	1 (7%)

2. Indicate your level of agreement with the following statement: It is necessary to have written specification for conventional staking when conducting construction surveying using GPS equipment (such as tolerances and stake spacing) included in a construction manual or other guidance documents.

Table 52: Survey results – Opinion towards having written specifications for conventional staking when conducting construction surveying using GPS equipment

	DOT-Construction	Contractor	Total
1: Very disagree	0	0	0
2: Disagree	0	0	0
3: Somewhat disagree	0	1 (25%)	1 (7%)
4: Somewhat agree	0	0	0
5: Agree	6 (55%)	3 (75%)	9 (60%)
6: Very agree	3 (27%)	0	3 (20%)
Do not know	2 (18%)	0	2 (13%)

3. Please provide the link to the manual or document that includes the DOT specifications for conventional staking when conducting construction surveying using GPS equipment.

   The following six relevant documents that include the DOT specifications for conventional staking were reported:

   - Illinois DOT Survey manual http://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Design-and-Environment/Survey%20Manual.pdf
   - West Virginia DOT Specifications http://www.transportation.wv.gov/highways/engineering/Pages/Specifications.aspx
   - Kentucky Transportation Cabinet Earthwork Specification Section 201 Staking http://transportation.ky.gov/Construction/Standard%20amd%20Supplemental%20Specifications/200%20Earthwork%2012.pdf

- Colorado DOT Survey Manual https://www.codot.gov/business/manuals/survey
- Oregon DOT Construction Surveying Manual for Contractors http://www.oregon.gov/ODOT/HWY/GEOMETRONICS/docs/ConstrSurvManForContr.pdf
- North Carolina DOT Manual for Construction Layout https://connect.ncdot.gov/projects/construction/Construction%20%20Stakeout%20Manual/Construction%20Stakeout%20Manual.pdf

4. Are the staking procedures when conducting construction surveying using GPS equipment written in a construction manual or other guidance documents?

Table 53: Survey results – Written procedures for staking when conducting construction surveying using GPS equipment

	DOT-Construction	Contractor	Total
Yes	5 (45%)	1 (25%)	6 (40%)
No	4 (36%)	3 (75%)	7 (47%)
Do not know	2 (18%)	0	2 (13%)

5. Indicate your level of agreement with the following statement: It is necessary to have written staking procedures when conducting construction surveying using GPS equipment included in a construction manual or other guidance documents.

Table 54: Survey results – Opinion towards having written procedures for staking when conducting construction surveying using GPS equipment

	DOT-Construction	Contractor	Total
1: Very disagree	0	0	0
2: Disagree	0	0	0
3: Somewhat disagree	1 (9%)	1 (25%)	2 (13%)
4: Somewhat agree	1 (9%)	0	1 (7%)
5: Agree	3 (27%)	3 (75%)	6 (40%)
6: Very agree	5 (46%)	0	5 (33%)
Do not know	1 (9%)	0	1 (7%)

6. Please provide the link to the manual or document that includes the staking procedures when conducting construction surveying using GPS equipment.

   The following five relevant documents that include the DOT's procedures for staking were reported:

- West Virginia DOT Specifications http://www.transportation.wv.gov/highways/engineering/Pages/Specifications.aspx

- Kentucky Transportation Cabinet Earthwork Specification Section 201 Staking http://transportation.ky.gov/Construction/Standard%20amd%20Supplemental%20Specifications/200%20Earthwork%2012.pdf
- Colorado DOT Survey Manual https://www.codot.gov/business/manuals/survey
- Oregon DOT Construction Surveying Manual for Contractors http://www.oregon.gov/ODOT/HWY/GEOMETRONICS/docs/ConstrSurvManForContr.pdf
- North Carolina DOT Manual for Construction Layout https://connect.ncdot.gov/projects/construction/Construction%20%20Stakeout%20Manual/Construction%20Stakeout%20Manual.pdf

7. Is subgrade staking still required when conducting construction surveying using GPS equipment?

Table 55: Survey results – Whether subgrade staking is still required when conducting construction surveying using GPS equipment

	DOT-Construction	Contractor	Total
Yes	5 (46%)	2 (50%)	7 (47%)
No	4 (36%)	2 (50%)	6 (40%)
Do not know	2 (18%)	0	2 (13%)

8. Is pavement staking still required when conducting construction surveying using GPS equipment?

Table 56: Survey results – Whether pavement staking is still required when conducting construction surveying using GPS equipment

	DOT-Construction	Contractor	Total
Yes	4 (36%)	3 (75%)	7 (47%)
No	5 (46%)	1 (25%)	6 (40%)
Do not know	2 (18%)	0	2 (13%)

9. Is slope staking still required when conducting construction surveying using GPS equipment?

Table 57: Survey results – Whether slope staking is still required when conducting construction surveying using GPS equipment

	DOT-Construction	Contractor	Total
Yes	5 (46%)	2 (50%)	7 (47%)
No	4 (36%)	2 (50%)	6 (40%)
Do not know	2 (18%)	0	2 (13%)

10. Is structure layout staking still required when conducting construction surveying using GPS equipment?

Table 58: Survey results – Whether structure layout staking is still required when conducting construction surveying using GPS equipment

	DOT-Construction	Contractor	Total
Yes	6 (55%)	3 (75%)	9 (60%)
No	2 (18%)	1 (25%)	3 (20%)
Do not know	3 (27%)	0	3 (20%)

11. Are electronic devices used to collect and compute positions and distances when staking?

Table 59: Survey results – Whether electronic devices are used to compute positions and distances when staking

	DOT-Construction	Contractor	Total
Yes	6 (56%)	4 (100%)	10 (67%)
No	1 (9%)	0	1 (6%)
Do not know	4 (36%)	0	4 (27%)

12. Which document should the Contractor refer to, in order to understand how to operate electronic devices or software used to gather, store, and/or calculate position data?

Table 60: Survey results – Documents contractors should refer to for understanding how to use electronic devices or software for position data

	DOT-Construction	Contractor	Total
Manufacturer’s manual	9 (82%)	3 (75%)	12 (80%)
Construction manual	1 (9%)	1 (25%)	2 (13%)
Do not know	0	1 (25%)	1 (7%)
Other	1 (9%)	0	1 (7%)

13. When the slope is not a “catch” and the slope stake is not on a constant cut/fill line, is the cut/fill shown on the stake computed using the digital models and the actual ground elevation with the help of electronic devices?

Table 61: Survey results – Whether electronic devices are used to facilitate slope staking

	DOT-Construction	Contractor	Total
Yes	6 (55%)	3 (75%)	9 (60%)
No	0	0	0
Do not know	5 (45%)	1 (25%)	6 (40%)

14. How is the ground measured?

Table 62: Survey results – Ground measurement interval

	DOT-Construction	Contractor	Total
At each grade break	3 (27%)	3 (75%)	6 (40%)
Every 25 foot	1 (9%)	0	1 (7%)
Do not know	3 (27%)	1 (25%)	4 (27%)
Other	4 (36%)	0	4 (27%)

Other responses include:

a) Distance is as needed

b) At grade breaks and random points

c) Distance Varies

15. When is the measurement stopped?

Table 63: Survey results – Position to stop ground measurement

	DOT-Construction	Contractor	Total
Until the profile grade line for the station is reached	2 (18%)	1 (25%)	3 (20%)
The difference between the measured ground elevation and the elevation computed is less than the tolerance	3 (27%)	1 (25%)	4 (27%)
Do not know	4 (37%)	1 (25%)	5 (33%)
Other	2 (18%)	1 (25%)	3 (20%)

16. The respondents provided no meaningful answers to the question asking about the horizontal tolerance used to determine the stop of the measurement.

17. The respondents provided no meaningful answers to the questions asking about the vertical tolerance used to determine the stop of the measurement.

18. Is the stake/field book automatically generated by the electronic devices?

Table 64: Survey results – Whether electronic devices are used to generate stake/field book automatically

	DOT-Construction	Contractor	Total
Yes	2 (18%)	2 (50%)	4 (26%)
No	3 (27%)	1 (25%)	4 (26%)
Do not know	6 (55%)	1 (25%)	7 (48%)

2.3.3.5 Digital Models and Electronic Data Exchange Practices

This section of the survey collected respondent feedback on digital models and electronic data exchange practices. Table 65 provides a summary of the main findings. All questions and a summary of their response results are shown below (see Table 66-Table 92).

Table 65: Summary of survey results of Section 6 (Digital Models and Electronic Data Exchange Practices)

	Responses
Use of digital models	1) Half of the respondents reported the use of digital models in some, but less than 25%, of the projects during the past year. 2) Respondents reported that MicroStation, GEOPAK, Trimble Business Center, InRoads, AutoCAD Civil 3D, and AutoCAD Map 3D are utilized in highway construction surveys that are using digital modes. The majority of respondents reported satisfaction with those applications. Some dissatisfaction was reported for MicroStation and GEOPAK.
Benefits	1) The majority of respondents reported the following benefits for the use of digital models in construction surveying of highways: simulate and visualize the project more accurately, deliver models of higher quality to Contractor for automated machine guidance, combine multiple types of data such as CAD and geospatial data, standardize the as-built data collection process, and improve access to highway project information, and improve bid accuracy. 2) Other reported benefits include: more quickly perform quantity takeoffs, facilitate information exchange among stakeholders, streamline the different project phases such as design and construction, and decrease the risk of redoing. 3) Different ranges of time savings (from less than 25% to over 50%) were reported. However, other respondents reported that the use of digital models does not save or add time, but results in spending more on earlier stages and less on later stages. The main activities reported as associated with time savings are: grading, earth work and excavation, and site calibration and check. Other activities reported as associated with time savings are: project control, preparation of deliverables, paving, and pipe and drainage construction. 4) Different ranges of cost savings ('less than 10%', and '10% but less than 25%' of project cost) were reported. The main activities reported as associated with cost savings are: staking for grading, staking slope, and preparation of survey data deliverables. Other activities reported as associated with cost savings are: automated machine guidance, staking for paving, staking base, project control surveying, staking drainage and pipeline, staking curb and gutter, and staking concrete barrier

Table 65 (Cont'd): Summary of survey results of Section 6 (Digital Models and Electronic Data Exchange Practices)

	Responses
Barriers and difficulties	1) The main barriers or challenges to successful implementation (when digital models are used in construction surveys) that were reported are: DOT lack of experience, contractor lack of experience, and procedural issues. 2) Other reported barriers or challenges are: training is difficult, cost issues, lack of DOT specifications, inefficient communication among stakeholders, software cannot fulfill certain tasks, and software getting updated frequently. 3) Other barriers and difficulties that were reported include: a) Specifications and workflows are under development. b) Many projects do not have 3D models developed in design due to type of project and cost.
Success factors	The factors that were ranked as most important for successful implementation are: cooperation of DOT designers, clear and comprehensive contract specifications, end-user training (DOT), and experience with software (DOT). In addition, half of respondents reported clear and comprehensive description of workflow and responsibilities, experience with the software (contractor), and cooperation of surveyors. Other reported factors are: end-user training (contractor), hardware/software vendor support, and equipment sharing between DOT and contractor.
Responsibility	1) The majority of respondents reported that the contractor is responsible for providing, updating, and revising the digital models used for AMG. 2) The majority of respondents reported that Contractor is responsible for any errors or omissions in the digital models, or any discrepancies between the design files provided by the DOT and the digital model generated by the contractor. 3) Half of the respondents reported that the digital models generated by the contractor are not allowed to be different from the design files provided by the DOT, while 30% of the respondents reported the opposite case.
Electronic data	1) The majority of respondents reported that cross section and alignment data files are provided by the DOT. Half of the respondents reported that background graphics files with roadway and drainage features such as centerlines, edges, and hull of ponds are provided by the DOT. Other electronic data that were reported are: machine control surface model files, existing and design surface models, and GPS site calibration data.

Table 65 (Cont'd): Summary of survey results of Section 6 (Digital Models and Electronic Data Exchange Practices)

	Responses
Electronic data	2) The most reported time for DOT to provide electronic data to the contractor is at request by the Contractor. Other reported times include: after the Contractor wins the bid, before the preconstruction conference, during the bidding of the project as part the Reference Information Documents, or at advertising prior to bid letting. 3) The majority of respondents reported that the main uses of electronic data are to check quantities, build digital models, survey layout, and acquire accurate information about position, distance, etc. It was reported that DOT recognizes electronic data as an approach to show contractors the designer's intent, thus the electronic data are for information purpose only and are not contractual. 4) The majority of respondents reported satisfaction with providing electronic data to the contractor. The main benefits that were reported are: time savings, improved project quality, and fast identification of errors. Other reported benefits include: more accurate digital models, cost savings, and more accurate bids.
Deliverables	1) The main deliverables, which should be submitted by the contractor to the DOT, that were reported are: as-built construction plan, quality control (QC) plan, and survey control report. Other reported deliverables include: GPS/AMG work plan, report of post project benchmarks, and survey notebooks. 2) The main formats of the digital models that were reported are: DGN (MicroStation drawing files), LandXML, and TIN (Triangulated Irregular Network). 3) The majority of respondents reported that the GPS/AMG work plan should contain description of equipment and software, project secondary control, site calibration procedure, and equipment calibration and maintenance procedure. In addition, half of respondents reported definition of project boundaries and scope of work to be accomplished using GPS/AMG as part of the GPS/AMG work plan. 4) A few respondents reported that the GPS/AMG work plan is required to be submitted 30 days prior to primary field operation. One respondent reported 5 working days or on week prior to primary field operation.

1. Based on your agency's experience in the past year, how many highway construction surveys are using digital models?

Table 66: Survey results – Use of digital models in the past year*

	DOT-Design	Contractor	Total
None	0	0	0
Less than 25%	4 (67%)	1 (25%)	5 (50%)
25% to 50%	1 (17%)	1 (25%)	2 (20%)
50% to 75%	0	0	0
More than 75%	0	1 (25%)	1 (10%)
All	0	1 (25%)	1 (10%)
Do not know	1 (17%)	0	1 (10%)

*The percentages in a certain column may not sum up to 100% due to rounding.

2. Based on your agency's experience in the past year, how many of these highway construction surveys (that are using digital models) are using the following software for creating and updating the digital models?

Table 67: Survey results – Software used to create and update the digital models

	None	Less than 25%	25% to 50%	50% to 75%	More than 75%	All	Do not know
AutoCAD Civil 3D	5 (50%)	1 (10%)	0	0	0	1	3 (30%)
AutoCAD Map 3D	5 (50%)	1 (10%)	0	0	0	1	3 (30%)
Autodesk Navisworks Simulate	6 (60%)	0	0	0	0	0	4 (40%)
Bentley ConstrucSim	6 (60%)	0	0	0	0	0	4 (40%)
MicroStation	2 (20%)	0	1 (10%)	2 (20%)	0	4 (40%)	1 (10%)
GEOPAK	3 (30%)	1 (10%)	0	2 (20%)	0	2 (20%)	2 (20%)
InRoads	5 (50%)	0	0	0	0	2 (20%)	3 (30%)
Trimble Business Center	3 (30%)	1 (10%)	0	0	0	3 (30%)	3 (30%)

3. Indicate your level of satisfaction with the use of the following software in supporting construction surveying

Table 68: Survey results – Level of satisfaction with digital modeling software in supporting construction surveying

	1: Very dissatisfied	2: Dissatisfied	3: Somewhat dissatisfied	4: Somewhat satisfied	5: Satisfied	6: Very satisfied	Do not know
AutoCAD Civil 3D	0	0	0	1 (10%)	0	0	9 (90%)
AutoCAD Map 3D	0	0	0	1 (10%)	0	0	9 (90%)
Autodesk Navisworks Simulate	0	0	0	0	0	0	10 (100%)
Bentley ConstrucSim	0	0	0	0	0	0	10 (100%)
MicroStation	0	1 (10%)	1 (10%)	2 (20%)	3 (30%)	1 (10%)	3 (30%)
GEOPAK	0	1 (10%)	1 (10%)	1 (10%)	2 (20%)	3 (30%)	4 (40%)
InRoads	0	0	0	0	1 (10%)	1 (10%)	8 (80%)
Trimble Business Center	0	0	0	0	2 (20%)	1 (10%)	8 (80%)

4. Which of the following benefits are involved with the use of digital models in construction surveying for highway projects?

Table 69: Survey results – Benefits of using digital models in construction surveying of highway projects

	DOT-Design	Contractor	Total
Simulate and visualize the project more accurately	5 (83%)	4 (100%)	9 (90%)
More quickly perform quantity takeoffs	1 (17%)	4 (100%)	5 (50%)
Deliver models of higher quality to Contractor for automated machine guidance	3 (50%)	4 (100%)	7 (70%)
Combine multiple types of data such as CAD and geospatial data	3 (50%)	3 (75%)	6 (60%)
Standardize the as-built data collection process	2 (33%)	4 (100%)	6 (60%)
Improve access to highway project information	2 (33%)	4 (100%)	6 (60%)
Facilitate information exchange among stakeholders	1 (17%)	4 (100%)	5 (50%)
Streamline different phases such as design, construction, operation, and maintenance	2 (33%)	2 (50%)	4 (40%)
Decrease the risk of redoing	1 (17%)	2 (50%)	3 (30%)
Improve bid accuracy	2 (33%)	4 (100%)	6 (60%)
Do not know	0	0	0
Other	1 (17%)	0	1 (10%)

5. How does the use of digital models affect the project time?

Table 70: Survey results – Effect of using digital models in construction surveying of highway projects on project time

	DOT-Design	Contractor	Total
Does not have any effect on project time	0	1 (25%)	1 (10%)
Saves less than 25% of project time	0	2 (50%)	2 (20%)
Saves over 25% but less than 50% of project time	1 (17%)	1 (25%)	2 (20%)
Saves over 50% of project time	1 (17%)	0	1 (10%)
Adds project time	0	0	0
Does not save or add time, but spend more on earlier stages and less on later stages	2 (33%)	0 (0%)	2 (20%)
Does not save or add time, but spend less on earlier stages and more on later stages	0	0	0
Do not know	1 (17%)	0	1 (10%)
Other	1 (17%)	0	1 (10%)

6. If time savings are reported, which of the activities are associated with the most time saving?

Table 71: Survey results – Activities associated with time savings when using digital models in construction surveying of highway projects

	DOT-Design	Contractor	Total
Project control	2 (33%)	1 (25%)	3 (30%)
Grading	3 (50%)	3 (75%)	6 (60%)
Paving	1 (17%)	1 (25%)	2 (20%)
Earthwork and excavation	3 (50%)	3 (75%)	6 (60%)
Curb and gutter construction	0	0	0
Pipe and drainage construction	1 (17%)	1 (25%)	2 (20%)
Structure construction	0	0	0
Site calibration and check	3 (50%)	2 (50%)	5 (50%)
Preparation of deliverable	1 (17%)	2 (50%)	3 (30%)
Do not know	2 (33%)	1 (25%)	3 (30%)
Other	1 (17%)	1 (25%)	2 (20%)

7. How does the use of digital models affect the project cost?

Table 72: Survey results – Effect of using digital models in construction surveying of highway projects on project cost*

	DOT-Design	Contractor	Total
Does not have any effect on project cost	0	0	0
Saves less than 10% of project cost	1 (17%)	2 (50%)	3 (30%)
Saves over 10% of project time but less than 25% of project cost	1 (17%)	2 (50%)	3 (30%)
Saves over 25% of project cost	0	0	0
Adds project cost	0	0	0
Does not save or add cost, but spend more on earlier stages and less on later stages	0	0	0
Does not save or add cost, but spend less on earlier stages and more on later stages	0	0	0
Do not know	3 (50%)	0	3 (30%)
Other	1 (17%)	0	1 (10%)

*The percentages in a certain column may not sum up to 100% due to rounding.

8. If cost savings are reported, which of the activities are associated with the most cost saving?

Table 73: Survey results – Activities associated with cost savings when using digital models in construction surveying of highway projects

	DOT-Design	Contractor	Total
Project control surveying	1 (17%)	1 (25%)	2 (20%)
Automated machine guidance	1 (17%)	2 (50%)	3 (30%)
Staking for grading	2 (33%)	3 (75%)	5 (50%)
Staking for paving	1 (17%)	2 (50%)	3 (30%)
Staking structure	0	0	0
Staking drainage and pipeline	0	1 (25%)	1 (10%)
Staking slope	1 (17%)	3 (75%)	4 (40%)
Staking base	1 (17%)	2 (50%)	3 (30%)
Staking curb and gutter	1 (17%)	0	1 (10%)
Staking concrete barrier	1 (17%)	0	1 (10%)
Preparation of surveying data deliverables	2 (33%)	2 (50%)	4 (40%)
Construction staking bid item measurement	1 (17%)	1 (25%)	1 (10%)
Do not know	1 (17%)	2 (50%)	2 (20%)
Other	1 (17%)	0	3 (30%)

9. If digital models are used in construction surveys, which of the following are barriers or challenges to successful implementation?

Table 74: Survey results – Barriers and challenges to successful use of digital models in construction surveying of highway projects

	DOT-Design	Contractor	Total
Training is difficult	2 (33%)	1 (25%)	3 (30%)
Software get updated frequently	1 (17%)	0	1 (10%)
Software cannot fulfil certain tasks	0	1 (25%)	1 (10%)
Inefficient communication among stakeholders	1 (17%)	0	1 (10%)
DOT lack of experience	2 (33%)	3 (75%)	5 (50%)
Contractor lack of experience	1 (17%)	3 (75%)	4 (40%)
DOT lack of specifications	1 (17%)	1 (25%)	2 (20%)
Procedural issues	2 (33%)	2 (50%)	4 (40%)
Cost issues	0	2 (50%)	2 (20%)
Do not know	2 (33%)	0	2 (20%)
Other	1 (17%)	0	1 (10%)

10. If digital models are NOT used in construction surveys, what are the reasons why they are not used or what are the barriers to implementation?

Table 75: Survey results – Reasons that digital models are not used in construction surveying of highway projects

	DOT-Design	Contractor	Total
Training is difficult	1 (17%)	0 (0%)	1 (10%)
Software get updated frequently	0	0	0
Software cannot fulfil certain tasks	0	0	0
Upfront cost of software and hardware is high	1 (17%)	2 (50%)	3 (30%)
Cost of implementation is high	1 (17%)	1 (25%)	2 (20%)
Lack of specifications	0	1 (25%)	1 (10%)
Reluctance to learn new technology	0	2 (50%)	2 (20%)
Unawareness of benefits of new technology	0	2 (50%)	2 (20%)
Legal concerns about sharing data	0	1 (25%)	1 (10%)
Do not know	2 (33%)	0	2 (20%)
Other	2 (33%)	0	2 (20%)

11. In construction projects using digital models, which of the following factors contribute to the success of implementation of the mentioned software?

Table 76: Survey results – Factors contributing to successful use of digital modeling software in construction surveying

	DOT-Design	Contractor	Total
Cooperation of surveyors	3 (50%)	2 (50%)	5 (50%)
Cooperation of DOT designers	3 (50%)	4 (100%)	7 (70%)
Clear and comprehensive contract specifications	4 (67%)	2 (50%)	6 (60%)
End-user training (DOT)	2 (33%)	4 (100%)	6 (60%)
End-user training (Contractor)	1 (17%)	3 (75%)	4 (40%)
Equipment sharing between DOT and contractor	0	2 (50%)	2 (20%)
Hardware/software vendor support	2 (33%)	2 (50%)	4 (40%)
Experience with the software (DOT)	2 (33%)	4 (100%)	6 (60%)
Experience with the software (Contractor)	2 (33%)	3 (75%)	5 (50%)
Clear and comprehensive description of workflow and responsibilities	3 (50%)	2 (50%)	5 (50%)
Do not know	1 (17%)	0	1 (10%)
Other	0	0	0

12. Who is responsible for providing the digital models used for AMG?

Table 77: Survey results – Agency responsible for providing the digital models for AMG

	DOT-Design	Contractor	Total
DOT	1 (17%)	0	1 (10%)
Contractor	4 (67%)	3 (75%)	7 (70%)
Do not know	1 (17%)	1 (25%)	2 (20%)

13. Who is responsible for updating and revising the digital models used for AMG?

Table 78: Survey results – Agency responsible for updating and revising the digital models for AMG

	DOT-Design	Contractor	Total
DOT	1 (17%)	0	1 (10%)
Contractor	3 (50%)	3 (75%)	6 (60%)
Do not know	2 (33%)	1 (25%)	3 (30%)

14. Who is responsible for any errors or omissions in the digital models used for AMG?

Table 79: Survey results – Agency responsible for errors or omissions in the digital models used for AMG

	DOT-Design	Contractor	Total
DOT	1 (17%)	0	1 (10%)
Contractor	4 (67%)	3 (75%)	7 (70%)
Do not know	1 (17%)	1 (25%)	2 (20%)

15. Are the digital models generated by the contractor allowed to be different from the design files provided by the DOT?

Table 80: Survey results – Whether Contractor's digital models used for AMG can be different from DOT's design files

	DOT-Design	Contractor	Total
Yes	1 (17%)	2 (50%)	3 (30%)
No	3 (50%)	2 (50%)	5 (50%)
Do not know	2 (33%)	0	2 (20%)

16. Who is responsible for any discrepancies between the design files provided by DOT and the digital models generated by the contractor?

Table 81: Survey results – Agency responsible for discrepancies between the digital models used for AMG and the DOT's design files

	DOT-Design	Contractor	Total
DOT	1 (17%)	1 (25%)	2 (20%)
Contractor	4 (67%)	3 (75%)	7 (70%)
Do not know	1 (17%)	0	1 (10%)

17. What electronic data are provided by the DOT to the contractor?

Table 82: Survey results – Electronic data provided by the DOTs to the contractor when AMG is used

	DOT-Design	Contractor	Total
Cross section	3 (50%)	4 (100%)	7 (70%)
Machine control surface model files	2 (33%)	1 (25%)	3 (30%)
Alignment data files	5 (83%)	4 (100%)	9 (90%)
Background graphics file with roadway and drainage features such as centerlines, edges and hull of ponds	3 (50%)	2 (50%)	5 (50%)
Do not know	1 (17%)	0	1 (10%)
Other	1 (17%)	0	1 (10%)

18. When are the electronic data provided to the Contractor?

Table 83: Survey results – Time when electronic data are provided by the DOTs to the contractor when AMG is used*

	DOT-Design	Contractor	Total
After the contractor wins the bid	1 (17%)	0	1 (10%)
Before the preconstruction conference	0	1 (25%)	1 (10%)
After the preconstruction conference	0	0	0
At request by the contractor	1 (17%)	3 (75%)	4 (40%)
Do not know	0	0	0
Other	4 (67%)	0	4 (40%)

*The percentages in a certain column may not sum up to 100% due to rounding.

19. Indicate your level of satisfaction with providing electronic data to the Contractor during construction.

Table 84: Survey results – Level of satisfaction with providing electronic data to the contractor when AMG is used

	DOT-Design	Contractor	Total
1: Very dissatisfied	0	1 (25%)	1 (10%)
2: Dissatisfied	0	1 (25%)	1 (10%)
3: Somewhat dissatisfied	0	0	0
4: Somewhat satisfied	1 (17%)	1 (25%)	2 (20%)
5: Satisfied	2 (33%)	2 (50%)	4 (40%)
6: Very satisfied	1 (17%)	0	1 (10%)
Do not know	2 (33%)	0	2 (20%)

20. What are the main uses of existing electronic data provided by the DOT?

Table 85: Survey results – Main uses of electronic data provided by DOT

	DOT-Design	Contractor	Total
Check quantities	3 (50%)	3 (75%)	6 (60%)
Build digital model	2 (33%)	4 (100%)	6 (60%)
Layout survey	3 (50%)	3 (75%)	6 (60%)
Exchanging information with DOT personnel	1 (17%)	1 (25%)	2 (20%)
Acquire accurate information about position, distance, etc.	3 (50%)	3 (75%)	6 (60%)
Do not know	0	0	0
Other	2 (33%)	0	2 (20%)

21. What are the additional electronic files that should be provided by the DOT if NOT provided now?

Table 86: Survey results – Additional electronic data that should be provided by the DOT to the contractor when AMG is used

	DOT-Design	Contractor	Total
Cross section	0	0	0
Machine control surface model files	1 (17%)	1 (25%)	2 (20%)
Alignment data files	2 (33%)	0	2 (20%)
Background graphics file with roadway and drainage features such as centerlines, edges and hull of ponds	2 (33%)	1 (25%)	3 (30%)
Do not know	2 (33%)	1 (25%)	3 (30%)
Other	3 (50%)	2 (50%)	5 (50%)

22. Which of the following benefits are involved with providing electronic data to the Contractor?

Table 87: Survey results – Benefits of providing electronic data to the contractor when AMG is used

	DOT-Design	Contractor	Total
Cost savings	1 (17%)	3 (75%)	4 (40%)
Time savings	3 (50%)	3 (75%)	6 (60%)
Improved project quality	2 (33%)	4 (100%)	6 (60%)
More accurate bids	2 (33%)	2 (50%)	4 (40%)
Fast identification of errors	2 (33%)	4 (100%)	6 (60%)
More accurate digital models	2 (33%)	3 (75%)	5 (50%)
Do not know	1 (17%)	0	1 (10%)
Other	2 (33%)	0	2 (20%)

23. How do additional electronic data affect the workload of the DOT?

Table 88: Survey results – Effect of additional electronic data on the workload of the DOTs for construction surveying*

	DOT-Design
No effect	0
Decreases the workload	0
Increases less than 25% of the workload	2 (33%)
Increases about or over 25% of the workload	0
Especially increases the workload during preparation of data provided to Contractor	2 (33%)
Especially increases the workload during construction stage due to additional quality control	0
Do not know	0
Other	2 (33%)

*The percentages in a certain column may not sum up to 100% due to rounding.

24. What are the specified deliverables that should be submitted by the Contractor to the DOT?

Table 89: Survey results – Deliverables submitted by contractors to DOTs when AMG is used

	DOT-Design	Contractor	Total
GPS/AMG work plan	2 (33%)	1 (25%)	3 (30%)
Survey control report	2 (33%)	2 (50%)	4 (40%)
Quality control (QC) plan	3 (50%)	2 (50%)	5 (50%)
Report of post project benchmarks	2 (33%)	1 (25%)	3 (30%)
As-built construction plan	3 (50%)	3 (75%)	6 (60%)
Survey notebooks	2 (33%)	0	2 (20%)
Do not know	1 (17%)	1 (25%)	2 (20%)
Other	1 (17%)	0	1 (10%)

25. What is the specified format of the digital models?

Table 90: Survey results – Specified format of digital models when AMG is used

	DOT-Design	Contractor	Total
ASCII	1 (17%)	1 (25%)	2 (20%)
LandXML	4 (67%)	1 (25%)	5 (50%)
ALG (InRoads geometry)	1 (17%)	0	1 (10%)
CSV (Comma-separated values)	0	0	0
DC (Data Collector file used in Trimble Survey Controller)	0	0	0
DGN (MicroStation drawing files)	6 (100%)	2 (50%)	8 (80%)
DWG (Native format of AutoCAD)	1 (17%)	0	1 (10%)
DXF (Data exchange file)	1 (17%)	0	1 (10%)
DTM (Digital terrain model)	3 (50%)	0	3 (30%)
GPK (GEOPAK coordinate geometry file)	1 (17%)	2 (50%)	3 (30%)
IRD (InRoads roadway definition file)	0	0	0
TIN (Triangulated Irregular Network)	3 (50%)	1 (25%)	4 (40%)
SHP (Shapefile spatial data format)	0	0	0
Do not know	0	0	0
Other	1 (17%)	4 (100%)	5 (50%)

26. What should the GPS/AMG work plan contain?

Table 91: Survey results – Content of GPS/AMG work plan

	DOT-Design	Contractor	Total
Description of equipment and software	4 (67%)	3 (75%)	7 (70%)
Contractor's experience	1 (17%)	1 (25%)	2 (20%)
Definition of project boundaries and scope of work to be accomplished using GPS/AMG	3 (50%)	2 (50%)	5 (50%)
Project secondary control	3 (50%)	3 (75%)	6 (60%)
Site calibration procedure	3 (50%)	3 (75%)	6 (60%)
Equipment calibration and maintenance procedure	3 (50%)	3 (75%)	6 (60%)
Do not know	1 (17%)	1 (25%)	2 (20%)
Other	2 (33%)	1 (25%)	3 (30%)

27. What is the specified time at which the GPS/AMG work plan should be submitted?

Table 92: Survey results – Time when GPS/AMG work plan should be submitted

	DOT-Design	Contractor	Total
5 working days or one week prior to primary field operation	0	1 (25%)	1 (10%)
5 working days or one week prior to preconstruction conference	0	0	0
30 days prior to primary field operation	2 (33%)	1 (25%)	3 (30%)
Do not know	3 (50%)	2 (50%)	5 (50%)
Other	1 (17%)	0 (0%)	1 (10%)

3 IDENTIFY POTENTIAL PRACTICES FOR EMPLOYMENT IN ILLINOIS

3.1 Typical Workflow for Projects Adopting AMG

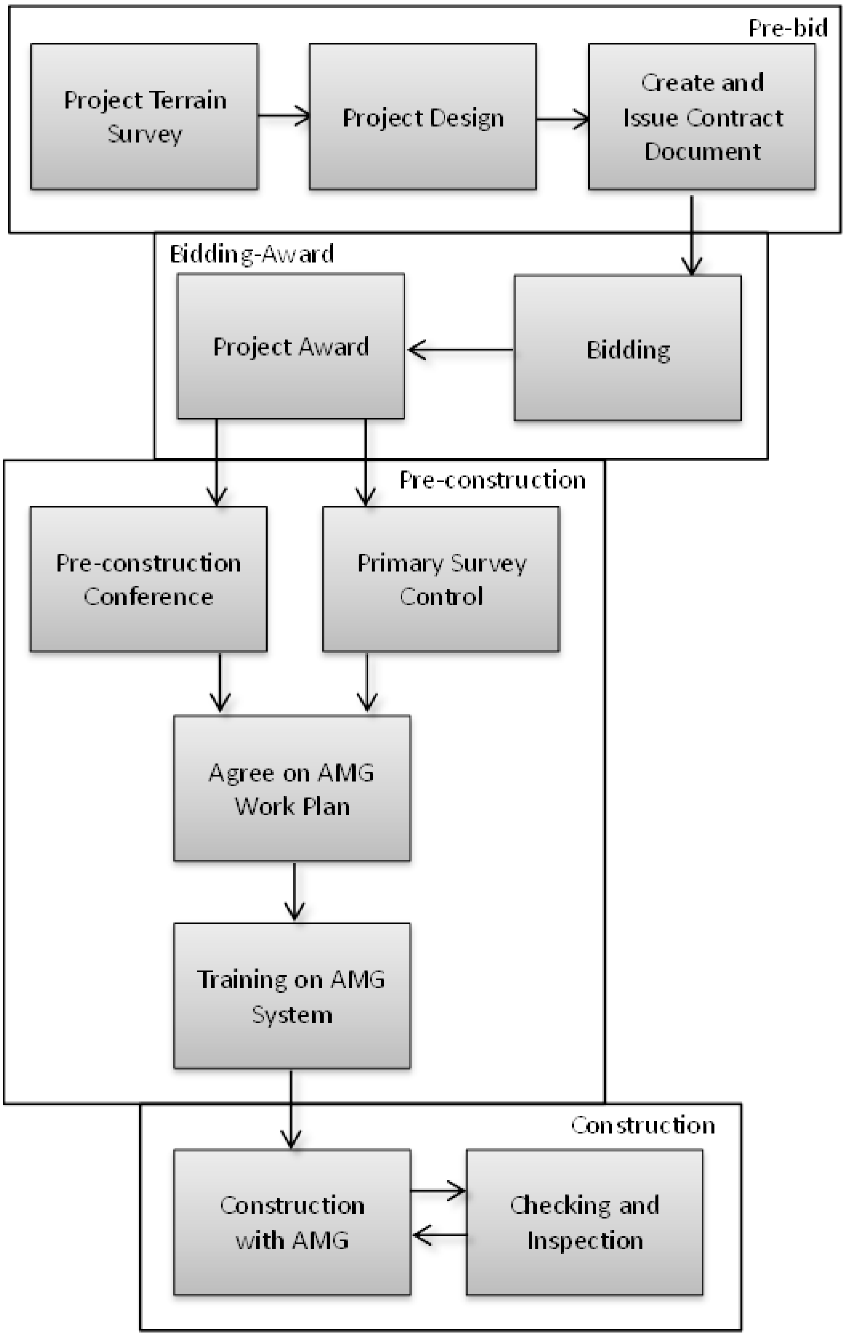


Figure 8: Typical AMG Project Workflow

As shown in Figure 8, there are four main phases for a project that adopts AMG: pre-bid, bidding, pre-construction, and construction. During the pre-bid phase, the decision has to be made about whether the project uses any types of AMG system or not. During the pre-construction phase, the decision has to be made about to what extent AMG will be used in the project, and how AMG will work under proper quality control. The phases are further decomposed into the following eleven steps:

1) Project terrain survey: collect and document original ground surface information and data, including location, traffic, environmental, and survey data. The data is collected using ground surveys, supported by CORS and RTK GPS.
2) Project design: develop the construction plan, possible alternatives, and drawings with specifications.
3) Contract document creation and issuance.
4) Receiving bids and project award: meanwhile, provide project information to the Contractor.
5) Primary survey control: provide primary project survey control. The result is provided to the contractor to set additional project control.
6) Preconstruction conference and agree on AMG work plan: The plan will be reviewed by the Department to ensure conformance to any contract or specification documents. And the Department and the Contractor will discuss any changes or alterations to the AMG plan and system.
7) Receive AMG training: determine the quantity and schedule of training (provided by the Contractor) on the utilized AMG system to the personnel specific to the project.
8) AMG construction, checking, and inspection: the Contractor should refer to the specifications and requirements for AMG construction. Some conventional staking might be required by the Department.

3.2 Identified Practices

The research team identified twelve primary potential practices, with details of how to implement them. Those practices will be the basis for developing the written procedures related to the use of modern technologies for construction staking of highway projects to be included in the IDOT's Construction Manual (Tasks 4, 5, and 6), including the next survey to IDOT employees (Task 4). The practices were developed following four key principles:

1) The practices cover the core issues of using AMG in construction surveying of highway projects, including: evaluation of construction methods, AMG equipment, AMG work plan, training, digital models, electronic files, project control, accuracy and tolerance, construction spot checks, site calibration and check, final check, and staking for grading and paving.
2) In describing the potential practices, some implementation details were covered (e.g., some roles and responsibilities by the Contractor and the Department). Other implementation details will be covered in Tasks 5 and 6.
3) These potential practices shall be read and interpreted together with other relevant documents including, but not limited to:
    a) IDOT Construction Manual Chapter 3, GPS.

   b) IDOT Construction Manual Chapter 10, Construction Surveys.
   c) IDOT CADD Roadway and Structure Project Deliverables Policy.
   d) IDOT Standard Specifications for Road and Bridge Construction.
4) The practices could be integrated in the AMG project workflow (see Section 3.1).

The following references were utilized when developing the written potential practices (***although not always cited at the specific locations in the report***):

- AASHTO, Quick Reference Guide for the Implementation of Automated Machine Guidance System (AMG).
- Kansas Department of Transportation (KDOT), 2015, KDOT's Construction Manual, Section 802, "Contractor Construction Staking of the Standard Specifications".
- Illinois Department of Transportation (IDOT), 2015, Survey Manual.
- Iowa Department of Transportation (IowaDOT), 2015, Standard Specification for Highway and Bridge Construction Section 2526.
- Mississippi Department of Transportation (MDOT), 2013, Special Provision No. 907-699-5 Construction Stakes.
- Pennsylvania Department of Transportation (PennDOT), 2016, Publication 408/2016 Specifications.
- Wisconsin Department of Transportation (WisDOT), 2016, Standard Specifications Section 650.
- WisDOT, 2015, Construction and Material Manual.

Some further decisions need to be made with respect to implementation details and terminology. Such decisions will be made in Task 4 and/or through TRP feedback. This applies to Sections 3.2.1 to 3.2.12. Examples of such implementation details and terminology issues are:

- When referring to the roles and responsibilities of IDOT, only mention the "Department" or specify a specific role (e.g., "Engineer", "Representative")
- Requirements for submissions by Contractor to IDOT are "for review" or "for approval"
- Specific times for submissions (e.g., "at least 5 days before the preconstruction conference", "at least 30 days prior to use", etc.)

3.2.1 Evaluation of Construction Methods

1) Construction surveying can be performed using conventional methods, automated machine guidance (AMG), or a combination of the two approaches. Not every project is suitable for AMG. AMG is, therefore, not mandatory.
2) The Department encourages the use of AMG if the project is suitable for AMG construction techniques. The machines can be guided by a GPS system, or a robotic total station system. Any use of AMG technology shall be approved by the Department during the pre-bid phase. Criteria from ASSHTO's AMG guidance could be used by the Department to evaluate the suitability of adopting such technology in a project. Generally, projects with the following characteristics will

be the best candidates for this technology: (ASSHTO, 2016)

a) large amounts of earthwork or paving,
b) new alignments,
c) a good Global Navigation Satellite System (GNSS),
d) a design based on an accurate Digital Terrain Modeling (DTM).

3) The evaluation should be completed by the Department before issuing the Contract Documents.

3.2.2 Automated Machine Guidance Equipment

1) The Contractor shall provide all AMG equipment. For the use of AMG equipment, the Contractor shall comply with the Contract Documents and all applicable standards and specifications. The Department will not provide a list of approved AMG equipment. The Contractor shall submit the equipment information (as part of the Automated Machine Guidance Work Plan) to the Engineer for approval, before or at the preconstruction meeting and at least 30 days prior to use. The equipment information shall include, but not limited to, the following: a description of the manufacturer, model, and software version of the AMG equipment.
2) The Contractor shall provide at least one GPS Rover to the Engineer for the review of the work, as needed. The GPS Rover should be ready for use prior to the start of the construction work. The GPS Rover or other hand-held devices should be compliant with the Contract Documents and any applicable standards and specifications.
3) The base station should be located at a stable, undisturbed place. The base station should provide radio signal coverage over the entire area constructed using the GPS-guided machine. If the base station cannot broadcast a signal that covers the entire site, provide adequate repeater radios or other communications. The Contractor shall submit the location of the base station to the Department for approval. The Contractor shall not relocate the base station without the approval of the Department. (PennDOT, 2016)
4) The Contractor is responsible for the storage and maintenance of the AMG equipment and all GPS Rovers. The GPS equipment shall be properly maintained at least once at the beginning of each surveying work. Equipment components to be maintained shall include, but not limit to: tripods, rods, cables, receivers and antennas, and handhelds. Equipment maintenance shall include, but not limited to: periodic manufacturer maintenance checks, cleaning, and calibration.

3.2.3 Automated Machine Guidance Work Plan

The Contractor shall submit a comprehensive written Automated Machine Guidance Work Plan to the Engineer for review before or at the preconstruction meeting and at least 30 days prior to use. The Automated Machine Guidance Work Plan shall include, but not limit to:

a) Definition of project boundaries and scope of work to be accomplished using the AMG equipment.

b) Description of the equipment including, but not limited to, a description of the manufacturer, model, and software version of the AMG equipment.
c) Project control report including, but not limited to, all contract control points, coordinates or elevation adopted, office procedures used for GPS technology, and the diagram of control points. When a GPS base station is on the site for checking or staking purposes, include the determined coordinate and elevation of the base station and the datum differential from the existing control provided by the Department.
d) Detailed site calibration procedure including, but no limited to, map of the control points used for site calibration and control points used to check the site calibration, site calibration procedure, frequency of calibration, plan for what information will be documented, and plan for what information will be submitted to the Department. The procedure must show a complete record of equipment check results (MDOT, 2013).
e) AMG equipment calibration plan including, but not limited to, equipment to be calibrated, the frequency of calibration, the location and time of calibration, and the status of each calibrated equipment.
f) AMG equipment maintenance plan including, but not limited to, frequency of maintenance, components to be maintained, and procedure for maintenance.
g) A quality control plan including, but not limited to, frequency and type of checks to be performed, and procedures used to perform the checks. The control plan must show how the Department and the Contractor conduct the initial and daily calibration checks, spot checks, and final acceptance check.
h) Description of construction checks including, but not limited to, method and frequency of field verification checks.
i) Contractor's prior experience with the use of AMG systems.
j) Contractor's primary contact and alternate contact for AMG issues.

3.2.4 Training

1) The Contractor shall provide the Contractor staff with training on the use and operation of the AMG equipment prior to the start of any AMG work.
2) The Contractor shall provide the Department staff with training on the use and operation of the AMG system and the use of GPS Rovers or other hand-held devices prior to the start of any AMG work.
3) The Contractor shall provide more training upon the request of the Department.
4) The Contractor shall seek technical support from the equipment manufacturer or vendor, if/as necessary.

***In Task 4, more information needs to be gathered, in order to add more details on the following aspects and decide which option(s) to select for each aspect*:**

- Content of training (e.g., training on equipment, software, and electronic data)
- Specify which Department staff (e.g., staff conducting review of work)
- Training frequency (e.g., at least one training prior to the start of any AMG work)
- How many sessions per training (e.g., 2 sessions)

- Duration (hrs) of each session (e.g., 8 hours minimum)

3.2.5 Digital Models

1) The Contractor is responsible for developing the digital models used for AMG. The Contractor is responsible for converting the information on the plans and/or the design files provided by the Department into a format compatible with the Contractor's AMG system. The Contractor shall submit the digital models used for AMG to the Engineer for review at least 30 days prior to the start of the AMG work.
2) The Contractor shall notify the Department of any errors or discrepancies in the design files or Contract Documents provided by the Department.
3) The Contractor is responsible for updating and revising the digital models.
4) The Contactor is responsible for any errors or omissions in the digital models used for AMG.
5) If any of the devices used for review or inspection by the Department requires the digital model data, the Contractor is responsible for providing those data to the Department prior to the review or inspection.
6) The Contractor shall bear all costs including, but not limited to, the cost of developing the digital models, the cost of manipulating the design files provided by the Department, the cost that may be incurred due to the discrepancies between the Contractor's digital models and the design files provided by the Department, and the cost of rework or reconstruction that may be incurred due to errors in application of AMG techniques.

3.2.6 Electronic Files

1) Available electronic files will be provided by the Department to the Contractor. These electronic files will be in the native format of the software application by which they were generated, which may be different from the format of the systems the Contractor use. The use of these electronic files to generate 3D data and/or digital models for AMG is at the discretion of the Contractor. The Department has no responsibility to provide these electronic files or 3D data used for the AMG system. The electronic files may include:
   a) Alignment data.
   b) Cross sections.
   c) Background graphics files with roadway and drainage features such as centerlines, edges, and hull of ponds.
   d) Machine control surface model, or existing and design surface models.
   e) GPS site calibration data.
   f) Project control information.
2) Available electronic files will be provided to the Contractor, if available, upon the request of the Contractor.
3) The electronic files are provided to the Contractor for convenience only, and are not part of the Contract Documents. The Department assumes no responsibility for the sufficiency or accuracy of the provided electronic files. The Contractor is

responsible for conducting all necessary investigations of conditions including, but not limited to, site visits, spot checks, and/or re-computation before bidding or developing the digital models for AMG (IowaDOT, 2016).

4) The Contractor shall notify the Department of any errors or discrepancies in the electronic files provided by the Department.

***In Task 4, more information needs to be gathered, in order to add more details on the following aspects and decide which option(s) to select for each aspect*:**

- Time for providing the electronic files to the Contractor (e.g., as part of the contract bid documents, during the bidding phase, upon request by Contractor)
- Types of electronic files to be provided.
- Responsibility (or commitment) by the Department to provide the files.

3.2.7 Project Control

1) All surveying work using GPS technology shall comply with IDOT's Surveying Manual, Chapter 3 GPS, 2015 version. This document includes the use of GPS survey equipment, field procedures, office procedures, and guidelines for Post-Processed GPS control surveys.
2) Office procedures include, but are not limited to:
   a) Compare check shots with the known values.
   b) Check the base station coordinates and ellipsoid height for correctness.
   c) Analyze the GPS site calibration for a high scale factor and high residuals.
   d) Check the data collector file for correctness and completeness.
3) Prior to the project, the Department will set primary control monuments. The project control information will be provided to the Contractor, before or at the preconstruction conference, for the purpose of developing digital models.
4) The Contractor shall set secondary horizontal and vertical control points using a conventional method or using a GPS method, including Post-Processed Fast Static and/or Real-Time GPS methods at accuracy levels 3 or 4 (IDOT, 2015). The secondary control points shall be set along the length of the project, and the intervals shall not exceed 1000 feet.
5) The Contractor is responsible for verifying, supplementing, and maintaining the project control points before construction and regularly during construction.
6) All of the project control points shall be documented in the project control report, which is a part of the aforementioned Automated Machine Guidance Work Plan.
7) The deliverables of control survey include, but are not limited to:
   a) Coordinates.
   b) Primary control check.
   c) GPS raw and solution files.
   d) Coordinate metadata.
   e) Project site map.
   f) Project narrative summary.
   g) Post-process report.
   h) Equipment logs.

i) Names of individuals and duties.

3.2.8 Accuracy and Tolerance

1) The Contractor shall meet the same accuracy and tolerance requirements when AMG is used as when conventional staking is used for grading or paving.
2) The accuracy and tolerance shall be compliant with the Contract Documents and applicable standards and specifications.

3.2.9 Construction Spot Checks

1) The Department Engineer will perform spot checks of the Contractor's machine control results, surveying calculations, field procedures, actual staking, and records and documentation, as necessary.
2) The Department will perform the checks, as needed, before construction and at any time during the construction. The Contractor shall facilitate the spot checks.
3) The spot checks will be conducted using conventional survey methods, or independent GPS equipment, or a combination of the two approaches.

3.2.10 Site Calibration and Check

1) The Contractor shall use at least three known horizontal control points for horizontal site calibration (IDOT, 2015), or two control points per mile along the project area if this results in more control points (WisDOT, 2016). The control points selected shall envelope the project area using AMG and be well-distributed within the area.
2) The Contractor shall perform daily site calibration checks as described in the Automated Machine Guidance Work Plan on two or more control points with a horizontal tolerance of +/- 0.03 foot (or 0.01 foot or less) and a vertical tolerance of +/- 0.065 foot (or 0.05 foot or less).
3) The site calibration shall follow IDOT's Surveying Manual, Chapter 3 GPS including, but not limited to, the following requirements:
   a) A vertical calibration requires a minimum of four NAVD 88 orthometric height benchmarks (IDOT, 2015)
   b) A horizontal calibration requires a minimum of three know control points and one NAVD 88 benchmark (IDOT, 2015)
   c) The results must be carefully analyzed before accepting. Residuals exceeding the survey accuracy determined by redundant observations, a scale factor significantly different than 1.0, or excessive slope of the plane may indicate failure of calibration. Additional control points might be added (IDOT, 2015)

   The Contractor shall check the manual for more information about the specifications and procedures for site calibration.

3.2.11 Final Check

1) Before the final check, the Contractor shall perform a quality control test, as stated in the Automated Machine Guidance Work Plan, in order to check randomly selected locations at all hinge points, centerline, edge of lane and edge of shoulders at all critical locations, and against plan elevations. The areas that are out of tolerances might be checked additionally by the Department Engineer before the final check.
2) The Contractor shall perform the final check of construction work. The Engineer may perform or witness the check. The Contractor shall notify the Engineer at least 2 business days before performing the checks, so the Engineer can observe the process.
3) The final check is conducted at random locations at 500 foot intervals at all hinge points, centerline, edge of lane and edge of shoulders at all critical locations. The Contractor shall perform 20 or more randomly selected checks per stage, per project, or per mainline roadway mile, whichever results in the most checks (WisDOT, 2016). The Contractor shall ensure that at least four of any five consecutive random checking points are within the tolerance.
4) If more than one of any five consecutive random checking points is out of tolerance (i.e., differs from the design by more than the vertical tolerance), the grade does not pass this check and the Contractor shall correct the grade (WisDOT, 2016).

***In Task 4, more information needs to be gathered, in order to add more details on the following aspects and decide which option(s) to select for each aspect*:**

- Number of checks
- Intervals of checks
- When to notify the Engineer

3.2.12 Staking

1) For areas constructed without AMG, the Contractor may refer to the staking procedure and specification in Chapter 10 Construction Surveys in IDOT Survey manual, 2015, and may refer to the IDOT Road and Bridge Specifications for staking specifications.
2) Staking for grading with AMG
   a) Set finished subgrade points on cross section at 1000 foot intervals on mainline and at least two cross sections on side roads and ramps, and at 250 foot intervals on curves, transitions, intersections, interchanges and break points (KDOT, 2016). Those points should be established using data other than the machine guidance surface, i.e., digital models, such as plan typicals and cross sections, for use by the Engineer to conduct independent checks (IowaDOT, 2016).

    b) Provide conventional grade stakes at critical points such as, but not limited to, PC's, PT's, super elevation points, and other critical points required for construction of drainage and roadway structures.

3) Surveying for paving with AMG
    a) When robotic total stations are used for the AMG paving system, set additional control points at maximum 500 foot intervals on each side of pavement (IowaDOT, 2016).
    b) Set paving stakes with cut or fill to finish pavement elevation at points along superelevated curve transitions and at station equation locations. (IowaDOT, 2016)

***In Task 4, more information needs to be gathered, in order to add more details on the following aspects and decide which option(s) to select for each aspect*:**

- Intervals of stakes (e.g., 1000 foot intervals or 500 foot intervals)

REFERENCES

1. AASHTO, Quick Reference Guide for the Implementation of Automated Machine Guidance System (AMG).
2. Kansas Department of Transportation (KDOT), 2015, KDOT's Construction Manual, Section 802, "Contractor Construction Staking of the Standard Specifications".
3. Illinois Department of Transportation (IDOT), 2015, Survey Manual.
4. Illinois Department of Transportation (IDOT), 2016, Standard Specifications for Road and Bridge.
5. Illinois Department of Transportation (IDOT), 2014, CADD Roadway and Structure Project Deliverables Policy.
6. Iowa Department of Transportation (IowaDOT), 2015, Standard Specification for Highway and Bridge Construction Section 2526.
7. Mississippi Department of Transportation (MDOT), 2013, Special Provision No. 907-699-5 Construction Stakes.
8. Pennsylvania Department of Transportation (PennDOT), 2016, Publication 408/2016 Specifications.
9. Wisconsin Department of Transportation (WisDOT), 2016, Standard Specifications Section 650.
10. WisDOT, 2015, Construction and Material Manual.

APPENDIX A

Questionnaire for Surveying Other State DOTs and Contractors on Current Practices Employed by Other States

Section 1: Respondent Information

Please provide the following information:
Name:
Agency:
Job title:
Years of experience:
Phone:
Email:

Section 2: Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying

1. Based on your agency's experience in the past year, how many highway projects constructed by your agency utilized GPS technology in construction surveying?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All projects)
2. Based on your agency's experience in the past year, how many highway projects regulated by your agency utilized GPS technology in construction surveying?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All projects)
3. If you did NOT answer "All projects" to the previous question, why was GPS technology NOT used during construction surveying?
   [Unawareness of benefits (DOT); Unawareness of benefits (Contractor); Not required by DOT; Lack of specifications by DOT; Procedural issues (DOT); Procedural issues (Contractor); Lack of GPS equipment (DOT); Lack of GPS equipment (Contractor); Lack of end-user technical skills (DOT); Lack of end-user technical skills (Contractor); Cost of acquiring and operating GPS equipment; Inconstant signals; Limited accuracy; Other]
4. Which of the following options best describe the DOT's specifications with respect to the use of GPS technology in construction surveying?
   (Allow unlimited use; Allow limited use; Prohibit use; Mandate use; Are silent)
5. Based on your agency's experience, indicate your level of satisfaction with the use of GPS technology in construction surveying for each of the following activities.
   (Project control surveying; Automated machine guidance; Staking for grading; Staking for paving; Staking structure; Staking drainage and pipeline; Staking slope; Staking base; Staking curb and gutter; Staking concrete barrier; Preparation of surveying data deliverable; Construction staking bid item measurement; Other)
   [1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied]
6. Which of the following benefits did your agency experience when using GPS technology in construction surveying?
   (Decrease crew size; Facilitate measurement of vertical distance; Decrease the

duration of surveying; Decrease the cost; Make it possible to work under bad weather conditions; Improve the precision of survey; Reduce staking workload; Other)

7. Based on your agency's experience, indicate the level of significance that the following factors had in contributing to the success of GPS implementation at your agency?

   [Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with GPS technologies (DOT); Experience with GPS technologies (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]

   [1: Very insignificant; 2: Insignificant; 3: Somewhat insignificant; 4: Somewhat significant; 5: Significant; 6: Very significant]

8. Based on your agency's experience, which of the following are difficulties or challenges to the use GPS technology in construction surveying?

   (None; Less trained equipment operators; Inefficient communication between Contractor and DOT; Harsh weather conditions; Interruption due to power failure; Reading and recording wrong antenna height; Unstable GPS signal; All parties need to be on the same site calibration; All parties need to use the same data files; Other)

<u>Section 3: Control Surveying Using GPS Technology and Real Time Kinematic (RTK) Method</u>

Based on your experience in using GPS technology in <u>control surveying and RTK method</u>, please answer the following questions:

1. Who is responsible for performing secondary control surveys for the project?

   (DOT; Contractor)

2. If Automated Machine Guidance (AMG) is used, are additional horizontal and vertical control surveys required?

   (Y/N)

3. Which of the following office procedures are done when conducting RTK control surveying?

   (Check the data collector file for correctness and completeness; Check the base station coordinates and ellipsoid height for correctness; Analyze the GPS site calibration for a high scale factor and high residuals; Compare check shots with the known values; Check all reports for high residuals; Other)

4. Which of the following types of base station networks are utilized by your agency?

   (CORS; OPUS; HARN; VRS; NDGPS; Other)

5. What are the deliverables that are required to be submitted by the Surveyor for a GPS control survey?

   (Project narrative summary; Names of individuals and duties; Coordinates; Coordinate metadata; Project site map; Equipment logs; Calibration report for all points used in the survey; Primary control checks; Post-process report; Weather condition report; GPS raw and solution files; Other)

6. Please provide the link to the manual or document that includes the DOT specifications about GPS RTK survey design, setup, and operation, including: Minimum number of horizontal and vertical Real Time Kinematic (RTK) control stations; Horizontal and vertical tolerances; Maximum Position Dilution of Precision (PDOP); Minimum number of satellites observed simultaneously; Maximum epoch interval for data sampling; Minimum number of epochs of collected data for each observation; Minimum time between repeat observations; Maximum difference in horizontal or vertical coordinates of the second occupation from the first occupation; Maximum distance from the base station to the rover units; Minimum satellite mask above the horizon; Geometry of control stations; Minimum level of accuracy of control stations; Whether the base station is occupied by an RTK control station; Whether the base station use a fixed height tripod.
   If the specifications are included in more than one document, please provide the links to ALL documents.
   If a document is not available online, please send a copy of the document to gohary@illinois.edu.

SECTION 4: CONSTRUCTION SURVEYING USING GPS EQUIPMENT

Based on your experience in construction surveying using GPS equipment, please answer the following questions:

1. Where is automated machine guidance (AMG) allowed to be used?
   (Rough grading; Finish grading; Paving; Curb; Pipe and drainage; Structure; Concrete barrier; Resurfacing; Other)
2. Where does the DOT plan to use automated machine guidance (AMG) besides the current use(s)?
   (Rough grading; Finish grading; Paving; Curb; Pipe and drainage; Structure; Concrete barrier; Resurfacing; Other)
3. Where does the Contractor plan to use automated machine guidance (AMG) besides the current use(s)?
   (Rough grading; Finish grading; Paving; Curb; Pipe and drainage; Structure; Concrete barrier; Resurfacing; Other)
4. Does the DOT require some conventional staking when conducting construction surveying using GPS equipment?
   (Y/N)
5. If yes to Question 4, indicate your level of agreement with the following statement: The DOT is requiring too much conventional staking, when conducting construction surveying using GPS equipment.
   (1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)
6. Based on your agency's experience in the past year, how many highway projects conducted construction surveying using GPS equipment?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)

7. Which of the following benefits did your agency experience when conducting construction surveying using GPS equipment for highway projects?
   (Reduced staking; Stakeless; More efficient processes; Improved accuracy; Less experienced construction staff required; Lower bids from contractors; Safer working environment; Other)
8. Does the DOT provide a list of approved GPS equipment?
   (Y/N)
9. What is the vendor of the GPS equipment that you use?
   (Trimble; Topcon; Other)
10. Do the DOT specifications require that construction surveying using GPS equipment have to achieve the same level of accuracy/tolerance compared with conventional staking?
    (Y/N)
11. What is the specified frequency to maintain the GPS equipment?
    (Not specified; Every six months; At the beginning of each survey; Weekly during the survey; Other)
12. If you answered "Not specified" to Question 11, how frequent do you maintain the GPS equipment?
    (Not regularly; Every six months; At the beginning of each survey; Weekly during the survey; Other)
13. What GPS equipment components are maintained?
    (Tripods; Fixed height tripods; Rods; Cables; Receivers and receiver antennas; Handhelds; Other)
14. What types of GPS equipment checks are specified/required?
    (None; Federal published calibration baseline check by NGS; Zero baseline check of antenna, receiver, and cables according to manufacturer; Primary control check; Other)
15. If you answered "None" to Question 14, what types of GPS equipment checks do you perform?
    (None; Federal published calibration baseline check by NGS; Zero baseline check of antenna, receiver, and cables according to manufacturer; Primary control check; Other)
16. What is the frequency of GPS equipment checks you perform?
    (At beginning and end of survey; Every six months; By request of Engineer or Contractor; Other)
17. Is the Contractor required to provide training on the use of Contractor's GPS system to the Contractor staff?
    (Y/N)
18. If yes to Question 17, what is the specified time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT; Other)
19. If no to Question 17, does the Contractor voluntarily provide training on the use of Contractor's GPS system to the Contractor staff?

(Y/N)

20. If yes to Question 19, what is the time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones as needed; Other)
21. Is the Contractor required to provide training on the use of Contractor's GPS system to DOT staff?
    (Y/N)
22. If yes to Question 21, what is the specified time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT; Other)
23. If no to Question 21, does Contractor voluntarily provide training on the use of Contractor's GPS system to the DOT staff?
    (Y/N)
24. If yes to Question 23, what is the time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones as needed; Other)
25. Is the Contactor required to perform daily site calibration checks?
    (Y/N)
26. If no to question 25, are daily site calibration checks voluntarily performed by the Contractor?
    (Y/N)
27. What is the horizontal tolerance for daily site calibration checks?
    (0.10 feet; Other)
28. What is the vertical tolerance for daily site calibration checks?
    (0.05 feet; Other)
29. Who is performing the spot checks of the control of work?
    (Contractor; Engineer; Both)
30. Who is responsible to perform the final check?
    (Contractor, witnessed by Engineer; Engineer; Other)
31. What is the vertical tolerance for the final check?
    (0.05 feet; 0.10 feet; Other)
32. What is the horizontal tolerance for the final check?
    (0.04 feet; 0.10 feet; Other)
33. How many consecutive randomly selected checking points should be within the tolerance to ensure conformance to the plan?
    (Not required; 4 of 5 randomly selected checking points should be within the tolerance; Other)

<u>Section 5: Conventional Staking When Conducting Construction Surveying using GPS Equipment</u>

Based on your experience in using conventional <u>staking when conducting</u>

construction surveying using GPS equipment, please answer the following questions about conventional staking specifications/tolerances/accuracies:

1. Does the DOT have specifications for conventional staking when conducting construction surveying using GPS equipment (such as tolerances and stake spacing) written in a construction manual or other guidance documents?
   (Y/N)
2. Indicate your level of agreement with the following statement: It is necessary to have written specification for conventional staking when conducting construction surveying using GPS equipment (such as tolerances and stake spacing) included in a construction manual or other guidance documents.
   (1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)
3. Please provide the link to the manual or document that includes the DOT specifications for conventional staking when conducting construction surveying using GPS equipment about the tolerances and stake spacing for subgrade staking, pavement staking, slope staking, and structure layout staking, including: Vertical tolerances; Horizontal tolerances; Maximum spaces or specific intervals between two stakes; Minimum number of shots needed to verify ground elevation; Where should the shots be taken; Whether the stakes should be set on a line offset from the structure centerline for roadway and substructure units.
   If the specifications are included in more than one document, please provide the links to ALL documents.
   If a document is not available online, please send a copy of the document to gohary@illinois.edu.
4. Are the staking procedures when conducting construction surveying using GPS equipment written in a construction manual or other guidance documents?
   (Y/N)
5. Indicate your level of agreement with the following statement: It is necessary to have written staking procedures when conducting construction surveying using GPS equipment included in a construction manual or other guidance documents?
   (1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)
6. Please provide the link to the manual or document that includes the staking procedures when conducting construction surveying using GPS equipment.
   If the procedures are included in more than one document, please provide the links to ALL documents.
   If a document is not available online, please send a copy of the document to gohary@illinois.edu.
7. Is subgrade staking still required when conducting construction surveying using GPS equipment?
   (Y/N)
8. Is pavement staking still required when conducting construction surveying using GPS equipment?
   (Y/N)

9. Is slope staking still required when conducting construction surveying using GPS equipment?
   (Y/N)
10. Is structure layout staking still required when conducting construction surveying using GPS equipment?
    (Y/N)
11. Are electronic devices used to collect and compute positions and distances when staking?
    (Y/N)
12. Which document should the Contractor refer to, in order to understand how to operate electronic devices or software used to gather, store, and/or calculate position data?
    (Manufacturer's manual; Construction manual; Other)
13. When the slope is not a "catch" and the slope stake is not on a constant cut/fill line, is the cut/fill shown on the stake computed using the digital models and the actual ground elevation with the help of electronic devices?
    (Y/N)
14. How is the ground measured?
    (At each grade break; Every 25 feet; Other)
15. When is the measurement stopped?
    (Until the profile grade line for the station is reached; The difference between the measured ground elevation and the elevation computed is less than the tolerance; Other)
16. If a tolerance is used to determine the stop of the measurement, what is the specified horizontal tolerance?
    (0.5 feet; Other)
17. If a tolerance is used to determine the stop of the measurement, what is the specified vertical tolerance?
    (0.1 feet; Other)
18. Is the stake/field book automatically generated by the electronic devices?
    (Y/N)

Section 6: Digital Models and Electronic Data Exchange Practices

Based on your experience in using digital models and electronic data exchange practices in construction surveying for highway projects, please answer the following questions:

1. Based on your agency's experience in the past year, how many highway construction surveys are using digital models?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
2. Based on your agency's experience in the past year, how many of these highway construction surveys (that are using digital models) are using the following software for creating and updating the digital models?
   [AutoCAD Civil 3D; AutoCAD Map 3D; Autodesk Navisworks Simulate; Bentley ConstrucSim; MicroStation; GEOPAK; InRoads; Trimble Business Center; Other]

(None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)

3. Indicate your level of satisfaction with the use of the following software in supporting construction surveying.
   [AutoCAD Civil 3D; AutoCAD Map 3D; Autodesk Navisworks Simulate; Bentley ConstrucSim; MicroStation; GEOPAK; InRoads; Other]
   (1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied)
4. Which of the following benefits are involved with the use of digital models in construction surveying for highway projects?
   (Simulate and visualize the project more accurately; More quickly perform quantity takeoffs; Deliver models of higher quality to Contractor for automated machine guidance; Combine multiple types of data such as CAD and geospatial data; Standardize the as-built data collection process; Improve access to highway project information; Facilitate information exchange among stakeholders; Streamline different phases such as design, construction, operation, and maintenance; Decrease the risk of redoing; Improve bid accuracy; Other)
5. How does the use of digital models affect the project time?
   (Does not have any effect on project time; Saves less than 25% of project time; Saves over 25% of project time but less than 50% of project time; Saves over 50% of project time; Add project time; Does not save or add time, but spends more time on earlier stages and less on later stages; Does not save or add time, but spends less time on earlier stages and more on later stages; Other)
6. If time savings are reported, which of the activities are associated with the most time saving?
   (Project control; Grading; Paving; Earthwork and excavation; Curb and gutter construction; Pipe and drainage construction; Structure construction; Site calibration and check; Preparation of deliverable; Other)
7. How does the use of digital models affect the project cost?
   (Does not have any effect on project cost; Saves less than 10% of project cost; Saves over 10% of project time but less than 25% of project cost; Saves over 25% of project cost; Adds project cost; Does not save or add cost, but spend more on earlier stages and less on later stages; Does not save or add cost, but spend less on earlier stages and more on later stages; Other)
8. If cost savings are reported, which of the activities are associated with the most cost saving?
   (Project control surveying; Automated machine guidance; Staking for grading; Staking for paving; Staking structure; Staking drainage and pipeline; Staking slope; Staking base; Staking curb and gutter; Staking concrete barrier; Preparation of surveying data deliverables; Construction staking bid item measurement; Other)
9. If digital models are used in construction surveys, which of the following are barriers or challenges to successful implementation?
   (Training is difficult; Software get updated frequently; Software cannot fulfill certain tasks; Inefficient communication among stakeholders; DOT lack of experience; Contractor lack of experience; DOT lack of specifications; Procedural issues; Cost

issues; Other)

10. If digital models are NOT used in construction surveys, what are the reasons why they are not used or what are the barriers to implementation?
    (Training is difficult; Software get updated frequently; Software cannot fulfil certain tasks; Upfront cost of software and hardware is high; Cost of implementation is high; Lack of specifications; Reluctance to learn new technology; Unawareness of benefits of new technology; Legal concerns about sharing data; Other)
11. In construction projects using digital models, which of the following factors contribute to the success of implementation of the mentioned software?
    [Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive contract specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with the software (DOT); Experience with the software (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]
12. Who is responsible for providing the digital models used for AMG?
    (DOT; Contractor)
13. Who is responsible for updating and revising the digital models used for AMG?
    (DOT; Contractor)
14. Who is responsible for any errors or omissions in the digital models used for AMG?
    (DOT; Contractor)
15. Are the digital models generated by the Contractor allowed to be different from the design files provided by the DOT?
    (Y/N)
16. Who is responsible for any discrepancies between the design files provided by DOT and the 3D models generated by the Contractor?
    (DOT; Contractor)
17. What electronic data are provided by the DOT to the Contractor?
    (Cross section; Machine control surface model files; Alignment data files; Background graphics file with roadway and drainage features such as centerlines, edges and hull of ponds; Other)
18. When are the electronic data provided to the Contractor?
    (After the Contractor wins the bid; Before the preconstruction conference; After the preconstruction conference; At request by the Contractor; Other)
19. Indicate your level of satisfaction with providing electronic data to the Contractor during construction.
    (1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied)
20. What are the main uses of existing electronic data provided by the DOT?
    (Check quantities; Build digital model; Layout survey; Exchanging information with DOT personnel; Acquire accurate information about position, distance, etc.; Other)
21. What are the additional electronic files that should be provided by the DOT if NOT provided now?

(Cross section; Machine control surface model files; Alignment data files; Background graphics file with roadway and drainage features such as centerlines, edges and hull of ponds; Other)

22. Which of the following benefits are involved with providing electronic data to the Contractor?
    (Cost savings; Time savings; Improved project quality; More accurate bids; Fast identification of errors; More accurate digital models; Other)
23. How do additional electronic data affect the workload of the DOT?
    (No effect; Decreases the workload; Increases less than 25% of the workload; Increases about or over 25% of the workload; Especially increases the workload during preparation of data provided to Contractor; Especially increases the workload during construction stage due to additional quality control; Other)
24. What are the specified deliverables that should be submitted by the Contractor to the DOT?
    (GPS/AMG work plan; Survey control report; Quality control (QC) plan; Report of post project benchmarks; As-built construction plan; Survey notebooks; Other)
25. What is the specified format of the digital models?
    [ASCII; LandXML; ALG (InRoads geometry); CSV (Comma-separated values); DC (Data Collector file used in Trimble Survey Controller); DGN (MicroStation drawing files); DWG (Native format of AutoCAD); DXF (Data exchange file); DTM (Digital terrain model); GPK (GEOPAK coordinate geometry file); IRD (InRoads roadway definition file); TIN (Triangulated Irregular Network); SHP (Shapefile spatial data format); Other]
26. What should the GPS/AMG work plan contain?
    (Description of equipment and software; Contractor's experience; Definition of project boundaries and scope of work to be accomplished using GPS/AMG; Project secondary control; Site calibration procedure; Equipment calibration and maintenance procedure; Other)
27. What is the specified time at which the GPS/AMG work plan should be submitted?
    (5 working days or one week prior to primary field operation; 5 working days or one week prior to preconstruction conference; 30 days prior to primary field operation; Other)

Section 7: Laser Scanning

Based on your experience in using laser scanning, please answer the following questions:

1. Based on your agency's experience in the past year, how many highway construction surveys are using laser scanning?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
2. Is laser scanning used for construction staking of highway projects?
   (Y/N)
3. Which of the following applications of laser scanning in highway projects have you used? Indicate your level of satisfaction for each one used.
   (Digital terrain modeling; Automated machine control; Post-construction quality

control; Quantities; Pavement analysis scans; Roadway/pavement topographic surveys; Structure and bridge clearance surveys; As-built surveys; Corridor planning survey; Earthwork surveys; Urban mapping and modeling)

[1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied]

4. If laser scanning is used in construction surveys, what are the benefits to the project?

   (Provides dense point cloud data in a short time; Provides reusable data; Makes it possible for surveyors to be at a safe distance from traffic; Facilitates survey about inaccessible area and vegetated area; Saves time and cost for example when generating digital terrain model from the point cloud data; Other)

5. If laser scanning is not used in construction surveys, what are the barriers or challenges to the implementation?

   [Cost and budget; Unawareness of benefits; End-user technical skill (DOT); End-user technical skill (Contractor); Lack of specification; Lack of laser scanning equipment (DOT); Lack of laser scanning equipment (Contractor); DOT procedural issues; Requiring supplemented measurement such as total station and GPS survey; Requiring post-processing; Requiring significant data storage; Other]

6. In construction projects using laser scanning, which of the following factors contribute to the success of implementation of laser scanning?

   [Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive contract specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with laser scanning (DOT); Experience with laser scanning (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]

APPENDIX B

Questionnaire for Surveying Contractors on Current Practices Employed about Adapting Construction Staking to Modern Technologies

The questionnaire consists of **seven** sections and has **92** questions. It will take you about **50 minutes** to complete all the questions.
If you **do not know** the answer to a question, please respond *Do not know* instead of randomly providing an answer.
If you choose *Other*, please provide **you own answer** to the question.

Section 1: Respondent Information
Please provide the following information:
Name:
Agency:
Job title:
Years of experience:
Phone:
Email:

Section 2: Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying

1. Based on your agency's experience in the past year, how many highway projects constructed by your agency utilized GPS technology in construction surveying? (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All projects)
2. If you did NOT answer "All projects" to the previous question, why was GPS technology NOT used during construction surveying?
   [Unawareness of benefits (DOT); Unawareness of benefits (Contractor); Not required by DOT; Lack of specifications by DOT; Procedural issues (DOT); Procedural issues (Contractor); Lack of GPS equipment (DOT); Lack of GPS equipment (Contractor); Lack of end-user technical skills (DOT); Lack of end-user technical skills (Contractor); Cost of acquiring and operating GPS equipment; Inconstant signals; Limited accuracy; Other]
3. Which of the following options best describe the DOT's specifications with respect to the use of GPS technology in construction surveying?
   (Allow unlimited use; Allow limited use; Prohibit use; Mandate use; Are silent)
4. Based on your agency's experience, indicate your level of satisfaction with the use of GPS technology in construction surveying for each of the following activities.
   (Project control surveying; Automated machine guidance; Staking for grading; Staking for paving; Staking structure; Staking drainage and pipeline; Staking slope; Staking base; Staking curb and gutter; Staking concrete barrier; Preparation of surveying data deliverable; Construction staking bid item measurement; Other)
   [1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied]

5. Which of the following benefits did your agency experience when using GPS technology in construction surveying?
   (Decrease crew size; Facilitate measurement of vertical distance; Decrease the duration of surveying; Decrease the cost; Make it possible to work under bad weather conditions; Improve the precision of survey; Reduce staking workload; Other)
6. Based on your agency's experience, indicate the level of significance that the following factors had in contributing to the success of GPS implementation at your agency?
   [Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with GPS technologies (DOT); Experience with GPS technologies (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]
   [1: Very insignificant; 2: Insignificant; 3: Somewhat insignificant; 4: Somewhat significant; 5: Significant; 6: Very significant]
7. Based on your agency's experience, which of the following are difficulties or challenges to the use GPS technology in construction surveying?
   (None; Less trained equipment operators; Inefficient communication between Contractor and DOT; Harsh weather conditions; Interruption due to power failure; Reading and recording wrong antenna height; Unstable GPS signal; All parties need to be on the same site calibration; All parties need to use the same data files; Other)

Section 3: Control Surveying Using GPS Technology and Real Time Kinematic (RTK) Method

Based on your experience in using GPS technology in control surveying and RTK method, please answer the following questions:

1. Who is responsible for performing secondary control surveys for the project?
   (DOT; Contractor)
2. If Automated Machine Guidance (AMG) is used, are additional horizontal and vertical control surveys required?
   (Y/N)
3. Which of the following office procedures are done when conducting RTK control surveying?
   (Check the data collector file for correctness and completeness; Check the base station coordinates and ellipsoid height for correctness; Analyze the GPS site calibration for a high scale factor and high residuals; Compare check shots with the known values; Check all reports for high residuals; Other)
4. Which of the following types of base station networks are utilized by your agency?
   (CORS; OPUS; HARN; VRS; NDGPS; Other)
5. What are the required deliverables that should be submitted by the Surveyor for a GPS control survey?

(Project narrative summary; Names of individuals and duties; Coordinates; Coordinate metadata; Project site map; Equipment logs; Calibration report for all points used in the survey; Primary control checks; Post-process report; Weather condition report; GPS raw and solution files; Other)

SECTION 4: CONSTRUCTION SURVEYING USING GPS EQUIPMENT

Based on your experience in construction surveying using GPS equipment, please answer the following questions:

1. Where is automated machine guidance (AMG) allowed to be used?
   (Rough grading; Finish grading; Paving; Curb; Pipe and drainage; Structure; Concrete barrier; Resurfacing; Other)
2. Where does the Contractor plan to use automated machine guidance (AMG) besides the current use(s)?
   (Rough grading; Finish grading; Paving; Curb; Pipe and drainage; Structure; Concrete barrier; Resurfacing; Other)
3. Does the DOT require some conventional staking when conducting construction surveying using GPS equipment?
   (Y/N)
4. If yes to Question 4, indicate your level of agreement with the following statement: The DOT is requiring too much conventional staking, when conducting construction surveying using GPS equipment.
   (1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)
5. Based on your agency's experience in the past year, how many highway projects conducted construction surveying using GPS equipment?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
6. Which of the following benefits did your agency experience when conducting construction surveying using GPS equipment for highway projects?
   (Reduced staking; Stakeless; More efficient processes; Improved accuracy; Less experienced construction staff required; Lower bids from contractors; Safer working environment; Other)
7. Does the DOT provide an approved list of GPS equipment?
   (Y/N)
8. What is the vendor of the GPS equipment that you use?
   (Trimble; Topcon; Other)
9. Do the DOT specifications require that construction surveying using GPS equipment have to achieve the same level of accuracy/tolerance compared with conventional staking?
   (Y/N)
10. What is the specified frequency to maintain the GPS equipment?
    (Not specified; Every six months; At the beginning of each survey; Weekly during the survey; Other)
11. If you answered "Not specified" to Question 10, how frequent do you maintain the GPS equipment?

(Not regularly; Every six months; At the beginning of each survey; Weekly during the survey; Other)

12. What GPS equipment components are maintained?
    (Tripods; Fixed height tripods; Rods; Cables; Receivers and receiver antennas; Handhelds; Other)
13. What types of GPS equipment checks are specified/required?
    (None; Federal published calibration baseline check by NGS; Zero baseline check of antenna, receiver, and cables according to manufacturer; Primary control check; Other)
14. If you answered “None” to Question 13, what types of GPS equipment checks do you perform?
    (None; Federal published calibration baseline check by NGS; Zero baseline check of antenna, receiver, and cables according to manufacturer; Primary control check; Other)
15. What is the frequency of GPS equipment checks you perform?
    (At beginning and end of survey; Every six months; By request of Engineer or Contractor; Other)
16. Is the Contractor required to provide training on the use of Contractor’s GPS system to the Contractor staff?
    (Y/N)
17. If yes to Question 16, what is the specified time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT; Other)
18. If no to Question 16, does Contractor voluntarily provide training on the use of Contractor’s GPS system to the Contractor staff?
    (Y/N)
19. If yes to Question 18, what is the time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones as needed; Other)
20. Is the Contractor required to provide training on the use of Contractor’s GPS system to DOT staff?
    (Y/N)
21. If yes to Question 20, what is the specified time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT; Other)
22. If no to Question 20, does Contractor voluntarily provide training on the use of Contractor’s GPS system to the DOT staff?
    (Y/N)
23. If yes to Question 22, what is the time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones

as needed; Other)

24. Is the Contactor required to perform daily site calibration checks?
    (Y/N)
25. If no to question 24, are daily site calibration checks voluntarily performed by the Contractor?
    (Y/N)
26. What is the horizontal tolerance for daily site calibration checks?
    (0.10 feet; Other)
27. What is the vertical tolerance for daily site calibration checks?
    (0.05 feet; Other)
28. Who is performing the spot checks of the control of work?
    (Contractor; Engineer; Both)
29. Who is responsible to perform the final check?
    (Contractor, witnessed by Engineer; Engineer; Other)
30. What is the vertical tolerance for the final check?
    (0.05 feet; 0.10 feet; Other)
31. What is the horizontal tolerance for the final check?
    (0.04 feet; 0.10 feet; Other)
32. How many consecutive randomly selected checking points should be within the tolerance to ensure conformance to the plan?
    (Not required; 4 of 5 randomly selected checking points should be within the tolerance; Other)

Section 5: Conventional Staking When Conducting Construction Surveying using GPS Equipment

Based on your experience in using conventional staking when conducting construction surveying using GPS equipment, please answer the following questions about conventional staking specifications/tolerances/accuracies:

1. Does the DOT have specifications for conventional staking when conducting construction surveying using GPS equipment (such as tolerances and stake spacing) written in a construction manual or other guidance documents?
   (Y/N)
2. Indicate your level of agreement with the following statement: It is necessary to have written specification for conventional staking when conducting construction surveying using GPS equipment (such as tolerances and stake spacing) included in a construction manual or other guidance documents.
   (1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)
3. Are the staking procedures when conducting construction surveying using GPS equipment written in a construction manual or other guidance documents?
   (Y/N)
4. Indicate your level of agreement with the following statement: It is necessary to have written staking procedures when conducting construction surveying using GPS equipment included in a construction manual or other guidance documents?

(1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)

5. Is <u>subgrade staking</u> still required when conducting construction surveying using GPS equipment?
   (Y/N)
6. Is <u>pavement staking</u> still required when conducting construction surveying using GPS equipment?
   (Y/N)
7. Is <u>slope staking</u> still required when conducting construction surveying using GPS equipment?
   (Y/N)
8. Is <u>structure layout staking</u> still required when conducting construction surveying using GPS equipment?
   (Y/N)
9. Are electronic devices used to collect and compute positions and distances when staking?
   (Y/N)
10. Which document should the Contractor refer to, in order to understand how to operate electronic devices or software used to gather, store, and/or calculate position data?
    (Manufacturer's manual; Construction manual; Other)
11. When the slope is not a "catch" and the slope stake is not on a constant cut/fill line, is the cut/fill shown on the stake computed using the digital models and the actual ground elevation with the help of electronic devices?
    (Y/N)
12. How is the ground measured?
    (At each grade break; Every 25 feet; Other)
13. When is the measurement stopped?
    (Until the profile grade line for the station is reached; The difference between the measured ground elevation and the elevation computed is less than the tolerance; Other)
14. If a tolerance is used to determine the stop of the measurement, what is the specified horizontal tolerance?
    (0.5 feet; Other)
15. If a tolerance is used to determine the stop of the measurement, what is the specified vertical tolerance?
    (0.1 feet; Other)
16. Is the stake/field book automatically generated by the electronic devices?
    (Y/N)

<u>Section 6: Digital Models and Electronic Data Exchange Practices</u>

Based on your experience in using digital models and electronic data exchange practices in construction surveying for highway projects, please answer the following questions:

1. Based on your agency's experience in the past year, how many highway construction surveys are using digital models?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
2. Based on your agency's experience in the past year, how many of these highway construction surveys (that are using digital models) are using the following software for creating and updating the digital models?
   [AutoCAD Civil 3D; AutoCAD Map 3D; Autodesk Navisworks Simulate; Bentley ConstrucSim; MicroStation; GEOPAK; InRoads; Trimble Business Center; Other]
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
3. Indicate your level of satisfaction with the use of the following software in supporting construction surveying.
   [AutoCAD Civil 3D; AutoCAD Map 3D; Autodesk Navisworks Simulate; Bentley ConstrucSim; MicroStation; GEOPAK; InRoads; Other]
   (1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied)
4. Which of the following benefits are involved with the use of digital models in construction surveying for highway projects?
   (Simulate and visualize the project more accurately; More quickly perform quantity takeoffs; Deliver models of higher quality to Contractor for automated machine guidance; Combine multiple types of data such as CAD and geospatial data; Standardize the as-built data collection process; Improve access to highway project information; Facilitate information exchange among stakeholders; Streamline different phases such as design, construction, operation, and maintenance; Decrease the risk of redoing; Improve bid accuracy; Other)
5. How does the use of digital models affect the project time?
   (Does not have any effect on project time; Saves less than 25% of project time; Saves over 25% of project time but less than 50% of project time; Saves over 50% of project time; Add project time; Does not save or add time, but spends more time on earlier stages and less on later stages; Does not save or add time, but spends less time on earlier stages and more on later stages; Other)
6. If time savings are reported, which of the activities are associated with the most time saving?
   (Project control; Grading; Paving; Earthwork and excavation; Curb and gutter construction; Pipe and drainage construction; Structure construction; Site calibration and check; Preparation of deliverable; Other)
7. How does the use of digital models affect the project cost?
   (Does not have any effect on project cost; Saves less than 10% of project cost; Saves over 10% of project time but less than 25% of project cost; Saves over 25% of project cost; Adds project cost; Does not save or add cost, but spend more on earlier stages and less on later stages; Does not save or add cost, but spend less on earlier stages and more on later stages; Other)
8. If cost savings are reported, which of the activities are associated with the most cost saving?
   (Project control surveying; Automated machine guidance; Staking for grading;

Staking for paving; Staking structure; Staking drainage and pipeline; Staking slope; Staking base; Staking curb and gutter; Staking concrete barrier; Preparation of surveying data deliverables; Construction staking bid item measurement; Other)

9. If digital models are used in construction surveys, which of the following are barriers or challenges to successful implementation?
   (Training is difficult; Software get updated frequently; Software cannot fulfill certain tasks; Inefficient communication among stakeholders; DOT lack of experience; Contractor lack of experience; DOT lack of specifications; Procedural issues; Cost issues; Other)
10. If digital models are NOT used in construction surveys, what are the reasons why they are not used or what are the barriers to implementation?
   (Training is difficult; Software get updated frequently; Software cannot fulfil certain tasks; Upfront cost of software and hardware is high; Cost of implementation is high; Lack of specifications; Reluctance to learn new technology; Unawareness of benefits of new technology; Legal concerns about sharing data; Other)
11. In construction projects using digital models, which of the following factors contribute to the success of implementation of the mentioned software?
   [Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive contract specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with the software (DOT); Experience with the software (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]
12. Who is responsible for providing the digital models used for AMG?
   (DOT; Contractor)
13. Who is responsible for updating and revising the digital models used for AMG?
   (DOT; Contractor)
14. Who is responsible for any errors or omissions in the digital models used for AMG?
   (DOT; Contractor)
15. Are the digital models generated by the Contractor allowed to be different from the design files provided by the DOT?
   (Y/N)
16. Who is responsible for any discrepancies between the design files provided by DOT and the 3D models generated by the Contractor?
   (DOT; Contractor)
17. What electronic data are provided by the DOT to the Contractor?
   (Cross section; Machine control surface model files; Alignment data files; Background graphics file with roadway and drainage features such as centerlines, edges and hull of ponds; Other)
18. When are the electronic data provided to the Contractor?
   (After the Contractor wins the bid; Before the preconstruction conference; After the preconstruction conference; At request by the Contractor; Other)
19. Indicate your level of satisfaction with providing electronic data to the Contractor

during construction.

(1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied)

20. What are the main uses of existing electronic data provided by the DOT?

    (Check quantities; Build digital model; Layout survey; Exchanging information with DOT personnel; Acquire accurate information about position, distance, etc.; Other)

21. What are the additional electronic files that should be provided by the DOT if NOT provided now?

    (Cross section; Machine control surface model files; Alignment data files; Background graphics file with roadway and drainage features such as centerlines, edges and hull of ponds; Other)

22. Which of the following benefits are involved with providing electronic data to the Contractor?

    (Cost savings; Time savings; Improved project quality; More accurate bids; Fast identification of errors; More accurate digital models; Other)

23. What are the specified deliverables that should be submitted by the Contractor to the DOT?

    (GPS/AMG work plan; Survey control report; Quality control (QC) plan; Report of post project benchmarks; As-built construction plan; Survey notebooks; Other)

24. What is the specified format of the digital models?

    [ASCII; LandXML; ALG (InRoads geometry); CSV (Comma-separated values); DC (Data Collector file used in Trimble Survey Controller); DGN (MicroStation drawing files); DWG (Native format of AutoCAD); DXF (Data exchange file); DTM (Digital terrain model); GPK (GEOPAK coordinate geometry file); IRD (InRoads roadway definition file); TIN (Triangulated Irregular Network); SHP (Shapefile spatial data format); Other]

25. What should the GPS/AMG work plan contain?

    (Description of equipment and software; Contractor’s experience; Definition of project boundaries and scope of work to be accomplished using GPS/AMG; Project secondary control; Site calibration procedure; Equipment calibration and maintenance procedure; Other)

26. What is the specified time at which the GPS/AMG work plan should be submitted?

    (5 working days or one week prior to primary field operation; 5 working days or one week prior to preconstruction conference; 30 days prior to primary field operation; Other)

<u>Section 7: Laser Scanning</u>

Based on your experience in using <u>laser scanning</u>, please answer the following questions:

1. Based on your agency’s experience in the past year, how many highway construction surveys are using laser scanning?

   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)

2. Is laser scanning used for construction staking of highway projects?

   (Y/N)

3. Which of the following applications of laser scanning in highway projects have you used? Indicate your level of satisfaction for each one used.

   (Digital terrain modeling; Automated machine control; Post-construction quality control; Quantities; Pavement analysis scans; Roadway/pavement topographic surveys; Structure and bridge clearance surveys; As-built surveys; Corridor planning survey; Earthwork surveys; Urban mapping and modeling)

   [1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied]

4. If laser scanning is used in construction surveys, what are the benefits to the project?

   (Provides dense point cloud data in a short time; Provides reusable data; Makes it possible for surveyors to be at a safe distance from traffic; Facilitates survey about inaccessible area and vegetated area; Saves time and cost for example when generating digital terrain model from the point cloud data; Other)

5. If laser scanning is not used in construction surveys, what are the barriers or challenges to the implementation?

   [Cost and budget; Unawareness of benefits; End-user technical skill (DOT); End-user technical skill (Contractor); Lack of specification; Lack of laser scanning equipment (DOT); Lack of laser scanning equipment (Contractor); DOT procedural issues; Requiring supplemented measurement such as total station and GPS survey; Requiring post-processing; Requiring significant data storage; Other]

6. In construction projects using laser scanning, which of the following factors contribute to the success of implementation of laser scanning?

   [Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive contract specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with laser scanning (DOT); Experience with laser scanning (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]

APPENDIX C

Questionnaire for Surveying Construction Staff in State Department of Transportation on Current Practices Employed about Adapting Construction Staking to Modern Technologies

The form consists of **four** sections and has **57** questions. It will take you about **30 minutes** to complete all the questions.
If you **do not know** the answer to a question, please respond *Do not know* instead of randomly providing an answer.
If you choose *Other*, please provide **you own answer** to the question.

Section 1: Respondent Information
Please provide the following information:
Name:
Agency:
Job title:
Years of experience:
Phone:
Email:

Section 2: Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying

1. Based on your agency's experience in the past year, how many highway projects regulated by your agency utilized GPS technology in construction surveying?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All projects)
2. If you did NOT answer "All projects" to the previous question, why was GPS technology NOT used during construction surveying?
   [Unawareness of benefits (DOT); Unawareness of benefits (Contractor); Not required by DOT; Lack of specifications by DOT; Procedural issues (DOT); Procedural issues (Contractor); Lack of GPS equipment (DOT); Lack of GPS equipment (Contractor); Lack of end-user technical skills (DOT); Lack of end-user technical skills (Contractor); Cost of acquiring and operating GPS equipment; Inconstant signals; Limited accuracy; Other]
3. Which of the following options best describe the DOT's specifications with respect to the use of GPS technology in construction surveying?
   (Allow unlimited use; Allow limited use; Prohibit use; Mandate use; Are silent)
4. Based on your agency's experience, indicate your level of satisfaction with the use of GPS technology in construction surveying for each of the following activities.
   (Project control surveying; Automated machine guidance; Staking for grading; Staking for paving; Staking structure; Staking drainage and pipeline; Staking slope; Staking base; Staking curb and gutter; Staking concrete barrier; Preparation of surveying data deliverable; Construction staking bid item measurement; Other)
   [1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat

satisfied; 5: Satisfied; 6: Very satisfied]

5. Which of the following benefits did your agency experience when using GPS technology in construction surveying?

   (Decrease crew size; Facilitate measurement of vertical distance; Decrease the duration of surveying; Decrease the cost; Make it possible to work under bad weather conditions; Improve the precision of survey; Reduce staking workload; Other)

6. Based on your agency's experience, indicate the level of significance that the following factors had in contributing to the success of GPS implementation at your agency?

   [Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with GPS technologies (DOT); Experience with GPS technologies (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]

   [1: Very insignificant; 2: Insignificant; 3: Somewhat insignificant; 4: Somewhat significant; 5: Significant; 6: Very significant]

7. Based on your agency's experience, which of the following are difficulties or challenges to the use GPS technology in construction surveying?

   (None; Less trained equipment operators; Inefficient communication between Contractor and DOT; Harsh weather conditions; Interruption due to power failure; Reading and recording wrong antenna height; Unstable GPS signal; All parties need to be on the same site calibration; All parties need to use the same data files; Other)

SECTION 3: CONSTRUCTION SURVEYING USING GPS EQUIPMENT

Based on your experience in construction surveying using GPS equipment, please answer the following questions:

1. Where is automated machine guidance (AMG) allowed to be used?

   (Rough grading; Finish grading; Paving; Curb; Pipe and drainage; Structure; Concrete barrier; Resurfacing; Other)

2. Where does the DOT plan to use automated machine guidance (AMG) besides the current use(s)?

   (Rough grading; Finish grading; Paving; Curb; Pipe and drainage; Structure; Concrete barrier; Resurfacing; Other)

3. Does the DOT require some conventional staking when conducting construction surveying using GPS equipment?

   (Y/N)

4. If yes to Question 3, indicate your level of agreement with the following statement: The DOT is requiring too much conventional staking, when conducting construction surveying using GPS equipment.

   (1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)

5. Based on your agency's experience in the past year, how many highway projects conducted construction surveying using GPS equipment?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
6. Which of the following benefits did your agency experience when conducting construction surveying using GPS equipment for highway projects?
   (Reduced staking; Stakeless; More efficient processes; Improved accuracy; Less experienced construction staff required; Lower bids from contractors; Safer working environment; Other)
7. Does the DOT provide a list of approved GPS equipment?
   (Y/N)
8. What is the vendor of the GPS equipment that you use?
   (Trimble; Topcon; Other)
9. Do the DOT specifications require that construction surveying using GPS equipment have to achieve the same level of accuracy/tolerance compared with conventional staking?
   (Y/N)
10. What is the specified frequency to maintain the GPS equipment?
    (Not specified; Every six months; At the beginning of each survey; Weekly during the survey; Other)
11. If you answered "Not specified" to Question 11, how frequent do you maintain the GPS equipment?
    (Not regularly; Every six months; At the beginning of each survey; Weekly during the survey; Other)
12. What GPS equipment components are maintained?
    (Tripods; Fixed height tripods; Rods; Cables; Receivers and receiver antennas; Handhelds; Other)
13. What types of GPS equipment checks are specified/required?
    (None; Federal published calibration baseline check by NGS; Zero baseline check of antenna, receiver, and cables according to manufacturer; Primary control check; Other)
14. If you answered "None" to Question 13, what types of GPS equipment checks do you perform?
    (None; Federal published calibration baseline check by NGS; Zero baseline check of antenna, receiver, and cables according to manufacturer; Primary control check; Other)
15. What is the frequency of GPS equipment checks you perform?
    (At beginning and end of survey; Every six months; By request of Engineer or Contractor; Other)
16. Is the Contractor required to provide training on the use of Contractor's GPS system to the Contractor staff?
    (Y/N)
17. If yes to Question 16, what is the specified time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones

upon the request of the DOT; Other)

18. If no to Question 16, does Contractor voluntarily provide training on the use of Contractor’s GPS system to the Contractor staff?
    (Y/N)
19. If yes to Question 18, what is the time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones as needed; Other)
20. Is the Contractor required to provide training on the use of Contractor’s GPS system to DOT staff?
    (Y/N)
21. If yes to Question 20, what is the specified time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones upon the request of the DOT; Other)
22. If no to Question 20, does Contractor voluntarily provide training on the use of Contractor’s GPS system to the DOT staff?
    (Y/N)
23. If yes to Question 22, what is the time and frequency of the training?
    (One training, prior to beginning the use of the GPS equipment; Multiple trainings, the first one prior to beginning the use of the GPS equipment, and the other ones as needed; Other)
24. Is the Contactor required to perform daily site calibration checks?
    (Y/N)
25. If no to question 24, are daily site calibration checks voluntarily performed by the Contractor?
    (Y/N)
26. What is the horizontal tolerance for daily site calibration checks?
    (0.10 feet; Other)
27. What is the vertical tolerance for daily site calibration checks?
    (0.05 feet; Other)
28. Who is performing the spot checks of the control of work?
    (Contractor; Engineer; Both)
29. Who is responsible to perform the final check?
    (Contractor, witnessed by Engineer; Engineer; Other)
30. What is the vertical tolerance for the final check?
    (0.05 feet; 0.10 feet; Other)
31. What is the horizontal tolerance for the final check?
    (0.04 feet; 0.10 feet; Other)
32. How many consecutive randomly selected checking points should be within the tolerance to ensure conformance to the plan?
    (Not required; 4 of 5 randomly selected checking points should be within the tolerance; Other)

Section 4: Conventional Staking When Conducting Construction Surveying using GPS Equipment

Based on your experience in using conventional staking when conducting construction surveying using GPS equipment, please answer the following questions about conventional staking specifications/tolerances/accuracies:

1. Does the DOT have specifications for conventional staking when conducting construction surveying using GPS equipment (such as tolerances and stake spacing) written in a construction manual or other guidance documents?
   (Y/N)
2. Indicate your level of agreement with the following statement: It is necessary to have written specification for conventional staking when conducting construction surveying using GPS equipment (such as tolerances and stake spacing) included in a construction manual or other guidance documents.
   (1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)
3. Please provide the link to the manual or document that includes the DOT specifications for conventional staking when conducting construction surveying using GPS equipment about the tolerances and stake spacing for subgrade staking, pavement staking, slope staking, and structure layout staking, including: Vertical tolerances; Horizontal tolerances; Maximum spaces or specific intervals between two stakes; Minimum number of shots needed to verify ground elevation; Where should the shots be taken; Whether the stakes should be set on a line offset from the structure centerline for roadway and substructure units.
   If the specifications are included in more than one document, please provide the links to ALL documents.
   If a document is not available online, please send a copy of the document to gohary@illinois.edu.
4. Are the staking procedures when conducting construction surveying using GPS equipment written in a construction manual or other guidance documents?
   (Y/N)
5. Indicate your level of agreement with the following statement: It is necessary to have written staking procedures when conducting construction surveying using GPS equipment included in a construction manual or other guidance documents?
   (1: Very disagree; 2: Disagree; 3: Somewhat disagree; 4: Somewhat agree; 5: Agree; 6: Very agree)
6. Please provide the link to the manual or document that includes the staking procedures when conducting construction surveying using GPS equipment.
   If the procedures are included in more than one document, please provide the links to ALL documents.
   If a document is not available online, please send a copy of the document to gohary@illinois.edu.
7. Is subgrade staking still required when conducting construction surveying using GPS equipment?
   (Y/N)

8. Is pavement staking still required when conducting construction surveying using GPS equipment?
   (Y/N)
9. Is slope staking still required when conducting construction surveying using GPS equipment?
   (Y/N)
10. Is structure layout staking still required when conducting construction surveying using GPS equipment?
    (Y/N)
11. Are electronic devices used to collect and compute positions and distances when staking?
    (Y/N)
12. Which document should the Contractor refer to, in order to understand how to operate electronic devices or software used to gather, store, and/or calculate position data?
    (Manufacturer's manual; Construction manual; Other)
13. When the slope is not a "catch" and the slope stake is not on a constant cut/fill line, is the cut/fill shown on the stake computed using the digital models and the actual ground elevation with the help of electronic devices?
    (Y/N)
14. How is the ground measured?
    (At each grade break; Every 25 feet; Other)
15. When is the measurement stopped?
    (Until the profile grade line for the station is reached; The difference between the measured ground elevation and the elevation computed is less than the tolerance; Other)
16. If a tolerance is used to determine the stop of the measurement, what is the specified horizontal tolerance?
    (0.5 feet; Other)
17. If a tolerance is used to determine the stop of the measurement, what is the specified vertical tolerance?
    (0.1 feet; Other)
18. Is the stake/field book automatically generated by the electronic devices?
    (Y/N)

APPENDIX D

Questionnaire for Surveying Design Staff in State Department of Transportation on Current Practices Employed about Adapting Construction Staking to Modern Technologies

The form consists of **three** sections and has **34** questions. It will take you about **20 minutes** to complete all the questions.
If you **do not know** the answer to a question, please respond *Do not know* instead of randomly providing an answer.
If you choose *Other*, please provide **you own answer** to the question.

Section 1: Respondent Information
Please provide the following information:
Name:
Agency:
Job title:
Years of experience:
Phone:
Email:

Section 2: Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying

1. Based on your agency's experience in the past year, how many highway projects regulated by your agency utilized GPS technology in construction surveying?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All projects)
2. If you did NOT answer "All projects" to the previous question, why was GPS technology NOT used during construction surveying?
   [Unawareness of benefits (DOT); Unawareness of benefits (Contractor); Not required by DOT; Lack of specifications by DOT; Procedural issues (DOT); Procedural issues (Contractor); Lack of GPS equipment (DOT); Lack of GPS equipment (Contractor); Lack of end-user technical skills (DOT); Lack of end-user technical skills (Contractor); Cost of acquiring and operating GPS equipment; Inconstant signals; Limited accuracy; Other]
3. Which of the following options best describe the DOT's specifications with respect to the use of GPS technology in construction surveying?
   (Allow unlimited use; Allow limited use; Prohibit use; Mandate use; Are silent)
4. Based on your agency's experience, indicate your level of satisfaction with the use of GPS technology in construction surveying for each of the following activities.
   (Project control surveying; Automated machine guidance; Staking for grading; Staking for paving; Staking structure; Staking drainage and pipeline; Staking slope; Staking base; Staking curb and gutter; Staking concrete barrier; Preparation of surveying data deliverable; Construction staking bid item measurement; Other)
   [1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat

satisfied; 5: Satisfied; 6: Very satisfied]

5. Which of the following benefits did your agency experience when using GPS technology in construction surveying?
   (Decrease crew size; Facilitate measurement of vertical distance; Decrease the duration of surveying; Decrease the cost; Make it possible to work under bad weather conditions; Improve the precision of survey; Reduce staking workload; Other)
6. Based on your agency's experience, indicate the level of significance that the following factors had in contributing to the success of GPS implementation at your agency?
   [Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with GPS technologies (DOT); Experience with GPS technologies (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]
   [1: Very insignificant; 2: Insignificant; 3: Somewhat insignificant; 4: Somewhat significant; 5: Significant; 6: Very significant]
7. Based on your agency's experience, which of the following are difficulties or challenges to the use GPS technology in construction surveying?
   (None; Less trained equipment operators; Inefficient communication between Contractor and DOT; Harsh weather conditions; Interruption due to power failure; Reading and recording wrong antenna height; Unstable GPS signal; All parties need to be on the same site calibration; All parties need to use the same data files; Other)

<u>Section 3: Digital Models and Electronic Data Exchange Practices</u>

Based on your experience in using digital models and electronic data exchange practices in construction surveying for highway projects, please answer the following questions:

1. Based on your agency's experience in the past year, how many highway construction surveys are using digital models?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
2. Based on your agency's experience in the past year, how many of these highway construction surveys (that are using digital models) are using the following software for creating and updating the digital models?
   [AutoCAD Civil 3D; AutoCAD Map 3D; Autodesk Navisworks Simulate; Bentley ConstrucSim; MicroStation; GEOPAK; InRoads; Trimble Business Center; Other]
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All)
3. Indicate your level of satisfaction with the use of the following software in supporting construction surveying.
   [AutoCAD Civil 3D; AutoCAD Map 3D; Autodesk Navisworks Simulate; Bentley ConstrucSim; MicroStation; GEOPAK; InRoads; Other]
   (1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat

satisfied; 5: Satisfied; 6: Very satisfied)

4. Which of the following benefits are involved with the use of digital models in construction surveying for highway projects?
   (Simulate and visualize the project more accurately; More quickly perform quantity takeoffs; Deliver models of higher quality to Contractor for automated machine guidance; Combine multiple types of data such as CAD and geospatial data; Standardize the as-built data collection process; Improve access to highway project information; Facilitate information exchange among stakeholders; Streamline different phases such as design, construction, operation, and maintenance; Decrease the risk of redoing; Improve bid accuracy; Other)
5. How does the use of digital models affect the project time?
   (Does not have any effect on project time; Saves less than 25% of project time; Saves over 25% of project time but less than 50% of project time; Saves over 50% of project time; Add project time; Does not save or add time, but spends more time on earlier stages and less on later stages; Does not save or add time, but spends less time on earlier stages and more on later stages; Other)
6. If time savings are reported, which of the activities are associated with the most time saving?
   (Project control; Grading; Paving; Earthwork and excavation; Curb and gutter construction; Pipe and drainage construction; Structure construction; Site calibration and check; Preparation of deliverable; Other)
7. How does the use of digital models affect the project cost?
   (Does not have any effect on project cost; Saves less than 10% of project cost; Saves over 10% of project time but less than 25% of project cost; Saves over 25% of project cost; Adds project cost; Does not save or add cost, but spend more on earlier stages and less on later stages; Does not save or add cost, but spend less on earlier stages and more on later stages; Other)
8. If cost savings are reported, which of the activities are associated with the most cost saving?
   (Project control surveying; Automated machine guidance; Staking for grading; Staking for paving; Staking structure; Staking drainage and pipeline; Staking slope; Staking base; Staking curb and gutter; Staking concrete barrier; Preparation of surveying data deliverables; Construction staking bid item measurement; Other)
9. If digital models are used in construction surveys, which of the following are barriers or challenges to successful implementation?
   (Training is difficult; Software get updated frequently; Software cannot fulfill certain tasks; Inefficient communication among stakeholders; DOT lack of experience; Contractor lack of experience; DOT lack of specifications; Procedural issues; Cost issues; Other)
10. If digital models are NOT used in construction surveys, what are the reasons why they are not used or what are the barriers to implementation?
    (Training is difficult; Software get updated frequently; Software cannot fulfil certain tasks; Upfront cost of software and hardware is high; Cost of implementation is high; Lack of specifications; Reluctance to learn new technology; Unawareness of

benefits of new technology; Legal concerns about sharing data; Other)

11. In construction projects using digital models, which of the following factors contribute to the success of implementation of the mentioned software?
    [Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive contract specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with the software (DOT); Experience with the software (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]
12. Who is responsible for providing the digital models used for AMG?
    (DOT; Contractor)
13. Who is responsible for updating and revising the digital models used for AMG?
    (DOT; Contractor)
14. Who is responsible for any errors or omissions in the digital models used for AMG?
    (DOT; Contractor)
15. Are the digital models generated by the Contractor allowed to be different from the design files provided by the DOT?
    (Y/N)
16. Who is responsible for any discrepancies between the design files provided by DOT and the 3D models generated by the Contractor?
    (DOT; Contractor)
17. What electronic data are provided by the DOT to the Contractor?
    (Cross section; Machine control surface model files; Alignment data files; Background graphics file with roadway and drainage features such as centerlines, edges and hull of ponds; Other)
18. When are the electronic data provided to the Contractor?
    (After the Contractor wins the bid; Before the preconstruction conference; After the preconstruction conference; At request by the Contractor; Other)
19. Indicate your level of satisfaction with providing electronic data to the Contractor during construction.
    (1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat satisfied; 5: Satisfied; 6: Very satisfied)
20. What are the main uses of existing electronic data provided by the DOT?
    (Check quantities; Build digital model; Layout survey; Exchanging information with DOT personnel; Acquire accurate information about position, distance, etc.; Other)
21. What are the additional electronic files that should be provided by the DOT if NOT provided now?
    (Cross section; Machine control surface model files; Alignment data files; Background graphics file with roadway and drainage features such as centerlines, edges and hull of ponds; Other)
22. Which of the following benefits are involved with providing electronic data to the Contractor?
    (Cost savings; Time savings; Improved project quality; More accurate bids; Fast

identification of errors; More accurate digital models; Other)

23. How do additional electronic data affect the workload of the DOT?
    (No effect; Decreases the workload; Increases less than 25% of the workload; Increases about or over 25% of the workload; Especially increases the workload during preparation of data provided to Contractor; Especially increases the workload during construction stage due to additional quality control; Other)
24. What are the specified deliverables that should be submitted by the Contractor to the DOT?
    (GPS/AMG work plan; Survey control report; Quality control (QC) plan; Report of post project benchmarks; As-built construction plan; Survey notebooks; Other)
25. What is the specified format of the digital models?
    [ASCII; LandXML; ALG (InRoads geometry); CSV (Comma-separated values); DC (Data Collector file used in Trimble Survey Controller); DGN (MicroStation drawing files); DWG (Native format of AutoCAD); DXF (Data exchange file); DTM (Digital terrain model); GPK (GEOPAK coordinate geometry file); IRD (InRoads roadway definition file); TIN (Triangulated Irregular Network); SHP (Shapefile spatial data format); Other]
26. What should the GPS/AMG work plan contain?
    (Description of equipment and software; Contractor’s experience; Definition of project boundaries and scope of work to be accomplished using GPS/AMG; Project secondary control; Site calibration procedure; Equipment calibration and maintenance procedure; Other)
27. What is the specified time at which the GPS/AMG work plan should be submitted?
    (5 working days or one week prior to primary field operation; 5 working days or one week prior to preconstruction conference; 30 days prior to primary field operation; Other)

APPENDIX E

Questionnaire for Surveying Surveying Staff in State Department of Transportation on Current Practices Employed about Adapting Construction Staking to Modern Technologies

The form consists of **four** sections and has **16** questions. It will take you about **10 minutes** to complete all the questions.
If you **do not know** the answer to a question, please respond *Do not know* instead of randomly providing an answer.
If you choose *Other*, please provide **you own answer** to the question.

Section 1: Respondent Information
Please provide the following information:
Name:
Agency:
Job title:
Years of experience:
Phone:
Email:

Section 2: Extent of Use, Satisfaction, Benefits, Success Factors, and Barriers of/with GPS Technology in Construction Surveying

1. Based on your agency's experience in the past year, how many highway projects regulated by your agency utilized GPS technology in construction surveying?
   (None; Less than 25%; 25% to 50%; 50% to 75%; More than 75%; All projects)
2. If you did NOT answer "All projects" to the previous question, why was GPS technology NOT used during construction surveying?
   [Unawareness of benefits (DOT); Unawareness of benefits (Contractor); Not required by DOT; Lack of specifications by DOT; Procedural issues (DOT); Procedural issues (Contractor); Lack of GPS equipment (DOT); Lack of GPS equipment (Contractor); Lack of end-user technical skills (DOT); Lack of end-user technical skills (Contractor); Cost of acquiring and operating GPS equipment; Inconstant signals; Limited accuracy; Other]
3. Which of the following options best describe the DOT's specifications with respect to the use of GPS technology in construction surveying?
   (Allow unlimited use; Allow limited use; Prohibit use; Mandate use; Are silent)
4. Based on your agency's experience, indicate your level of satisfaction with the use of GPS technology in construction surveying for each of the following activities.
   (Project control surveying; Automated machine guidance; Staking for grading; Staking for paving; Staking structure; Staking drainage and pipeline; Staking slope; Staking base; Staking curb and gutter; Staking concrete barrier; Preparation of surveying data deliverable; Construction staking bid item measurement; Other)
   [1: Very dissatisfied; 2: Dissatisfied; 3: Somewhat dissatisfied; 4: Somewhat

satisfied; 5: Satisfied; 6: Very satisfied]

5. Which of the following benefits did your agency experience when using GPS technology in construction surveying?
   (Decrease crew size; Facilitate measurement of vertical distance; Decrease the duration of surveying; Decrease the cost; Make it possible to work under bad weather conditions; Improve the precision of survey; Reduce staking workload; Other)
6. Based on your agency's experience, indicate the level of significance that the following factors had in contributing to the success of GPS implementation at your agency?
   [Cooperation of surveyors; Cooperation of DOT designers; Clear and comprehensive specifications; End-user training (DOT); End-user training (Contractor); Equipment sharing between DOT and contractor; Hardware/software vendor support; Experience with GPS technologies (DOT); Experience with GPS technologies (Contractor); Clear and comprehensive description of workflow and responsibilities; Other]
   [1: Very insignificant; 2: Insignificant; 3: Somewhat insignificant; 4: Somewhat significant; 5: Significant; 6: Very significant]
7. Based on your agency's experience, which of the following are difficulties or challenges to the use GPS technology in construction surveying?
   (None; Less trained equipment operators; Inefficient communication between Contractor and DOT; Harsh weather conditions; Interruption due to power failure; Reading and recording wrong antenna height; Unstable GPS signal; All parties need to be on the same site calibration; All parties need to use the same data files; Other)

<u>Section 3: Control Surveying Using GPS Technology and Real Time Kinematic (RTK) Method</u>

Based on your experience in using GPS technology in <u>control surveying and RTK method</u>, please answer the following questions:

1. Who is responsible for performing secondary control surveys for the project?
   (DOT; Contractor)
2. If Automated Machine Guidance (AMG) is used, are additional horizontal and vertical control surveys required?
   (Y/N)
3. Which of the following office procedures are done when conducting RTK control surveying?
   (Check the data collector file for correctness and completeness; Check the base station coordinates and ellipsoid height for correctness; Analyze the GPS site calibration for a high scale factor and high residuals; Compare check shots with the known values; Check all reports for high residuals; Other)
4. Which of the following types of base station networks are utilized by your agency?
   (CORS; OPUS; HARN; VRS; NDGPS; Other)
5. What are the required deliverables that should be submitted by the Surveyor for a

GPS control survey?

(Project narrative summary; Names of individuals and duties; Coordinates; Coordinate metadata; Project site map; Equipment logs; Calibration report for all points used in the survey; Primary control checks; Post-process report; Weather condition report; GPS raw and solution files; Other)

6. Please provide the link to the manual or document that includes the DOT specifications about GPS RTK survey design, setup, and operation, including: Minimum number of horizontal and vertical Real Time Kinematic (RTK) control stations; Horizontal and vertical tolerances; Maximum Position Dilution of Precision (PDOP); Minimum number of satellites observed simultaneously; Maximum epoch interval for data sampling; Minimum number of epochs of collected data for each observation; Minimum time between repeat observations; Maximum difference in horizontal or vertical coordinates of the second occupation from the first occupation; Maximum distance from the base station to the rover units; Minimum satellite mask above the horizon; Geometry of control stations; Minimum level of accuracy of control stations; Whether the base station is occupied by an RTK control station; Whether the base station use a fixed height tripod.

   If the specifications are included in more than one document, please provide the links to ALL documents.

   If a document is not available online, please send a copy of the document to gohary@illinois.edu.

SECTION 4: CONSTRUCTION SURVEYING USING GPS EQUIPMENT

Based on your experience in construction surveying using GPS equipment, please answer the following questions:

1. What types of GPS equipment checks are specified/required?
   (None; Federal published calibration baseline check by NGS; Zero baseline check of antenna, receiver, and cables according to manufacturer; Primary control check; Other)
2. If you answered "None" to Question 1, what types of GPS equipment checks do you perform?
   (None; Federal published calibration baseline check by NGS; Zero baseline check of antenna, receiver, and cables according to manufacturer; Primary control check; Other)
3. What is the frequency of GPS equipment checks you perform?
   (At beginning and end of survey; Every six months; By request of Engineer or Contractor; Other)

ICT Project R27-163

Adapting Construction Staking and Inspection to Modern Technology

Internal Interim Report #3
(DRAFT)

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For Period:	September 01, 2016-March 15, 2017
Status:	**DRAFT**

1 INTRODUCTION

1.1 Project Motivation

The Illinois Department of Transportation (IDOT) has no written specifications, guidelines, or policies for the use of 3D computer-aided design and drafting (CADD) models, information models for highways [known as civil information models (CIM)], global positioning system (GPS), or other modern technologies that have developed over the past 10 years for highway construction. Such technologies could support various construction processes (e.g., staking) and could offer major opportunities for quality improvements, cost savings, and expediting project delivery. Many contractors also request the project CADD files for positioning devices used on their construction equipment for grading and paving. However, IDOT's policies and guidelines (e.g., IDOT's Construction Manual) do not address this practice and are out of date with modern technologies. As such, IDOT needs to develop written procedures for the use of these modern technologies in construction staking of highway projects for inclusion in IDOT's Construction Manual.

1.2 Project Objectives

The main goal of this research project is to develop written procedures for the use of modern technologies (such as GPS, CADD models, and civil information models) in construction staking of highway projects in the State of Illinois for inclusion in IDOT's Construction Manual, which would enable the employment of these technologies in Illinois, and in turn offer major opportunities for quality improvements, cost savings, and expediting project delivery.

To accomplish this critical goal, the research objectives of this project are:

1) Provide a comprehensive literature review of the use of modern technologies by industry and other state DOTs, relevant construction manuals by other state DOTs that cover the use of these modern technologies (e.g., WisDOT's 2014 Construction and Material Manual), relevant state and federal regulations, guidelines, and protocols/policies on the use of these technologies, and relevant research studies on the use of these technologies. The scope will focus on technologies that could support construction staking of highway projects such as GPS, CADD models, and civil information models.
2) Conduct a survey to gather information from state DOTs and contractors on current practices employed by other states that successfully adopted these technologies for construction of highways.
3) Identify a set of potential practices for employment in the State of Illinois, based on the literature review and the survey results (i.e., based on the results of Objectives 1 and 2).

4) Conduct a survey to gather feedback from IDOT staff and Illinois contractors on the potential success and suitability of these potential practices in the State of Illinois.
5) Develop recommendations for IDOT's written procedures for the use of these technologies in construction staking of highway projects to be included in the IDOT's Construction Manual, based on the data collected and the survey results (i.e., based on the results of Objectives 3 and 4). This written procedures are intended to support construction staking processes when a contractor employs such technologies.

1.3 Project Tasks and Deliverables

The methodology breaks down the research work into six primary tasks that lead to four project deliverables, as shown in Figure 1.

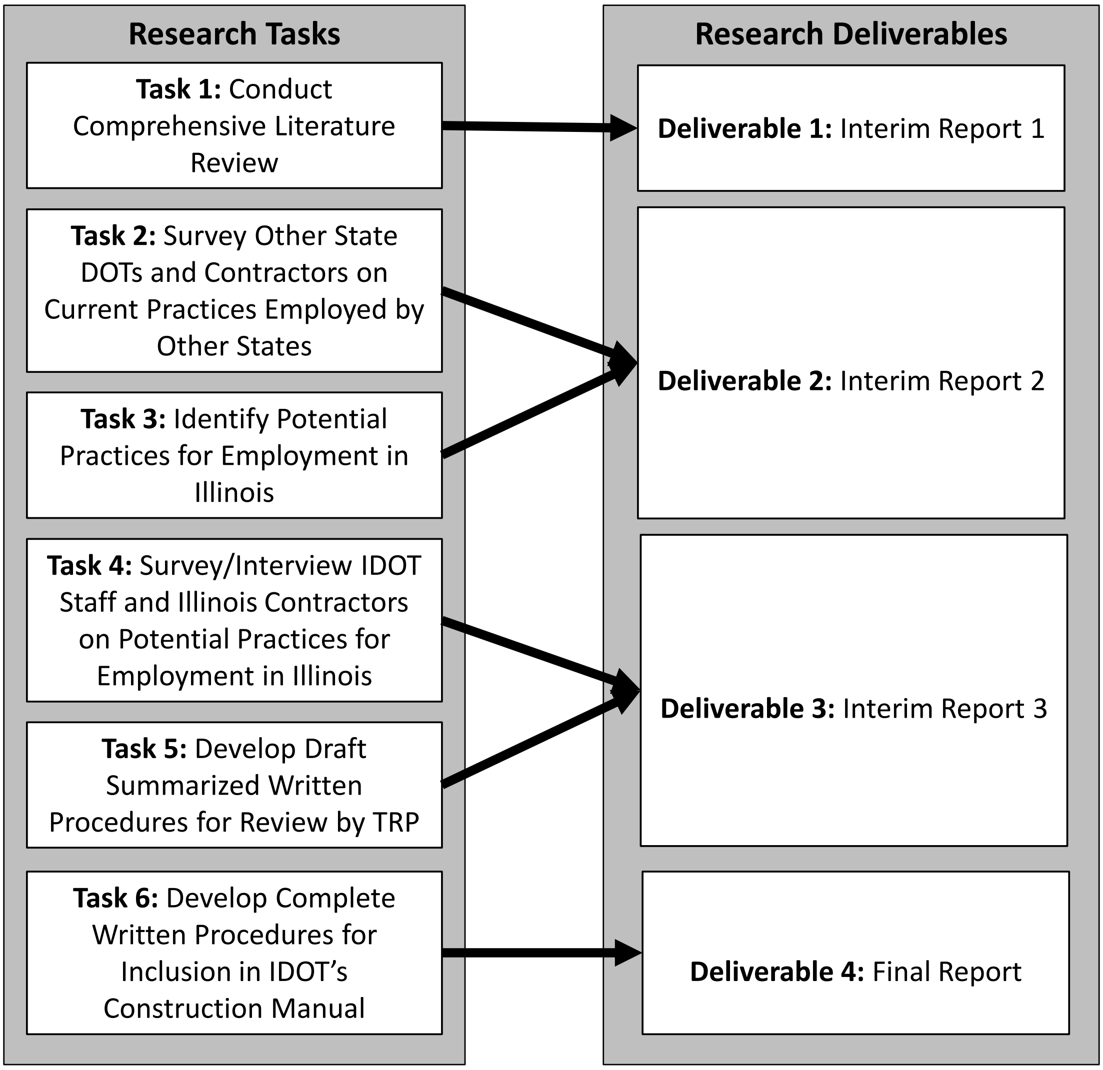

Figure 1: Research methodology.

1.4 Scope and Organization of this Report

This interim report intends to summarize the outcomes of Task 4 (Survey/Interview IDOT Staff and Illinois contractors on Potential Practices for Employment in Illinois) and Task 5 (Develop Draft Summarized Written Procedures for Review by TRP). Task 4 started on August 16, 2016 and was completed on December 15, 2016. Task 5 started on December 16, 2015 and was completed on March 15, 2017. Task 4 focused on conducting a personal interview survey (using a questionnaire) to gather feedback from IDOT staff (from all the nine Districts) and Illinois contractors on the potential practices to use for automated machine guidance (AMG) and digital models, which were identified and developed in the previous tasks. In Task 5, the research team revised the potential practices for employment in Illinois based on the analysis of the results of the survey in Task 4 and developed the practices into draft written procedures related to the use of modern technologies for construction staking of highway projects to be included in the IDOT's construction manual. The draft will be the basis of the complete written procedures (Task 6), which is the final outcome of this research project.

2 TASK 4: SURVEY/INTERVIEW IDOT STAFF AND ILLINOIS CONTRACTORS ON POTENTIAL PRACTICES FOR EMPLOYMENT IN ILLINOIS

2.1 Survey Purpose and Methodology

The purpose of the survey was to gather feedback from IDOT staff and Illinois contractors on the potential practices for adopting modern technologies for construction staking of highways in the State of Illinois (identified in Task 3). The practices were organized into eleven groups: (1) evaluation of construction methods, (2) automated machine guidance equipment, (3) automated machine guidance work plan, (4) training, (5) electronic design files, (6) digital models used for AMG, (7) project control, (8) accuracy and tolerance, (9) quality assurance, (10) site calibration and check, and (11) final check.

The research team conducted a personal interview survey (also called face-to-face survey) using a questionnaire. The research team first developed a draft questionnaire including the potential practices (identified in Task 3) and a corresponding set of questions (to solicit detailed feedback on each of the potential practices). In the September 28, 2016 TRP meeting, the research team discussed the draft questionnaire with the TRP. Based on the discussions during the meeting, the research team revised the questionnaire. Feedback was solicited on different aspects of the practices, including technical content, relevance, suitability, clarity, wording, etc. For example, the wording was discussed to ensure that it reflects the intent of serving as guidelines not specifications. The final questionnaire was then approved by the TRP and the survey was launched on October 15, 2016.

The target respondents included: (1) resident and field engineers, inspectors, technicians, and surveyors from all nine IDOT Districts, and (2) contractors from the Associated General Contractors of Illinois and the Illinois Road and Transportation Builders Association. One interview meeting was scheduled at each District, where the meeting was attended by multiple IDOT staff from that District. The date, location, and number of participants for each interview meeting are listed in Table 1. A total of 78 responses were received from the IDOT Districts, and 1 response from the contractors.

Table 1: Dates, Locations, and Participants for Interview Meetings with IDOT Districts/Contractors

IDOT District/contractor	Date	Location	Number of respondents
District 1	October 31	Schaumburg	7
District 2	November 15	Dixon	11
District 3	October 28	Ottawa	4
District 4	November 15	Peoria	9
District 5	November 3	Champaign	8
District 6	November 1	Springfield	5
District 7	November 3	Effingham	18
District 8	November 1	Collinsville	8
District 9	November 2	Carbondale	8
K-Five Construction	December 1	Chicago*	1

*The meeting was done through phone, not face-to-face.

2.2 Questionnaire Design

The questionnaire was composed of twelve sections: (1) respondent information, (2) evaluation of construction methods, (3) automated machine guidance equipment, (4) automated machine guidance work plan, (5) training, (6) digital models used for AMG, (7) electronic design files, (8) project control, (9) accuracy and tolerance, (10) quality assurance, (11) site calibration and check, and (12) final check.

Each section in the questionnaire was composed of two parts:

1) The practice part: this part included the full description of the potential practice. Some words/sentences were underlined to draw the attention of the respondents to particular parts that required extra feedback. Some alternative wording was also included in square brackets. Figure 2a shows an example of the practice part [of Section 5 (Training)].
2) The question part: this part consisted of questions on the respective practice to gather the respondents' feedback. Respondents were requested to first read the practice part, and then answer the questions based on their knowledge and experience with the use of AMG. The last question of each section is a comprehensive question asking the respondent whether he/she generally agrees with the content of the section as written. Figure 2b shows an example of the question part [of Section 5 (Training)].

The full questionnaire is included in Appendix A.

5. Section 5: Training

1) The Contractor shall provide [the Contractor staff] with training [on the use and operation] of the AMG equipment [prior to the start of any AMG work]. The Contractor shall provide [the Department staff] with training [on the use and operation] of the AMG system [and the use of GPS Rovers or other hand-held devices] [prior to the start of any AMG work]. The Department and the Contractor shall discuss and determine which Contractor staff and Department staff will participate in the training. As part of the staff, the Surveyors (IDOT's Surveyors and Contractor's Surveyors) may participate in the training to get familiar with the Contractor's AMG system or the GPS Rovers used for checking and inspection. The Surveyors can stay involved in the project using AMG by learning the capabilities of the AMG system and Rovers and being available to provide information to new surveyors and equipment operators who have difficulties in using such system or devices.
2) The Contractor shall provide more training upon the request of the Department. The Department shall request more training based on need.
3) The Contractor shall seek technical support from the equipment manufacturer or vendor, as appropriate, if/as necessary. The Department shall encourage the Contractor to seek such technical support, if/as needed.

(a)

Questions: (6)

1) Who shall receive the training?
   [District engineer; Surveyors; Other]
2) For each, what is the frequency of training?
   [One; At least one; Each month; Other]
3) For each, when shall the training be provided?
   [Prior to the start of any AMG work; At the beginning of each month; Other]
4) For each, how many sessions per training?
   [One; Two; As specified by the Department; Other]
5) For each, what shall be covered in the training?
   [AMG equipment; Digital models; Software; Devices for review such as rovers; Other]
6) Do you agree with roles and responsibilities, types of training, time and frequency of training, and requirements that are described in the "Training" Section?
   [1 to 6 scale]

(b)

Figure 2: Example section (Section 5) from the questionnaire.

Three types of questions were developed: (1) multiple choice questions, which ask the respondents to select one or more options among a number of options/alternatives, (2) dichotomous questions, where there are two possible responses (e.g., yes/no), and (3) short answer questions, which ask the respondents to provide a specific information (e.g., specify other characteristics that make projects the best candidates for AMG methods). For multiple choice questions that require respondent's rating of agreement level, a six-point Likert scale was used, with 6 being very agree and 1 being very disagree. For most multiple choice questions, an "other" option was added – with a blank – so that the respondents can provide additional responses/information, without being constrained by the response options provided. The respondents were encouraged to answer as many as questions as possible, and make comments on the practices or the questions. The face-to-face format helped ensure high engagement in the interview and high response rate for all questions.

The questions aimed to gather expert feedback on the details of technology implementation such as responsibilities, submissions, timelines, methods and equipment, work planning, training, use of digital models and electronic files, project control, accuracy and tolerances, quality assurance, site calibration, and checking. The questions also aimed to gather feedback on whether a certain practice is suitable for being included in the Construction Manual or not. The content of each of the twelve sections is summarized as follows:

1) Section 1 (Respondent Information) solicited respondent information, including name, agency, job title, role, years of experience, phone, and email.
2) Section 2 (Evaluation of Construction Methods) aimed to gather respondent feedback on the evaluation of construction methods, including best candidate projects for the implementation of AMG, conditions that would limit the use of AMG, and evaluation of suitability of use of AMG.
3) Section 3 (Automated Machine Guidance Equipment) aimed to gather respondent feedback on automated machine guidance equipment, including the use of a list of approved AMG equipment, submission of AMG equipment information, provision of AMG equipment, setup of GPS base station, and storage and maintenance of AMG equipment.
4) Section 4 (Automated Machine Guidance Work Plan) aimed to gather respondent feedback on the Automated Machine Guidance Work Plan, including the scope and items to be covered in the plan, as well as the review and evaluation of the plan by the Department.
5) Section 5 (Training) aimed to gather respondent feedback on training related to the use of AMG, including provision of training to both contractor and Department staff, and seeking technical support from the manufacturer. Questions covered issues such as frequency and timing of training, scope of training, number of training sessions, etc.
6) Section 6 (Digital Models Used for AMG) aimed to gather respondent feedback on the use of digital models for AMG, including developing, submitting, updating, and revising the digital models; responsibility for errors or omissions in the models; reviewing and inspecting the models; and the responsibility for bearing the respective costs.
7) Section 7 (Electronic Design Files) aimed to gather respondent feedback on the use of electronic files provided by the Department, including the scope of

electronic files provided to the contractor, the timing to provide the files, the use and maintenance of the files, and the notification of errors or discrepancies in the files.

8) Section 8 (Project Control) aimed to gather respondent feedback on project control when AMG is used in the project, including setup of control points, deliverables, and responsibility for provision of control points.
9) Section 9 (Accuracy and Tolerance) aimed to gather respondent feedback on accuracy and tolerance requirements when AMG is used in the project.
10) Section 10 (Quality Assurance) aimed to gather respondent feedback on quality assurance practices when AMG is used in the project, including responsibility, timing, and methods for conducting spot checks; and provision and review of progress information.
11) Section 11 (Site Calibration and Check) aimed to gather respondent feedback on site calibration and check when AMG is used in the project, including site calibration procedures, number of points, and tolerances; and procedures to follow when the site calibration check does not pass.
12) Section 12 (Final Check) aimed to gathering respondent feedback on the final check procedures when AMG is used, including locations and intervals to set stakes for checking, number of final checks, and checking criteria.

2.3 Survey Results

2.3.1 Distribution of Respondents

The research team received 78 responses from all nine IDOT Districts. The names and distribution of respondents by District is shown in Table 2. The respondents included: engineers, surveyors (including survey crew chief), inspectors, supervisors, and technicians. The titles of the respondents included: field engineer, engineer technician, civil engineer, construction engineer, resident engineer, construction inspector, supervising field engineer, land surveyor, resident technician, engineer technician – surveyor, acting project implementation engineer, survey crew chief/data coordinator, and area construction supervisor. The research team also received a response from Justin Smith, who represented K-Five Construction Corp. and is a member of the Illinois Road and Transportation Builders Association.

Table 2: Names of Respondents and Distribution by District

IDOT District	Respondents	
	Names*	Number
District 1	Phillip Gibson, Jonathan M. Schumacher, Michael Denne, Christopher Haydel, Raymond Bolyn, Jean Carlo Ruge, Kurt Kaldenberger	7
District 2	Ryan Hippen, Matthew Kelly, Nick Richmond, Alan Swearingen, Mark Morgan, Ryan Hockman, Stephanie McMeekan, David von Kaenel, Lucas Megli, Chad Pink, Sara Renkes	11
District 3	Nathan Sell, Jim Snyder, Jim Vaninger, Joe Wick	4
District 4	Bob Hack, Eric Prichard, Nick Volk, Josh Knowles, Letisha Davis, James Berry, Bill Lewis, Ben Tellerson, Imad Mohamed	9
District 5	Mitchell Baird, Mike Carnahan, Ken Crawford, Mike Young, Dan Craddock, Doug Clement, Jason Smith, Joseph Herbert	8
District 6	Rich Bruce, Todd Johnson, Dave Weuer, Dave Shah, Ron Archambeau	5
District 7	Richard Murray, Brian Stirrett, Glen Bushur, Phil Barrett, Steve E. Miller, Patrick Platz, Matt Baird, Scott Cole, Mark Tucker, Jerry Mastin, Rod Pearson, Lyle Heitman, Randy Alwardt, Doug Holland, Mike Fox, Scott McGuire, Joey Czyzewski, Voan Nava-Sifurntrs	18
District 8	Paul Grabowsky, Dan Hartwk, John Schubal, Breh Schwalb, Jim Cox, Tom Borsch, Ted Nemsky, John Adcock	8
District 9	Mike Fuhrhop, Luke Estel, Paul Platz, Bill Barnes, Travis Bradlay, Aaron Hayes, Bill Zdankicwich, John Eaton	8
Total		78

* Spelling errors are possible due to unrecognizable handwriting.

2.3.2 Survey Results

2.3.2.1 General Feedback

Most of the respondents thought that the questionnaire provides rich information about the use of AMG and is comprehensive. The average time needed to finish the whole questionnaire was about 1 hour and 15 minutes. The remainder of this subsection summarizes the respondents' general feedback on: (1) the overall content and scope of the practices and the written procedures (in view of its planned inclusion in IDOT's Construction Manual), and (2) the wording/writing style of the written procedures.

Most of the respondents provided the following feedback:

- All the main practices (i.e., 11 main sections and general content) should be covered in the written procedures (which would be included in IDOT's Construction Manual). The overall content and scope of the practices and the written procedure was viewed as suitable and relevant.

- Some of the written details provided, such as intervals of stakes and tolerance requirements, are project specific and can be found in IDOT's construction specifications; and therefore these do not need to be repeated in the subject written procedures.
- The wording/writing style of the practices/procedures should be modified, where/as applicable, so that the document is not worded like specifications to the contractor.

One respondent suggested that IDOT may, in the future, reuse some of the descriptions in the written procedures when developing future specifications: "Much of this document implies it will be included in some future specifications. I believe that some points in this document would be well served in a specification (e.g., contractor providing the engineer with a rover and training)."

Respondents had diversified opinions on the following issues:

- Contractor providing AMG equipment such as rovers: Some respondents thought that it is not a good idea that contractors provide rovers, because it is difficult to include in pay items. On the other hand, other respondents believed that it is a good arrangement that contractors provide rovers, and suggested that contractors provide more than one rover (e.g., a rover for the use of the Department independent from the one used by the contractor).
- Whether conventional stakes are needed and how many stakes are needed: Generally, respondents from Districts that use AMG less intensely agreed that the same number of stakes is needed when using AMG (compared to conventional staking). On the other hand, respondents from Districts that commonly use AMG agreed that only a few stakes are needed and no stakes are needed. The contractor respondent also agreed that no stakes are needed for the process of AMG checks at the time of construction, as long as the checks and tolerances are met.
- Whether checks are needed and how many checks shall be performed: Some respondents reported that no checks are needed unless there is a problem. On the other hand, most respondents reported that checks are needed, with the majority of them agreeing that the Department inspector should conduct such checks rather than the contractor conducting the check with the Department's staff witnessing.

Some respondents pointed out that the term "IDOT surveyor" is too general and suggested the use of more specific terms to describe the role(s) such as "resident engineer/technician", "field engineer/technician", and "inspector".

The detailed respondent feedback and questionnaire responses are summarized in the following subsections.

2.3.2.2 Evaluation of Construction Methods

Responses to the Questions

The following points provide a summary of the main findings:

1) The respondents agreed to include this section in the Construction Manual.
2) Most of the respondents agreed that the conditions that limit or exclude the use of AMG should be included in the written procedures. But opinions slightly varied.
3) Most of the respondents thought that the contractor should submit the notification for use of AMG before or at the preconstruction meeting.

All questions and a summary of their response results are shown below (see Table 3-Table 6).

1. If you suggest other characteristics that make projects the best candidates for AMG methods, please specify.

Table 3: Survey Results – Characteristics Making Projects the Best Candidates for AMG Methods

No.	Result
1	Complex project. The more complex the project is the more useful the use of AMG and digital models are.
2	Urban reconstruction and larger reconstruction projects.
3	Small earthwork projects.
4	Projects with limited site width due to construction staging or physical constraints.

2. Do you agree that the conditions that limit or exclude the use of AMG shall be included in the guidance document? Such conditions include, but not limit to:
   - Widening with narrow strip additions
   - Designs, such as overlays, that are not based on an existing (Digital Terrain Modeling) DTM. Overlays with new profiles or cross slope construction benefit from AMG
   - Designs that do not exist in a 3D digital environment (note that all jobs are capable of being modeled)
   - Structures
   - Projects that are under a tree canopy, in narrow canyons, or next to tall buildings that interfere with GNSS signals (note that robotic total stations or traditional methods are viable solutions)
   - Design difficulties that would prevent the creation of an accurate and complete DTM (if a surface model can be prepared in difficult situations, it saves on rework).

Table 4: Survey Results – Conditions that Limit or Exclude the Use of AMG

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q2	4 (5%)	6 (8%)	5 (6%)	15 (19%)	39 (51%)	8 (10%)	4.34	5	5	1.29	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

3. When shall the Contractor submit the notification for use of AMG?

Table 5: Survey Results – When Shall Contractors Submit Notification of Using AMG

Response Option	Result
After project award	12 (18%)
Before the preconstruction meeting	36 (54%)
Other	a) At preconstruction meeting: 16 (22%) b) Prior to use/start of project: 2 (3%) c) Both options: 2 (3%)

4. Do you agree with the roles and responsibilities, submissions, timeline, evaluation criteria, and requirements that are described in the "Evaluation of Construction Methods" Section?

Table 6: Survey Results – Summary Question for Section 2 (Evaluation of Construction Methods)

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q4	0 (0%)	0 (0%)	2 (3%)	16 (22%)	49 (67%)	6 (8%)	4.81	5	5	0.61	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

<u>Respondents' Comments</u>

1) Whether to use AMG or not should be the contractor's decision/choice.
2) The following conditions always limit the use of AMG:
    - Designs, such as overlays, that are not based on an existing Digital Terrain Modeling (DTM). Overlays with new profiles or cross slope construction benefit from AMG.
    - Structures.
3) The following conditions might or might not limit the use of AMG – it is project specific, and should be assessed case by case:
    - Widening with narrow strip additions.
    - Designs that do not exist in a 3D digital environment (note that all jobs are capable of being modeled).
    - Projects that are under a tree canopy, in narrow canyons, or next to tall buildings that interfere with GNSS signals (note that robotic total stations or traditional methods are viable solutions).

- Design difficulties that would prevent the creation of an accurate and complete DTM (if a surface model can be prepared in difficult situations, it saves on rework).

2.3.2.3 Automated Machine Guidance Equipment

Responses to the Questions

The following points provide a summary of the main findings:

1) The respondents agreed to include this section in the Construction Manual, with minor changes.
2) Most of the respondents agreed that the AMG equipment information should be included in the AMG Work Plan.
3) Most of the respondents agreed that the AMG equipment information should include a description of the manufacturer, the model used, and the software version. Other information mentioned by the respondents includes accuracy, radio frequency, operation manual, and last calibration date of the equipment.
4) Most of the respondents agreed that the Department does not have to provide a list of approved AMG equipment, thereby leaving the choice of specific AMG equipment to use to the contractor.
5) The most repeated response option for maintenance frequency is “as needed”.

All questions and a summary of their response results are shown below (see Table 7-Table 11).

1. Do you agree that the Contractor submits the AMG equipment information as a part of the AMG plan?

Table 7: Survey Results – Contractor Submits AMG Equipment Information

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q1	0 (0%)	0 (0%)	1 (1%)	6 (8%)	45 (59%)	24 (32%)	5.21	5	5	0.63	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

2. What shall the AMG equipment information include?

Table 8: Survey Results – Content of AMG Equipment Information

Response Option	Result
A description of the manufacturer	32 (82%)
A description of the model	32 (82%)
A description of the software version	31 (79%)
Other	Accuracy, radio frequency, operating manual, and last calibration date of equipment

3. Do you agree that the Department does not provide a list of approved AMG equipment?

Table 9: Survey Results – Department Provides a List of Approved Equipment

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q3	0 (0%)	5 (7%)	11 (15%)	17 (23%)	31 (41%)	11 (15%)	4.43	5	5	1.11	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

4. What is the preferred frequency for equipment maintenance?

Table 10: Survey Results – Preferred Frequency for Equipment Maintenance

Response Option	Result
At least once at the beginning of each surveying work	7 (13%)
Every six months	12 (24%)
Weekly during the survey	5 (7%)
As needed	23 (43%)
Other	a) As manufacturer requires/recommends and if problem arises b) Annually c) Once a month, bi-month, or daily

5. Do you agree with roles and responsibilities, submissions, timeline, equipment operation and maintenance guidelines, requirements that are described in the "Automated Machine Guidance Equipment" Section?

Table 11: Survey Results – Summary Question for Section 3 (Automated Machine Guidance Equipment)

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q5	0 (0%)	0 (0%)	3 (4%)	21 (28%)	48 (63%)	4 (5%)	4.70	5	5	0.63	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

Respondents' Comments

1) A list of approved AMG equipment will help the engineer be familiar with the equipment from job to job.
2) When the contractor provides new equipment, training should be provided "as necessary".
3) The Department should have access to the equipment provided by the contractor at all times during the work.
4) The Department field staff needs to receive technical support from the contractor.

5) On larger projects, two different rovers should be used to check against each other for errors.
6) Before the job starts, the contractor can send the Department field staff tutorial videos on how to use the rover.
7) Asking the contractor to submit the equipment information 30 days prior to use is too early and might cause contractual problems. Submission 14 days prior to use is suggested.
8) Some respondents thought that it is difficult to include rovers in pay items.
9) Some respondents believed that it is better that the contractor provides the equipment. In addition, they suggested that:
    a) The contract should specify that the contractor is required to provide the equipment.
    b) The provided equipment must be compatible to the earth software programs to calculate cut and fill used by the District.
    c) More than one rover would be better on longer or more complex project.
    d) The equipment should be provided at least seven days before actual use.

2.3.2.4 Automated Machine Guidance Work Plan

Responses to the Questions

The following points provide a summary of the main findings:

1) The respondents agreed to include this section in the Construction Manual.
2) The AMG Work Plan should be submitted, if necessary, to the engineer, survey crew chief, and/or consultant.
3) More than half of the respondents selected that the AMG Work Plan should be submitted "for review"; and more than 40% of the respondents selected "for information" or "for approval". The main reason for not selecting "for approval" is that the AMG Work Plan will change, so approval is not necessary. In addition, "for approval" might put too much responsibility on the Department.
4) In addition to the listed items, respondents mentioned other items to be included in the AMG Work Plan (please see the detailed results of the second question).
5) The majority of the respondents agreed that if the contractor does not have experience with the use of AMG systems or the experience is not applicable to the specific project, the engineer may ask the contractor to perform a test session.

    Respondents agreeing with this statement also suggested that:
    a) A technical representative from the contractor should be on hand at the start of job and/or for the test session.
    b) Training to the contractor staff might be needed.

    Respondents disagreeing with the statement suggested that:
    a) Additional checks at the start up and for the first portion of the project should be required.
    b) If the experience is not applicable, decline the use of AMG for the project.

All questions and a summary of their response results are shown below (see Table 12-Table 17).

1. Considering the submitting of the AMG Work Plan:
    a. Should the AMG Work Plan be submitted to "the Engineer"?

Table 12: Survey Results – Submission of AMG Work Plan

Response Option	Result
To Engineer	61 (94%)
Other	a) IDOT surveyor, District survey staff, survey crew chief, consultant b) Should not submitted to the engineer

    b. Should the AMG Work Plan be submitted "for information", "for review", or "for approval"?

Table 13: Survey Results – Purpose of AMG Work Plan Submission

Response Option	Result
For information	29 (42%)
For review	38 (55%)
For approval	31 (45%)

    c. When shall the Contractor submit the AMG Work Plan?

Table 14: Survey Results – Time to Submit the AMG Work Plan

Response Option	Result
Before the preconstruction meeting	20 (29%)
At the preconstruction meeting	36 (52%)
At least 30 days prior to use	20 (29%)
Other	At least 14 days prior to use

2. In addition to the aforementioned items, what else shall the AMG Work Plan include? If any, please specify.

Table 15: Survey Results – Additional Items to Include in the AMG Work Plan

No.	Result
1	Contractor personnel responsible for AMG.
2	Backup plan in case AMG is malfunctioning.
3	Personnel to be using AMG equipment on a daily basis.
4	Data/model to be entered.
5	Radio frequencies to be used.
6	Designated contact person with contractor to answer questions or issues during the project.
7	Proof that the contractor's specified software is compatible to use with the Department's software. If it is not compatible with the Department's software, provide an alternative.
8	Proposed digital model and control file for QA/QC by Department.

9	Tutorial videos.
10	Where AMG will be used.
11	Software update information.

3. In addition to the aforementioned items, what else shall IDOT's Surveyor conduct in order to review and evaluate the AMG Work Plan? If any, please specify.
   Responses:
   No additional items reported/suggested.

4. Do you agree that if the Contractor does not have experience with the use of AMG systems or the experience is not applicable to the specific project, the Engineer may ask the Contractor to perform a test section?

Table 16: Survey Results – Test section if Contractor Has No Experience with AMG

Response Option	Result
Yes	59 (86%)
No	7 (10%)
Other	a) Require additional base stations b) Should apply to all or none c) Ultimately contractor's responsibility

5. Do you agree with the roles and responsibilities, submissions, timeline, and requirements that are described in the "AMG Work Plan" Section?

Table 17: Survey Results – Summary Question for Section 4 (AMG Work Plan)

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q5	0 (0%)	0 (0%)	3 (4%)	17 (23%)	52 (70%)	2 (3%)	4.72	5	5	0.58	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

<u>Respondents' Comments</u>

1) If using contractor staking/layout, a District surveyor may not be needed.
2) The description of equipment should include a proof that all latest software updates have been completed.
3) The quality control plan should include daily checks.
4) For the contractor's prior experience with the use of AMG systems, a minimum number of years of recent experience shall be defined, such as the last three years.
5) The review of the AMG Work Plan could be conducted during a separate meeting from the preconstruction meeting. In addition to the resident/field engineer and the technicians, a dedicated IDOT construction survey crew or the consultant survey crew should also participate in the meeting.

2.3.2.5 Training

Responses to the Questions

The following points provide a summary of the main findings:

1) The respondents agreed to include this section in the Construction Manual, with further revision.
2) For the recipients of AMG training, most of the respondents selected “engineer” and/or “surveyor”. Other respondents additionally mentioned inspector, on site Department and contractor construction staff, contractor laborers/workers on the project, and anyone involved with layout.
3) For the frequency of training, most of the respondents preferred “as needed” or “initial one and then as needed” rather than a specific number.
4) For the time for the training, most of the respondents selected “prior to start of any AMG work”.
5) For the number of training sessions, more than half of the respondents selected “as needed or as specified by the Engineer”.
6) For the training content, all the four options (AMG equipment, digital models, software, and rovers) were selected by more than half of the respondents.

All questions and a summary of their response results are shown below (see Table 18-Table 20).

1. Who shall receive the training?

Table 18: Survey Results – Recipients of AMG training

Response Option	Result
Engineer	29 (47%)
Surveyor	23 (37%)
Other	a) Inspector: 12 (19%) b) On site Department and contractor construction staff/technicians: 10 (16%) c) Contractor laborers/workers on the project: (5%) d) Anyone involved with layout (layout technicians): (3%) e) All potential users of the equipment: 1 (2%)

2. Details about training:

Table 19: Survey Results – Details about Training

Questions	Response Option	Options Offered by Respondents
What is the frequency of training?	One: 21 (31%) At least one: 19 (28%)	a) As needed. b) Initial one with optional follow-ups or annual refresher/updating training. c) Yearly basic training and more in-depth training before project.
When shall the training be provided?	Prior to the start of any AMG work: 59 (86%)	a) As needed. b) After preconstruction meeting. c) At the start of work.
How many sessions per training?	One: 12 (19%) Two: 7 (11%) As specified by Engineer or as needed: 42 (66%)	Until the construction staff is trained.
What shall be covered in the training?	AMG equipment: 40(68%) Digital models: 39 (66%) Software: 40 (68%) Devices for review such as rovers: 45 (76%)	a) As needed. b) AMG equipment: how to use, where to use, and examples. c) Upload of electronic data. d) Full overview once and specific rover training. e) QC/QA procedures. f) AMG equipment for checking and layout.

3. Do you agree with roles and responsibilities, types of training, time and frequency of training, and requirements that are described in the "Training" Section?

Table 20: Survey Results – Summary Question for Section 5 (Training)

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q3	0 (0%)	1 (1%)	2 (3%)	25 (33%)	43 (57%)	4 (5%)	4.63	5	5	0.69	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

Respondents' Comments

1) It might be costly if the contractor provides training. In addition, it is not clear how does the contractor bid the training.
2) Someone properly trained must be available at all times to answer questions from the Department staff.
3) Respondents who disagreed that the contractor should provide training thought

that the Department will either need a dedicated construction survey crew above and beyond the inspection staff, or a survey consultant to deal with GPS issues in AMG projects.

2.3.2.6 Digital Models

Responses to the Questions

The following points provide a summary of the main findings:

1) The respondents agreed to include this section in the Construction Manual.
2) Most of the respondents agreed that the contractor is responsible for developing, updating, and revising the digital models, and is responsible for any errors or omissions in the digital models. Respondents who disagreed thought that in the future, the Department will assume those responsibilities. Opinions varied on the contractor's responsibility for errors or discrepancies in the design files provided by the Department.
3) Most of the respondents agreed that the contractor should bear the costs associated with the digital models (because currently contractors are responsible for developing and providing the digital models).
4) Most of the respondents agreed that the contractor should submit the digital models to the engineer at least 30 days prior to the start of the AMG work. More than half of the respondents thought that the digital models should be submitted "for information".
5) Most of the respondents agreed that the contractor should provide the digital model data required by devices used for inspection to the engineer at least 30 days prior to the start of the AMG work.
6) Most of the respondents agreed that the contractor should provide the digital models in a specific data format or compatible with the specific software used.

All questions and a summary of their response results are shown below (see Table 21-Table 28).

1. Do you agree that Contractor is responsible for:
    a. Developing the digital models.
    b. Updating and revising the digital models.
    c. Any errors or omissions in the digital models.
    d. Any errors or discrepancies in the design files or Contract Documents provided by the Department.
    e. Bearing all respective costs, including, but not limited to, the cost of developing the digital models, the cost of manipulating the design files provided by the Department, the cost that may be incurred due to the discrepancies between the Contractor's digital models and the design files provided by the Department, and the cost of rework or reconstruction that may be incurred due to errors in the application of AMG techniques.

Table 21: Survey Results – Responsibilities Related to the Digital Models

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q1.a	1 (1%)	6 (8%)	4 (5%)	8 (11%)	31 (41%)	25 (33%)	4.83	5	5	1.25	Agree
Q1.b	2 (3%)	2 (3%)	3 (4%)	7 (9%)	30 (39%)	30 (42%)	5.04	5	6	1.16	Agree
Q1.c	1 (1%)	3 (4%)	2 (4%)	7 (9%)	27 (36%)	34 (45%)	5.14	5	6	1.11	Agree
Q1.d	7 (9%)	16 (21%)	13 (17%)	6 (8%)	26 (35%)	7 (9%)	3.65	4	5	1.57	Somewhat agree
Q1.e	1 (1%)	2 (3%)	6 (7%)	9 (12%)	33 (46%)	23 (31%)	4.89	5	5	1.10	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

2. Do you agree that the Contractor shall submit the digital models to the Engineer?

Table 22: Survey Results – Submission of Digital Models by Contractor

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q2	0 (0%)	2 (3%)	2 (3%)	12 (17%)	37 (51%)	20 (27%)	4.97	5	5	0.89	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

If agree (4-6 on the scale):

a. Should the digital models be submitted “for information”, “for review”, “for approval”?

Table 23: Survey Results – Purpose of Digital Model Submission

Response Option	Result
For information	38 (55%)
For review	34 (49%)
For approval	20 (29%)

b. When shall the Contractor submit the digital models?

Table 24: Survey Results – Time to Submit the Digital Models

Response Option	Result
At least 30 days prior to the start of the AMG work	46 (73%)
Other	• At preconstruction meeting • Prior to the start of work without specific days • Two weeks • As soon as possible

c. What is the method for the Engineer to check the digital models? Specify Responses:
   - Not checking the digital models
     - The digital models are only for information purpose and the Department is not responsible for checking the models.
     - Currently unable to check the digital models.
     - The engineer should not check the digital models, because if he/she does, then the Department would assume responsibility for errors or omissions in the models.
   - Methods used to check the digital models:
     - Check line/grade against plan line/grade.
     - Hand check of selected points.
     - Microstation spot check in the field: whether the model is compatible with Microstation plans.
     - Verify with cross section 10% of job.
     - Use profile, station, and cross section to calculate spot checks.
     - Spot check with rover supplied by contractor.
     - Independent check with Department equipment; independent side-by-side check.
     - The dedicated construction survey staff should be responsible for checking; the project engineer does not have the required knowledge.
     - Check with existing terrain elevations; check with tape measure against typical cross sections; and check with the Department design/CADD staff.

3. Do you agree that the Contractor shall provide digital model data required by devices used for review or inspection to the Engineer?

Table 25: Survey Results – Contractor Providing Digital Model Data for Use in Review or Inspection Equipment

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q3	0 (0%)	2 (3%)	3 (4%)	15 (21%)	42 (58%)	11 (15%)	4.78	5	5	0.85	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

If agree (4-6 on the scale), when shall the Contractor provide such data?

Table 26: Survey Results – Time to Provide Data for Review or Inspection Equipment

Response Option	Result
At least 30 days prior to the start of the AMG work	36 (64%)
Other	a) Prior to the start of work without specific days b) Two weeks c) As soon as possible

4. Do you agree that the Contractor shall provide the digital models in a specific data format or compatible with specific software?

Table 27: Survey Results – Contractor Providing the Digital Models in Format Compatible with Specific Software

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q4	0 (0%)	5 (7%)	7 (10%)	8 (11%)	39 (54%)	13 (18%)	4.67	5	5	1.09	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

If agree (4-6 on the scale), please specify the data format or the software.
Responses:

- Whatever format is compatible with AMG equipment being used.
- Whatever software the District is using.
- Compatible with Department equipment or supplied computer with software.
- Compatible with GeoPAK/trimble (e.g., power Geopak and trimble business center).

5. Do you agree with the roles and responsibilities, submissions, timeline, and requirements that are described in the "Digitals Models" Section?

Table 28: Survey Results – Summary Question for Section 6 (Digital Models)

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q5	1 (1%)	1 (1%)	2 (3%)	26 (36%)	39 (54%)	4 (5%)	4.55	5	5	0.81	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

<u>Respondents' Comments</u>

1) The Department needs to catch up and start to supply plans/models that can be used in AMG equipment.
2) Contractor's digital models should be submitted to the engineer upon request, but the information should be reviewed or checked by the dedicated survey staff, or CADD or design staff, if necessary (e.g., when an error is found). The submission is not a must.

3) The respondents agreed that currently the contractor is responsible for developing the digital models, whereas in the future, the Department will be responsible for developing the digital models. Thus, the Department might also be responsible for the errors or omissions.
4) If the contractor chooses to use AMG, then he/she should bear all the costs except those costs arising from errors in the design files provided by the Department.
5) The digital models should not be submitted for approval, because if the Department approves it while there are errors, the contractor will assume the Department is responsible for all costs arising from those errors.

2.3.2.7 Electronic Files

Responses to the Questions

The following points provide a summary of the main findings:

1) The respondents agreed to include this section in the Construction Manual.
2) Opinions varied on the time to provide the electronic files, but the most selected options were "after project award and before the preconstruction meeting", "upon the request of the Contractor", and "before bidding".
3) Most of the respondents agreed that the Department should provide the electronic files in the native format of the software application by which they were generated and take no responsibilities to convert the file format.
4) Most of the respondents disagreed that the Department has no responsibility to provide these electronic files or 3D data used for the AMG system.
5) Most of the respondents agreed that the electronic files provided to the contractor are for convenience only, and the Department assumes no responsibility for the sufficiency or accuracy of the provided electronic files. But, the opinions slightly varied.

All questions and a summary of their response results are shown below (see Table 29-Table 34).

1. When shall the Department provide the following electronic files?
    a) Alignment data.
    b) Cross sections.
    c) Background graphics files with roadway and drainage features such as centerlines, edges, and hull of ponds.
    d) Machine control surface model, or existing and design surface models.
    e) GPS site calibration data.
    f) Project control information.

Table 29: Survey Results – Time to Provide Electronic Files

Response Option	Result
Before biding	15 (22%)
During biding	5 (7%)
After project award and before the preconstruction meeting	27 (40%)
After the preconstruction meeting and before any construction work using AMG starts	3 (4%)
Upon the request of the Contractor	16 (24%)
Other	a) Before any construction work b) At the preconstruction meeting

2. Do you agree that the Department provides electronic files in the native format of the software application by which they were generated and take no responsibilities to convert the file format?

Table 30: Survey Results – Department Providing Electronic Files in the Native Format

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q2	0 (0%)	0 (0%)	3 (4%)	9 (13%)	34 (48%)	25 (35%)	5.14	5	5	0.79	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

3. In addition to the electronic files mentioned in Item 1, what other electronic files shall be provided by the Department and when shall the Department provide such electronic files, if any? Specify

   Responses:

   - Site map and plan

4. Do you agree that the Department has no responsibility to provide these electronic files or 3D data used for the AMG system?

Table 31: Survey Results – Department's Responsibility to Provide Electronic Files

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q4	3 (4%)	14 (20%)	19 (27%)	14 (20%)	17 (24%)	3 (4%)	3.54	3	3	1.28	Somewhat disagree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

5. Do you agree that the electronic files provided to the Contractor are for convenience only, and are not part of the Contract Documents?

Table 32: Survey Results – Purpose of Electronic Files

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q5	3 (4%)	4 (6%)	10 (14%)	19 (27%)	28 (40%)	6 (9%)	4.19	4	5	1.21	Somewhat Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

6. Do you agree that the Department assumes no responsibility for the sufficiency or accuracy of the provided electronic files?

Table 33: Survey Results – Department's Responsibility on Sufficiency and Accuracy of Electronic Files

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q6	2 (3%)	8 (11%)	14 (20%)	15 (21%)	26 (37%)	6 (8%)	4.03	4	5	1.27	Somewhat Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

7. Do you agree with the roles and responsibilities, deliverables, and requirements that are described in the "Electronic Files" Section?

Table 34: Survey Results – Summary Question for Section 7 (Electronic Files)

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q7	2 (3%)	2 (3%)	6 (9%)	26 (37%)	30 (43%)	4 (6%)	4.31	4	5	1.01	Somewhat Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

<u>Respondents' Comments</u>

1) About the time to provide electronic files:
   a) If the information is given out before bidding, it must be provided to every prospective bidder – along with the letting plans. The electronic files should be probably listed at letting as being available after award.
   b) The electronic files should be provided if requested; the contractor should know the condition of the electronic files for bid, because currently there is little consistency.
2) The Department should make every effort to provide electronic. It is very helpful to the resident/field personnel during the project.
3) It would be better to accept all responsibilities for the accuracy of the electronic files provided to the contractor, but this would require significantly more QA/QC in

the design phase of the project.

4) The first point of this practice (about the engineer developing survey data) is problematic (and might better be removed).
5) It is the contractor's responsibility to verify the elevations and locations of all ties in points to existing pavement or structures and provide verification and any adjustments made to the model.

2.3.2.8 Project Control

Responses to the Questions

The following points provide a summary of the main findings:

1) The respondents agreed to include this section in the Construction Manual.
2) Most of the respondents agreed that control surveying using GPS method shall comply with IDOT's Surveying Manual, Chapter on GPS.
3) Most of the respondents agreed that the Department is responsible for setting the primary control points and providing the project control information to the contractor before or at the preconstruction meeting.
4) More than half of the respondents agreed that the contractor is responsible for setting the secondary control points and any additional control points; and is also responsible for verifying, maintaining, and documenting all project control points. But opinions slightly varied.
5) More than 40% of the respondents selected "1000 feet" as the interval for secondary control points when GPS guided machine systems are used.

All questions and a summary of their response results are shown below (see Table 35-Table 40).

1. Do you agree that the control surveying using GPS method shall comply with IDOT's Surveying Manual, Chapter on GPS?

Table 35: Survey Results – Complying with IDOT's Surveying Manual, Chapter on GPS

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q1	0 (0%)	0 (0%)	0 (0%)	11 (15%)	47 (64%)	15 (21%)	5.05	5	5	0.59	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

2. Do you agree that the Department is responsible for:
   a) Setting the primary control points
   b) Providing the project control information to the Contractor

Table 36: Survey Results – Department's Responsibility Related to Primary Control

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q2.a	0 (0%)	2 (3%)	5 (7%)	11 (15%)	42 (58%)	13 (18%)	4.81	5	5	0.90	Agree
Q2.b	1 (1%)	1 (1%)	1 (1%)	4 (5%)	52 (70%)	15 (20%)	5.03	5	5	0.80	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

3. When shall the Department provide the project control information to the Contractor?

Table 37: Survey Results – Time to Provide the Project Control Information to Contractor

Response Option	Result
Before preconstruction meeting	24 (36%)
At the preconstruction meeting	28 (42%)
Other	When requested (8)
	Before start of work (e.g., 14 days) (2)
	After award (2)
	Currently in plans (5)
	Include as a bid document; the contractor needs the information to develop the AMG plan, should be included as part of the AMG plan.

4. Which party shall be responsible for:

Table 38: Survey Results – Responsibilities Associated with Setting and Maintaining Control Points

Item	Department	Contractor	Both	Project specific
Setting the secondary control points	0 (0%)	54 (72%)	13 (17%)	6 (8%)
Setting any additional control points	1 (1%)	52 (69%)	14 (19%)	6 (8%)
Verifying, supplementing, and maintaining the project control points before construction and regularly during construction	1 (1%)	49 (67%)	20 (26%)	2 (3%)
Documenting all project control points in the project control report	3 (4%)	40 (57%)	22 (31%)	4 (6%)

5. What is the interval of secondary control points when GPS guided machine system is used?

Table 39: Survey Results – Interval of Secondary Control Points

Response Option	Result
Not exceed 2640 feet	6 (11%)
1000 feet	25 (44%)
Other	a) Based on equipment/manufacturer b) As requested c) Job specific d) 500 feet e) 250 feet

6. In addition to the information mentioned above, what other deliverables about the control survey shall be provided? Specify
   Responses:
   - Alignment points and benchmarks.
   - Datums.

7. Do you agree with the roles and responsibilities, submissions, timeline, and requirements that are described in the "Project Control" Section?

Table 40: Survey Results – Summary Question for Section 8 (Project Control)

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q7	0 (0%)	0 (0%)	2 (3%)	18 (24%)	48 (65%)	6 (8%)	4.78	5	5	0.62	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

<u>Respondents' Comments</u>

1) The responsibilities associated with setting and maintaining control points are project specific and depend on the Contract Documents. For example, if it is a new roadway through a rough terrain or large area it may be beneficial for the contractor to help in setting the primary control points.
2) The secondary control points should be determined by the contractor and provided in the AMG plan.
3) When the contractor sets the secondary and any additional control points, the Department shall be involved by:
   a) Checking and verifying those control points.
   b) Witnessing and helping in setting those control points.
   c) Setting additional control points if needed.
4) Verifying, supplementing, maintaining, and documenting the project control points before construction should be the responsibility of the Department, and should be the responsibility of the contractor after construction begins.
5) The intervals of control points are project specific and could be determined as recommended by the survey equipment manufacturer.

2.3.2.9 Accuracy and Tolerance

Responses to the Questions

The respondents agreed to include this section in the Construction Manual. All questions and a summary of their response results are shown below (see Table 41).

1. Do you agree with the roles and responsibilities and the accuracy and tolerance requirements that are described in the "Accuracy and Tolerance" Section?

Table 41: Survey Results – Summary Question for Section 9 (Accuracy and Tolerance)

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q1	0 (0%)	0 (0%)	0 (0%)	6 (8%)	46 (61%)	24 (32%)	5.24	5	5	0.58	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

Respondents' Comments

1) The engineer (or the reader of this written procedures) should refer to the "specifications" to find the requirements on accuracy and tolerances for different projects.
2) One respondent suggested adding a statement of no pay if the AMG does not work for layout.

2.3.2.10 Quality Assurance

Responses to the Questions

The following points provide a summary of the main findings:

1) The respondents agreed to include this section in the Construction Manual.
2) More than half of the respondents agreed that the spot checks should be performed by the engineer.
3) Most of the respondents thought that the spot checks could be performed at any time during construction.
4) Most of the respondents thought that the spot checks should include checks of machine control results and actual stakes (if any).
5) Most of the respondents agreed that the spot checks (and other construction checks) should be conducted using conventional survey methods, or independent GPS equipment (such as rovers with project digital models), or a combination of the two approaches.

All questions and a summary of their response results are shown below (see Table 42-Table 46).

1. Who shall perform spot checks?

Table 42: Survey Results – Responsibility to Perform Spot Checks

Response Option	Result
Engineer	48 (67%)
Other	Contractor, surveyor, field technicians

2. When shall spot checks be performed?

Table 43: Survey Results – Time to Perform Spot Checks

Response Option	Result
Before construction	16 (22%)
At any time during the construction	65 (89%)
Other	a) Daily b) Monthly c) As needed

3. What are the elements that are included in a spot check?

Table 44: Survey Results – Contents of Spot Check

Response Option	Result
Machine control results	39 (72%)
Surveying calculations	32 (59%)
Field procedures	32 (59%)
Actual staking	42 (78%)
Records and documentation	32 (59%)
Other	Any elements deemed necessary by the engineer

4. Do you agree that the spot checks (and other construction checks) will be conducted using conventional survey methods, or independent GPS equipment (such as rovers with project digital model), or a combination of the two approaches?

Table 45: Survey Results – Methods for Spot Checks

Response Option	Result
Yes	69 (92%)
No	6 (8%)

5. Do you agree with the roles and responsibilities, timeline, and requirements that are described in the “Quality Assurance” Section?

Table 46: Survey Results – Summary Question for Section 10 (Quality Assurance)

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q1	0 (0%)	1 (1%)	0 (0%)	18 (24%)	47 (64%)	8 (11%)	4.82	5	5	0.66	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

Respondents' Comments

1) Some respondents disagreed with this section because it is very hard to specify when and how to check. Most checks are done as constructed, for example, earth grade, subbase grade, edge of pavement layout, sewer layout, etc.
2) Spot checks should be performed on a daily basis.
3) Spot checks depend on what is being checked – earthwork and PCC/PVR should have different checks.
4) The decision to conduct construction checks using conventional survey methods, or independent GPS equipment, or a combination of the two approaches depends on accuracy requirements of pay items and should be left to the engineer and the inspector.

2.3.2.11 Site Calibration and Check

Responses to the Questions

The following points provide a summary of the main findings:

1) The respondents agreed to include this section in the Construction Manual.
2) More than half of the respondents agreed that three horizontal control points are needed. Opinions on other options varied.
3) Most of the respondents agreed that two or more control points are needed to perform the daily site calibration check.
4) Nearly half of the respondents selected +/- 0.03 foot as horizontal tolerance, and more than half of the respondents selected 0.05 foot or less as vertical tolerance.
5) More than half of the respondents agreed that the contractor should submit the daily site calibration check results to the engineer.

All questions and a summary of their response results are shown below (see Table 47-Table 52).

1. How many control points shall the Surveyor use to perform site calibration?

Table 47: Survey Results – Number of Control Points Used for Site Calibration

Response Option	Result
Three known horizontal control points for horizontal site calibration	30 (54%)
Two control points per mile along the project area if this results in more control points than the minimum	8 (14%)
Other	a) Four points surrounding site. b) Five points each project. c) Minimum three horizontal points and one vertical point. d) Depends on project size/scope. e) Depends on survey equipment. f) Three or two points per mile.

2. How many control points shall the Contractor's Surveyor use to perform the daily site calibration check?

Table 48: Survey Results – Number of Control Points Used for Site Calibration Check

Response Option	Result
Two or more	53 (95%)
Other	a) At least three control points b) As needed

3. What are the tolerances for site calibration?

Table 49: Survey results – Tolerances for Site Calibration

Response Option	Result
Horizontal tolerance	
+/- 0.03 foot	23 (49%)
0.01 foot or less	14 (30%)
Vertical tolerance	
+/- 0.065 foot	10 (24%)
0.05 foot or less	28 (67%)
Other	a) 0.02 feet or less b) 0.02 to 0.03 feet c) 0.04 feet d) Depends on type of job, e.g., dirt or bridge work Equipment specific and based on owner's manual

4. Shall the Contractor's Surveyor submit the daily site calibration check results to the Engineer?

Table 50: Survey Results – Submission of Site Calibration Check Results

Response Option	Result
Yes	45 (70%)
No	19 (30%)

If yes, who shall review such results?

Table 51: Survey Results – Review of Site Calibration Check Results

Response Option	Result
Survey engineer	31
Other	2 (Resident engineer, for information)

5. Do you agree with the roles and responsibilities and the requirements on selection of control points, tolerances, and procedure for site calibration that are described in the "Site Calibration and Check" Section?

Table 52: Survey Results –Summary Question for Section 11 (Site Calibration and Check)

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q5	0 (0%)	1 (1%)	3 (4%)	19 (28%)	40 (60%)	4 (6%)	4.64	5	5	0.73	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

<u>Respondents' Comments</u>

1) The tolerances should depend on the type of work. The mentioned tolerances here would work for rough dirt work. Tighter tolerances will be needed for sub-bases and pavements. Bridge work requires the tightest tolerance – should be +/- 0.01 feet.
2) The tolerances also depends on AMG equipment. The mentioned tolerances are OK for GPS equipment but not for total stations.
3) Site calibration requires one vertical control point (benchmark) and three horizontal control points instead of four benchmarked mentioned in the proposed written procedures. Too many control points might cause the project surface to be tilted.
4) The number of control points depends on the project size and scope, and manufacturer requirements.
5) The site calibration results should be submitted for information only, and on a weekly basis, or only if there is a problem. Daily is too often. The calibration check should be done and documented daily by the contractor.
6) The resident engineer and inspector should review the site calibration results, and if a problem is evident, they should contact the Department's surveyor. Approval to continue is required in this case.

2.3.2.12 Final Check

Responses to the Questions

The following points provide a summary of the main findings:

1) The respondents agreed to include this section in the Construction Manual.
2) Opinions on some items in this section varied.
3) Most of the respondents agreed that before the final check, the contractor should perform a quality control test and the engineer might check the areas that are out of tolerances.
4) Most of the respondents agreed that the contractor should perform the final check of construction work and the engineer may perform or witness the check. But, the opinions slightly varied.
5) Most of the respondents agreed that the contractor should notify the engineer of the final checks 2 days in advance.
6) The respondents somewhat agreed that only finish grade stakes (blue tops) are needed and no additional centerline stakes, slope stakes, or grade stakes (except at the critical points such as, but not limited to, PC's, PT's, super elevation points) are needed. But, opinions varied.
7) Most of the respondents reported that the stake intervals are project specific.
8) Opinions varied on whether paving stakes are needed at superelevated curve transitions and station equation locations or not.
9) More than half of the respondents agreed with the number and criteria of final checks.

All questions and a summary of their response results are shown below (see Table 53-Table 63).

1. Do you agree that before the final check, the Contractor shall perform a quality control test and the Engineer might check the areas that are out of tolerances?

Table 53: Survey Results – Quality Control Test by Contractor and Check of Out-of-tolerance Areas by Engineer

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q1	1 (1%)	0 (0%)	0 (0%)	16 (23%)	46 (66%)	7 (10%)	4.81	5	5	0.72	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

2. Do you agree that the Contractor shall perform the final check of construction work and the Engineer may perform or witness the check?

Table 54: Survey Results – Contractor Performing Final Check with Engineer Witnessing

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q2	1 (1%)	3 (4%)	1 (1%)	17 (25%)	35 (51%)	11 (16%)	4.69	5	5	1.00	Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

3. When shall the Contractor notify the Engineer of the final checks?

Table 55: Survey Results – Time to Notify the Engineer of the Final Check

Response Option	Result
At least 2 business days before performing the checks	47 (85%)
Other	a) One day before b) One week c) Five days d) Ten days e) As soon/early as possible

4. Do you agree that only finish grade stakes (blue tops) are needed and NO additional centerline stakes, slope stakes, or grade stakes, except at the aforementioned critical points, are needed?

Table 56: Survey Results – Types of Stakes Needed

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q4	1 (2%)	9 (15%)	8 (13%)	19 (32%)	21 (35%)	2 (3%)	3.93	4	5	1.17	Somewhat Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

If disagree (1-3 on the scale), please specify the staking interval for additional stakes.

Responses:

- 100 feet.
- 250 feet to 500 feet.
- Stake intervals are determined by the engineer.
- Not needed if check is performed electronic data collector.

5. What is the interval for finished subgrade points that are set at points on cross sections on mainline?

Table 57: Survey Results – Interval for Finished Subgrade Points on Mainline

Response Option	Result
1000 feet	6 (11%)
500 feet	28 (52%)
Other	a) Job/project specific b) No stakes c) 50 feet d) 100 feet e) 100-200 feet f) 250 feet g) 1000 feet

6. What is the number of cross sections used to set finished subgrade points on side roads and ramps?

Table 58: Survey Results – Number of Cross Sections to Set Finished Subgrade Points

Response Option	Result
At least two	30 (68%)
Other	a) At least three b) Project specific c) Depends on length and typically two d) For side road two are fine, for ramps 500 feet intervals might be needed e) None (cross section is not needed any more)

7. What is the interval for finished subgrade points that are set on curves, transitions, intersections, interchanges, and break points?

Table 59: Survey Results – Interval for Finished Subgrade Points on Curves, Transitions, Intersections, Interchanges, and Break Points

Response Option	Result
250 feet	25 (52%)
Other	a) 500 feet b) 100 feet c) 50 feet for curves d) Depends on locations but likely 25-50 feet e) Project dependent

8. Are paving stakes only needed at superelevated curve transitions and station equation locations?

Table 60: Survey Results – Position to Place Paving Stakes

Response Option	Result
Yes	26 (57%)
No	20 (43%)

If no, where shall the paving stakes be set? Specify.

Responses:

- Not needed if the engineer is witnessing the check.
- Approaches, bridges, intersections.
- Grade changes and supers.
- At 100/250/1000 feet intervals.
- Not needed if the engineer has electronic data collection equipment.
- Various locations, as needed.

9. What is the number of final checks?

Table 61: Survey Results – Number of Final Checks

Response Option	Result
20 or more randomly selected checks per stage, per project, or per mainline roadway mile, whichever results in the most checks	22 (58%)
Other	a) 20 or more per mile/stage/mainline roadway mile only b) As needed or project specific

10. What are the criteria of final check?

Table 62: Survey Results – Criteria of Final Check

Response Option	Result
At least four of any five consecutive random checking points are within the tolerance	28 (85%)
Other	a) 80% b) 90% within tolerance c) 100% in tolerance d) At the discretion of the engineer

11. Do you agree with the roles and responsibilities, procedures, timeline, staking specifications and requirements that are described in the “Final Check” Section?

Table 63: Survey Results – Summary question for Section 12 (Final Check)

	Responses[1]						Statistics of Results				
	1	2	3	4	5	6	Mean	Median	Mode	SD	Interpretation[2]
Q11	2 (3%)	3 (5%)	3 (5%)	26 (41%)	25 (39%)	5 (8%)	4.31	4	4	1.06	Somewhat Agree

[1] 1=Very disagree; 2=Disagree; 3=Somewhat disagree; 4=Somewhat agree; 5=Agree; 6=Very agree.
[2] Interpretation based on median.

<u>Respondents' Comments</u>

1) Final checks
    a) Are unnecessary: respondents from some Districts commented that final check shall be performed ONLY when necessary – when some failure or errors are apparent and require corrective action.
    b) Could be performed by the contractor staff: some respondents thought that if the contractor staff performs the final check, the Department construction staff needs to witness.
    c) Should be performed by the Department staff: other respondents thought that the engineer needs to perform the final check.
2) Finish grade stakes
    a) Are necessary: The finish grade stakes are set not for documentation purposes, but only to determine that the AMG equipment is working properly.
    b) Are unnecessary under certain conditions: If all crews have access to the AMG equipment during their work efforts or at least the engineer is provided with electronic means of checking, the finish grade stakes are unnecessary.
    c) Are generally unnecessary: If the projects are 100% digital, the traditional stakes will be only as requested, otherwise we are paying for both digital models and traditional staking. Thus, traditional staking should be kept to a minimum.
3) Stake intervals: The intervals depend on the project specifications and conditions. For example, for finished subgrade staking, the intervals depend on area. For paving staking, it could be at 25' intervals if in a complex area.

3 TASK 5: DEVELOP DRAFT SUMMARIZED WRITTEN PROCEDURES FOR REVIEW BY TRP

The research team revised the potential practices based on the results of the survey (Task 4) and developed the practices into draft written procedures for the use of modern technologies for construction staking of highway projects for inclusion in IDOT's Construction Manual. This draft will be the basis of the complete written procedures (Task 6), which is the final outcome of this research project. The draft written procedures are organized into 12 sections: (1) General, (2) Evaluation of construction methods, (3) Automated Machine Guidance equipment, (4) Automated Machine Guidance Work Plan, (5) Training, (6) Electronic design files, (7) Digital models used for AMG, (8) Project control, (9) Accuracy and tolerance, (10) Site calibration and check, (11) Spot checks, and (12) Final check.

3.1 General

1) Automated Machine Guidance (AMG) systems use positioning techniques such as GPS, robotic total stations, and/or laser scanning to determine the horizontal coordinates and elevation of the equipment and check the equipment position against a 3D digital model. AMG has the potential to reduce the number of stakes required and increase the efficiency and productivity of the Contractor. As defined by FHWA (2013), AMG "uses enhanced location referencing to provide accurate horizontal and vertical positioning for precise grading, milling, or paving. Bulldozers, graders, milling machines, and paving machines can be programmed to use AMG when performing grading or paving tasks in the field. Moreover, scrapers, excavators, and trenching machines can be equipped with AMG for a wide variety of earthwork."

   An AMG equipment/system (FHWA, 2013):
   a) "Uses AMG references the position of the cutting edges or pavement molds using GPS satellites, robotic total station, lasers, or combinations of these methods."
   b) "It calculates the finished-grade for that location using an electronic model of the proposed constructed facility that resides in its onboard computer."
   c) "Then, it adjusts the cutting edges or pavement molds automatically for small differences in elevation or provides the cut or fill amount via the computer-user interface to the machine operator for large differences in elevation."

2) Some of the main decisions that the Engineer and the technicians have to make, together with the Contractor, are listed as follows. Those decisions are discussed in more detail in the rest of the written procedures.
   a) Evaluation of construction methods:

- Whether the project is a good candidate for use of AMG or not?

b) AMG equipment:
- Whether the Department provides a list of approved AMG equipment for the project or not?
- Whether the Contractor provides rover(s) to the Department for the checking/inspection or not?
- What are the practices that will be used for storing and maintaining the AMG equipment?

c) Automated Machine Guidance Work Plan
- What items should be included in the AMG Work Plan?
- What is the process that will be used for reviewing the AMG Work plan and who will be involved in the review (e.g., the Engineer, survey crew chief, and/or the consultant)?
- Whether the Engineer uses the AMG Work Plan Check List or not?

d) AMG Training
- Whether the Contractor provides training to the Department construction staff or not?
- If yes, who will participate in the training? And, what is the content and timing of the training, and how many training sessions?
- If not (or in addition to the Contractor's training), will the Engineer, technicians, or other staff participate in training provided by the Department (Central Office or District) or otherwise familiarize themselves with the AMG system and the use of rovers? If yes, who will participate in this kind of training? And, what is the content, form, and timing of the training?

e) Digital models used for AMG
- Whether the Engineer reviews the Contractor's digital models used for AMG or not, and what is the process that he/she will use to review the models?

f) Project control
- Whether the Department is responsible for the AMG project control densification or not?
- And if the Department is responsible for project control, what are the best practices to set the control points?

g) Spot checks
- Whether and how the Engineer and technicians perform spot checks and at which locations?

h) Final check
- Who performs the final check, the Engineer or the Contractor?
- If the Engineer performs the final check, how does he/she perform the check?
- Whether staking is needed for the final check or not?

3) When you use this guidance document, keep in mind that:
   a) This guidance document provides guideline practices for the Engineer and technicians to follow in different scenarios related to the use of AMG in highway construction projects.
   b) This guidance document leaves some decisions (some of them listed in item 2 above) to the Engineer and technicians to make (sometimes together with the Contractor).
   c) This guidance document suggests good relations between the Contractor and the Department construction staff (i.e., the Engineer and technicians), as well as good communication and coordination between the Department construction staff (i.e., the Engineer and technicians) and the survey and design staff.
   d) This guidance document shall be used in conjunction with the *IDOT's Standard Specifications for Road and Bridge Construction*: http://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Construction/Standard-Specifications/Standard%20Specifications%20for%20Road%20and%20Bridge%20Construction%202016.pdf

3.2 Evaluation of Construction Methods

1) Decision to use AMG

   Not every project is suitable for AMG. AMG is, therefore, not mandatory. The Department encourages the use of AMG if the project is suitable for AMG construction techniques, but leaves the decision to use AMG or not to the Contractor. The Engineer should be aware that the Contractor should notify the Engineer of the intent to use AMG before or at the preconstruction meeting. To evaluate the suitability of adopting such technology in a project, the Contractor could follow AASHTO's criteria, which are defined in *AASHTO's Quick Reference Guide for the Implementation of Automated Machine Guidance System*. The Engineer could participate in the evaluation of the suitability of adopting such technology in a project.

2) Types of projects that are generally suitable for the use of AMG

   Generally, based on *AASHTO's Quick Reference Guide for the Implementation of Automated Machine Guidance System*, projects with the following characteristics are the best candidates for this technology:

   - large amounts of earthwork or paving, such as subgrade.
   - new alignments.
   - a good Global Navigation Satellite System (GNSS).
   - a design based on an accurate Digital Terrain Modeling (DTM).

   Based on the Department's experience, the following types of projects are best candidates for this technology:

- Complex projects.
- Projects with flat and long drainage areas.
- Urban reconstruction and larger reconstruction projects.
- Small earthwork projects.
- Projects with limited site width due to construction staging or physical constraints.

3) Types of projects that might NOT be suitable for the use of AMG
   a) The following conditions always limit the use of AMG:
      - Designs, such as overlays, that are not based on an existing Digital Terrain Modeling (DTM). Overlays with new profiles or cross slope construction benefit from AMG.
      - Structures.
   b) The following conditions might or might not limit the use of AMG – it is project specific, and should be assessed case by case:
      - Widening with narrow strip additions.
      - Designs that do not exist in a 3D digital environment (note that all jobs are capable of being modeled).
      - Projects that are under a tree canopy, in narrow canyons, or next to tall buildings that interfere with GNSS signals (note that robotic total stations or traditional methods are viable solutions).
      - Design difficulties that would prevent the creation of an accurate and complete DTM (if a surface model can be prepared in difficult situations, it saves on rework).

3.3 Automated Machine Guidance Equipment

1) AMG equipment and equipment information

   The Engineer should be aware that the Contractor should provide the AMG equipment, in compliance with the Contract Documents and all applicable standards and specifications. The Engineer should ask the Contractor to submit the equipment information (as part of the Automated Machine Guidance Work Plan) before or at the preconstruction meeting and at least 14 days prior to use. It is recommended that the equipment information includes, but not limited to, the following: a description of the manufacturer, model, software version, accuracy, radio frequency, operating manual, and last calibration date of the AMG equipment.

2) List of approved AMG equipment

   The Department is not required to provide a list of approved AMG equipment, but may choose to provide such list.
   - If the Department does not provide such list, then the Contractor should submit the equipment information to the Engineer. In this case, the Engineer should review this information.

- If the Department provides such list, the Department should decide whether this list is a suggested list (i.e., a contractor can still choose to use an equipment from outside of the list) or a required list (i.e., only the contractors who use one of the equipment in the list are qualified). The Department could develop the list based on the equipment used on previous successful AMG projects. Note that the use of a list of approved equipment could be beneficial in helping the Engineers get familiar with those AMG equipment from job to job (thereby avoiding the use of a new equipment for every project).

3) Rovers for inspection

The Contractor may or may not provide rover(s) to the Engineer for inspection purposes. This depends on the Contract terms and conditions and pay items.

- If the Contractor provides the rover(s), at least one GPS rover should be provided to the Engineer for the review of the work. In this case, the Engineer and whoever is reviewing the work must have access to the rover(s) provided by the Contractor.
- If the Contractor does not provide the rover, the Engineer can use the Department's rover, if they have one, or make a request to get the rover from the Contractor depending on pay items.

In both cases, whether provided by the Contractor or the Department, the GPS rover should be ready for use prior to the start of the construction work. The technicians familiar with GPS rovers may aid the Engineer – and/or anyone who is responsible for the inspection – in using the GPS rover. The GPS rover or other hand-held devices should be compliant with the Contract Documents and any applicable standards and specifications. If needed, the Engineer could require one or more independent rovers. On larger and complex projects, it is suggested to have two independent rovers to check against each other for errors.

4) Setup of GPS base station

When the AMG system is guided by GPS, the Surveyor (Contractor's Surveyor or Department's Surveyor, depending on the responsibility defined in the Contract Documents) will be in charge of setting up the GPS base station, which is important to the success of the project. The Surveyor should locate the base station at a stable, undisturbed place. The base station should provide radio signal coverage over the entire area constructed using the GPS-guided machine. If the base station cannot broadcast a signal that covers the entire site, provide adequate repeater radios or other communications. If the base station is to be relocated, document the current location. The Contractor should submit the location of the base station to the Engineer for approval, and should not relocate the base station without the approval of the Engineer. The Engineer should provide such approval in a timely manner.

5) Storage and maintenance of AMG equipment and rovers

The Contractor is responsible for the storage and maintenance of the AMG equipment and his/her GPS rover(s). In this case, the Engineer and technicians should have access to the equipment provided by the Contractor throughout the work. The Department is responsible for the storage and maintenance of its own GPS rover(s). The GPS equipment should be properly maintained at least once at the beginning of each surveying work, every six months, and as needed. The equipment components that should be maintained include, but not limit to: tripods, rods, cables, receivers and antennas, and handhelds. Equipment maintenance should include, but not limited to: periodic manufacturer maintenance checks, cleaning, and calibration.

6) References for GPS equipment setup, operation, maintenance, and storage

The following is a list of useful references for GPS equipment setup, operation, maintenance, and storage:

- The *NGS Guidelines for Single Base Real Time GNSS Positioning* provide a typical Real Time GNSS positioning checklist.
  - When operating any GPS equipment, pay attention to the items in the Checklist. Some of the items in the checklist include:
    - DOP varieties.
    - Multipath.
    - Baseline RMS.
    - Number of satellites.
    - Elevation mask.
    - Base accuracy – datum level, local level.
    - Base security.
    - Redundancy.
    - Space weather.
  - The *Chapter II: Equipment of NGS Guidance* of the document provides best practices for typical Real Time GPS setup.
- The *Methods of Practice and Guidelines for Using Survey-Grade Global Navigation Satellite Systems (GNSS) to Establish Vertical Datum in the United States Geological Survey* also provide detailed introduction to GPS equipment and a Checklist for equipment maintenance and quality control/quality assurance (QA/QC) of both Real-time GNSS single base RTK and Real-time GNSS single base RTK network, which is shown in Figure 3.
- *NGS Guidelines for Single Base Real Time GNSS Positioning* https://www.ngs.noaa.gov/PUBS_LIB/NGSRealTimeUserGuidelines.v2.1.pdf
- *Methods of Practice and Guidelines for Using Survey-Grade Global Navigation Satellite Systems (GNSS) to Establish Vertical Datum in the United States Geological Survey* https://pubs.usgs.gov/tm/11d1/tm11-D1.pdf

Real-time GNSS-single-base RTK	
Equipment	Quality assurance and accessories
Fixed-height GNSS base receiver tripod	Check height with tape, condition not warped or bent, sandbags for stability.
Fixed-height GNSS rover receiver bipod	Check height with tape, condition not warped or bent.
Traditional tripod for GNSS broadcast radio and antenna mast	Tribrach or flat plate for antenna mast; no loose legs.
GNSS broadcast radio antenna	Full-size whip antenna, tribrach or flat plate, cables, range pole.
GNSS broadcast radio battery	Marine (hybrid deep cycle) battery for long occupations, backup battery.
GNSS rover receiver extended range antenna	Full-size whip antenna, mounting brackets, cables, range pole.
GNSS base receiver	Dual frequency required, backup batteries, GPS+GLONASS+Galileo** tracking preferred, latest firmware upgrades, minimize multipath design, operating manual.
GNSS rover receiver	Dual frequency required, backup batteries, GPS+GLONASS+Galileo tracking preferred, latest firmware upgrades, minimize multipath design, operating manual.
Benchmarks	Monumented or non-monumented considerations, anchoring construction materials, datasheets with directions "to-reach" the benchmark location.

Real-time GNSS-networks	
Equipment***	Quality assurance and accessories
Fixed-height GNSS rover receiver bipod	Check height with tape, condition not warped or bent.
GNSS rover receiver	Dual frequency required, backup batteries, GPS+GLONASS+Galileo tracking preferred, latest firmware upgrades, minimize multipath design.
Wireless modem with static internet protocol (IP) address	Assess broadband or cellular coverage area before campaign.
Benchmarks	Monumented or non-monumented considerations, anchoring construction materials, datasheets with directions "to-reach" the benchmark location.

Figure 3: Real-time GNSS-single-base RTK checklist by the United States Geological Survey.

3.4 Automated Machine Guidance Work Plan

1) Submission of the Automated Machine Guidance Work Plan

   It is recommended that the Contractor develops and submits a comprehensive written AMG Work Plan to the Engineer and survey crew chief or consultant, for information only, before or at the preconstruction meeting and at least 30 days prior to use. Although the plan is submitted for information only, it is a good practice that the Engineer, survey crew chief, and/or the consultant review the information in the Work Plan.

2) Content of the Automated Machine Guidance Work Plan

   The content of AMG Work Plan is project specific. Generally, the AMG Work Plan could include, but not limit to:

   a) Definition of project boundaries and scope of work to be accomplished using the AMG equipment.
   b) Description of the equipment including, but not limited to, a description of the manufacturer, model, and software version of the AMG equipment.
   c) Project control report including, but not limited to, all contract control points, coordinates or elevation adopted, office procedures used for GPS technology, and the diagram of control points. When a GPS base station is on the site for checking or staking purposes, include the determined coordinate and elevation of the base station and the datum differential from the existing control provided by the Department.
   d) Detailed site calibration procedure including, but no limited to, map of the

control points used for site calibration and control points used to check the site calibration, site calibration procedure, frequency of calibration, plan for what information will be documented, and plan for what information will be submitted to the Engineer. The procedure must show a complete record of equipment check results.

e) AMG equipment calibration plan including, but not limited to, equipment to be calibrated, the frequency of calibration, the location and time of calibration, and the status of each calibrated equipment.
f) AMG equipment maintenance plan including, but not limited to, frequency of maintenance, components to be maintained, and procedure for maintenance.
g) A quality control plan including, but not limited to, frequency and type of checks to be performed, and procedures used to perform the checks. The control plan should show how the Engineer and the Contractor conduct the initial and daily calibration checks, spot checks, and final acceptance check.
h) Description of construction checks including, but not limited to, method and frequency of field verification checks.
i) Contractor's prior experience within the last three years with the use of AMG systems on similar projects (similarity should be assessed by the Engineer). If the Contractor does not have such experience, the Engineer may ask the Contractor to perform a test session, or may require additional checks at the beginning of the project, or may decline the use of AMG for part of the project.
j) Contractor's primary contact and alternate contact for AMG issues.
k) Personnel to be using the AMG equipment on a daily basis.

3) <u>Review of the Automated Machine Guidance Work Plan</u>

The Engineer and technicians should review and discuss the AMG Work Plan with the Contractor during the preconstruction meeting. If necessary, a separate meeting should be held to review and discuss the AMG Work Plan, and the survey crew chief or consultant should attend the meeting. During the meeting, the Engineer should try to establish a working relationship with the Contractor, including discussing tentative schedules and safety issues related to AMG. It is recommended to conduct the following, but not limited to, as part of the review:

a) Reviewing the AMG equipment information.
b) Reviewing the project control report, checking all control points and base station location, and discussing the needs for additional control points.
c) Reviewing the site calibration report and performing checks on site, if/as needed.
d) Reviewing the equipment calibration and maintenance and providing suggestions based on the knowledge of and experience with GPS.
e) Reviewing the quality control plan and discussing the needs for stakes for the checking and inspection of the project.

4) <u>Automated Machine Guidance Work Plan Checklist</u>

To relieve the Engineer and technicians from potential heavy documentation work, the Engineer and technicians are encouraged to keep an AMG Work Plan Checklist. The Engineer is encouraged to use the Checklist to understand and track how the Contractor will implement the AMG system on the project and request additional information for clarification whenever needed. A sample Checklist is shown in Table 64.

Table 64: A Sample AMG Work Plan Checklist

AMG Work Plan Checklist			
Item	*Yes*	*No*	*Remarks*
Is the scope where AMG will be used clearly defined?			
Did the Contractor submit his/her experience with AMG?			
Did the Contractor submit the AMG equipment information?			
Is the project control clearly designed? And what is the interval of control points?			
Did the Contractor addressed equipment calibration and maintenance?			
Are conventional stakes needed? If so, at which location(s)?			
… …			

3.5 Training

1) Training on AMG to the Department staff by Contractor

The Contractor typically provides training to his/her own staff. The Contractor may or may not provide training on AMG to the Department staff. However, if the Contractor provides the rover, the Engineer could/should (depending on pay items) ask the Contractor to provide the Department construction staff, such as the Engineers and technicians who participate in the project, with training.

- Content of training: The training should cover the use and operation of devices used for review of AMG work, such as the use of GPS rovers or other hand-held devices.
- Time of training: The initial training should be completed prior to the start of any AMG work. In addition to this initial training, the Engineer could ask the Contractor to provide more training, if needed (and also depending on pay items).
- Number of training sessions: The number of training sessions is project specific. The Engineer, together with the Contractor, should determine the number of training sessions based on the project duration, project size, Contractor's schedule, and other project characteristics and conditions.
- Participants of training: The Engineer and the Contractor should discuss and determine which Contractor staff and Department staff, if applicable, will participate in the training.

2) Training on AMG to the Department staff by the Department

The Engineer and technicians should get themselves familiar with the AMG system and the use of rovers before they start to use it, especially if the Contractor does not provide the training or the Department uses its own rovers.

- Content of training: The trainees are encouraged to learn about how the whole AMG system is operated, in addition to the use of rovers.
- Time of training: The training about the use of rovers should be completed prior to the start of any AMG work. Other training should be at least yearly.
- Form of training: The goals of this training could be achieved through informal ways, for example, training provided by experienced staff or watching tutorial videos provided by the Contractor on how to use rovers for inspection, or formal classes organized by the Department's Central Office or the District.
- Participants of training: The Engineers and technicians and all the other staff that is determined to be included in the training by the Central Office or the District.

3) Designated survey group or consultant to assist with the use of AMG

It is recommended that the Department designates a survey crew or consultant to assist with the use of AMG. A designated survey crew or consultant can provide information or help to the Engineer, technicians, and any AMG equipment/rover operators who have difficulties in using such system or devices.

4) Technical support

The Engineer and technicians could seek technical support from the Contractor, if/as needed, who might in turn seek technical support from the equipment manufacturer or vendor, as appropriate. The Engineer could ask the Contractor to designate a technical representative from the Contractor (or from the equipment manufacturer or vendor) to be on hand at least at the beginning of the project and to be in contact with the Engineer for issues related to the AMG system throughout the AMG part of project.

5) Web-based training resources

The Federal Highway Administration together with AASHTO provides training modules about the use of 3D models and Automated Machine Guidance. The link to the training modules is: https://www.fhwa.dot.gov/construction/3d/wbt.cfm.This training has four modules and all of the Department construction staff are encouraged to complete the training, with priority attached to the last module, which is about the applications of 3D engineered models in highway construction and QA/QC. This module has four lessons:

- Lesson 1: 3D Applications in Highway Construction;
- Lesson 2: Constructability Review;
- Lesson 3: Automated Machine Guidance (AMG) and Control Systems; and
- Lesson 4: Quality Assurance in Construction with 3D Engineered Modeling.

3.6 Electronic Design Files

1) <u>Use and purpose of the electronic design files in the context of AMG</u>
The Department could provide available electronic design files (2D or 3D) to the Contractor, which the Contractor may use to generate the digitals models for AMG. The electronic design files provided by the Department to the Contractor could be for convenience only, and are not necessarily part of the Contract Documents. Whether the provided design files are part of the Contract Documents or not is project specific and depends on common Department practices for the provision of electronic design files. Note that the Department's practices for the provision of electronic design files are expected to change in the near future (and in general could change from time to time).

In general, if the electronic design files are available, it is a good practice to provide such files to the Contractor before the preconstruction meeting, or upon the request of the Contractor (within 7 business days of receiving the request).

The electronic files may include, but not limited to:

a) Alignment data.
b) Cross sections.
c) Background graphics files with roadway and drainage features such as centerlines, edges, and hull of ponds.
d) Machine control surface model, or existing and design surface models.
e) GPS site calibration data.
f) Project control information.

The use of these electronic files to generate the digital models for AMG is at the discretion of the Contractor. These electronic design files provided by the Department will probably be in the native format of the software application by which they were generated, which may be different from the format of the AMG system that the Contractor uses.

2) <u>Responsibilities associated with the use and provision of the electronic design files in the context of AMG</u>
The Engineer should be aware that the use of electronic design files provided by the Department – whether it is for convenience only or part of the Contract Documents – does not relieve the Contractor from the responsibility to conduct all necessary investigations of conditions including, but not limited to, site visits, spot checks, and/or re-computation before bidding or developing the digital models for AMG.

While preparing the digital models used for AMG (see Section 3.7), the Contractor should notify the Engineer of any errors or discrepancies in the electronic design files provided by the Department, if such files were provided. In this case, the

Engineer should reply to the Contractor within 7 business days of receiving the notification.

If the electronic design files are provided as part of the Contract Document, then the responsibility for the sufficiency or accuracy of the provided electronic files is determined based on the Contract terms and conditions. Otherwise, if the files are provided for convenience only, the Department should assume no responsibility for the sufficiency or accuracy of the provided files.

3.7 Digital Models Used for AMG

1) Developing the digital models used for AMG
The Contractor is typically responsible for developing the digital models used for AMG. The Contractor is responsible for converting the information on the design files (the 2D plans or 3D models) provided by the Department (see Section 3.6 for the description of electronic design files provided by the Department) into a format that is compatible with the Contractor's AMG system. The Engineer should ask the Contractor to submit the digital models used for AMG, for information only, at least 14 days prior to the start of the AMG work. The Department should assume no responsibility for any errors or omissions in the developed digital models used for AMG (it is the responsibility of the Contractor).

2) Updating and revising the digital models used for AMG
The Contractor is responsible for updating and revising the digital models used for AMG. The Engineer should ask the Contractor to submit the revised or updated digital models (if the digital models get revised or updated) to the Engineer at least 5 business days prior to AMG operation in the affected areas. If the revised or updated digital models are not provided in time, the Engineer may request to postpone the AMG work in the affected area.

3) Digital models as input to the devices for inspection
If any of the devices used for review or inspection by the Engineer requires the digital model data, the Contractor should provide those data to the Engineer prior to the review or inspection, as early as possible. The Engineer should ask for the digital model data if the Contractor does not provide such data on time.

4) Cost associated with the digital models used for AMG
The Engineer should be aware that the Contractor is responsible to bear all costs including, but not limited to, the cost of developing the digital models, the cost of manipulating the design files (2D or 3D) provided by the Department, the cost that may be incurred due to the discrepancies between the Contractor's digital models and the design files provided by the Department, and the cost of rework or reconstruction that may be incurred due to errors in the application of AMG techniques.

5) <u>Review of the Contractor's digital model</u>

The Engineer must review the Contractor's digital model first after receiving the digital model to independently verify that the digital model matches the Contract Documents. The Engineer should NOT provide approval to the Contractor based on this review because the Department does not assume responsibility for errors or omissions in the digital models, and the review process only acts as a necessary QA/QC step. The Engineer could use one or more of the following methods to check the digital models:

a) Check line or grade in the digital model against line or grade in the MicroStation plan.
b) Spot check of select points using an independent rover from the Department or the Contractor.
c) Check with existing terrain elevations.
d) Check with tape measure against typical cross sections.
e) Ask dedicated construction survey staff to facilitate the checks.
f) Check with Department design/CADD staff.

3.8 Project Control

1) <u>Primary project control</u>

Project control is a network of control points whose position and heights relative to the project datum (x, y, z coordinates) are known. The control points include horizontal control points and vertical control points, i.e., benchmarks. The Department is responsible to set primary control points whether or not AMG is used in the project. This will be completed by the Department designated survey crew or consultant.

2) <u>AMG control densification</u>

AMG requires different control points than needed for projects constructed using conventional methods. In addition to the primary control points established prior to the project by the Department, the Surveyor (Contractor's Surveyor or Department's Surveyor, depending on the responsibility defined in the Contract Documents, with possible cases presented in Table 65) has to set the secondary/densification control points specified in the plans for grading and preserved for all other project constructions.

Table 65: AMG Project Control Responsibility

	IDOT Specifications 105.09 Survey control points	AMG secondary and additional control points (densification)
Contractor staking (Contractor staking pay item)	Engineer	Contractor
Engineer staking (No Contractor staking pay item)	Engineer	Engineer

3) Project control setup procedures

The Surveyor (Contractor's Surveyor or Department's Surveyor, depending on the responsibility defined in the Contract Documents, with possible cases presented in Table 65) may follow the following recommended steps:

a) Select points at locations that are likely to survive project construction.
b) Place the control stakes along the project corridor with intervals of adjacent points. The interval could be 300 feet to 1000 feet, depending on accuracy requirements, AMG equipment, field conditions, and pay items.
c) Establish elevation of secondary control points using different leveling from project vertical control points, forming closed loops.
d) Perform an independent traverse check between the secondary control stakes using GPS.
e) When a robotic total station is used to guide a paving machine, a denser network of control points of higher vertical accuracy than GNSS controlled systems is required. Figure 4 shows a diagram of typical control points for a robotic total station guided paving system. Set additional control points at maximum 500 feet intervals on each side of pavement. The actual distance may vary by the type of equipment used by the Contractor. The vertical accuracy of the total station could be of +/- 0.01 ft.
f) Document horizontal and vertical coordinates and station offset information for each control point.
g) Replace any control stakes that are disturbed during project construction using the recommended steps.
h) Add additional control points as required by the Engineer. Department's Surveyor is responsible to update the Contractor with the latest project control point information.
i) For projects where the plans do not show a centerline or other survey control line for the construction of the work (e.g., resurfacing, safety modifications, etc.) the surveyor will provide only points marking the beginning and ending of the project.

4) GPS control survey

The Surveyor shall refer to *IDOT's Surveying Manual* (Chapter on GPS) for the use of GPS surveying equipment, field procedures, office procedures, and guidelines for Post-Processed GPS control surveys when performing surveying work using GPS. If GPS is used to set control points, the Surveyor shall use Post-Processed Fast Static and/or Real-Time GPS methods at accuracy levels 3 or 4 according to the Surveying Manual. The deliverables of control survey include, but are not limited to:

a) Coordinates.
b) Primary control check.
c) GPS raw and solution files.
d) Coordinate metadata.

e) Project site map.
f) Project narrative summary.
g) Post-process report.
h) Equipment logs.
i) Names of individuals and duties.

The link to this manual is:
http://idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Design-and-Environment/Survey%20Manual.pdf

5) Record of project control points

If the Contractor adds supplemental project control points, those points should be documented along with other project control points set by the Department in the project control report, which is a part of the aforementioned Automated Machine Guidance Work Plan. The Engineer should be aware that the Contractor is also responsible for verifying, supplementing, and maintaining the project control points before construction and regularly during construction. If the project control points are changed/updated, the Engineer and the Contractor should share the record of coordinates and elevation for the local survey control calibration points to ensure project consistency.

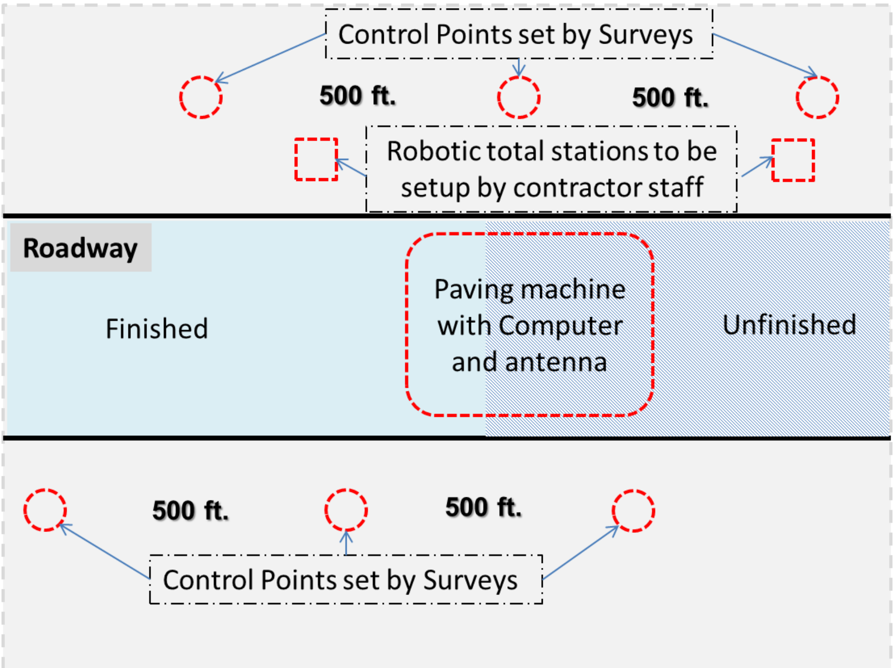

Figure 4: Diagram of control points for robotic total station guided paving system.

3.9 Accuracy and Tolerance

1) Accuracy and tolerance requirements for AMG compared with that for conventional staking

The Engineer should be clear that at least the same accuracy and tolerance requirements shall be met when AMG is used as when conventional staking is used for grading or paving.

2) Reference for accuracy and tolerances
The accuracy and tolerances shall be compliant with the Contract Documents and applicable standards and specifications such as *IDOT Standard Specifications for Road and Bridge Construction*. This is the current link to the specifications:

http://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Construction/Standard-Specifications/Standard%20Specifications%20for%20Road%20and%20Bridge%20Construction%202016.pdf

3) Actions to take if the tolerance and accuracy requirements are not met
If the tolerance and accuracy requirements are not met, the Engineer may suspend the AMG operation; and the Engineer should discuss with the Contractor and technicians to help the Contractor evaluate and address the AMG operation deficiencies. The Contractor should proceed with AMG only after the approval of the Engineer. Alternatively, the Contractor could proceed with construction using conventional staking and without AMG.

3.10 Site Calibration and Check

1) Site calibration procedures
The Surveyor (Contractor's Surveyor or Department's Surveyor, depending on the responsibility defined in the Contract Documents) shall use at least three known horizontal control points for horizontal site calibration or two control points per mile along the project area if this results in more control points. The control points selected shall envelope the project area using AMG and be well-distributed within the area.
The site calibration shall follow *IDOT's Surveying Manual* (Chapter on GPS) including, but not limited to, the following requirements:
   a) A vertical calibration requires a minimum of one NAVD 88 orthometric height benchmarks.
   b) A horizontal calibration requires a minimum of three know control points and one NAVD 88 benchmark.
   c) The results must be carefully analyzed before accepting. Residuals exceeding the survey accuracy determined by redundant observations, a scale factor significantly different than 1.0, or excessive slope of the plane may indicate failure of calibration. Additional control points might be added.
   d) For more information about the specifications and procedures for site calibration, check the *IDOT's Surveying Manual* (Chapter on GPS).

2) Daily site calibration check procedures
The Contractor should perform the daily site calibration checks as described in the Automated Machine Guidance Work Plan on two or more control points with the specific tolerances described in the Contract Documents, *IDOT's Standard*

Specifications for Road and Bridge Construction, and IDOT's Surveying Manual (Chapter on GPS). The tolerances will depend on the type of work, for example, +/- 0.03 feet for rough dirt work, and tighter tolerance (less than +/- 0.03 feet) for sub-bases and pavements, and tightest tolerance (less than +/- 0.01 feet) for bridge work. The tolerances also depend on the equipment. Table 66 shows some of the equipment and common tolerances.

Table 66: Equipment and obtainable tolerances

Equipment	Horizontal tolerance	Vertical tolerance
GPS rover	0.04 feet	0.07 feet
Total station	0.02 feet	0.02 feet
Laser augmented GPS	0.04 feet	0.02 feet

The Engineer should ask the Contractor to submit the daily site calibration check results for information only. If necessary, the Engineer should review these results for extra QA/QC.

If the site calibration check exceeds the tolerances, the Surveyor could follow the following steps:

a) Measure the check again at the same independent control points to ensure that there are no problems with the check measurements.
b) Perform a second site calibration check using another independent control point. If the tolerances are not met, then there is a problem with the site calibration.
   - Redo the site calibration measurements and computation procedures to ensure that there is no problem with the initial site calibration measurements.
   - If site calibration problems persist, consult the vendor or manufacturer manual or seek technical support.
c) If the measurements of the second site calibration are in close agreement with that of the initial one, then there is a problem with the control points used in the initial site calibration.
   - Perform the site calibration while excluding the control points with the largest horizontal and/or vertical error estimates. Select another control point and document the one with the problem.

3.11 Spot Checks

1) Performing spot checks

The Engineer, technician, or the inspector is responsible to perform continuous and independent QA/QC, including spot checks of the Contractor's machine control results, surveying calculations, field procedures, actual staking (if any), and records and documentation, as necessary.

The Engineer or technicians should perform the checks, as needed, before construction and at any time during the construction. The Engineer or technicians should perform spot checks on a daily basis, if necessary.

The spot checks could be at random locations, or at positions deemed by the Engineer or technicians as prone to errors or problems, or at certain intervals determined by the Engineer or technicians based on project conditions.

The Engineer or technicians should/could ask the Contractor to facilitate the spot checks. Most checks could be done as constructed, for example, earth grade, subbase grade, sewer layout, etc.

2) No staking does not mean no spot checking

As stated in 105.11 Duties of the Inspector of *IDOT's Construction Manual*: "It is the Inspector's job to review all phases of the work periodically including various operations being performed by the Contractor to ensure that his/her instructions are being followed and to keep the Resident well informed of progress, problems and instructions to the Contractor." Therefore, spot checking is required.

The use of AMG might eliminate the need for some of the Contractor's staking items. The Engineer must be clear which staking items are eliminated due to the use of AMG. The Engineer must be also clear that no staking at those positions does NOT mean that there is no need for QA/QC by the Engineer at those positions.

The spot checks may be conducted using conventional survey methods, or independent GPS equipment, or a combination of the two approaches. The Contractor's Surveyor should assist the Engineer with the inspection of line and grade in areas without conventional staking by using or furnishing the GPS equipment, the project digital models, and survey control points, if/as needed. The Contractor's Surveyor should also assist the Engineer with the use of the rover if the Contractor is the party providing the rover. The decision to conduct construction checks using conventional survey methods, or independent GPS equipment, or a combination of the two approaches depends on accuracy requirements and pay items, and should be left to the Engineer and technicians.

3) Progress evaluation

As stated in 108.02 Progress Schedules of *IDOT's Construction Manual*: "The progress schedule is the Contractor's statement of how he or she intends to complete all of the contract work within the contract time limits." And when AMG is used in the project, the progress schedule and report should reflect the implementation of AMG, the sequence of AMG work, rates of progress, etc.

The Engineer should ask the Contractor's field staff to report the progress to assist with the evaluation of the work completed by AMG methods. When conventional staking is used, the stakes act as a ready source of progress information for the Engineer. AMG eliminates most of the stakes and, in some cases, the machine operator may have access to the progress information in the AMG system and send the information to the Contractor or the Engineer; otherwise the Contractor's field staff could choose to periodically collect and develop progress information such as cut/fill maps and report them to the Engineer. The Engineer should review the progress reports in a timely manner. The Engineer may request additional information from the Contractor, or notify the Contractor if there is any discrepancy between the actual progress and the reported progress.

3.12 Final Check

1) Quality control test before the final check

The final check of the grade is an important part of QA/QC. Thus, it is highly needed in most occasions. The Contractor should notify the Engineer of the plan to conduct the final check at least two business days before performing the check.

Before performing the final check, the Engineer may want to direct the Contractor to perform a quality control test, as stated in the Automated Machine Guidance Work Plan, in order to check randomly selected locations at all hinge points, centerline, edge of lane and edge of shoulders at all critical locations, and against plan elevations. The areas that are out of tolerances could be checked additionally by the Engineer before the final check. The Engineer should direct the Contractor to facilitate these checks by using or furnishing the GPS equipment, the project digital models, and survey control points, if/as needed. The Engineer should also direct the Contractor to facilitate the checks by furnishing rovers, if the Contractor is the party providing the rover(s) for the project. The Engineer should pay attention to the critical points, including the following:

a) Beginning and end of the project.
b) Bridge clearances.
c) Ramp gore areas.
d) Above and below ground utility crossings.
e) Bridge approaches.
f) Intersections and side road matches.
g) Clearances over pipes.

2) Performing the final check

The Engineer or technicians may be responsible for performing the final check, if deemed necessary. Otherwise, in most occasions, the final check is performed by the Contractor, and the Engineer or technicians should be present during the final check, witness the check, and make note of each check in the field diary. It is possible that for some projects, the final check will not be needed unless there are failures of AMG work or errors that are apparent and require corrective action.

Whether to perform the final check or not, and how much final check work shall be performed, are project specific and should be carefully determined by the Engineer and technicians.

3) <u>A possible method to perform the final check of finished subgrade</u>
The final check is conducted at random locations at the finished subgrade points. The Contractor or the Engineer shall perform 20 or more randomly selected checks per stage, per project, or per mainline roadway mile, whichever results in the most checks. If at least four of any five consecutive random checking points are within the tolerance, the grade passes this check. If more than one of any five consecutive random checking points is out of tolerance (i.e., differs from the design by more than the vertical tolerance), the grade does not pass this check and the Contractor shall correct the grade.

4) <u>The final check could be performed with or without stakes</u>
- If the Contractor chooses AMG, the following types of staking might be eliminated:
  a) Slope stakes, subgrade stakes, undercut stakes, and clearing stakes.
  b) Pavement stakes.

  Before the Contractor eliminates those staking items, the Contractor should describe the AMG operations either to the Engineer, or in the AMG Work Plan. If the Contractor is only using GPS machine guidance, then staking items in a) might be eliminated but conventional stakes in b) might still be needed. If the Contractor is only performing stringless paving operations using AMG (e.g., robotic total stations), then staking in b) and part of staking in a) are not needed but some of staking in a) might still be needed.
- Staking might be deemed necessary for final checking purposes. The following are examples of possible stakes that might be set:
  a) Conventional survey grade stakes at 500 feet intervals and at critical points such as, but not limited to, PC's, PT's, super elevation points, and other critical points required for construction of drainage and roadway structures or as requested by the Engineer.
  b) Finished subgrade points on cross sections at 500 feet intervals on mainline and at least two cross sections on side roads and ramps, and at 250 feet intervals on curves, transitions, intersections, interchanges, and break points. Those points should be established using data other than the machine guidance surface, i.e., digital models, such as plan typicals and cross sections, for use by the Engineer to conduct independent checks.
  c) Paving stakes with cut or fill to finish pavement elevation at points along superelevated curve transitions and at station equation locations.

References

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[5] U.S. Geological Survey. (2012). "Methods of Practice and Guidelines for Using Survey-Grade Global Navigation Satellite Systems (GNSS) to Establish Vertical Datum in the United States Geological Survey." <https://pubs.usgs.gov/tm/11d1/tm11-D1.pdf> (Mar. 1, 2017).

Appendix A

Questionnaire for Surveying/Interviewing IDOT Staff and Illinois Contractors on Potential Practices for Employment in Illinois

1. Section 1: Respondent Information

Please provide the following information:
Name:
Agency:
Job title:
Years of experience:
Phone:
Email:

The questionnaire has three types of questions:

1) Multiple choice questions: please select one or more options among a number of options/alternatives. If you select "Other", please specify your option. If the options are 1 to 6 scale, 1 to 6 represent very disagree, disagree, somewhat disagree, somewhat agree, agree, and very agree, respectively.
2) Yes/no questions: please select yes or no.
3) Short answer questions: please specify your answer.

2. Section 2: Evaluation of Construction Methods

1) Automated Machine Guidance (AMG) systems use positioning techniques such as GPS, robotic total stations, and/or laser scanning to determine the horizontal coordinates and elevation of the equipment and check the equipment position against a 3D digital model. AMG has the potential to reduce the number of stakes required and increase the efficiency and productivity of the Contractor. Construction surveying can be performed using conventional methods, AMG, or a combination of the two approaches. Not every project is suitable for AMG. AMG is, therefore, not mandatory.
2) The Department will allow the use of AMG if the project is suitable for AMG construction techniques. The machines can be guided by a GPS system, or a robotic total station system. The Contractor shall notify [the Engineer] of the intent to use AMG [after project award, before the preconstruction meeting]. To evaluate the suitability of adopting such technology in a project, [the Department] could follow ASSHTO's criteria, which is defined in ASSHTO's Quick Reference Guide for the Implementation of Automated Machine Guidance System. Generally, projects with the following characteristics will be the best candidates for this technology:
   a) large amounts of earthwork or paving,
   b) new alignments,
   c) a good Global Navigation Satellite System (GNSS),

d) a design based on an accurate Digital Terrain Modeling (DTM).

Questions: (4)

1) If you suggest other characteristics that make projects the best candidates for AMG methods, please specify.

____

2) Do you agree that the <u>conditions that limit or exclude the use of AMG</u> shall be included in the guidance document? Such conditions include, but not limit to:
   - Widening with narrow strip additions
   - Designs, such as overlays, that are not based on an existing (Digital Terrain Modeling) DTM. Overlays with new profiles or cross slope construction benefit from AMG
   - Designs that do not exist in a 3D digital environment (note that all jobs are capable of being modeled)
   - Structures
   - Projects that are under a tree canopy, in narrow canyons, or next to tall buildings that interfere with GNSS signals (note that robotic total stations or traditional methods are viable solutions)
   - Design difficulties that would prevent the creation of an accurate and complete DTM (if a surface model can be prepared in difficult situations, it saves on rework)

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

3) When shall the Contractor submit the notification for use of AMG?
   [After project award; Before the preconstruction meeting; Other_______________]

4) Do you agree with the roles and responsibilities, submissions, timeline, evaluation criteria, and requirements that are described in the "Evaluation of Construction Methods" Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

3. **Section 3: Automated Machine Guidance Equipment**

1) The Contractor shall provide all AMG equipment. For the use of AMG equipment, the Contractor shall comply with the Contract Documents and all applicable standards and specifications. The Department is not required to provide a list of approved AMG equipment. The Contractor shall submit the equipment information (as part of the Automated Machine Guidance Work Plan) to [the Engineer], [before or at the preconstruction meeting and at least 30 days prior to use]. The equipment information shall include, but not limited to, the following: [a description of the manufacturer, model, and software version of the AMG equipment].
2) The Contractor shall provide [at least one] GPS Rover to [the Engineer] for the review of the work, as needed. The GPS Rover should be ready for use prior to the start of the construction work. IDOT's Surveyors familiar with GPS Rovers may aid the Engineer in using the GPS Rover for the review of the work. The GPS Rover or other hand-held devices shall be compliant with the Contract Documents and any applicable standards and specifications.
3) When the AMG system is guided by GPS, [the Surveyor (Contractor's Surveyor or IDOT's Surveyor, depending on the responsibility defined in the Contract Documents)] will be in charge of setting up the GPS base station, which is important to the success of the project. The Surveyor shall locate the base station at [a stable, undisturbed place]. The base station should provide radio signal coverage [over the entire area constructed using the GPS-guided machine]. If the base station cannot broadcast a signal that covers the entire site, provide adequate repeater radios or other communications. If the base station is to be relocated, document the current location. The Contractor shall submit the location of the base station to [the Engineer] [for approval]. The Contractor shall not relocate the base station without [the approval] of [the Engineer].
4) The Contractor is responsible for the storage and maintenance of the AMG equipment and all GPS Rovers. The GPS equipment shall be properly maintained [at least once at the beginning of each surveying work; every six months; weekly during the survey; as needed]. Equipment components to be maintained shall include, but not limit to: [tripods, rods, cables, receivers and antennas, and handhelds]. Equipment maintenance shall include, but not limited to: [periodic manufacturer maintenance checks, cleaning, and calibration].

Questions: (5)

1) Do you agree that the Contractor submits the AMG equipment information as a part of the AMG plan?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

If you disagree, when shall the Contractor submit the information?
[Before the preconstruction meeting; At the preconstruction meeting; At least 30 days prior to use; Other____]

2) What shall the AMG equipment information include?

[A description of the manufacturer; A description of the model; A description of the software version; Other____]

3) Do you agree that the Department does not provide a list of approved AMG equipment?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

If you disagree, when shall the Department provide that list?
[The Department will provide a general list that is applicable to all projects using AMG and update the list if/when needed; The Department will provide a specific list that is applicable to this particular project right after evaluating the suitability of AMG use for the project; Other____]

4) What is the preferred frequency for equipment maintenance?
[At least once at the beginning of each surveying work; Every six months; Weekly during the survey; As needed; Other_____________________________________]

5) Do you agree with roles and responsibilities, submissions, timeline, equipment operation and maintenance guidelines, requirements that are described in the "Automated Machine Guidance Equipment" Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

4. Section 4: Automated Machine Guidance Work Plan

1) The Contractor shall submit a comprehensive written Automated Machine Guidance Work Plan to [the Engineer] [for review; for approval] [before or at the preconstruction meeting and at least 30 days prior to use]. The Automated Machine Guidance Work Plan shall include, but not limit to:
   a) Definition of project boundaries and scope of work to be accomplished using the AMG equipment.
   b) Description of the equipment including, but not limited to, a description of [the manufacturer, model, and software version of the AMG equipment].
   c) Project control report including, but not limited to, [all contract control points, coordinates or elevation adopted, office procedures used for GPS technology, and the diagram of control points]. When a GPS base station is on the site for checking or staking purposes, include the determined coordinate and elevation of the base station and the datum differential from the existing control provided by the Department.
   d) Detailed site calibration procedure including, but no limited to, [map of the control points used for site calibration and control points used to check the site calibration, site calibration procedure, frequency of calibration, plan for what information will be documented, and plan for what information will be submitted to the Engineer]. The procedure must show a complete record of equipment check results.
   e) AMG equipment calibration plan including, but not limited to, [equipment to be calibrated, the frequency of calibration, the location and time of calibration, and the status of each calibrated equipment].
   f) AMG equipment maintenance plan including, but not limited to, [frequency of maintenance, components to be maintained, and procedure for maintenance].
   g) A quality control plan including, but not limited to, [frequency and type of checks to be performed, and procedures used to perform the checks]. The control plan must show how the Engineer and the Contractor conduct the initial and daily calibration checks, spot checks, and final acceptance check.
   h) Description of construction checks including, but not limited to, [method and frequency of field verification checks].
   i) Contractor's prior experience with the use of AMG systems.
   j) Contractor's primary contact and alternate contact for AMG issues.
2) [IDOT's Surveyor] shall participate in the preconstruction meeting. During the meeting, [IDOT's Surveyor] shall establish a working relationship with the Engineer and the Contractor, including discussing tentative schedules and safety issues. [IDOT's Surveyor] shall also discuss the Automated Machine Guidance Work Plan with the Engineer and the Contractor, and shall review and evaluate the Automated Machine Guidance Work Plan by:
   a) Reviewing the equipment information.
   b) Reviewing the project control report, checking all control points and base station location, and discussing the needs for additional control points.
   c) Reviewing the site calibration report and performing checks on site, if/as

needed. If the report is rejected, IDOT's Surveyor shall inform the Engineer and the Contractor and provide aid to resolve any problems.

d) Reviewing the equipment calibration and maintenance and providing suggestions based on knowledge of and experience with GPS.

e) Reviewing the quality control plan and discussing the needs of stakes for the checking and inspection of the project.

Questions: (5)

1. Considering the submitting of the AMG Work Plan:
   a. Should the AMG Work Plan be submitted to "the Engineer"?
   [Engineer; Other______________________________]

   b. Should the AMG Work Plan be submitted "for information", "for review", or "for approval"?
   [For information; For review; For approval; Other______________________]

   c. When shall the Contractor submit the AMG Work Plan?
   [Before the preconstruction meeting; At the preconstruction meeting; At least 30 days prior to use; Other______________________________]

2. In addition to the aforementioned items, what else shall the AMG Work Plan include? If any, please specify.

   ____

3. In addition to the aforementioned items, what else shall IDOT's Surveyor conduct in order to review and evaluate the AMG Work Plan? If any, please specify.

   ____

4. Do you agree that if the Contractor does not have experience with the use of AMG systems or the experience is not applicable to the specific project, the Engineer may ask the Contractor to perform a test section?
   [Y/N]

5. Do you agree with the roles and responsibilities, submissions, timeline, and requirements that are described in the "AMG Work Plan" Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

5. Section 5: Training

1) The Contractor shall provide [the Contractor staff] with training [on the use and operation] of the AMG equipment [prior to the start of any AMG work]. The Contractor shall provide [the Department staff] with training [on the use and operation] of the AMG system [and the use of GPS Rovers or other hand-held devices] [prior to the start of any AMG work]. The Engineer and the Contractor shall discuss and determine which Contractor staff and Department staff will participate in the training. As part of the staff, the Surveyors (IDOT's Surveyors and Contractor's Surveyors) may participate in the training to get familiar with the Contractor's AMG system or the GPS Rovers used for checking and inspection. The Surveyors can stay involved in the project using AMG by learning the capabilities of the AMG system and Rovers and being available to provide information to new surveyors and equipment operators who have difficulties in using such system or devices.
2) The Contractor shall provide more training upon the request of the Engineer. The Engineer shall request more training based on need.
3) The Contractor shall seek technical support from the equipment manufacturer or vendor, as appropriate, if/as necessary. The Engineer shall encourage the Contractor to seek such technical support, if/as needed.

Questions: (3)

1. Who shall receive the training?
   [Engineer; Surveyors; Other____]

2. Details about the training:

Question	Engineer	Surveyor	Other__________
a) What is the frequency of training? [One; At least one; Each month; Other______________________________]			
b) When shall the training be provided? [Prior to the start of any AMG work; At the beginning of each month; Other__________]			
c) How many sessions per training? [One; Two; As specified by the Engineer; Other______________________________]			
d) What shall be covered in the training? [AMG equipment; Digital models; Software; Devices for review such as rovers; Other______________________________]			

3. Do you agree with roles and responsibilities, types of training, time and frequency of training, and requirements that are described in the "Training" Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

6. Section 6: Digital Models

1) The Contractor is responsible for developing the digital models used for AMG. The Contractor is responsible for converting the information on [the plans and/or the design files] provided by the Department into a format compatible with the Contractor's AMG system. The Contractor shall submit the digital models used for AMG to [the Engineer] [for review; for information; for approval] [at least 30 days] prior to the start of the AMG work. The [Engineer] shall reply to the Contractor within [7;14] business days of receiving the submission.
2) The Contractor shall notify the Engineer of any errors or discrepancies in the [design files] or Contract Documents provided by the Department. The [Engineer] shall reply to the Contractor within [7;14] business days of receiving the notification.
3) The Contractor is responsible for updating and revising the digital models. The Contractor shall submit the revised or updated digital models to the Engineer [at least 2 business days prior to AMG operation in the affected areas]. If the revised or updated digital models are not provided in time, the Engineer [may request conventional staking in the affected area].
4) The Contactor is responsible for any errors or omissions in the digital models used for AMG.
5) If any of the devices used for review or inspection by the Engineer requires the digital model data, the Contractor is responsible for providing those data to [the Engineer] [prior to the review or inspection].
6) The Contractor shall bear all costs including, but not limited to, [the cost of developing the digital models, the cost of manipulating the design files provided by the Department, the cost that may be incurred due to the discrepancies between the Contractor's digital models and the design files provided by the Department, and the cost of rework or reconstruction that may be incurred due to errors in the application of AMG techniques].

Questions: (5)

1. Do you agree that Contractor is responsible for:
   a. Developing the digital models

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

   b. Updating and revising the digital models

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

   c. Any errors or omissions in the digital models

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

d. Any errors or discrepancies in the design files or Contract Documents provided by the Department

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

e. Bearing all respective costs, including, but not limited to, the cost of developing the digital models, the cost of manipulating the design files provided by the Department, the cost that may be incurred due to the discrepancies between the Contractor's digital models and the design files provided by the Department, and the cost of rework or reconstruction that may be incurred due to errors in the application of AMG techniques

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

2. Do you agree that the Contractor shall submit the digital models to the Engineer?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

If agree (4-6 on the scale):

a. Should the digital models be submitted "for information", "for review", or "for approval"?
[For information; For review; For approval; Other________________________]

b. When shall the Contractor submit the digital models?
[At least 30 days prior to the start of the AMG work; Other_________________]

c. What is the method for the Engineer to check the digital models?
____

3. Do you agree that the Contractor shall provide digital model data required by devices used for review or inspection to the Engineer?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

If agree (4-6 on the scale), when shall the Contractor provide such data?
[At least 30 days prior to the start of the AMG work; Other____________________]

4. Do you agree that the Contractor shall provide the digital models in a specific data format or compatible with specific software?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

If agree (4-6 on the scale), please specify the data format or the software.
____

5. Do you agree with the roles and responsibilities, submissions, timeline, and requirements that are described in the "Digitals Models" Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

7. **Section 7: Electronic Files**

1) In preparing the electronic files by the Department, [IDOT's Surveyor] shall provide [the Engineer] with the 3D data of the existing ground surface, and shall review the electronic files and survey data developed by [the Engineer].
2) The Department shall provide available electronic files to the Contractor. These electronic files will be [in the native format of the software application by which they were generated], which may be different from the format of the systems the Contractor uses. The use of these electronic files to [generate 3D data and/or digital models for AMG] is at the discretion of the Contractor. The Department has no responsibility to provide these electronic files [or 3D data] used for the AMG system, but is encouraged to do so if available. The electronic files may include:
    a) Alignment data.
    b) Cross sections.
    c) Background graphics files with roadway and drainage features such as centerlines, edges, and hull of ponds.
    d) Machine control surface model, or existing and design surface models.
    e) GPS site calibration data.
    f) Project control information.
3) Electronic files will be provided to the Contractor, [if available], [upon the request of the Contractor]. The Department shall provide available information within [5; 7] business days of receiving the request.
4) The electronic files are provided to the Contractor for [convenience only], and are not part of the Contract Documents. The Department assumes no responsibility [for the sufficiency or accuracy of the provided electronic files]. The Contractor is responsible for conducting all necessary investigations of conditions including, but not limited to, [site visits, spot checks, and/or re-computation before bidding or developing the digital models for AMG].
5) The Department shall maintain copies of the electronic files provided to the Contractor using the Department's designated file management system or other method to ensure that both parties utilize the same data to establish locations and measure quantities.
6) The Contractor shall notify [the Engineer] of any errors or discrepancies in the electronic files provided by the Department. The [Engineer] shall reply to the Contractor within [7;14] business days of receiving the notification.

Questions: (7)

1. When shall the Department provide the following electronic files?
    a) Alignment data.
    b) Cross sections.
    c) Background graphics files with roadway and drainage features such as centerlines, edges, and hull of ponds.
    d) Machine control surface model, or existing and design surface models.
    e) GPS site calibration data.
    f) Project control information.

    [Before biding; During biding; After project award and before the preconstruction meeting; After the preconstruction meeting and before any construction work using AMG starts; Upon the request of the Contractor; Other________________]

2. Do you agree that the Department provides electronic files in the native format of the software application by which they were generated and take no responsibilities to convert the file format?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

3. In addition to the electronic files mentioned in Item 1, what other electronic files shall be provided by the Department and when shall the Department provide such electronic files, if any?

   ____

   [Before biding; During biding; After project award and before preconstruction meeting; After preconstruction meeting and before any construction work using AMG starts; Upon the request of the Contractor; Other_____________________]

4. Do you agree that the Department has no responsibility to provide these electronic files or 3D data used for the AMG system?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

5. Do you agree that the electronic files provided to the Contractor are for convenience only, and are not part of the Contract Documents?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

6. Do you agree that the Department assumes no responsibility for the sufficiency or accuracy of the provided electronic files?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

7. Do you agree with the roles and responsibilities, deliverables, and requirements that are described in the “Electronic Files” Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

8. Section 8: Project Control

1) AMG requires different control points than needed for projects constructed using conventional methods. In addition to the primary control points established prior to the project by the Department, [the Surveyor (Contractor's Surveyor or IDOT's Surveyor, depending on the responsibility defined in the Contract Documents)] has to set the secondary control points specified in the plans for grading and preserved for all other project constructions. The Surveyor may follow the following recommended steps:
   a) Select points at locations that are likely to survive project construction.
   b) Place the control stakes along the project corridor with intervals of adjacent points that shall not exceed [2640 feet; 1000 feet].
   c) Establish elevation of secondary control points using different leveling from project vertical control points, forming closed loops.
   d) Perform an independent traverse check between the secondary control stakes using GPS.
   e) When a robotic total station is used to guide a paving machine, a more dense network of control points of higher vertical accuracy than GNSS controlled systems is required. Figure 1 shows a diagram of typical control points for a robotic total station guided paving system. Set additional control points at maximum [500 feet] intervals on each side of pavement. The actual distance may vary by the type of equipment used by the Contractor. The vertical accuracy of the total station shall be of +/- 0.01 ft.
   f) Document horizontal and vertical coordinates and station offset information for each control point.
   g) Replace any control stakes that are disturbed during project construction using the recommended steps.
   h) Add additional control points as required by the Engineer. IDOT's Surveyor is responsible to update the Contractor with the latest project control point information.
   i) For projects where the plans do not show a centerline or other survey control line for construction of the work (e.g., resurfacing, safety modifications, etc.) the surveyor will provide only points marking the beginning and ending of the project.
2) The Surveyor shall refer to IDOT's Surveying Manual (Chapter on GPS) for the use of GPS surveying equipment, field procedures, office procedures, and guidelines for Post-Processed GPS control surveys when performing surveying work using GPS. If GPS is used to set control points, the Surveyor shall use Post-Processed Fast Static and/or Real-Time GPS methods at accuracy levels 3 or 4 according to the Surveying Manual. The deliverables of control survey include, but are not limited to:
   a) Coordinates.
   b) Primary control check.
   c) GPS raw and solution files.
   d) Coordinate metadata.

e) Project site map.
f) Project narrative summary.
g) Post-process report.
h) Equipment logs.
i) Names of individuals and duties.

3) If the Contractor adds supplemental project control points, those points shall be documented along with other project control points set by the Department in the project control report, which is a part of the aforementioned Automated Machine Guidance Work Plan. The Contractor is also responsible for verifying, supplementing, and maintaining the project control points before construction and regularly during construction.
4) The Department shall provide the Contractor with the latest control points. Provide the Engineer and the Contractor with coordinates and elevation for the local survey control calibration points to ensure project consistency.

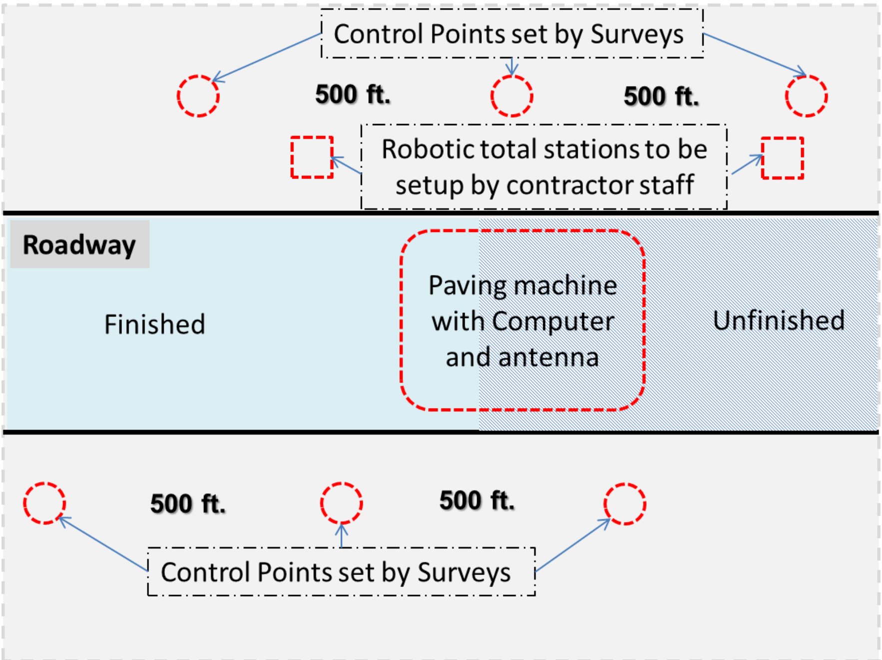

Figure 1: Diagram of typical control points for robotic total station guided paving system

Questions: (7)

1. Do you agree that the control surveying using GPS method shall comply with IDOT's Surveying Manual, Chapter on GPS?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

2. Do you agree that the Department is responsible for:
   a) Setting the primary control monuments

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

   b) Providing the project control information to the Contractor

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

3. When shall the Department provide the project control information to the Contractor?
   [Before preconstruction meeting; At the preconstruction meeting; Other____]

4. Which party shall be responsible for:
   a) Setting the secondary control points?
      [Department; Contractor; Both; Project specific]
   b) Setting any additional control points?
      [Department; Contractor; Both; Project specific]
   c) Verifying, supplementing, and maintaining the project control points before construction and regularly during construction
      [Department; Contractor; Both; Project specific]
   d) Documenting all project control points in the project control report
      [Department; Contractor; Both; Project specific]

5. What is the interval of secondary control points when GPS guided machine system is used?
   [Not exceed 2640 feet; 1000 feet; Other______________________________]

6. In addition to the information mentioned above, what other deliverables about the control survey shall be provided?
   ____

7. Do you agree with the roles and responsibilities, submissions, timeline, and requirements that are described in the “Project Control” Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

9. Section 9: Accuracy and Tolerance

1) The Engineer should be clear that the same accuracy and tolerance requirements shall be met when AMG is used as when conventional staking is used for grading or paving.
2) The accuracy and tolerance shall be compliant with the Contract Documents and [applicable standards and specifications] such as IDOT Standard Specifications for Road and Bridge Construction.
3) If the tolerance and accuracy are not met, the Engineer may suspend the AMG operation and the Contractor shall discuss with the Engineer and the Surveyor to evaluate and address the AMG operation deficiencies. The Contractor shall proceed with AMG only after the approval of the Engineer. Alternatively, the Contractor shall proceed with construction using conventional staking and without AMG.

Questions: (1)

1. Do you agree with the roles and responsibilities and the accuracy and tolerance requirements that are described in the "Accuracy and Tolerance" Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

10. Section 10: Quality Assurance

1) [The Engineer] shall perform spot checks of the Contractor's [machine control results, surveying calculations, field procedures, actual staking, and records and documentation], [as necessary].
2) The Engineer shall perform the checks, as needed, [before construction and at any time during the construction]. The Contractor shall facilitate the spot checks.
3) The spot checks may be conducted using conventional survey methods, or independent GPS equipment, or a combination of the two approaches. The Contractor's Surveyor shall assist the Engineer with the inspection of line and grade in areas without conventional staking by using or furnishing the GPS equipment, Rovers, the project digital models, and survey control points, if/as needed.
4) The Contractor's Surveyor shall report the progress to the [Engineer] to assist with the evaluation of the work completed by AMG methods. When conventional staking is used, the stakes act as a ready source of progress information for the [Engineer]. AMG eliminates most of the stakes and, in some cases, the machine operator may have access to the progress information in the AMG system and send the information to the Contractor or the [Engineer]; otherwise the Contractor's Surveyor may have to periodically collect and develop progress information such as cut/fill maps and report them to the [Engineer]. The [Engineer] shall review the progress reports in a timely manner. [The Engineer may request additional information from the Contractor, or notify the Contractor if there is any discrepancy between the actual progress and the reported progress].

Questions: (5)

1. Who shall perform spot checks?
   [Engineer; Other____]

2. When shall spot checks be performed?
   [Before construction; At any time during the construction; Other_____________]

3. What are the elements that are included in a spot check?
   [Machine control results; Surveying calculations; Field procedures; Actual staking; Records and documentation; Other___________________________________]

4. Do you agree that the spot checks (and other construction checks) will be conducted using conventional survey methods, or independent GPS equipment (such as rovers with project digital model), or a combination of the two approaches?
   [Y/N]

5. Do you agree with the roles and responsibilities, timeline, and requirements that are described in the "Construction Spot Checks" Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

11. Section 11: Site Calibration and Check

1) The [Surveyor (Contractor's Surveyor or IDOT's Surveyor, depending on the responsibility defined in the Contract Documents)] shall use at least [three known horizontal control points for horizontal site calibration or two control points per mile along the project area if this results in more control points]. The control points selected shall [envelope the project area using AMG and be well-distributed within the area].
2) The Contractor shall perform daily site calibration checks as described in the Automated Machine Guidance Work Plan on [two or more] control points with a horizontal tolerance of [+/- 0.03 foot; 0.01 foot or less] and a vertical tolerance of [+/- 0.065 foot; 0.05 foot or less].
3) The site calibration shall follow IDOT's Surveying Manual (Chapter on GPS) including, but not limited to, the following requirements:
   a) A vertical calibration requires a minimum of four NAVD 88 orthometric height benchmarks
   b) A horizontal calibration requires a minimum of three know control points and one NAVD 88 benchmark
   c) The results must be carefully analyzed before accepting. Residuals exceeding the survey accuracy determined by redundant observations, a scale factor significantly different than 1.0, or excessive slope of the plane may indicate failure of calibration. Additional control points might be added

   The Contractor shall check the manual for more information about the specifications and procedures for site calibration.
4) If the site calibration check exceeds the tolerance, the Surveyor may follow the following steps:
   a) Measure the check again at the same control points to ensure that there are no problems with the check measurement.
   b) Perform a second site calibration check using another independent control point. If the tolerances are not met, then there is a problem with the site calibration. Redo the site calibration.
   c) If the measurement of the second site calibration approximates that of the first one, then there is a problem with the control points. Select another control point and document the one with problem.

Questions: (5)

1. How many control points shall the Surveyor use to perform site calibration?
   [Three known horizontal control points for horizontal site calibration; Two control points per mile along the project area if this results in more control points than the minimum; Other____]

2. How many control points shall the Contractor's Surveyor use to perform the daily site calibration check?
   [Two or more; Other____]

3. What are the tolerances for site calibration?
Horizontal: [+/- 0.03 foot; 0.01 foot or less; Other__________________________]
Vertical: [+/- 0.065 foot; 0.05 foot or less; Other____________________________]

4. Shall the Contractor's Surveyor submit the daily site calibration check results to the Engineer?
[Y/N]
If yes, who shall review such results?
[Survey Engineer; Other____]

5. Do you agree with the roles and responsibilities and the requirements on selection of control points, tolerances, and procedure for site calibration that are described in the "Site Calibration and Check" Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

12. Section 12: Final Check

1) Before the final check, the Contractor shall perform a quality control test, as stated in the Automated Machine Guidance Work Plan, in order to check [randomly selected locations] [at all hinge points, centerline, edge of lane and edge of shoulders at all critical locations, and against plan elevations]. The areas that are out of tolerances might be checked additionally by the Engineer before the final check. The Contractor's Surveyor shall assist the Engineer with these checks by using or furnishing the GPS equipment, Rovers, the project digital models, and survey control points, if/as needed.
2) The Contractor shall perform the final check of construction work. [The Engineer] may [either perform or witness] the check. If [Engineer] performs the check, the [Surveyor (IDOT's Surveyor or Contractor's Surveyor)] shall set stakes and assist him/her to perform such checks. Otherwise, the Contractor shall notify the Engineer at least [2 business days] before performing the checks, so the Engineer [can observe the process].
3) The Surveyor should provide/set
   a) conventional survey grade stakes at [500 feet] intervals and at critical points such as, but not limited to, PC's, PT's, super elevation points, and other critical points required for construction of drainage and roadway structures or as requested by the Engineer.
   b) finished subgrade points on cross sections at [500 feet] intervals on mainline and at least two cross sections on side roads and ramps, and at [250 feet] intervals on curves, transitions, intersections, interchanges, and break points. Those points should be established using data other than the machine guidance surface, i.e., digital models, such as plan typicals and cross sections, for use by [the Engineer] to conduct independent checks.
   c) paving stakes with cut or fill to finish pavement elevation at points along superelevated curve transitions and at station equation locations.
4) The final check is conducted at random locations at the finished subgrade points. The Contractor or the Engineer shall perform [20 or more randomly selected checks per stage, per project, or per mainline roadway mile, whichever results in the most checks].
5) If [at least four of any five consecutive random checking points are within the tolerance], the grade passes this check. If more than [one of any five consecutive random checking points] is out of tolerance (i.e., differs from the design by more than the vertical tolerance), the grade does not pass this check and the Contractor shall correct the grade.

Questions: (11)

1. Do you agree that before the final check, the Contractor shall perform a quality control test and the Engineer might check the areas that are out of tolerances?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

2. Do you agree that the Contractor shall perform the final check of construction work and the Engineer may perform or witness the check?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

3. When shall the Contractor notify the Engineer of the final checks?
   [At least 2 business days before performing the checks; Other__________________]

4. Do you agree that only finish grade stakes (blue tops) are needed and NO additional centerline stakes, slope stakes, or grade stakes, except at the aforementioned critical points, are needed?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree

   If disagree (1-3 on the scale), please specify the staking interval for additional stakes.

   ____

5. What is the interval for finished subgrade points that are set at points on cross sections on mainline?
   [1000 feet; 500 feet; Other____]

6. What is the number of cross sections used to set finished subgrade points on side roads and ramps?
   [At least two; Other____]

7. What is the interval for finished subgrade points that are set on curves, transitions, intersections, interchanges, and break points?
   [250 feet; Other____]

8. Are that paving stakes only needed at superelevated curve transitions and station equation locations?
   [Y/N]
   If no, where shall the paving stakes be set?

   ____

9. What is the number of final checks?
   [20 or more randomly selected checks per stage, per project, or per mainline roadway mile, whichever results in the most checks; Other___________________]

10. What is the criteria of final check?
   [At least four of any five consecutive random checking points are within the tolerance; Other____]

11. Do you agree with the roles and responsibilities, procedures, timeline, staking specifications and requirements that are described in the "Final Check" Section?

1	2	3	4	5	6
Very disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Very agree