

# **Final Report**

## **Implementation of GPS Controlled Highway Construction Equipment**

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## **1. Introduction**

### **1.1 Problem Statement**

Use of the Global Positioning System (GPS) to guide earth moving equipment such as dozers, motor graders, and excavators is quickly becoming common place in private sector construction because it speeds project delivery and cuts costs. Use of this technology is expanding quickly into other construction equipment areas such as pavers, milling machines, and boring machines because of the advantages it offers both contractors and owners. Some State Highway Agencies (SHA's) have started to implement this new technology, but not without concern and reservations. There are questions about accuracy (e.g., large error margins in vertical control, multiple sources of error, and signal variability), equipment compatibility (e.g., software for making geoid corrections, receiver equipment, and antenna types), and liability issues (e.g., digital design file accuracy and integrity, construction errors, and rework). Those states that have utilized GPS equipment guidance have been reluctant to develop special technical requirements to govern GPS use because of the developing nature of this technology. Thus, most have allowed its use at the contractor's discretion. This has resulted in contractors investing in a variety of equipment types and proprietary systems, which now complicates development and implementation of controlling specifications.

The technology is somewhere on the continuum between infancy and maturity and with the rapid increase in its use, SHA's are forced to either a) develop specifications to ensure the completed work meets standards and that all contractors are competing on a level playing field, or b) state that compliance with standards is the contractor's responsibility and thus they are free to choose methods and techniques to achieve the end product and must live with the consequences. Given the public's expectation that quality work will be done as quickly as possible and that the SHA is in charge, the latter approach does not seem prudent since the technology is still developing. Controlling specifications need to be developed that establish accuracy limits, define quality control, quality assurance, and verification processes, allocate risk for errors, and establish payment mechanisms. The Wisconsin Department of Transportation (WisDOT) has been a leader in providing electronic plans and thus digital plan and file transfer protocols have already been established. However, issues remain in providing fully three-dimensional design files to contractors. Also, all file transfer requirements need to be coordinated with any GPS machine guidance and control specifications. Development of these specifications will need to be done in cooperation with the contracting industry, equipment suppliers, GPS equipment suppliers, survey and layout control personnel, project designers, construction managers, and field inspectors.

WisDOT would like to implement GPS guidance and control technology for grading equipment on roadway projects. Implementation requires that the technology be thoroughly investigated, specification language developed, design implementation guidance written, field inspection and control systems developed and documented, and industry acceptance gained. WisDOT is seeking assistance in all phases of the implementation process.

## **1.2. Objectives of this Project**

The objectives of this project were to:

1. Develop specifications for adoption by WisDOT to allow use of GPS machine guidance in grading operations for selected pilot projects during the 2007 construction season.
2. Develop implementation strategies for adoption of this technology by WisDOT and engineering consulting firms.
3. Provide a process for incorporating this technology into future construction areas such as paving.

## **1.3. Project Approach**

Background material for this project was developed through literature and electronic media reviews, interviews with 27 individuals, and a site visit to a highway construction project on which GPS machine guidance was being used for earth moving and grading operations. The background material provides information on 1) WisDOT's current use of, and future directions for, GPS; 2) WisDOT's plans for implementing three-dimensional design which is intrinsically linked to GPS machine guidance; 3) other state SHAs' experiences with GPS machine guidance; 4) perspectives of the contractor, engineering, and vendor communities on benefits, impediments to implementation, and current and expected future capabilities of GPS machine guidance and 5) the extent of adoption of the technology by Wisconsin contractors. Contact information for the interviewees appears in Appendix A of this report. Specifications and / or special provisions for GPS machine guidance were obtained from SHAs in Iowa, Maryland, Minnesota, Missouri, and New York. These documents appear in Appendix B of this report.

The background material was synthesized to produce a draft framework for a WisDOT specification that appears in Section 6 of this report. This framework formed the basis for a half-day stakeholder workshop conducted in January, 2007. Workshop participants were asked to address issues, provide input, and strive for consensus on the principles and details of the specification. Results of the workshop were incorporated in a formal specification that was delivered to workshop participants for review. The specification will be used on the selected pilot projects during the 2007 construction season. In addition, guidance language for both design and construction were developed to address issues not included explicitly in the specification and to assist field and office personnel in meeting the requirements of the specification. It is expected that experiences gained from the pilot projects will be used to further refine the specification and guidance language as WisDOT and the construction and engineering communities move forward with implementation of GPS machine guidance.

Advice and guidance for project directions were provided by a 12-member advisory group, consisting of WisDOT staff and representatives from the contractor and engineering communities. Advisory group members are identified in the acknowledgements section of this report.

## **2. WisDOT's Experience with GPS**

### **2.1. Historical Developments**

Historically, the Wisconsin Department of Transportation has been a national leader in adoption of GPS technology for transportation applications. In 1984, WisDOT participated in Wisconsin's first demonstration and experiments with GPS. As the GPS satellite constellation became fully operational in the late 1980's and early 1990's, WisDOT moved towards adoption of static GPS positioning for project control. Field personnel soon realized that the existing national network of geodetic control was inadequate, from both accuracy and accessibility standpoints, to support consistent statewide use of GPS for transportation construction projects. From within WisDOT, emerged the idea for a local high-accuracy reference network, consisting of about 80 well-monumented points, selected for accessibility and utility, and uniformly spaced such that no project would be more than a 45-minute drive from the nearest reference point. WisDOT proposed and built this network in the early 1990's (Hartzheim, 1990). The idea caught on nationally and, today, each state has its own HARN (High Accuracy Reference Network). Furthermore, WisDOT later undertook an effort, with local government agencies, to densify the HARN with secondary control to support local surveying and mapping needs (Hartzheim and Fosburgh, 1994).

In the mid-1990's WisDOT acquired its first Real-Time Kinematic (RTK) GPS base and rover receivers. This technology provides centimeter-level accuracies in real time, as opposed to the delayed post processing required for static GPS. RTK surveys are typically limited to a few miles because accuracy degrades with distance between the base station and the rover(s). This is due, primarily, to variation in atmospheric conditions, and resulting differences in refraction of the satellite signals, at the base station and the rover(s). At limited distances, the differences in atmospheric effects on the satellite signals do not significantly impact accuracies. This fact, along with a significant recent advancement in GPS technology, has led to a new direction for GPS implementation at WisDOT (see Section 2.3.1).

### **2.2. Current Activities**

#### **2.2.1. Height Modernization**

Until recently, GPS had always been limited in its ability to produce vertical accuracies that were compatible with its horizontal accuracies. There are two reasons for this. Firstly, all satellites are above the horizon. In fact, they must be at certain vertical angles above the horizon to prevent their signals from being obstructed. As a result, the geometric configuration of satellites, that are usable at any one time and place, yields a positioning solution that is stronger horizontally than it is vertically. Secondly, elevations or "orthometric heights" are referenced to a vertical datum that is based upon gravity and does not coincide with the horizontal datum surface. The separation between the two datum surfaces varies with location. Until recently, the separation between the datum surfaces was not well-enough measured or modeled to be able to accurately determine the elevation component of position using GPS.

"Height modernization" is a nationwide effort, implemented at the state level, to integrate the national horizontal and vertical geodetic control networks so that elevations and latitude / longitude can be determined compatibly with GPS. In Wisconsin, the height

modernization program is currently underway as a WisDOT-led activity that includes the National Geodetic Survey and private sector partners. The goal is statewide facilitation of RTK GPS surveying to within  $\pm 2$  cm (90% confidence) in all three components of position (Hartzheim, 2006). This is being done by developing a high-accuracy three-dimensional network of monumented points at 10-km spacing. Funding is provided by the National Oceanic and Atmospheric Administration, FHWA, and WisDOT. The latest development in height modernization is continuously operating reference stations (CORS) for RTK GPS positioning (see Section 2.3.1).

## **2.2.2 Revisions to Specifications and Guidelines**

WisDOT has a number of specifications, entries in its Construction and Materials Manual, and entries in its Facilities Development Manual, that govern and provide guidance for surveying, construction staking, monumentation, and standards for exchange of digital design and construction data. These include:

1. C&MM 3.5.102 on construction surveying initial layout.
2. FDM 9-30-30 on standards and specifications for RTK GPS surveys.
3. FDM 9-30-5 on classification, standards, and specifications for three-dimensional control.
4. 650.3 on tolerances for construction staking.
5. FDM 19-7-1 on construction staking as a bid item.
6. FDM 19-10-43 on digital data exchange and project data archive.
7. C&MM 3.1.10 which is a contractor staking packet.
8. FDM 9-25-1 on perpetuation of survey monumentation.

Many of these documents have been recently revised, or are currently under revision, to modernize standard practice and facilitate use of new technologies.

## **2.3. Future Directions**

### **2.3.1. CORS to Support RTK Positioning**

Within the past year, a new technological development has emerged that dramatically enhances the utility of RTK GPS positioning. For a number of years, various agencies of the federal government have cooperated in developing a network of continuously operating reference stations (CORS) for GPS. These facilities 1) continuously receive and archive signals from all GPS satellites that are visible to them and 2) broadcast corrections to coarse acquisition (CA) pseudoranges to be used for differential positioning by any receiver that can receive them. This form of differential positioning produces accuracies of  $\pm 2-5$  m and is suitable for applications such as automatic vehicle location, personal navigation, and mapping of natural resources. The more recent development in CORS applies to more accurate RTK GPS surveys that employ carrier phase measurements instead of the coarse acquisition code. Achievable accuracies are at the centimeter level. RTK technology is used in GPS machine guidance.

Continuously operating reference stations, in support of RTK GPS positioning, relay their received signals to a regional server that analyzes the data from multiple CORS, receives additional signals from rovers, calculates corrections to the signals being received at each rover, and sends to each rover corrections to the carrier phase ranges it is computing. The corrections sent to a rover are based upon a combined atmospheric

model for the surrounding CORS stations. This innovation eliminates the need for a local base station and facilitates RTK GPS surveys that use only rovers, significantly reducing the necessary investment in equipment and simplifying logistical requirements in the field.

WisDOT has adopted the CORS approach to support RTK GPS positioning and is currently installing CORS stations in the eastern part of the state. CORS also reduces the necessary density of high-precision control points because local base stations no longer need to be placed over points of known position. This fact has had a significant impact on the density of points being established during the remaining phases of height modernization. Only the primary framework is now being monumented, reducing the number of control points by 80% or more.

The impact of CORS for RTK GPS surveys on GPS machine guidance could be significant. Contractors who adopt the technology will no longer need to operate project base stations. It might also be feasible to eventually reduce the required amount of local project control.

### **2.3.2. Three-Dimensional Design and Models**

Engineering design for highway construction has traditionally resulted in a set of plans, specifications, and estimates. Plans are a graphical representation of the existing and designed surfaces and features. They consist of a series of two-dimensional views of the three-dimensional world (i.e., plan, profile, and cross-section views). This manner of decomposing and visualizing three-dimensional reality is a holdover from the slide-rule-and-pen-and-ink era and is deeply embedded in engineering and construction practice.

Digital computer technology has now evolved to the point where truly three-dimensional design and visualization are practical. Three-dimensional representations of the world are one level of abstraction closer to reality, contain more detail, and facilitate more comprehensive understanding and analysis. Furthermore, it is these three-dimensional models that are required for GPS machine guidance. In an operational setting, an on-board computer positions the machine within the three-dimensional model by registering coordinates for the machine, computed by RTK GPS methods, to the local coordinate system of the model. The position of the machine with respect to the design surface is then known and the necessary amount of cut or fill for grading operations is continuously available as the machine moves in three-dimensional space.

WisDOT is currently evaluating two software products that support three-dimensional engineering design. The evaluation team expects to make a recommendation for software acquisition, and to provide an implementation plan, by May, 2007. The move towards three-dimensional modeling involves more than changing enterprise CAD software. It requires a new way of thinking about how the world is represented and how work is done. Thus, the evaluation team is also studying process improvement and workflow and will be making recommendations accordingly in their implementation plan.

### **2.3.3. GPS Machine Guidance**

Some Wisconsin contractors began using GPS machine guidance for grading operations on highway projects during 2005. The technology was used on the Marquette interchange by Edgerton Contractors. During 2006, Hoffman Construction used GPS



machine guidance on 12 WisDOT projects. Currently, there are at least 16 Wisconsin contractors who do highway work and have invested in GPS machine guidance (see Appendix C). Some have installed the technology on only one machine. Others have the technology on-board at least 11 dozers and graders. Contractors typically see significant benefits in the technology and there is growing momentum for widespread adoption.

WisDOT currently has no specifications or field procedure guidelines that are specific to GPS machine control, although the agency's use of GPS for surveying is quite mature and it is facilitating adoption of technological advances in GPS as described in Section 2.3.1. WisDOT's desire to move forward with GPS machine guidance spurred the project for which this report is a part.

### **3. Review of State Transportation Agencies**

A number of SHAs have experience with GPS machine guidance. Strong advocates include Minnesota, New York, and North Carolina. Some have developed specifications and / or guidelines. Some have not. There is a general lack of standard approach. There are very few quantitative specifications.

#### **3.1. Georgia**

Georgia DOT has three evaluation projects underway and the potential for doing two more. Evaluation is facilitated by special provisions in the contracts for the projects. Their Research and Materials Section expected to produce a report near the end of calendar 2006. Their evaluation process includes on-site observations and detailed questionnaires for contractors and project engineers. They are evaluating the technology for both rough and finished grading operations. Georgia has determined that finished grading requires laser augmentation of GPS guidance because of higher accuracy requirements in the vertical. They expect their final specification to be quantitative and to contain tolerances.

#### **3.2. Iowa**

The Iowa Department of Transportation (IaDOT) has two GPS machine guidance projects underway. One of them is on a large interchange near Des Moines. They are using the technology for rough grading, but see a future potential for paving operations.

IaDOT does its highway design in-house using Bentley's Microstation and Geopak to produce plans, profiles and cross-sections. IaDOT has developed the three-dimensional models for their GPS machine guidance projects. In the contracts for these projects, the plans control over the three-dimensional models if there is conflict between them.

Iowa has developed a quantitative specification for GPS machine guidance that appears in Appendix B.1. The specification is enabling, not prescriptive, of GPS machine guidance. According to the specification, plans show where IaDOT provides a three-dimensional model and the contractor can develop more model coverage at no cost to IaDOT. The contractor must convert electronic data into a format necessary for their equipment. Any GPS machine guidance equipment that achieves the required accuracies can be used. End results must meet IaDOT's standard specifications.

The project engineer sets initial horizontal and vertical control and provides the localized coordinate system calibration information. These are the parameters for a three-dimensional conformal coordinate transformation that relates RTK GPS-measured coordinates to the coordinate system of the project control and three-dimensional model.

IaDOT does not provide a guarantee of compatible electronic data systems. The specification contains caveats on data representing reality and use of data for other than intended purposes. Assumptions about the data and manipulation of it are made at the contractor's risk. Electronic data are provided as part of the contract documents. The contractor must ensure they can use the data. IaDOT provides CAD files, machine guidance surface models, and alignment data files in various formats. The contractor provides the project engineer with electronic as-built construction data for the final roadway surface models in ASCII format.

The project engineer may perform spot checks of contractor's calculations, staking, records, field procedures, and earthwork. The contractor provides the project engineer with a RTK GPS rover and eight hours of training.

The contractor submits a machine guidance grading work plan prior to the pre-construction conference. The contractor must check the GPS machine guidance system at the beginning of each work day and re-calibrate if necessary. Delays due to problems with reception of satellite signals do not incur cost to IaDOT

The contractor establishes secondary control at intervals no greater than 1000 ft. Horizontal control work is done by static GPS or traverse and vertical control work is done by differential leveling. The contractor sets stakes for subgrade at all hinge points every 1000 ft on the mainline and for two cross-sections on all side roads and ramps. The contractor provides control points and conventional grade stakes at PCs, PTs, superelevation points, and other critical points (e.g., drainage).

### **3.3. Maryland**

The Maryland State Highway Administration (MDSHA) has a special provision for projects that use machine guidance either by GPS or robotic total station. The special provision appears in Appendix B.2. These technologies may be used for the placement of subgrade, subbase, base courses, and other roadway materials.

The contractor develops the three-dimensional model, using contract documents and MDSHA digital terrain data if available, and submits it to the project engineer for review. If MDSHA digital terrain data is used in development of the three-dimensional model, the contractor releases MDSHA and its designers from all liability associated with the accuracy of the data.

The contractor establishes project primary control at intervals not to exceed 1000 ft. Horizontal control work is done by static GPS or traverse. Vertical control work is done by differential leveling. The contractor provides control and grade stakes at critical points such as PCs, PTs, and superelevation points. The contractor provides additional control and staking necessary for coordination with environmental agencies, utility companies, and contractors on adjacent projects.

RTK GPS used to control equipment must be within tolerances of  $\pm 0.1$  ft. Robotic total station control is used where grade tolerances are less than  $\pm 0.1$  ft. The contractor furnishes a GPS rover for MDSHA use and provides eight hours of training. The contractor performs test sections to demonstrate they have the capability, knowledge, equipment, and experience to properly operate the systems and achieve acceptable tolerances.

### **3.4. Minnesota**

The Minnesota Department of Transportation (MNDOT) is an early adopter and advocate for GPS machine guidance. The technology has been used by contractors on MNDOT projects since 2004. MNDOT had a consultant preparing an evaluation report that was expected to be available in January, 2007.

MNDOT prepares all the three-dimensional models for GPS machine control. Model preparation is demanding, time-consuming, and creates a bottleneck. Models are provided to contractors without guarantee of accuracy. The plans are the basis for the contract and the three-dimensional models are developed from them. If errors in a model are discovered in the field, MNDOT has three days to update the model. Contractors must reformat the three-dimensional models for use with their equipment if MNDOT's Microstation GEOPAK format is not readily usable.

There are parts of the state that are not suitable for GPS machine guidance because of dense tree canopy or, especially in the iron belt, an irregular geoid that approximates the vertical datum surface. In those areas, the geoid undulates due to gravitational irregularities and this significantly affects the accuracy of elevations that can be obtained with GPS. The central office must often coordinate bid package preparation with district surveyors.

MNDOT is moving towards including GPS machine guidance as a bid item, but they do not necessarily have prior information on which projects will be bid by contractors with the technology. The central office also does not necessarily have good prior information on site conditions that might affect suitability of a project for GPS machine guidance.

In the field, MNDOT has done some completely stakeless projects except at bridges and intersections where the three-dimensional models might have problems. Some of their projects are of great enough extent that the computers on-board the machine cannot manage the size of the model for the full project. In these cases, the models must be broken into manageable components. Field checking has consistently shown final grades to be within  $\pm 0.05$  ft of design. Typically, surveyors follow a grader and do spot checks every 100 ft on straightaways and every 50 ft on curves. Check elevations are based upon the same three-dimensional model being used for GPS machine guidance, but total stations are used for the check surveys instead of GPS. It is felt that using GPS for check surveys would be subject to the same errors inherent in the GPS machine guidance systems.

MNDOT has a special provision for GPS machine guidance that appears in Appendix B.3. The provision provides a method specification. MNDOT has not made any revisions to its quality specification. The special provision identifies two approved GPS machine guidance systems but allows for others if it can be demonstrated that they will work with MNDOT data. Contractors can also use GPS machine guidance on projects where

MNDOT has not provided three-dimensional models. In those cases, the contractors must develop the models from the contract documents (i.e., plans, profiles, and cross-sections). Delays due to problems with satellite signal reception incur no costs to MNDOT. The provision includes project-specific examples of contract language.

### **3.5. Missouri**

The Missouri Department of Transportation's (MoDOT) first GPS machine guidance project was conducted in 2002. In Missouri, contractors build three-dimensional models from electronic files of plans, profiles, and cross-sections provided by MoDOT. Consultants submit plans, specifications, and estimates on two CDs (see Appendix B.4). One CD contains files formatted for two-dimensional drawings. The second CD contains files formatted to facilitate building of the three-dimensional models by contractors. MoDOT uses Bentley's Microstation / GEOPAK.

MoDOT has recently adopted contractor staking procedures and staking requirements are reduced when GPS machine guidance is used. Plans for use of GPS machine guidance are discussed at pre-construction conferences. Field checks of finished work are rigorous (see Appendix B.4). Check elevations are based upon project plans, not the three-dimensional model being used for GPS machine guidance. The thinking is that the model is derived from the plans and is therefore subject to error propagation.

### **3.6. Montana**

The Montana Department of Transportation (MTDOT) has been using GPS machine guidance on projects since 2002. Montana has a small contracting community. There are eight contractors in the State who do grading. Adoption of GPS machine guidance has been driven by the contractors.

Contractors build the necessary three-dimensional models from paper plans. There is no checking of the models by MTDOT. Quality control on GPS machine guidance projects is the responsibility of the contractor. This includes the configuration of project control, calibration of the GPS system to the model, and the spacing of GPS base stations. MTDOT has a quality specification on the final product. Field checks have never revealed problems with end results. Field checks are performed by radial survey with total stations, a technology that is independent of GPS. Blue top stakes are allowed but not required.

GPS machine guidance has been used on projects up to 10 miles in length. Finished grading is sometimes done without stakes. There are some issues with satellite visibility in the mountainous western part of the State. Contractors sometimes experience up to 20 minutes down time. On these occasions, GPS machine guidance is often supplemented laser guidance technology.

### **3.7. New York**

The New York Department of Transportation (NYDOT) is a strong advocate for GPS machine guidance. They had two pilot projects underway in 2006 and expect to conduct four or five more in 2007. NYDOT uses Bentley's In-Roads and the CEI tool set.

NYDOT provides three-dimensional models for GPS machine guidance as part of the contract documents. They have a specification on use, modification, and sharing of the models (see Appendix B.5). The specification references the Department's land surveying and photogrammetry manuals for point spacing when developing surface models. Checks are made only on originally-measured points, not on interpolated surfaces. The final, updated three-dimensional model can be used for pay item quantities. Contractor changes to the model must be approved by the project engineer. All electronic data is shared, exchanged, and kept current between the contractor and the project engineer. The contractor and the project engineer must use the Department's CADD software.

In New York, contractors provide detailed contract control plans that, among other things, include both the method for initial site calibration to the horizontal and vertical project control and the method and frequency of calibration checks to ensure consistent positional results. The contract control plan indicates which points are to be used for calibration. The contractor and the Department utilize the same project control, existing terrain data, proposed feature data, accuracy and tolerance limits, and equivalent survey verification techniques to ensure that field features are constructed as designed.

The specification opens the door to use of new technologies by enabling introduction of them upon demonstration to, and approval by, the project engineer.

### **3.8. North Carolina**

The North Carolina Department of Transportation (NCDOT) began using GPS machine guidance on projects during 2003. Seventy-five percent of North Carolina's regions have had at least one project upon which GPS machine guidance was used. Even the more mountainous conditions in the western parts of the State have not been prohibitive to use of GPS machine guidance.

Typically, NCDOT provides paper plans to contractors who then hire consultants to develop the necessary three-dimensional models from the plans. NCDOT is considering requiring engineers or surveyors to build the models. They are also considering developing the models in-house to ensure that the models match the plans. There can be multiple interpretations of plans, leading to variance in the three-dimensional models from the plans of record. Regional preferences, such as superelevations of shoulders meeting pavement superelevations, might not be in the two-dimensional plans but must be in the three-dimensional models. Ultimately, NCDOT wants to move towards automatic as-builts based upon coordinates, not stationing. There are issues concerning the transfer, storage, and archiving of all the digital information.

NCDOT has not revised any of its specifications. They currently require full staking of all projects, whether or not GPS machine guidance is to be used. Stakes are used for inspection, not control of the work, on the GPS machine guidance projects. Currently, grade checking is done at 50-ft. intervals. Rough grades must be within 0.1 ft of plan and subgrades must be within 0.5 inches of plan. NCDOT wants to move towards more sparse checking and staking.

NCDOT sees many potential benefits in three-dimensional modeling and GPS machine guidance. These include having three-dimensional utilities considered during design as opposed to causing delays during construction, reduced requirements for staking and

inspection, and the potential for automatic as-builts. Identified issues include modifications to workflow and business processes, compatibility between various vendor products for GPS machine guidance versus inspection, and lack of standards for reduced staking and inspection requirements.

### 3.9. Comparison of Specifications and Provisions

Table 1 compares key aspects of the specifications and provisions of Iowa, Maryland, Minnesota, and New York. It is noted that blank entries in Table 1 indicate lack of information in the specification particular to GPS machine guidance, that is, such information might appear elsewhere in a state’s conventional specifications. It is also noted that the other four interviewed states have either made no modifications or only minor modifications to their specifications, even though some of them had GPS machine guidance used on projects as early as 2002.

Table 1.  
Key Aspects of Four State DOTs’ GPS Machine Guidance Specifications

Specification Aspect	Iowa	Maryland	Minnesota	New York
<b>Grading only?</b>	Grading only	Subgrade, subbase, base course, others	Grading only	Excavation, fill, material placement, grading
<b>Full project or part of project?</b>	Parts		Either	
<b>Staking?</b>	Hinge points every 1000 ft, 2 X-sections on side roads, grade stakes at critical points	Grade stakes at critical points		Apparently can go stakeless except at bridges
<b>Machine guidance by GPS only?</b>		GPS and robotic total station	GPS and robotic total station	GPS, robotic total station, other demonstrably reliable new technologies
<b>Approved equipment list?</b>	Allows any		Yes, but contractor may request others	
<b>Contractor provides rover to engineer?</b>	Yes	Yes		
<b>Contractor provides training to engineer?</b>	Yes – 8 hours	Yes – 8 hours		
<b>Who provides primary control?</b>	Engineer	Engineer		

Table 1 (continued).  
Key Aspects of Four State DOTs' GPS Machine Guidance Specifications

Specification Aspect	Iowa	Maryland	Minnesota	New York
<b>Who provides project control?</b>	Contractor	Contractor		Contractor
<b>Who develops 3D model?</b>	DOT	Contractor	DOT	DOT
<b>Plans or model has priority?</b>	Plans	Plans	Plans	Model
<b>Project control plan from contractor?</b>	One week before pre-construction conference			Prior to field operations - may include use of State CORS
<b>3D model revisions?</b>		DOT has 3 days to make corrections		By supplemental survey and agreed upon by all parties
<b>Track master 3D model?</b>				DOT is custodian
<b>Calibration procedure / tolerance?</b>	Engineer provides calibration			Included in control plan
<b>DOT checking / inspection</b>	Spot checks			Yes
<b>Provide updated 3D model for as-builts?</b>	Yes			Yes – DOT has master – used for pay items
<b>Contractor provides qualifications of staff?</b>		Demonstrates on test sections		
<b>Contractor performs field checks on quality of grading?</b>				Yes
<b>Contractor checks 3D model?</b>	Yes			
<b>Payment</b>	Lump sum			Lump sum

#### 4. Review of Industry

##### 4.1. Contractors' Perspective

Some contractors have invested in GPS machine guidance technology and many are eager to begin. According to [Engineering News Record](#), between 5% and 10% of all earth moving machines are now equipped with GPS machine guidance.

Benefits include accurate grading, real-time decision making, improved material usage, lower operating costs, automated controls, daily as-built reports, and safer operation (Fenton (2006); Taylor (2006)). The need for re-work is greatly reduced because, for example, scrapers work more closely to the final grade so dozers have less work to do (McAninch, 2005). There is less survey preparation work, fewer passes with the machines, fewer machines, no waiting for surveys, and no re-surveys (Fenton, 2006). Building of three-dimensional models from plans can identify problems before work begins in the field, thereby reducing the need for expensive change orders (Street, 2006). The technology provides for pre-construction simulation and remote viewing of the site (Fenton (2006); Taylor (2006)). In addition, production research is facilitated by such things as automated recording of vehicle routes, leading to analysis of cycle times. Production rates show increases of 15% to 30% (Fenton, 2006), and there are estimated savings of 4% to 6% on the total project costs (Street, 2006). According to MNDOT, road building contractors who use GPS machine guidance have already submitted bids that were lower than expected.

Impediments to adoption of the technology by contractors include necessary assimilation time, the need for computer and GPS expertise, and upfront costs for outfitting existing machines (McAninch, 2005). Difficulties in development of the three-dimensional models can arise from inconsistencies in the two-dimensional plans and in the layer content and format of electronic files (Taylor, 2006). Building the three-dimensional model for a ten-mile stretch of interstate highway can require up to six months.

Care must be taken with the machinery. The antenna height can be incorrect; blade wear must be accounted for; pitch sensors must be calibrated; and all wiring must be correct. The technology must be ruggedized for heavy use under poor conditions. Some downtime can be expected due to poor satellite geometry and loss of lock on the satellites' signals. Fortunately, the technology alerts users when these problems occur. There is an extensive and continuing need for training on the parts of project managers and equipment operators.

Typically, contractors desire a single source for all control information; a single source for all electronic data (with verification that it matches design); conducting their own quality control checks in the field; and having quality assurance checks, made by the project engineer, referenced to the same three-dimensional model that was used for construction. DOT oversight of three-dimensional model building, primary control, site calibration file, and construction results is required. Staking should be de-emphasized, but entirely stakeless operations might be undesirable. Slope stakes serve for visual reference in the field. In addition, subcontractors without GPS machine guidance, who often follow along after grading, require stakes. Furthermore, stakes will be required at overpasses, in urban canyons, at other locations where reception of satellite signals is inadequate for GPS machine guidance. Stakes will usually be required at intersections, gores, taper points, and structures.

## **4.2. Engineers' Perspective**

In general, the engineering community is very positive towards GPS machine guidance. Their experience proves that use of the technology saves time over staking, three-dimensional model surfaces allow field staff to quickly verify grades, plan errors are found prior to construction when building the models, model building allows the engineer



to quickly check different parts of a plan at once for possible conflicts, and the contractor can move more quickly in the field when not waiting for grade checks (Kucza, 2006).

On the other hand, model surfaces must still be checked against true field conditions; GPS has errors when satellite geometry is poor, in low spots, and in areas not within good range of the base station or repeaters (Kucza, 2006). Concerns include the potential for the vast power of the technology causing large errors if used incorrectly and future problems with poor design, poor modeling, and poor project control. On the design and model building side of things, it is estimated that only 5% of engineering firms do prepare three-dimensional products (Barrett, 2006).

On a recent WisDOT project where GPS machine guidance was used, rough slopes were much more uniform than when conventional grading is used, so much so that material and 25% of time was saved on finish dozing because no shaping was required. On the same project, ditch work was so uniform that there was no standing water along a 0.5% grade. On a separate WisDOT project, auto-level checks were made every 1000 to 2000 feet, centerline blue tops were set at every station and at two offsets every 500 feet. Superelevation transitions were also staked. Grade checks consistently showed the work to be within 0.05 feet.

Some engineers were initially skeptical of the technologies capability for accurate grading. Experience alleviated their doubts. They note reduced survey crew time and little need for blue tops and red tops. They also note that working with an experienced contractor provides an advantage (Kucza, 2006).

It is understood that contractors will be involved in project control, GPS calibration, and coordinate system transformations. Problems can arise within a project if the control is not well-distributed for calibration, or between adjacent projects if they have independent control networks. There is a need for contractors to employ very knowledgeable surveyors who understand these things. Some feel that WisDOT should sign-off on the contractor's calibration plan and, perhaps, on the calibration results. The same engineers believe that there should be a sign-off procedure on the three-dimensional model to be used for GPS machine guidance.

### **4.3. Vendors' Perspective**

Wisconsin contractors have adopted technology from two primary vendors: TOPCON and Trimble. Leica is also a provider of GPS machine guidance technology, but they appear to have very little presence in Wisconsin.

Vendors are strong advocates of the technology as it is their business. Their assertions of 30% productivity increases and 30% reduction in level of effort for quality control and quality assurance are at the high ends of reports from the contractor and engineering communities.

GPS is now recognized as a component of the Global Navigation Satellite System (GNSS) that includes the Russian GLONASS system and the European Union Galileo system. Current GPS receivers can track up to 20 satellites and there may soon be so many aloft that this capacity will have to be increased. As GNSS continues to improve (e.g., more satellites, increased numbers and powers of signals, continuously operating reference stations), the results of GPS machine guidance will improve in accuracy and

the applications will increase in number. Concrete paving to within 0.01 feet is already possible if laser augmentation is used in conjunction with GPS machine guidance.

Vendors estimate that 75% to 90% of problems with use of the technology arise from human error such as integer transposition on data entry. These are the same kinds of mistakes that are made frequently in surveying practice, and vendors are moving away from the need for manual data entry as quickly as possible.

Removal of paper trails and the need for reverse engineering processes from the three-dimensional survey-design-construct-inspect workflow is expected to lead to 185% return on overall investment (Fenton, 2006). The traditional design process must and will change to give contractors what they want and need (Bowman, 2006). Even the problem of digital signatures on three-dimensional models and other electronic products is being addressed by the vendor community.

## **5. Current Issues**

Some current issues associated with GPS machine guidance have been identified. The most critical ones, that have the potential to impede adoption of the technology in Wisconsin, are migration from two-dimensional plans to three-dimensional models, lack of standard approaches to quality control and quality assurance in the field, and sorting out of responsibilities among WisDOT, its contractors, and the engineering community.

### **5.1. Change in Business Processes**

There is consensus across the experienced community that the greatest bottleneck in workflow for GPS machine guidance is development of the necessary three-dimensional models from two-dimensional plans, profiles, and cross-sections. Ultimately, the new direction is towards a much more seamless three-dimensional survey / design / construct / inspect workflow. This requires a new set of business processes and, truly, a new way of thinking about how the virtual world and its infrastructure are represented. Designers will be required to create and maintain three-dimensional models. The models will become primary and the plans will become secondary. Digital signatures and digital rights will be used to maintain control of data. A comprehensive, managed, work and information technology environment is needed to make this happen (Fenton, 2006).

WisDOT currently has a committee, namely the Computer Aided Engineering (CAE) Advisory Group, distinct from the Advisory Group for this project, that will be addressing these issues during 2007. There is some shared membership between the committee and this project's Advisory Group.

### **5.2. Lack of Standard Approaches to Quality Control and Quality Assurance**

There is no industry standard for quality control and quality assurance of GPS machine guidance for highway construction. Many SHAs are either hesitant to make changes (e.g., North Carolina) or allowing project engineers considerable discretion in the field (e.g., Minnesota). Control configurations, tolerances, and frequencies for calibration are not uniform across the SHAs. Neither are tolerances and frequencies for field checks of grading work.

Furthermore, the nature of GPS machine guidance operations is quite different than conventional operations that use staking. With GPS machine guidance, the operator has continuous information on the relationship of the machine to the design surface. With conventional staking, the operator has such information only at the locations of stakes and, is therefore, required to use judgment based upon experience for guidance of the machine between stakes. In addition, random checks, across the surface of a finished grade, with a GPS rover, with a level, or with a total station, are quite different than the setting of blue top stakes to control the construction of the finished grade. For example, random checking with a rover is referenced to the entire project control network through site calibration while blue tops are referenced to individual control points.

These differences, and the associated lack of standard approaches to field verification, will certainly be addressed over time as the technology gains acceptance and its use continues to grow. At present, the construction community needs to do its best to recognize the issue and reach consensus on how to move forward.

### **5.3. Responsibilities**

As in any contracting situation, the responsibilities of the parties to a GPS machine guidance grading contract must be clearly spelled out. These include identification of the controlling project documents (e.g., plans or model); the manner in which revisions are made to the model; and who is responsible for, and what are the means for, primary and project control, calibration procedures, quality control, and quality assurance. Delivery methods, formats, and content for digital data exchange must be identified, as must the custodians of digital data. The capabilities of technology, and the qualifications of staff to apply it, must be ensured. Lines of communication, reporting requirements, and methods for reporting must be established. The manner in which work shall be measured and the basis for payment on the contract must be well understood.

## **6. Draft Specification Outline**

This section contains a draft outline for a specification to be used by WisDOT on the 2007 construction season GPS machine guidance pilot projects.

### GPS Controlled Highway Grading Equipment Key Specification Elements

#### Specification Subsection Headings

1. General
2. Equipment
3. Construction
  - 3.1 Department Responsibilities
    - 3.1.1 Before
    - 3.1.2 During
    - 3.1.3 After
  - 3.2 Contractor Responsibilities
    - 3.2.1 Before
    - 3.2.2 During
    - 3.2.3 After

4. Measurement
5. Payment

### Draft Specification Outline

1. General.
  - \* This specification is a project-specific special provision that modifies 650.3.3 of the Standard Specifications.
  - \* For grading operations.
  - \* For a portion of the project.
  - \* Reserve right to revert to conventional survey should machine control grading tolerances or methods diverge from acceptable practice or accuracy in the opinion of the engineer.
  - \* Slope stake placed as usual.
  - \* No subgrade stakes to be placed.
  - \* Engineer makes spot checks with rover.
  - \* Machine guidance portion of work must be an agenda item for weekly progress meetings.
  - \* This special provision focuses upon GPA machine guidance only, not upon technologies that supplement or augment GPS.
2. Equipment
  - \* List of approved equipment with contractor option to demonstrate that others will meet requirements and receive approval of engineer.
  - \* Contractor provides engineer with rover and training.
3. Construction
  - 3.1 Department Responsibilities
    - 3.1.1 Before Construction
      - \* Provide electronic files and other information:
      - \* Survey information: control information, existing surface, etc.
        - \*Utilize existing guidance for contract staking package as noted in CMM, 3-1-10.
          - \*At least two weeks prior to pre-construction conference, provide at least six initial control points or at least two per mile; whichever is greater. All control points shall have horizontal and vertical project coordinates published.
          - \*Provide horizontal and vertical datums.
        - \* R.O.W. irons, if used as control, as opposed to coordinates off the plat.
      - \* Design information: alignments, profiles, design surfaces
        - \*Utilize existing guidance for DDE contract staking package as noted in FDM, DDE standards.
        - \* Reference 105.6 and 650 for department responsibility for this information.
        - \*At least two weeks prior to pre-construction conference,
          - \*Provide electronic files in a 3-D CAD format for:
            - \*Alignments
            - \*Profiles

- \*Break lines/Linework ditch bottom line

- \*ROW

- \*Provide electronic files in LandXML format for:

- \*Existing ground surface

- \*Proposed subgrade surface. This surface would be subgrade elevations within pavement structure and finished elevations in topsoiled areas.

- \* Other

- \* Need to verify available project control, some concerns that it is not always intact prior to construction.

- \* ROW irons, if used as control as opposed to coordinates off the plat.

- \* Coordinate with contractor to identify 3D model used for construction.

### 3.1.2 During Construction

- \* Department checking/inspection of earthwork - Qa or Qv

- \*Perform independent random checking.

- \* Address needed changes/updates to existing and/or design surfaces

- \* Review all discrepancies reported by contractor. Then, provide contractor with resolution.

- \*Department has two working days to make needed changes to model unless by agreement to extend.

- \* Department identifies and documents current master 3D model.

### 3.1.3 After Construction

- \* Earthwork quantities

- \* Develop as-built surface model from electronic as-built information provided by contractor.

- \* Compute quantities but leave payment basis as is.

## 3.2 Contractor Responsibilities

### 3.2.1 Before Construction

- \* Provide information on the qualifications of staff.

- \* Provide contract control plan/work plan?

- \* Include plan for project control list and map of points that will envelop the site.

- \* Include plan for mechanical calibration of equipment.

- \* Include plan for site calibration.

- \* Control configuration.

- \* Calibrate/localize site to tolerances of 0.10' or less horizontally and a precision of 0.05' or less vertically.

- Calibration results shall be published and reported to engineer prior to the start of staking and grading.

- \* Frequency of checking calibration.

- \*Minimum of 1 control point check at start of work and a minimum of one check after each 5 hours of continuous work. Document point number, precision, date, and time.

- \* Set project control.

\*Utilize existing guidance that contractor provide to match with operations, see supplemental control. Minimum of six control points every two miles.

\* Control points shall be set using conventional methods, i.e. using total stations and level loops.

\* Perform field checks of 3D model and inform engineer of problems.

\*Could and should use contractor staking specs if at all possible.

\* Provide training on use of rover and 3D model to engineer.

\* Perform site calibration according to contract control plan. Report discrepancies to project engineer.

\* Perform and document the checks of all control points supplied by the Department. Report any errors/discrepancies to project engineer.

### 3.2.2 During Construction

\* Use methodologies that properly apply the technology. Spec to reference proper methodologies for use of GPS.

\* Check calibration according to contract control plan.

\* Provide information on what is being constructed – Qc.?

\* Check subgrade at intervals determined by project engineer. WisDOT guidelines for checking surface models suggest a minimum of 20 points per mile.

\* Check points on subgrade shall be within 0.06 feet of design (vertically).

\* Default parameters, set by the manufacturer for strength of satellite geometry and signals, are not to be modified.

\* Provide all documentation to project engineer.

### 3.2.3 After Construction

\* Provide electronic as-builts to project engineer for computation of earthwork.

## 4. Measurement

\* As noted above, this specification is a special provision modifying the Construction Staking Subgrade bid item, and we would retain the current measurement unit of lineal foot.

## 5. Payment

\* Payment for Construction Staking Subgrade also includes all costs associated with the use of GPS machine controlled equipment.

## 7. Workshop

A one-half day stakeholders' workshop was conducted on January 11, 2007 in Madison, Wisconsin. Invitees included WisDOT personnel, engineers, contractors, and vendors. The final list of 58 workshop participants appears in Appendix D. The workshop objectives were to:

1. Provide participants with information on this project's activities and status.
2. Obtain participants' ideas and feedback on the draft specification outline (see Section 6).

3. Set the stage for refinement of the draft outline into formal specification and guidance language.

Workshop participants were provided with Section 6, Table 1, and the materials in Appendices D and E of this report. Copies of this project's interim report (Vonderohe, 2007) were also available at the workshop.

The workshop consisted of an introductory general session, breakout sessions, and a closing general session where the breakout groups reported their deliberations. The sessions addressed the issues raised in this project's interim report and the draft specification outline that appears in Section 6 of this report. Each workshop participant was pre-assigned to one of four breakout groups. Group 1 addressed issues associated with equipment. Group 2 addressed issues associated with department responsibilities. Groups 3 and 4 addressed issues associated with contractor responsibilities, measurement, and payment. Breakout groups were encouraged to include discussion beyond the scope of their assigned focus, if they felt there were critical contributions to be made. The breakout sessions were facilitated by Advisory Group members.

## **8. Development of Specification and Guidance Language**

The workshop breakout group facilitators prepared summary reports of their sessions and submitted them to the author. These were synthesized and then used to revise the draft specification outline and identify unresolved issues (e.g., gaps and conflicts in breakout group recommendations). A summary report on this work appears in Appendix F.

The Advisory group met to consider the revised specification outline and the unresolved issues. Revisions and additions were made to the outline. Components of the outline were categorized, by Jerry Zogg, as more suited for either the specification or for guidance language. The revised and categorized outline was provided to a WisDOT specification scrivener (Michael Hall) who developed draft formal specification language. Writing assignments for guidance language were given to various members of the Advisory Group. The draft formal specification language was distributed to all workshop participants for review. A summary of reviewers' comments appears in Appendix G. Zogg, Vonderohe, and Hall met once again to consider reviewers' comments and make further revisions to the draft specification. The newly-revised draft specification was distributed to the Advisory Group for final review. After resolving all outstanding issues, the specification and guidance was finalized. The final specification and guidance for the 2007 pilot projects on GPS machine guidance appear in Appendix H.

## **9. Implementation Strategy**

A phased implementation strategy to GPS machine guidance is recommended. This project arose from WisDOT's need and desire to move forward with implementation of GPS machine guidance as a number of Wisconsin contractors have begun to adopt the technology and use it on WisDOT projects. This project engaged a broader community in Wisconsin through conduct of a stakeholders' workshop where participants provided feedback on a draft specification and, later had the opportunity to review a draft of the formal specification. The final specification and guidance language, appearing in Appendix H of this report, will be used on as many as five pilot projects during the 2007 construction season.

The experience and evaluation of these initial pilot projects should be used to refine the specification and lay the foundation for second group of pilot projects during the 2008 construction season. Statewide implementation and adoption of the final specification should then follow.

### **9.1. 2007 Pilot Projects**

The 2007 pilot projects should be carefully selected.

1. At least two of them should be large enough so that portions can be done with GPS machine guidance and other portions can be done by conventional staking (for comparison purposes).
2. Projects in urban canyons or in areas with considerable tree canopy should be avoided, due to the potential for blockage of satellite signals. High voltage power lines should also be avoided due to potential for interference with satellite signals.
3. All projects should be in areas of the State where the height modernization program is complete and RTK GPS positioning with tight vertical accuracies is thus facilitated.
4. There should be variance in soil conditions between the projects (for comparison across projects).
5. It is desirable to have each of the two primary vendors' (TOPCON and Trimble) products in use.

Note: The RTK CORS network is being established by WisDOT during 2007. Utility of this network for GPS machine guidance should be evaluated during the 2008 pilot projects.

### **9.2. Issues to be Resolved by Pilot Projects**

The 2007 pilot projects should be used to address at least the following questions:

#### Equipment

1. What are the frequency, duration, and types of problems with operation of the technology (e.g., poor satellite geometry, loss of lock, multipath, software glitches, data entry and other human errors, technology incompatibilities)?
2. What are the vertical tolerances that are achievable using GPS Machine guidance?
3. What are the necessary knowledge and skill levels for project engineers, contractor project managers, and machine operators?
4. What other efficiencies are realized with GPS machine guidance?
5. What other difficulties arose with GPS machine guidance?

#### Department Responsibilities

1. Are three-dimensional model components provided by WisDOT readily usable by contractors?
2. What are the frequency and causes of revisions to three-dimensional models?



3. Are data exchange standards and rates sufficient for updating models during construction?
4. What is the appropriate spatial frequency for quality assurance checks and what are the appropriate tolerances?
5. Are there issues, during construction, with utility coordination, subcontractors, or others due to reduced staking requirements?

### Contractor Responsibilities

1. What is the appropriate control configuration for GPS site calibration?
2. What are the appropriate tolerances for GPS site calibration?
3. What is the appropriate frequency for GPS site calibration checking / re-calibration?
4. What is the maximum geographic extent over which a single GPS site calibration is valid?
5. What is the appropriate spatial frequency for quality control checks and what are the appropriate tolerances?
6. What needs to be staked and what staking can be eliminated?

### **Acknowledgements**

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Appendix A.  
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## Appendix B.

# Specifications and Provisions from Other States

## **B.1. Iowa**

DS-01077

(Replaces DS-01073)

### **DEVELOPMENTAL SPECIFICATIONS FOR GLOBAL POSITIONING SYSTEM MACHINE CONTROL GRADING**

Effective Date March 21, 2006

**THE STANDARD SPECIFICATIONS, SERIES 2001, ARE AMENDED BY THE FOLLOWING MODIFICATIONS AND ADDITIONS. THESE ARE DEVELOPMENTAL SPECIFICATIONS AND THEY SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.**

#### **01077.01 GENERAL.**

This specification contains requirements for grading construction utilizing Global Positioning System (GPS) machine control grading techniques and shall be used in conjunction with Section 2526, of the Standard Specifications.

The Contractor shall may utilize grading equipment controlled with a GPS machine control system in the construction of the roadway embankment. This requirement includes the finishing of the final subgrade surface.

A Value Engineering Incentive Proposal as described in Article 1105.15 of the Standard Specifications will not be considered for the removal of the GPS Machine Control requirements. The plans indicate the areas of the project where the IDOT is providing electronic surface models of the roadway embankment construction. shall be accomplished with GPS machine control techniques and the The remaining areas that may be constructed with conventional construction survey techniques unless the Contractor chooses to build the required surface models to facilitate GPS machine control grading for those areas at no additional cost to the Contracting Authority. The Contractor may use any type of GPS machine control equipment and systems that results in achieving the existing grading requirements. The Contractor shall convert the electronic data provided by the Contracting Authority into the format required by their system.

#### **01077.02 EQUIPMENT.**

All equipment required to accomplish GPS machine control grading shall be provided by the Contractor and shall be able to generate end results that meet the Standard Specifications.

#### **01077.03 CONSTRUCTION**

##### **A. Contracting Authority Responsibilities.**

1. The Engineer will set the initial horizontal and vertical control points in the field for the project as indicated in the contract documents.
2. The Engineer will provide the project specific localized coordinate system. The control information utilized in establishing the localized coordinate system, specifically the rotation, scaling, and translation can be obtain from the Engineer upon request.
3. The Contracting Authority will provide the data listed below in an electronic format with the proposal form.

No guarantee is made that the data systems used by the Engineer will be directly compatible with the systems used by the Contractor.

Article 1105.4 of the Standard Specifications shall apply with the additional clarification that information shown on the plans shall govern over the provided electronic data.

This information shall not be considered a representation of actual conditions to be encountered during construction. Furnishing this information does not relieve the Contractor from the responsibility of making an investigation of conditions to be encountered including, but not limited to site visits, and basing the bid on information obtained from these investigations, and the professional interpretations and judgment of the Contractor. The Contractor shall assume the risk of error if the information is used for any purposes for which the information was not intended. Any assumptions the Contractor makes from this electronic information shall be at their risk. The Contracting Authority will develop and provide electronic data to the Contractor for review as part of the contract documents. The Contractor shall independently ensure that the electronic data will function in their machine control grading system.

The files that are provided were originally created with the computer software applications MicroStation (CADD software) and GEOPAK (civil engineering software). The data files will be provided in the native formats and other software formats as described below. The Contractor

shall perform necessary conversion of the files for their selected grade control equipment. The Contracting Authority will furnish the Contractor with the following electronic data files:

a. CAD Files:

- ⌚ GEOPAK TIN files representing the design surfaces.
- ⌚ GEOPAK GPK file containing all horizontal and vertical alignment information.
- ⌚ GEOPAK documentation file describing all of the chains and profiles.
- ⌚ MicroStation primary design file.
- ⌚ MicroStation cross section files.
- ⌚ MicroStation ROW data file.
- ⌚ MicroStation photogrammetry and text files.

b. Machine Control Surface Model Files:

- ⌚ ASCII format.
- ⌚ LandXML format.
- ⌚ Trimble Terramodel format.

Note: TIN files and surface model files of the proposed finish grade include the topsoil placement where required in the plans.

c. Alignment Data Files:

- ⌚ ASCII format.
- ⌚ LandXML format.
- ⌚ Trimble Terramodel format.

4. The Engineer may perform spot checks of the Contractor's machine control grading results, surveying calculations, records, field procedures, and actual staking. If the Engineer determines that the work is not being performed in a manner that will assure accurate results, the Engineer may order the Contractor to redo such work, to the requirements of the contract documents, at no additional cost to the Contracting Authority.

**B. Contractor's Responsibilities.**

1. The Contractor shall provide the Engineer with a GPS rover for use during the duration of the contract. At the end of the contract, the GPS rover unit will be returned to the Contractor. This unit shall have the same capabilities as units utilized by the Contractor. The Contractor shall provide 8 hours of formal training on the Contractor's GPS machine control systems to the Engineer.

2. The Contractor shall review and apply the data provided by the Contracting Authority to perform GPS machine control grading.

3. The Contractor shall bear all costs, including but not limited to the cost of actual reconstruction of work, that may be incurred due to errors in application of GPS machine control grading techniques. Grade elevation errors and associated quantity adjustments resulting from the Contractor's activities shall be at no cost to the Contracting Authority.

4. The Contractor shall convert the electronic data provided by the Contracting Authority into a format compatible with their system.

5. The Contractor understands that any manipulation of the electronic data provided by the Contracting Authority shall be taken at their own risk.

6. The Contractor shall check and recalibrate, if necessary, their GPS machine control system at the beginning of each work day.

7. The Contractor shall meet the same accuracy requirements as conventional grading construction as detailed in the Standard Specifications.

8. The Contractor shall establish secondary control points at appropriate intervals and at locations along the length of the project and outside the project limits and/or where work is performed beyond the project limits as required at intervals not to exceed 1000 feet (300 m). The horizontal position of these points shall be determined by static GPS sessions or by traverse connection from the original baseline control points. The elevation of these control points shall be established using differential leveling from the project benchmarks, forming closed loops. A copy of all new control point information shall be provided to the Engineer prior to construction activities. The Contractor shall be responsible for all errors resulting from their efforts and shall correct deficiencies to the satisfaction of the Engineer and at no additional cost to the Contracting Authority.

9. The Contractor shall preserve all reference points and monuments that are established by the



Engineer within the project limits. If the Contractor fails to preserve these items they shall be reestablished by the Contractor shall reestablished at no additional cost to the Contracting Authority.

10. The Contractor shall set hubs at the top of the finished subgrade at all hinge points on the cross section at 1000 foot (300 m) intervals on mainline and at least two cross sections on the side roads and ramps. These hubs shall be established using conventional survey methods for use by the Engineer to check the accuracy of the construction.

11. The Contractor shall provide controls points and 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 the construction of drainage and roadway structures.

12. The Contractor shall provide the Engineer with electronic as-built construction data for the final roadway TIN surface models in ASCII format.

13. At least one week prior to the preconstruction conference, the Contractor shall submit to the Engineer for review a written machine control grading work plan which shall include the equipment type, control software manufacture and version, and the proposed location of the local GPS base station used for broadcasting differential correction data to rover units.

**01077.04 METHOD OF MEASUREMENT**

The bid item for GPS Machine Control Grading will be measured and paid for at the lump sum contract price.

**01077.05 BASIS OF PAYMENT**

The bid item for GPS Machine Control Grading will be paid for at the lump sum contract price. This payment shall be full compensation for all work associated with preparing the electronic data files for use in the Contractor's machine control system, the required system check and needed recalibration, training for the Engineer, and all other items described in the Contractors Responsibilities section of this Developmental Specification.

Delays due to satellite reception of signals to operate the GPS machine control system will not result in adjustment to the "Basis of Payment" for any construction items or be justification for granting contract extensions.

**B.2. Maryland**

**CATEGORY 100  
PRELIMINARY**

**SECTION 107 — CONSTRUCTION STAKEOUT**

**107.03 CONSTRUCTION.**

**107.03.04 Control Stakes.**

186 **ADD:** The following as the second paragraph.

The Engineer as specified in 107.03.01 will provide control stakes and preserve those stakes for the correct layout and inspection activities. When the Contractor utilizes construction equipment guided by Global Positioning System (GPS) and Robotic Total Station (RTS), the Contractor shall set additional stakes directed by the Engineer for horizontal and vertical controls as necessary for the correct layout and inspection of the work.

**107.03.08 Subgrade, Subbase and Base Controls.**

187 **ADD:** The following after the second paragraph.

- (a) **Automated Machine Control.** The Contractor may elect to use construction equipment guided by a Global Positioning System (GPS) or Robotic Total Station (RTS) equipment in the placement of subgrade, subbase, base courses, and other roadway materials.
- (1) The Contractor utilizing this approach shall develop and submit a Digital Terrain Model (DTM) to the Engineer for review. The Contractor using the Contract Documents and any Administration furnished DTM data, if available, shall independently develop the DTM. To use any Administration furnished DTM data, the Contractor shall release the Administration and its designers from all liability for the accuracy of the data and its conformance to the Contract Documents furnished by the Administration.
  - (2) The Contractor shall establish primary control points at appropriate intervals and at locations along the length of the project and outside the project limits and where project work is performed by the Contractor beyond the project limits as required at intervals not to exceed 1000 ft. The horizontal position of these points shall be determined by static GPS sessions or by traverse connection from the original base line control points. The elevation of these control points shall be established using differential leveling from the project benchmarks, forming closed loops where practical. A copy of all new control point information shall be provided to the Engineer prior to construction activities. The Contractor shall be responsible for all errors resulting from their efforts and shall correct the deficiencies to the satisfaction of the Engineer and at no additional cost to the Administration.
  - (3) The Contractor shall provide control points and conventional grade stakes at critical points such as, but not limited to, all PC's, PT's and super elevation points begin full super, half-level plane inclined, etc., along with other critical points required for the construction of structures and utility relocation or coordination. The Engineer will determine whether additional control points and stakeout are necessary.
  - (4) The Contractor shall provide adequate control points, stationing and stakes for coordination activities involving environmental agencies, utility companies and Contractors on adjacent projects at no additional cost to the Administration.
- (b) **Real-Time Kinematic (RTK) GPS.** RTK GPS may be utilized to control equipment and shall be within tolerances of  $\pm 0.1$  ft.
- (c) **RTS Positioning.** RTS positioning shall be utilized where grade tolerances are less than  $\pm 0.1$  ft. The index error of the vertical circle of the RTS shall be checked and adjusted as necessary prior to each day's operations. Each work session shall begin and end by checking between adjacent control points.

- (d) **Grade Busts.** Grade busts and all associated quantity adjustments or errors resulting from the Contractor's activities shall be corrected by the Contractor to the satisfaction of the Engineer at no additional cost to the Administration.
- (e) **Utilizing Automated Controlled Equipment.** When the Contractor chooses to utilize automated controlled equipment, the Contractor shall furnish a GPS Rover instrument for Administration use during the project, along with 8 hours of formal training on GPS/RTS and the Contractor's systems. The Contractor shall provide a surveyor to perform verification when discrepancies arise.
- (f) **Test Sections.** The Contractor shall perform test sections with both GPS and RTS systems to demonstrate they have the capability, knowledge, equipment, and experience to properly operate the systems and achieve acceptable tolerances. If the Contractor fails to demonstrate this ability, the Contractor shall conform to the requirements for the conventional stakeout.

### B.3. Minnesota

Machine Control  
October 18, 2005

#### S-1 (2011) MACHINE CONTROL

This Contractor may make use emerging technologies of machine control of the grading equipment for this Project as described herein;

S-1.1 Mn/DOT will furnish the Contractor MicroStation 2D DWG background file and 3D DWG, or TTM files for *(the designer needs to specify which areas and types of work files will be made available for)*, upon Contract approval. These files are created in MicroStation (CADD software) and GEOPAK (Civil engineering software that runs with MicroStation). It shall be the Contractor's responsibility to do any necessary conversion of the provided files for the Contractor's selected grade control equipment.

S-1.2 Mn/DOT shall be given 72 hours prior to delivering any referenced MicroStation / GEOPAK data to the Contractor. Mn/DOT shall have three (3) working days to update any files after the Department approves any Contractor requested changes. Delays due to satellite reception of signals to operate this system will not result in any adjustment to the "Basis of Payment" for any construction items or to Contract time.

*{use the following ONLY if there is GPS}*

S-1.3 Systems that have been approved are:

Trimble GPS system (SiteVision Office)

TOPCON GPS system (3D-GPS+)

The Contractor may request approval of another system, but use will only be approved if the Survey Equipment-Machine Control System will work with the data in the form Mn/DOT currently produces.

*{use the following ONLY if there is NO GPS and a robotic total station will be required}*

S-1.4 The machine control equipment utilized on this Project shall utilize a robotic total station for control. The Contractor shall be required to provide a robotic total station for control for the State's use during their inspection and record keeping for this Project. This may be the same unit as utilized for the Contractor's machine control or an additional unit. The actual machine control may also require more than a single unit. The State's usage shall be coordinated between the Engineer and the Contractor to minimize the number of units required.

S-1.5 Mn/DOT believes the electronic data it will provide is accurate, but does not guarantee it.

The documents originally provided with the Contract remain the basis of the Contract, and the electronic data being provided is for informational use only in order to assist the Contractor with the use of machine

control. Therefore, if use of this data causes an error, any costs to the Contractor in time or money to make corrections as a result of this error will not be considered "extra work".

S-1.6 The system equipment will remain the property of the Contractor.

S-1.7 All machine control work shall be considered incidental work for which no direct payment will be made.

*Use the following if Machine Control will not be supported by Mn/DOT.*

### **S-2 (2011) MACHINE CONTROL**

This Contractor may make use emerging technologies of machine control of the grading equipment for this Project. Mn/DOT does not intend to share files or models with the Contractor.

### **S-3 (2011) MACHINE CONTROL**

The Contractor is hereby advised that this Project is located in an area of the State that does not have adequate GPS reception to support the use of GPS technologies

SP2903-09 (T.H. 64=193):

In Hubbard County on T.H. 64 from Co. Rd. 33 to W. Jct. T.H. 34;

Grading, Bituminous Surfacing, Aggregate Base & Shoulder, Curb & Gutter, Sidewalk, Storm Sewer, Lighting, Edge Drains, & Watermain: 3.916 miles

### **S-1 (2011) MACHINE CONTROL**

This work shall consist of utilizing the emerging technologies of machine control on the grading equipment for this Project as described herein:

S-1.1 The Contractor shall utilize machine control for all grading and blue top work in Earthwork Balance Number 5, as well as during the construction of the storm water treatment pond. Based on the success of this work, the Engineer and Contractor may mutually agree to continue this machine control usage on the remainder of the Project or to adjust the Construction Staking item to provide for conventional staking of the remainder of the Project. Such adjustments to the Construction Staking Item shall be made in accordance with the provisions of Mn/DOT 1904.

S-1.2 The machine control equipment utilized on this portion of the Project shall be a robotic total station for control. The Contractor shall be required to provide a robotic total station for control for the State's use during their inspection and record keeping for the entire Project. This may be the same unit as utilized for the Contractor's machine control or an additional unit. The actual machine control may also require more than a single unit. The State's usage shall be coordinated between the Engineer and the Contractor to minimize the number of units required.

S-1.3 After completion of the work in Earthwork Balance Number 5 and at the storm water treatment pond, the Contractor may elect to utilize GPS technologies for additional work. The use of GPS control and the Contract items, for which it may be used, shall be approved by the Engineer. Should the Contractor and the Engineer agree to use GPS technology for control, the robotic total station will continue to be provided for usage by the State.

S-1.4 Within 15 days after award of Contract, the Contractor needs to specify the manufacturer of equipment that he intends to utilize on the Project so the correct files may be furnished.

Files to be provided include:

(A) Background graphics file with centerline alignments, edges of pavement, and hull of ponds.

(B) 3D TTM files of proposed finish grade from tie down point to tie down point, and grading grade between intersection with inslope and continuing along bottom of topsoil to the tiedown point.

Please note that Mn/DOT believes this electronic data to be accurate, but does not guarantee it.

The documents originally provided with the Contract remain the basis of the Contract, and the electronic data being provided is for informational use only in order to assist the Contractor with the use of machine control surveying. Therefore, if use of this data causes an error in the surveying, any costs to the Contractor in time or money to make corrections as a result of this error will not be considered extra work as that term is defined in Mn/DOT Standard Specifications for Construction, 2000 Edition.

Any changes to the initial model furnished will require a minimum of 72 hours to complete.

S-1.5 All machine control work shall be considered incidental work for which no direct payment will be made.

S.P. 7008-45 (T.H. 169=005)

In Scott County on T.H. 169 from 0.6 miles S.W. of T.H. 25 to 0.7 miles NE T.H. 25 AND on T.H. 25/CR 64 from 0.5 miles W. of T.H. 169 to 0.5 miles E. of T.H. 169

Grading, Concrete & Bituminous Surfacing, Signing, Lighting, Temporary Traffic Signal, and Bridges  
70043 & 70044: 1.193 miles

## **S-2 (2011) MACHINE CONTROL**

This work shall consist of utilizing emerging technologies of machine control on the grading equipment for this Project as described herein:

S-2.1 The Contractor shall utilize machine control for all grading on this Project, except for subcut cut-and-fill grading around all bridge abutments.

S-2.2 The use of Global Positioning System (GPS) control and the Contract items for which it may be used, shall be approved by the Engineer.

S-2.3 Systems that have been approved are:

Trimble GPS system (Site Vision Office)

TOPCON GPS system (3D-GPS+)

The Contractor may request approval of another system, but its use will only be approved if the Survey Equipment-Machine Control System will work with the data in the form Mn/DOT currently produces.

S-2.4 Delay due to satellite reception of signals to operate this system will not result in any adjustment to the "Basis of Payment" for any construction items or to Contract time.

S-2.5 Within fifteen (15) days after Award of Contract, the Contractor needs to specify to the Engineer the manufacturer and model of equipment that he intends to utilize on the Project so the correct files may be furnished to him.

Files to be provided include:

(A) Background graphics file with centerline alignments, edges of pavement, and hull of ponds, if any.

(B) 3D TTM files of proposed finish grade from tie down point to tiedown point, and grading grade between intersection with inslope and continuing along bottom of topsoil to the tiedown point in rural (shoulder, no curb) areas.

(C) 3D TTM files of proposed finish grade from tiedown point to tiedown point, and grading grade between intersection with ½:1 subcut. If the grading grade intersects the inslope, the model will include the grading grade and continue along bottom of topsoil to the tiedown point in urban (curb) areas.

(D) 3D TTM files on ponds, if applicable.

Please note that Mn/DOT believes this electronic data to be accurate, but does not guarantee it.

The documents originally provided with the Contract remain the basis of the Contract, and the electronic data being provided is for informational use only in order to assist the Contractor with the use of machine control. Therefore, if use of this data causes an error, any costs to the Contractor in time or money to make corrections as a result of this error will not be considered Extra Work as that term is defined in Mn/DOT Standard Specifications for Construction, 2000 Edition.

Any changes to the initial model furnished will require a minimum of seventy-two (72) hours to complete and are at the discretion of Mn/DOT. Mn/DOT shall also have three (3) working days to update any files after the Department approves any Contractor requested changes.

S-2.6 The machine control equipment utilized on this Project shall utilize a robotic total station for control. The Contractor shall be required to provide a robotic total station for control for the State's use during their inspection and record keeping for this Project. This may be the same unit as utilized for the Contractor's machine control, or an additional unit. The actual machine control may also require more than a single unit. The State's usage shall be coordinated between the Engineer and the Contractor to minimize the number of units required.

S-2.7 The system equipment will remain the property of the Contractor.

S-2.8 All machine control work **shall be considered incidental work** for which no direct payment will be made.

S.P. 6280-304 (T.H. 35E=390), S.A.P. 62-649-11 CTB, S.A.P. 62-658-11, S.A.P. 200-010-02

In Ramsey County on T.H. 35E from 1000 feet North of T.H. 36 to 900 feet North of County Road E in the Cities of Little Canada and Vadnais Heights

Grading, Concrete & Bituminous Surfacing, Noise & Retaining Walls, Traffic Signal, Lighting, Signing, and Bridge Nos. 62902, 62904, 62905, 62907, 62908, 62909, 62910, 62914, 99191, and 99192 3.762 miles

## **S-3 (2011) MACHINE CONTROL**

This Contractor may make use of emerging technologies of machine control of the grading equipment for this Project as described herein.

S-3.1 Mn/DOT will furnish the Contractor DXF or DWG and TTM files for:

1) Grading Grade elevation for all permanent construction of the mainline roadway and ramps to within 100 feet of bridges or matching inplace roadways.

2) Grading Grade elevation for the following bypasses:

Stage 1 Phase 1

BP 01 from 22+00 to 41+50

BP 42 from 19+50 to 30+00

BP 14 from 13+00 to 15+50

BP 14 from 56+50 to 66+50

BP 16 from 28+00 to 33+00

BP 21A from 66+50 to 92+00

BP 02 from 65+00 to 71+50

BP 03 from 65+00 to 72+50

BP 54 from 9+50 to 13+ 80

Stage 1 Phase 2

BP 10 from 31+00 to 37+00

BP 56 from 60+85 to 63+50

BP 12 from 21+50 to 25+50

Stage 1 Phase 3

BP 10

BP 55 (EB) 6+00 to 10+00

BP 55 (WB) 22+50 to 30+00

BP 11 from 52+00 to 58+00

BP 24 from 11+50-22+00

BP 21B from 84+50- 87+50

BP 44 from 19+00 to 25+00

Stage 2 Phase 1

BP 10 from 18+00 to 29+00

BP 31 from 14+00 to 17+00

BP 32 from 32+00 to 35+00

BP 17 from 10+00 to 17+50

BP 50 from 15+00 to 19+00

BP 58 from 17+75 to 19+30

BP 57 from 30+00 to 34+00

BP 24 from 22+00 to 27+00

BP 19 from 95+50 to 100+00

BP 68 from 24+00 to 28+50

BP 26 from 37+00 to 49+50

BP 26 from 56+50 to 58+50

Stage 2 Phase 2

BP 70 from 60+00 to 63+00

BP 58 from 17+50 to 19+50

BP 63 from 41+75 to 47+00

BP 09 from 63+00 to 78+00

BP 64 from 48+50 to 52+00

Stage 2 Phase 3

BP 49 from 93+25 to 95+25

BP 60 from 16+75 to 19+50

Stage 3 Phase 1

BP 62 from 42+25 to 44+25

BP 46 from 8+50 to 12+00

Stage 3 Phase 2

BP 52 from 63+ 00 to 65+00

BP 52 from 69+00 to 72+00

BP 53 from 90+00 to 93+75

3) The Finished Grade elevations for the following ponds:

Alfalfa

Breezy  
Buckwheat  
Chubby  
Curly  
Darla  
Farina  
Froggy  
Larry  
Moe  
Petey  
Porkey  
Shemp  
Spanky  
Stymie  
Waldo  
Wheezer  
Woim

This list subject to changes. Mn/DOT Surveys will work with the Contractor to determine the extent of what can be produced. If Bypasses are coming off or adjacent to in-place roads, **.ttm** files will not be produced. In the case of Bypasses built detached from in-place roads, Mn/DOT will produce the **.ttm** files and **.dwg** or **.dxf** files if possible. The intent of this list is to provide the Contractor a guide of what areas Mn/DOT can provide. These files are created in MicroStation (CADD software) and GEOPAK (Civil engineering software that runs with MicroStation). It shall be the Contractor's responsibility to do any necessary conversion of the provided files for the Contractor's selected grade control equipment.

**S-3.2 Mn/DOT will provide these files on an ongoing basis throughout the Contract. The Contractor will be required to submit a written request for a specific file at least 72 hours prior to delivering any referenced MicroStation / GEOPAK data. Due to the nature of the Project, the Contractor will not be allowed to request all files at once. Files will be made available to the Contractor in stages as the Contract work progresses.** Mn/DOT shall have three (3) working days to update any files after the Department approves any Contractor requested changes. Delays due to satellite reception of signals to operate this system will not result in any adjustment to the "Basis of Payment" for any construction items or to Contract time.

S-3.3 Systems that have been approved are:

Trimble GPS system (SiteVision Office)

TOPCON GPS system (3D-GPS+)

The Contractor may request approval of another system, but use will only be approved if the Survey Equipment-Machine Control System will work with the data in the form Mn/DOT currently produces.

S-3.4 Mn/DOT believes the electronic data it will provide is accurate, but does not guarantee it. The documents originally provided with the Contract remain the basis of the Contract, and the electronic data being provided is for informational use only in order to assist the Contractor with the use of machine control. Therefore, if use of this data causes an error, any costs to the Contractor in time or money to make corrections as a result of this error shall not be considered "extra work".

S-3.5 The system equipment will remain the property of the Contractor.

S-3.6 All machine control work shall be considered incidental work for which no direct payment will be made.

## **B.4. Missouri**

### **GCM Section 627 Contractor Surveying And Staking**

#### **627.1 Pre-Construction**

The contractor's surveyor is expected to perform the staking required by the contract. MoDOT surveyors are not to be used as back-ups if the contractor's surveyors are

unavailable. MoDOT will furnish the contractor's surveyor with additional working points and bench-marks prior to the beginning of construction if needed. The contractor's surveyor should make working points available to MoDOT upon request. MoDOT will check all staking of larger structures such as box culverts and bridges. (Try to give 2-days notice as to when these will be ready for checking.) MoDOT will spot-check the staking of smaller structures, slope stakes and paving grades. General guidance on the frequency and tolerance of checks is found in the Construction Manual. If the contractor's surveying is outside of tolerance they will be notified to correct in writing. The contractor is responsible for final line and grade of the end product. The contractor's surveyor should provide enough information and staking upon request so MoDOT can adequately check the staking on the project. Staking the profile outlined in the Specifications may not be required for each project, depending on the scope of the work.

The clearing limits are generally marked 10' beyond the planned slope line to allow for grading and the adjustment of slope-stakes to fit original ground. MoDOT will survey everything directly related to pay. The contractor should maintain adequate working points during and after construction. (Working points may be needed for staking R/W after construction is completed.) The surveyor is considered a subcontractor with the same requirements of any sub with the exception of certified payrolls. This work is considered a non-regulated job so no prevailing wage rates are required. Utilities that may have to be staked should be done by MoDOT or should be considered additional work by the contractor and compensated. The above guidelines are attached as a pre-construction check list.

## **627.2 Quality Assurance**

Quality assurance checks by MoDOT do not relieve the contractor of his responsibility to construct the project to the specified lines and grades. Our checks are to identify any contractor staking errors to minimize any adverse impacts to the project. They are also to help spot any plan errors. The contractor should be willing to assist in any checks. It is in both parties interest to catch any busts early on. They should place any additional stakes necessary for MoDOT to properly check their surveying. If a contractor's instrument and ours do not agree a third instrument should be brought in to find out what equipment is out of calibration. The following is a guideline only. If there were something that doesn't look right you would need to check it.

**Structures:** On a bridge each stake should be checked. The check should be within 0.01 ft. for vertical and horizontal. \*Surveyors and inspectors should note that the end bents should be staked at the fill face and not centerline of bent. This is a common problem, which has often resulted in piling driven at the wrong location.

**Culverts:** Each stake should be checked. The vertical and horizontal tolerance should be within 0.5 inches.



**Pipes:** Pipes stakes should check within 1/10<sup>th</sup> of a foot. \*Some pipes have a very flat grade. Always check to make sure the pipe will still flow correctly within the tolerances surveyed.

**Retaining Walls:** Each stake should be checked. The tolerance should be within 0.04 ft. horizontal and vertical.

**Drop Inlets:** Tolerance 0.04 ft. if in the roadway and 0.10 ft. if it falls outside the road-way.

**Slope Stakes:** The entire cross section should be checked every 500 ft. The slope stake (or first cut stake. Tolerance should be within 0.2 ft.

**Paving Grades:** Everything should be set to finish grade. Checks should be made not only at the individual stake but also at the next stake forward and backward. \*It is recommended to produce a Doc. Record with a diagram of the way the pavement is staked. This assures both parties are in concurrence. Grading and Paving contractor's often like things staked differently. Hub Line tolerances should be horizontal 0.10 ft. and vertical 0.04 ft.

**MISSOURI DEPARTMENT OF TRANSPORTATION (MoDOT)**  
**Specifications for Delivery of Electronic Design Data**  
**Effective November, 2005 Letting**

**General Requirements**

The Missouri Department of Transportation uses MicroStation version 8.5 for highway, bridge design and drafting. Highway design surveys and road design computation shall be achieved by using the GEOPAK software.

**Delivery of Electronic Design Data from Consultant Contracts.**

Consultant contracts shall continue to be in compliance with the Specifications of Computer Deliverable Contract Plans stated in the Project Development Manual Section 4-01.3 (4). In addition, to those requirements, the consultant shall deliver two additional CD ROMs.

The first CD-ROM shall be labeled "Electronic Design Data for MoDOT Project Office", and shall contain the following electronic design files.

1. Final GEOPAK coordinate geometry database file (.gpk) containing all final chains, profile, control points, special profiles, and other elements needed to construct the final plans. The chains and profiles shall have names pertaining to the items they represent. Documentation of all chains and profiles are to be supplied in an ASCII text file as described in paragraph 5 of this section.
2. All contract plan drawings for an entire project as MicroStation files (.dgn) including all reference drawings containing both existing and proposed plan and/or profile view geometry.
3. All GEOPAK cross section drawings (.dgn) containing GEOPAK cross section cells, existing ground line and any subsurface geometry, proposed template including proposed finish grade and all pavement and aggregate layers.

4. All Microstation cross-section drawings (.dgn) containing the cross-section geometry, sheet borders and earthwork end areas/volume notes. The cross sections in the sheets shall match their equivalent GEOPAK cross-section drawing.
5. A text file describing the contents including project name, drawing names, and coordinate geometry descriptions. This file shall be named CONTENTS.TXT and be located in the root directory of the disk.

The second CD-ROM shall be labeled “Electronic Design Data for Contractor GPS Grading”, and shall contain the following electronic design files.

1. Final GEOPAK coordinate geometry database file (.gpk) containing all final chains, profile, control points, special profiles, and other elements needed to construct the final plans. The chains and profiles shall have names pertaining to the items they represent. Documentation of all chains and profiles are to be supplied in an ASCII text file as described in paragraph 5 of this section.
2. Contract plan view drawings showing “strip map” proposed geometry as MicroStation files (.dgn).
3. All main alignment (including ramps) GEOPAK cross section drawings (.dgn) containing GEOPAK cross section cells, existing ground line and proposed template including proposed finish grade and all pavement and aggregate layers. Any sub-surfaces such as rock lines, etc. shall be removed from this file.
4. A GEOPAK XS-List report (.xsr) for each alignment.
5. The ASCII text file including superelevation transition stations, i.e. pattern\_shape.inp file.
6. A text file describing the contents including project name, drawing names, and coordinate geometry descriptions. This file shall be named CONTENTS.TXT and be located in the root directory of the disk.

Consultants shall turn in the two CD-ROMs to the district project manager at the time they submit their plans. The project manager shall be responsible for sending the first CD labeled “Electronic Design Data for MoDOT Project Office” to the appropriate construction office. The second CD labeled “Electronic Design Data for Contractor GPS Grading” shall be submitted to the Central Office at the time plans are due.

Send the CD labeled “Electronic Design Data for Contractor GPS Grading” to:

CADD Support  
601 West Main  
Jefferson City, MO 65101  
Attention: Alexa Mitchell  
RE: Electronic Deliverables

## Electronic Design Files

### General

Beginning with the November 2005 letting, MoDOT will provide a CD-ROM containing electronic design data along with the bidding documents to aid the bidder in the use of automation of bid estimates, and/or GPS grading and staking.

### **Will electronic design data be provided for all projects?**

Only projects with total earthwork volume exceeding 250,000 cubic yards and designed with the GEOPAK software will qualify for delivery of electronic design data.

### **Exactly what design data is being provided and in what format? [Guidelines for Consultants](#)**

The design data will be provided in the native format of MicroStation and/or GEOPAK files as used by the department, which include

1. MicroStation drawings (.dgn files) showing proposed master (strip map) plan view geometry.
2. MicroStation drawings (.dgn files) showing master GEOPAK intelligent cross sections for main alignments.
3. Geopak XS-List report (.xsr files) for each alignment with GEOPAK intelligent cross sections. [How To Create XS Reports](#)
4. GEOPAK coordinate geometry database (.gpk file) containing final horizontal and vertical alignments, special ditch profiles, and control points.
5. An ASCII text file including superelevation transition stations.
6. A text file describing the contents including project name, drawing names, and coordinate geometry descriptions.

**For additional information regarding electronic design data, please contact:**

**MoDOT Design Division**  
**P.O. Box 270**  
**Jefferson City, MO 65102**  
**Phone: 573-751-5653**  
**Fax: 573-526-4535**  
**Email: [Alexa.Mitchell@modot.mo.gov](mailto:Alexa.Mitchell@modot.mo.gov)**

### **B.5. New York**

**Title: REVISION TO STANDARD SPECIFICATIONS: SECTION 105-10, SURVEY AND STAKEOUT;  
SECTION 625, SURVEY OPERATIONS, ROW MARKERS & PERMANENT SURVEY MARKERS**

#### **ADMINISTRATIVE INFORMATION:**

- **Effective Date.** This Engineering Instruction (EI) is effective beginning with projects submitted for the letting of September 7, 2006.
- **Superseded Issuances.** This EI does supersede a portion (Section 105-10) of EI 05-011, which modified Section 100 of the 2002 Standard Specifications.
- **Disposition of Issued Material.** The guidance transmitted in this EI will be incorporated into a future revision of the Standard Specifications.

**PURPOSE:** The purpose of this EI is to revise the subject specifications and incorporate the use of new technologies into the construction of Capital Projects.

**TECHNICAL INFORMATION:** The transmitted materials modify the Standard Specification Sections 105-10 and 625 as follows:

- Section 105-10 This specification is revised to incorporate surveying parameters and standards for quality control of positioning terrain data, and provide guidance on the appropriate interpretation of terrain data provided in contract documents.
- Section 625 This specification is revised as follows:
  - To incorporate the use of new survey and automated equipment operations.
  - To require the sharing of electronic engineering data, when available, between the Contractor and Department.
  - To clarify which survey operations require direct oversight by a licensed Land Surveyor or Professional Engineer.
  - To require the submission of a Contract Control Plan at the beginning of a construction contract which describes what control will be jointly used by the Contractor and the Department for the construction of the contract. The Contract Control Plan is intended to document which control points, datum, correction factors, and stakeout methods will be used in the field prior to beginning operations.
  - To standardize engineering data processing and formats to promote sharing of that data between all stakeholders.
  - To incorporate the use of CADD applications in the field for modeling construction features, determining potential conflicts, and calculating quantities.

**IMPLEMENTATION:**

- The Main Office Design Quality Assurance Bureau will insert these two standard specification shelf notes beginning with projects submitted for the letting of September 7, 2006.

**TRANSMITTED MATERIALS:**

- Standard Specifications shelf notes of the revised *Section 105-10 Survey & Stakeout*, and *Section 625 Survey Operations, Row Markers & Permanent Survey Marker*.

**BACKGROUND:**

- New technologies are emerging in the construction industry and NYSDOT Standard Specifications need to be revised to accommodate methods which leverage these new systems and operations.
- The Department and the Association of General Contractors (AGC) have a joint committee which is focused on addressing the needs of emerging technologies. Many of these changes have come about through the discussions of this committee.

**CONTACT:** Direct questions regarding this EI to Dan Streett of the Design Services Bureau at (518) 485-8227 (e-mail [dstreett@dot.state.ny.us](mailto:dstreett@dot.state.ny.us)).

**REVISIONS TO SECTION 105-10, SURVEY AND STAKEOUT**

Make the following changes to the Standard Specifications dated January 2, 2002, and as modified by EI 05-011:

**delete** Section 105-10 entirely and **add** the following:

**105-10 SURVEY AND STAKEOUT.** Prior to the start of construction work, all right of way markers, property line markers and survey control markers located in or adjacent to areas which may be disturbed during construction shall be properly protected and tied to fixed reference points or located from established contract control. Upon completion of the work, all right of way or property line markers or survey markers that have been disturbed by the Contractor, shall be reset under the direction of a Land Surveyor. Field location notes shall be recorded and made available to the Engineer upon request at no additional cost to the State.

All survey control and boundary location work shall be performed in accordance with the Department's *Land Surveying Standards and Procedures Manual* under the direction of a Land Surveyor.

All survey work performed for quality control by the Contractor and for quality assurance by the Department should both utilize: (1) similar levels of measurement precision and methods to perform positional measurements, (2) the same control network from which measurements are made, and (3) the same survey measurement procedures to ensure consistency of results.

Terrain features are measured and positioned by various methods relative to the contract control network established for each contract. The precision with which an instrument or equipment positions a point is related to the quality of the method by which measurements are made, and the ability to duplicate the same measurement.

The accuracy of a located point is the closeness of the measured or computed value to a standard or accepted value (actual spatial position on the earth). Positional tolerance is the allowable spatial difference between making measurements by two different methods or by the same method at separate times, all of which have the same level of precision.

Horizontal coordinates and vertical elevations of existing features provided in contract documents are located in the field based on accuracies achievable for each positional point relative to the contract control.

Positional accuracies are directly related to the strength of the contract control network closure, the precision of the instruments used to measure to the feature, and how definable the feature is which is being located. Point feature locations represent a single position (for example: property line marker, sign post, utility pole, or fire hydrant) and can be reidentified or verified in the field to within a small variation (high confidence level) from where they were initially positioned.

Linear feature locations define the alignment position of that feature. That alignment can be verified to within a specific tolerance depending on the spacing or frequency at which the points were originally measured to define that alignment. Straight or uniformly curved linear features (for example: curbline, edge of roadway, or edge of sidewalk) which can be easily defined in the field should have a relatively small positional variation from their coordinated position when compared to a verified field location. Irregular shaped or not as clearly defined linear features (for example: break lines, ditchlines, treelines, or environmental area perimeters) which are sometimes difficult to define or delineate precisely in the field, could have a larger variation from where they were initially positioned when compared to a field-verified location.

Digital terrain model (DTM) surfaces which are provided in the contract documents are made up of a combination of point and linear features used to produce a DTM surface. The precision of a data collection instrument does not necessarily indicate what positional tolerance should be expected of any feature verified from an existing DTM. The location or elevation of a feature selected from a DTM surface can, at best, be determined by interpolating the horizontal position or elevation between previously positioned points. The verification of any specific elevation on the DTM surface is directly related to: (1) the spacing of collected data used to produce that surface; (2) the uniformity of the surface being measured; (3) the steepness of the slope of that surface; and (4) how obscured the surface is from the measuring technique used to originally locate the surface. Standardized procedures for determining the spacing/frequency of point and linear features (including break lines), are critical to providing consistent results. Department standardized procedures for determining feature locations are described in both the "Land Surveying Standards and Procedures Manual," and the "Specifications for Photogrammetric Stereocompilation."

## **REVISIONS TO SECTION 105-10, SURVEY AND STAKEOUT**

Any true verification of the positional tolerance of the DTM surface elevation shall require a comparison of the original collected point data with recollected point data which are measured at the same horizontal locations.

Field comparisons to interpolated DTM surfaces or recreated surface information (from paper drawings) shall not be used for verification of the positional tolerance of a feature. Comparisons of remeasured point data can only be made with the original collected point data, not to interpolated positions. Measurements for verification of DTM point data shall also be made from the same contract control network, and by instruments capable of an equal or greater precision.

## **REVISIONS TO SECTION 625, SURVEY OPERATIONS, ROW MARKERS & PERMANENT SURVEY MARKERS**

Make the following changes to Volume II of the Standard Specifications dated January 2, 2002: page 6-117, line 39 through page 6-122, line 11, **delete** entirely and **add** the following:

### **SECTION 625 - SURVEY OPERATIONS, ROW MARKERS, AND PERMANENT SURVEY MARKERS**

#### **625-1 DESCRIPTION**

**625-1.01 Survey Operations.** This work shall consist of providing all necessary surveying to establish, spatially position, measure, navigate to and verify the locations of existing and proposed terrain features and measure quantities of items in accordance with the contract documents or as directed by the Engineer. This work includes but is not limited to the establishment or reestablishment of primary and secondary control, the stakeout of proposed features or the initialization and navigation of automated equipment operations, the location or verification of existing terrain or of constructed features, and the coordination and sharing of engineering data with the Department or other contract stakeholders.

The following types of Survey Operations shall be completed under the direction of a Land Surveyor. This requirement is directly or indirectly associated with the professional license requirements contained in Article 145 of the NYS Education Law.

1. Establishment or reestablishment of primary or secondary control which shall be used for:
  - a. Establishing boundaries of new right of way appropriated for this contract.
  - b. Location of property or highway boundary markers.
  - c. Tie measurements to, or resetting of control points.
2. Location or resetting of existing highway and property boundary markers by reference ties to or from contract control to protect their integrity.
3. Establishment or certification of location of right of way markers and permanent survey markers.

The following types of Survey Operations shall be completed under the direction of either a Land Surveyor or Professional Engineer:

1. Establishment or reestablishment of primary or secondary control which shall be used for:
  - a. Establishing location for horizontal or vertical roadway alignment.
  - b. Establishing location for the horizontal or vertical alignment of a structure.
  - c. Establishing reference station for Global Positioning System (GPS) control work.
2. Establishing new horizontal or vertical roadway alignment in the field from contract control either by conventional stakeout methods or by use of automated equipment operations.

**Contract Control Plan** – The Contractor shall develop and submit a Contract Control Plan for all contracts which include the *Contract Pay Item 625.01 Survey Operations*. Contract control includes all primary and secondary horizontal and vertical control which will be used for the construction of the contract. Upon the Contractor's completion of initial survey reconnaissance and control verification, but prior to beginning primary field operations, the Contractor shall submit a Contract Control Plan document (signed and sealed by the Land Surveyor or Professional Engineer who oversees its preparation) for acceptance by the Engineer which includes:

1. A control network diagram of all existing horizontal and vertical control recovered in the field as contract control.

2. Include a summary of the calculated closures of the existing control network, and which control has been determined to have been disturbed or out of tolerance from its original positioning.
3. An explanation of which horizontal and vertical control points will be held for construction purposes (include a NYSPCS coordinate list). If necessary, include all adjustments which may have been made to achieve required closures.
4. An explanation of what additional horizontal and vertical control (including base stations) was set to accomplish the required stakeout or automated machine operations. Include how the position of these new control points was determined.
5. Describe the proposed method and technique (technology and quality control) for utilizing the control to establish the existing and/or proposed feature locations and to verify the completed feature location and/or measured quantity.
6. A listing of the horizontal and vertical datums to be used, the NYS Plane Coordinate System (NYSPCS) zone, and the combined factor to be used to account for the ellipsoidal reduction factor and the grid scale factor.
7. If the NYS Continuously Operating Reference Stations (CORS) Network was used to establish the initial control for the design of this contract, or if the Contractor proposes to use CORS with any construction operation, the survey reconnaissance and control verification shall include verifying the contract control against at least two NYS CORS Stations, and reporting the accuracy results in the contract control plan.
8. If the Contractor chooses to use automated machine operations as a method for measuring and controlling excavation, fill, material placement or grading operations, the Contract Control Plan shall include the method by which the automated machine guidance system will initially be site calibrated to both the horizontal and vertical contract control, and shall describe the method and frequency of the calibrations to ensure consistent positional results.

All establishment or reestablishment of contract primary or secondary control shall be done in accordance with the Department's "*Land Surveying Standards and Procedures Manual.*"

**625-3.01 Survey Operations.** All available contract control, alignment or terrain data to be used to establish, position, measure, guide and verify the locations and quantities of existing and proposed features for the contract, will be managed and stored by the Department and shared electronically with the Contractor.

Survey Operations shall utilize: *A. Conventional Survey Stakeout* or *B. Automated Machine Operations*, or a combination of both, for the establishment, positioning, equipment guidance or verification of features. The proposed method shall be approved by the Engineer as part of the Contract Control Plan prior to beginning any field construction operations. Both methods include the same basic requirements that: (1) both parties (Contractor and Department) utilize the same contract control, the same existing terrain data, and the same proposed feature data; (2) both parties utilize the same accuracy and tolerance limits; and (3) both parties utilize equivalent survey verification techniques to ensure that field features are constructed as designed.

After completion of the work, the Contractor shall reestablish and retie the contract control points as described in the Department's current "*Land Surveying Standards and Procedures Manual.*"

If an existing Digital Terrain Model (DTM) was developed during design and provided for construction purposes, and possibly updated during construction by supplemental survey, the Department will use that information to develop contract pay item quantities. If a proposed Digital Terrain Model (DTM) was developed during design and provided for construction purposes, or revised during construction due to site changes or redesign, the Department may use that information to develop applicable contract pay item quantities. If the Contractor does not agree with any of the information used, it may verify all or any portion of the existing or proposed DTM, at no additional cost to the State. All exceptions/changes to the supplied existing terrain data shall be brought immediately to the attention of the Engineer, in writing, and terrain data modifications shall be mutually agreed upon prior to beginning construction activities within

the area(s) being modified. All existing terrain data supplied by the Department shall be considered as being within acceptable tolerances, except where changes or additions have been approved by the Engineer. Terrain data (DTM) changes will not be accepted by the Department where existing terrain is verified to be within Departmental accepted positional tolerances. If a proposed Digital Terrain Model (DTM) was not developed, the Department may use line and grade information contained in the contract documents, in conjunction with the original ground survey plus any supplemental survey it collected, to develop contract pay item quantities. If the Contractor does not agree with any of the information used, it may verify all or any portion of the information, at no additional cost to the State.

The Contractor shall establish the center line of bearings for bridge abutments and piers, by setting offset hubs or reference points, so located and protected to ensure they remain undisturbed until such time as they are no longer needed. The Contractor shall mark the location of anchor bolts to be installed, establish the elevation of bearing surfaces and check bearing plates to ensure installation at their proper elevation. Before the erection of structural steel the Contractor shall verify the locations, both vertically and horizontally, of all bearings.

**A. Conventional Survey Stakeout.** The field location of all features to be constructed shall be established from survey control points which were identified in the Contract Control Plan. Any error, apparent discrepancy or absence in the data shown or required to appropriately accomplish the stakeout survey shall be referred to the Engineer immediately for interpretation when such is observed or required.

The Contractor shall place two offset stakes or reference points along the center line at maximum intervals of 20 meters and at such intermediate locations as required to determine location and direction. From computations and measurements made by the Contractor, these stakes shall be clearly and legibly marked with the center line station number, offset and cut or fill from which the establishment of the centerline location and elevation can be determined. If markings become illegible for any reason the markings shall be restored by the Contractor. The Contractor shall locate and place all cut, fill, slope, fine grade, or other stakes and points for the proper progress of the work (maximum station spacing of 20meters). All control points shall be properly protected and flagged for easy identification.

The Contractor shall be responsible for the accuracy of the work and shall maintain all applicable reference points, stakes, etc. Damaged or destroyed reference points or bench marks made inaccessible by the progress of the construction shall be replaced or transferred by the Contractor. All control points shall be referenced by ties (4 minimum) to specific points on acceptable objects and recorded. Any alterations or revisions in the ties shall be so noted and the information furnished to the Engineer. All stakeout survey work related to highway control shall be referenced to the control line shown in the contract documents.

Computations and survey notes necessary to establish the position of the work from control points, shall be made and maintained in a neat, legible and acceptable format by the Contractor. Computations, survey notes and other survey information shall be made available to the Engineer within 3 days from the request.

The Engineer may check all or any portion of the stakeout survey work or notes made by the Contractor.

Such checking by the Engineer shall not relieve the Contractor of any responsibilities for the accuracy or completeness of the work.

**B. Automated Machine Operations.** The Contractor may choose an automated method for the establishment, layout, measurement, equipment guidance or verification of work to be constructed. Under this method, all horizontal and vertical control, alignment control, existing terrain data and proposed design data shall be shared/exchanged electronically and kept current between the Contractor and the Engineer.

All original active files of electronic contract data shall be maintained and stored by the Department. Prior to beginning field operations, the Contractor and Engineer shall mutually



determine acceptable uses of and procedures for the technology being used, and how data can be exchanged for use in stakeout, automated equipment operations, verification and quantity calculations. All engineering data shall be stored and shared in Department standard formats, and shall be derived primarily from the original electronic data provided by the Department.

Automated equipment operations have a high reliance on accurate control networks from which to take measurements, establish positions, and verify locations of features. Therefore, a strong contract control network in the field which is the same or is strongly integrated with the project control used during the design of the contract is essential to the successful use of this technology with the proposed Digital Terrain Model (DTM). Consistent and well designed site calibration for all automated machine operations (as described above under *Contract Control Plan*) are required to ensure the quality of the contract deliverables. The Contract Control Plan is intended to document which horizontal and vertical control will be held for these operations. Continued incorporation of NYS CORS Stations (if included in the initial project control) is essential to maintaining the integrity of positional locations and elevations of features.

The Engineer may perform quality assurance verifications of feature positions and elevations at any time during the contract. Dimensional tolerances shall hold a higher order of importance than positional tolerances, but both may require verification. Quality assurance activities by the Engineer will not relieve the Contractor of any responsibilities for the quality control of the accuracy or completeness of the work.

Verification of the positional locations of features, calculation and creation of supplemental DTM surfaces, and the measurement and calculation of quantities shall be developed through the use of Department standard CADD software. Both the Contractor and the Department shall utilize the following standards: (1) All CADD alignment and land boundary data shall be processed using the Department's standard CADD software. (2) All terrain data collected for the purpose of being used for or merged with Department provided terrain data and/or for the calculation of pay quantities shall be formatted and displayed in accordance with the current "*CADD Standards and Procedure Manual*." (3) Field data collection and DTM creation shall be in accordance with procedures required in the current "*Land Surveying Standards and Procedures Manual*." (4) The Department will maintain electronic data files for access by the Contractor using the Department's designated file management system. This will ensure that both parties utilize the same credible data from which to establish locations and measure quantities. The Department will provide all available CADD resource files for use by the Contractor.

The Contractor may choose to introduce an additional new automated method which involves a different technique for positioning features, measuring quantities, or verifying constructed locations. The quality and accuracy of this data produced by this method shall be demonstrated to the Engineer, for acceptance, by a comparison of this method to previously accepted techniques over a mutually agreed upon portion of the work. The new technology shall meet or exceed the quality and accuracy results provided by previously accepted techniques, and the Engineer shall make the final determination as to the acceptability of its use based on the performance, cost savings, and effectiveness of the operation. Previous uses of this same method on other contracts or by other contractors are not acceptable evidence of a technology's viability, due to inherent variations in operator's experience levels, data availability, changing field conditions and differing technologies.

**625-3.02 Right of Way Markers.** The Contractor shall verify with the Engineer that it has the most current vested Right of Way Acquisition Maps to determine the locations of the proposed right of way markers. Right of way marker locations shall be determined under the direction of a Land Surveyor from a closed traverse or GPS network which is included in the contract control plan and in accordance with Federal Geographic Data Committee (FGCC) C2-II, Second-Order, Class II (1 part in 20,000) accuracy, ensuring a local positional accuracy of 20 mm as described in the Department's "*Land Surveying Standards and Procedures Manual*."

The Contractor shall install right of way markers at the station/offset positions specified on the vested Right of Way Acquisition Maps in accordance with the Standard Sheets to within an absolute positional tolerance of 20 mm.

The Land Surveyor shall certify the as-built location of each installed right of way marker on certification forms provided by the Engineer, including contract information, and control line station and offset (proposed and as-built) to the marker. The record location of all right of way markers shall be recorded to the nearest millimeter and reflect as-built coordinates from a closed traverse or GPS network which is included in the contract control plan and in accordance with FGCC C2-II, Second-Order, Class II (1 part in 20,000) accuracy.

Prior to placing the cap on a steel pin right of way marker, the cap shall be filled 2/3 full of silicone sealant and then fastened to the bar by threading or by force fit. During the driving operation for the steel pin right of way marker, the lettering on the cap shall be protected by the use of a metal sleeve or cushion block. The marker shall be driven so that the cap is flush with the ground surface.

**625-3.03 Permanent Survey Markers.** Permanent survey markers shall be installed in accordance with the standard sheet at locations described in the contract documents and approved by the Engineer prior to installation.

The sequential numbering required on the permanent survey marker caps shall be coordinated with the Engineer and the Regional Land Surveyor.

The Land Surveyor shall certify the as-built location of each installed permanent survey marker on certification forms provided by the Engineer, including contract information, as-built State Plane Coordinate values, control line and centerline station and offset to the marker, distance and direction to adjacent markers, the elevation of the marker, and a sketch which shows the relative positions to the control line points, four physical ties to the markers, and a north arrow. The record location of all permanent survey markers shall be recorded to the nearest millimeter and reflect as-built coordinates from a closed traverse or GPS network which is included in the contract control plan and in accordance with FGCC C2-II, Second-Order, Class II (1 part in 20,000) accuracy as described in the Department's "*Land Surveying Standards and Procedures Manual*."

#### **625-4 METHOD OF MEASUREMENT**

**625-4.01 Survey Operations.** This work will be measured on a lump sum basis.

**625-4.02 Right of Way Markers.** The quantity to be measured for payment will be the number of right of way markers installed.

**625-4.03 Permanent Survey Markers.** The quantity to be measured for payment will be the number of permanent survey markers installed.

#### **625-5 BASIS OF PAYMENT**

**625-5.01 Survey Operations.** The price bid shall include the cost of furnishing all labor, materials and equipment necessary to satisfactorily complete the work. Progress payments will be made in proportion to the amount of work completed as determined by the Engineer.

**625-5.02 Right of Way Markers.** The unit price bid per each shall include the cost of furnishing all labor, materials, and equipment necessary to satisfactorily complete the work. Payment will be made upon the complete and proper installation of the marker, receipt of the certification form by the Engineer, and approval of the certification by the Regional Land Surveyor.

**625-5.03 Permanent Survey Markers.** The unit price bid per each shall include the cost of furnishing all labor, materials, and equipment necessary to satisfactorily complete the work. Payment will be made upon the complete and proper installation of the marker, receipt of the certification form by the Engineer, and approval of the certification by the Regional Land Surveyor.

***Payment will be made under:***

**Item No. Item Pay Unit**

625.01 Survey Operations Lump Sum  
625.03 Concrete Right of Way Markers Type H (High) Each  
625.04 Concrete Right of Way Markers Type L (Low) Each  
625.05 Steel Pin and Cap Right of Way Markers Each  
625.06 Permanent Survey Markers Each

## Appendix C.

# Wisconsin Contractors That Do Highway Work and Have GPS Machine Guidance Technology

1. Speedway Sand & Gravel
2. Wondra Excavating
3. Integrity Grading
4. F & K Excavating
5. H James & Sons
6. Buteyn-Peterson
7. RG Huston Construction
8. Riverview Construction
9. A-1 Excavating
10. Koplín & Kinas
11. A W Oakes Construction
12. Mann Bros. Construction
13. Edgerton Contractors
14. Hoffman Construction
15. Bacco Construction
16. Musson Bros. Construction

Appendix D.  
Workshop Participants

## January 11 Workshop Invitees

### Advisory Group and Project Team

Michael Bradley	Ayres & Associates
Kenneth Brockman	WisDOT
Chris Goss	Hoffman Construction
Donald Greuel	WisDOT
Paul Hartzheim	WisDOT
Robert Hubing	WisDOT
Richard Larson	WisDOT
Alan Rommel	WisDOT
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#### Vendors

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Appendix E.

Additional Workshop Materials

# Implementation of GPS Controlled Highway Construction Equipment

## January 11 Workshop Schedule and Content

Howard Johnson's – East Washington Avenue – Madison.

1:00 – 1:10 Welcome and Introductions (Jerry Zogg).

1:10 – 1:20 Project Overview and Objectives (Alan Vonderohe).

1:20 – 1:30 Workshop Overview and Objectives (Alan Vonderohe).

1:30 – 1:45 Interim Report / Draft Specification Outline (Alan Vonderohe).

1:45 – 2:00 Issues: Equipment; Department Responsibilities; Contractor Responsibilities; Measurement and Payment (Alan Vonderohe).

2:00 – 2:10 Break.

2:10 – 3:10 Breakout Sessions:

### 1. Equipment (Facilitators: Ken Brockman, Paul Hartzheim)

- Contractor supplies equipment they want as long as they can meet the specifications
- Use GPS only or GPS with augmentation
- Contractor supplies equipment to engineer
- Contractor provides training to engineer
- Other?

### 2. Department Responsibilities (Facilitators: Jerry Zogg, Rick Larson)

- Design issues related to department providing 3D models. What responsibility/liability should contractor have relative to 3D models?
- Department issues related to addressing needed changes to 3D models during construction. How will this work with consultant prepared plans?
- Mechanics/procedures of identifying/documenting the initial and revised 3D models to be used in the field
- Pilots to use current contractual basis for determining yardage; however, as parallel effort do yardage computations by comparing existing and design surfaces
- Other?

### 3. Contractor Responsibilities / Measurement / Payment (Facilitators: Don Greuel, Chris Goss)

- Determine what all the elements of the contractor's quality control plan/work plan should be
- Discuss Advisory Group recommendation that no subgrade staking is necessary - or should some reduced level still be done?
- Is contractor providing enough staking to accommodate engineer's need to do random checking?
- Does specification say enough about our expectations regarding what the contractor should do to check the survey and design information provided by the department and report problems?
- Contractor will still do Slope Staking and Supplemental Control and use those bid items
- Okay to use current Subgrade Staking Bid item (as modified with GPS machine control specs) on lineal foot basis? Or is there need to create new bid item?
- Other?

### 4. Contractor Responsibilities / Measurement / Payment (Facilitators: Alan Rommel, Mike Bradley)

- Determine what all the elements of the contractor's quality control plan/work plan should be
- Discuss Advisory Group recommendation that no subgrade staking is necessary - or should some reduced level still be done?
- Is contractor providing enough staking to accommodate engineer's need to do random checking?
- Does specification say enough about our expectations regarding what the contractor should do to check the survey and design information provided by the department and report problems?
- Contractor will still do Slope Staking and Supplemental Control and use those bid items
- Okay to use current Subgrade Staking Bid item (as modified with GPS machine control specs) on lineal foot basis? Or is there need to create new bid item?
- Other?

3:10 – 3:20 Break.

3:20 – 3:50 Reports from Breakout Groups (Facilitators).

3:50 – 4:00 Wrap up (Alan Vonderohe / Jerry Zogg).

## Workshop on Implementation of GPS-Controlled Highway Construction Equipment

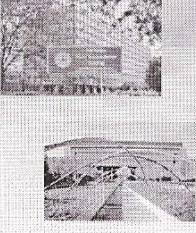
January 11, 2007

## Emerging Technology


- GPS machine control is emerging as a viable technology
  - Potential for considerable costs savings
  - 3D information flow is map-design-construct
  - Contractors are adopting the technology
- DOTs have started to implement, but not without reservations
  - Issues include accuracy, data compatibility, and liability
- Need for specifications
  - Accuracy, QA/QC/verification, risk allocation, payment mechanisms

**CMSC** Construction and Materials Support Center

Partnership between WisDOT and UW-Madison for collaborative problem solving and implementation of research findings



COLLEGE OF ENGINEERING  
UNIVERSITY OF WISCONSIN-MADISON



## Project Objectives

- Develop initial specifications for GPS machine controlled grading operations
  - Pilot 2 – 3 projects in 2007
  - Just GPS initially, not laser augmentation
- Develop associated implementation strategies for adoption of the technology
- Identify future construction applications as the technology matures

### Project Approach

- Summarize WisDOT's current use and future directions of GPS
- Identify the following regarding GPS machine control:
  - Current usage
  - Lessons learned
  - Available construction specifications & procedures
  - Benefits & concerns
  - Current state-of-the-practice of the technology
- Contact the following:
  - Other state DOTs
  - Wis Contractors & Consultants
  - Vendors & Equip Suppliers
  - WisDOT staff

### Project Approach

- Develop interim report
  - Summary of current state-of-the-practice
  - Identify key elements/issues for specifications & procedures
  - Discussion of implementation strategy
- Conduct ½-day workshop
  - Objective: Feedback on interim report
  - WisDOT staff, contractors, engineering consultants, equipment manufacturers, other stakeholders

### Project Approach

- Refine specifications and procedures based upon feedback from workshop
  - Will provide revised documents to workshop participants for further feedback
- Prepare final report
  - All pertinent findings
  - Specifications
  - Design/DTM guidance for FDM
  - Field guidance for CMM

### Advisory Group

- Alan Vonderohe - Principal Investigator
- Jerry Zogg - PM
- Ken Brockman - PM
- Michael Bradley - ACEC
- Tim Moore & Joe Gruber - WSLS
- Chris Goss - Grading Industry
- Donald Greuel - GLS Technical Committee
- Paul Hartzheim - GPS
- Robert Hubing - Field Operations
- Richard Larson - Design/DTM's
- Alan Rommel - Survey

## Workshop Overview and Objectives

- Objectives:
  - Provide you with information on project activities and status.
  - Obtain your ideas and feedback on draft specification outline.
  - Set the stage for refinement of the draft outline into formal specification and guideline language.

## Workshop Overview and Objectives

- Approach:
  - Present draft specification outline.
  - Present identified issues.
  - One-hour break out session with four groups.
  - Break out group reports.
  - Next steps.

## Workshop Overview and Objectives

- Workshop Materials:
  - Electronic by e-mail:
    - Schedule.
    - Interim report.
    - Draft specification outline.
    - Comparison table.
    - Pilot project issues categorized by specification headings.
  - Hardcopy:
    - All of the above.
    - Project problem statement / work plan.
    - List of workshop participants with break out group assignments.

## Interim Report

- WisDOT's experience with GPS.
  - Latest development is continuously operating reference stations in support of high-accuracy RTK GPS work (statewide).
- Other state DOTs' experiences with GPS machine guidance.
  - Georgia, Iowa, Maryland, Minnesota, Missouri, Montana, New York, North Carolina.
  - Appendices contain GPS machine guidance specifications.
  - Comparison table.

### Interim Report

- Review of Industry.
  - Contractors' perspective.
  - Engineers' perspective.
  - Vendors' perspective.
- Identified issue headings.
  - Change in business processes.
  - Lack of standards (ad hoc approaches to implementation).
  - Responsibilities.

### Interim Report

- Draft specification outline .
  - Focus of today's break out sessions.
- Phased implementation strategy.
  - On-going interaction with construction community.
  - 2007 pilot projects.
    - Issues to be resolved.
  - 2008 pilot projects.
  - Potential statewide implementation as an option for 2009 construction season.

### Draft Specification Outline

1. General.

- \* Project-specific special provision.
- \* For grading operations.
- \* For a portion of the project.
- \* Can revert to conventional survey if GPS machine guidance results diverge from acceptable practice.
- \* Slope stakes as usual; no subgrade stakes.
- \* Engineer makes spot checks with rover.
- \* Machine guidance portion of work on weekly progress meeting agenda.
- \* Focus on GPS machine guidance only, not on technologies that supplement GPS.

### Draft Specification Outline

2. Equipment

- \* List of approved equipment with option to demonstrate that others will meet requirements.
- \* Contractor provides engineer with rover and training.

3. Construction

3.1 Department Responsibilities

3.1.1 Before Construction

- \* Provide electronic files and other information:
  - \* Survey information: control, existing surface, etc.
  - \* Two weeks prior to pre-construction conference, provide at least 6 initial control points or at least 2 per mile.
  - \* Provide horizontal and vertical datums.
  - \* R.O.W. irons, if used as control, as opposed to coordinates off the plat.

## Draft Specification Outline

- \* Design information: alignments, profiles, design surfaces.
  - \* Use existing guidance for DDE contract staking package as noted in FDM, DDE standards.
  - \* At least 2 weeks prior to pre-construction conference:
    - \* Provide electronic files in a 3-D CAD format for:
      - \* Alignments.
      - \* Profiles.
      - \* Break lines/linework ditch bottom line.
      - \* ROW.

## Draft Specification Outline

- \* Provide electronic files in LandXML format for:
  - \* Existing ground surface.
  - \* Proposed subgrade surface.
- \* Other.
  - \* Need to verify available project control.
  - \* Coordinate with contractor to identify 3D model used for construction.
- 3.1.2 During Construction.
  - \* Perform independent random checking of earthwork.
  - \* Address needed changes to 3D model.
    - \* Review and resolve all discrepancies.
    - \* Needed changes made in 2 working days.
    - \* Identify and document current master 3D model.

## Draft Specification Outline

- 3.1.3 After Construction.
  - \* Earthwork quantities.
    - \* Develop as-built surface model from electronic as-built information provided by contractor.
    - \* Compute quantities but leave payment basis as is.
- 3.2 Contractor Responsibilities.
  - 3.2.1 Before Construction.
    - \* Provide information on qualifications of staff.
    - \* Provide contract control plan / work plan.
      - \* List and map of control points that will envelop site.
      - \* Mechanical calibration of equipment.
      - \* Site calibration.

## Draft Specification Outline

- \* Control configuration.
  - \* 0.10' horizontal and 0.06' vertical tolerances.
  - \* Calibration results published and reported to engineer prior to staking and grading.
  - \* Frequency of calibration checks.
    - \* Minimum of 1 control point check at start of work and minimum of one check after each 5 hours of continuous work.
    - \* Document point number, precision, date, and time.
- \* Set project control.
  - \* Minimum of 6 control points every 2 miles.
  - \* Use conventional methods, i.e. total stations and level loops.
- \* Perform field checks of 3D model and inform engineer.
- \* Train engineer on use of rover and 3D model.
- \* Perform site calibration according to contract control plan.
- \* Perform checks of all control points supplied by the Department.



## Draft Specification Outline

### 3.2.2 During Construction

- \* Use methods that properly apply the technology.
- \* Check calibration according to contract control plan.
- \* Provide quality control checks.
  - \* Check subgrade at intervals determined by project engineer. WisDOT guidelines for checking surface models suggest a minimum of 20 points per mile.
  - \* Check points on subgrade shall be within 0.06' of design (vertically).
- \* Do not modify default parameters for strength of satellite geometry and signals.
- \* Provide all documentation to engineer.

### 3.2.3 After Construction

- \* Provide electronic as-builts to engineer for computation of earthwork.

## Draft Specification Outline

### 4. Measurement.

- \* Specification is a special provision modifying the Construction Staking Subgrade bid item. The current measurement unit of lineal foot is retained.

### 5. Payment.

- \* Payment for Construction Staking Subgrade also includes all costs associated with use of GPS machine controlled equipment.

## Issues for Break Out Groups

- Group 1: Equipment (Facilitators: Ken Brockman, Paul Hartzheim).
  - Contractor supplies equipment they want as long as they can meet the specifications.
  - Use GPS only or GPS with augmentation?
  - Contractor supplies equipment to engineer.
  - Contractor provides training to engineer.
  - Other?

## Issues for Break Out Groups

- Group 1: Equipment (Facilitators: Ken Brockman, Paul Hartzheim).
  - Pilot project questions:
    - Can the Wisconsin CORS network be used to support GPS machine guidance?
    - What are the frequency, duration, and types of problems with operation of the technology (e.g., poor satellite geometry, loss of lock, multipath, software glitches, data entry and other human errors, technology incompatibilities)?
    - What are the necessary knowledge and skill levels for project engineers, contractor project managers, and machine operators?
    - What efficiencies are realized with GPS machine guidance?
    - What difficulties arose with GPS machine guidance?

### Issues for Break Out Groups

- Group 2: Department Responsibilities (Facilitators: Jerry Zogg, Rick Larson)
  - Design issues related to Department providing 3D models. What responsibility / liability should contractor have relative to 3D models?
  - Department issues related to addressing needed changes to 3D models during construction. How will this work with consultant prepared plans?
  - Mechanics / procedures of identifying / documenting initial and revised 3D models to be used in the field.
  - Pilots to use current contractual basis for determining yardage; however, as parallel effort do yardage computations by comparing existing and design surfaces.
  - Other?

### Issues for Break Out Groups

- Group 2: Department Responsibilities (Facilitators: Jerry Zogg, Rick Larson)
  - Pilot project questions:
    - Are 3D models provided by WisDOT readily usable by contractors?
    - What are the frequency and causes of revisions to 3D models?
    - Is 2 days sufficient time for WisDOT to make revisions to 3D models?
    - Are data exchange standards and rates sufficient for updating models during construction?
    - What is appropriate spatial frequency for quality assurance checks and what are appropriate tolerances?

### Issues for Break Out Groups

- Group 3: Contractor Responsibilities / Measurement / Payment (Facilitators: Don Greuel, Chris Goss)
- Group 4: Contractor Responsibilities / Measurement / Payment (Facilitators: Alan Rommel, Mike Bradley)
  - Determine what the elements of the contractor's quality control plan/work plan should be.
  - Discuss Advisory Group recommendation that no subgrade staking is necessary - or should some reduced level still be done?
  - Is contractor providing enough staking to accommodate engineer's need to do random checking?
  - Does specification say enough about what the contractor should do to check survey and design information provided by the Department and report problems?
  - Contractor will still do slope staking and supplemental control and use those bid items.
  - Okay to use current Subgrade Staking Bid item (as modified with GPS machine control specs) on lineal foot basis? Or is there need to create new bid item?
  - Other?

### Issues for Break Out Groups

- Group 3: Contractor Responsibilities / Measurement / Payment (Facilitators: Don Greuel, Chris Goss)
- Group 4: Contractor Responsibilities / Measurement / Payment (Facilitators: Alan Rommel, Mike Bradley)
  - Pilot project questions:
    - What is the appropriate control configuration for GPS site calibration?
    - What are the appropriate tolerances for GPS site calibration?
    - What is the appropriate frequency for GPS site calibration checking / re-calibration?
    - What is the maximum geographic extent over which a single GPS site calibration is valid?
    - What is the appropriate spatial frequency for quality control checks and what are the appropriate tolerances?
    - What needs to be staked and what staking can be eliminated?

## Tools for Break Out Groups

- Comparison table.
- Interim report.
- List of draft specification issues.
- List of pilot project issues.
- Example specifications from other states.
- These slides.
- YOUR EXPERTISE!

## Remaining Schedule

- 10 minute break.
- 1 hour break out session.
- 10 minute break.
- 30 minutes for reports from breakout groups.
- 10 minute wrap up.

## Wrap Up

- What happens with what we did today?
  - Analyze and synthesize workshop ideas.
  - Modifications to draft specification outline.
  - Prepare draft of formal specification (by end of January).
  - Provide draft formal specification to you for further feedback (feedback needed by February 14).
  - Final revisions to specification and preparation of project final report by end of February.

## Wrap Up

- What happens after that?
  - 2-3 pilot construction projects during 2007.
  - Experience of pilot projects used to refine the specification.
  - Additional pilot projects during 2008.
  - Potential statewide implementation as option during 2009.

## **Issues to be Resolved by Pilot Projects**

The 2007 pilot projects should be used to address at least the following questions:

### Equipment

1. Can the Wisconsin CORS network be used to support GPS machine guidance?
2. What are the frequency, duration, and types of problems with operation of the technology (e.g., poor satellite geometry, loss of lock, multipath, software glitches, data entry and other human errors, technology incompatibilities)?
3. What are the necessary knowledge and skill levels for project engineers, contractor project managers, and machine operators?
4. What other efficiencies are realized with GPS machine guidance?
5. What other difficulties arose with GPS machine guidance?

### Department Responsibilities

1. Are three-dimensional models provided by WisDOT readily usable by contractors?
2. What are the frequency and causes of revisions to three-dimensional models?
3. Is two days sufficient time for WisDOT to make revisions to the three-dimensional models?
4. Are data exchange standards and rates sufficient for updating models during construction?
5. What is the appropriate spatial frequency for quality assurance checks and what are the appropriate tolerances?

### Contractor Responsibilities

1. What is the appropriate control configuration for GPS site calibration?
2. What are the appropriate tolerances for GPS site calibration?
3. What is the appropriate frequency for GPS site calibration checking / re-calibration?
4. What is the maximum geographic extent over which a single GPS site calibration is valid?
5. What is the appropriate spatial frequency for quality control checks and what are the appropriate tolerances?
6. What needs to be staked and what staking can be eliminated?

## Appendix F.

### Summary of Workshop Results

## **Results of the January 11, 2007 Workshop on Implementation of GPS Controlled Highway Construction Equipment**

### **Revised Specification Outline**

This document summarizes the results of the break out sessions at the January 11, 2007 Workshop on Implementation of GPS Controlled Highway Construction Equipment, held in Madison, Wisconsin. The break out groups addressed issues associated with the draft specification outline that appears in Vonderohe (2007). This summary presents aspects of the outline with which the break out groups 1) agreed, 2) suggested modifications, and 3) had split opinions. A revised specification outline is then presented, based upon the workshop results. This document concludes with a list of unresolved issues and items of note that should be addressed prior to development of formal specification language.

### **Qualifications of Staff**

- One group suggested that certification should not be required but the contractor should demonstrate staff capabilities on the project. Another group suggested that the contractor needed a foreman or other responsible project person trained by the Machine Control equipment supplier.
- Pilot project engineers should have basic GPS knowledge / skills.
- For specification, the contractor should provide a minimum of eight hours of training to the project engineer on hardware, software, and three-dimensional modeling.

### **Equipment**

- There should be a list of approved equipment with the option to approve others based on demonstrated capability to meet requirements (i.e., satisfy tolerances).
- One group suggested machinery should be checked (e.g., for blade wear and pitch sensor calibration) every five hours. Checks should be documented. Another group suggested that machinery checks should be eliminated and the specifications should focus upon results. **NOTE: It is Vonderohe's opinion that the written record of the first group is probably in error. Checking blade wear and pitch sensor calibration every five hours is not necessary.**
- It was recommended that contractors be able use any machine guidance technology on the pilot projects, including laser augmentation of GPS.
- The contractor should provide a GPS RTK rover to the project engineer. The department should be responsible for loss or damage to the rover, beyond normal wear and tear, while it is in possession of the project engineer.

### **GPS Site Calibration**

- One group suggested one control point check at the start of work each day and a minimum of one checkpoint after every five hours of continuous work. Another group

suggested two calibration checks each time a base station is set up (one at the beginning of the session and another at the end of the session).

- There should be one calibration file per project and all parties should share and use the same data.
- The contractor and project engineer must use the same control framework that was used for the original survey and design.
- Calibration control shall include a minimum of six horizontal and vertical points, or two per mile, whichever is greater.
- Suggested tolerance of calibration (0.10 ft. horizontal and 0.05 ft. vertical) is acceptable.

### **Project Control**

- Contractor validates all control points provided by the department.
- Contractor provides additional project control to a density of 6-10 points per mile.  
**NOTE: This is more than double the requirement in the initial draft outline.**

### **Information Provided by Department**

- The department will utilize existing guidance for the DDE contract staking package to provide survey info, control info, and design info (alignments, profiles, x-sections from plans) with the addition of the existing surface DTM. The department will have contractual responsibility for this info as described in 105.6 and 650 of the Standard Specifications.

### **Three-Dimensional Models**

- The department will provide its design surface DTM to the contractor for information purposes only, but will not take contractual responsibility for it.
- The contractor is responsible for creating the design surface DTM they intend to use, for coordinating with the department to confirm it matches the plans, and for providing a copy to the department.
- Interactions between the department and the contractor to address field issues will largely be a continuation of current practice where the course of action is determined on a case-by-case basis, and the extent or size of the problem is a key factor in determining who does what, and whether Extra Work is needed.
- Responsibility for revisions to the existing surface DTM, arising from field conditions not agreeing with plans, will be decided on a case-by-case basis.

- If the existing surface DTM is revised, the department will review and revise the design as necessary, and provide the revised design information to the contractor.
- The contractor is responsible for revising the design surface DTM they are using; and similar to the beginning of the project, they will need to coordinate with the department to confirm it matches the revised design, and provide the department with a copy.

### **Staking**

- Subgrade staking is not required.
- Slope staking is required. Intervals can be widened to 200 feet in the future, but not for pilots.
- Station, offset, and ground elevation at slope stakes shall be published.

### **Field Checks**

- Checks shall be done at a frequency of 20 random checks per mile, and recorded.
- Checks shall be done using GPS rover, not traditional methods.
- One group suggested that rover checks of subgrade should have a tolerance of 0.06 ft. for pilot projects. Another group suggested (with some dissension) a tolerance of 0.10 ft.

### **Payment**

- Pay item to be a change order with a lineal foot unit of measure. In addition, an item of Rover Cost, measured as lump sum, shall be included to help reduce the burden of high up-front cost of supplying a rover.
- Any contractor's work to revise the design surface DTM, due to the design not agreeing with field conditions, would be eligible for Extra Work as if they had to redo contractor staking to accommodate a design revision.

### **Revised Draft Specification Outline**

#### GPS Controlled Highway Grading Equipment Key Specification Elements

#### Specification Subsection Headings

1. General



2. Equipment
3. Construction
  - 3.1 Department Responsibilities
    - 3.1.1 Before
    - 3.1.2 During
    - 3.1.3 After
  - 3.2 Contractor Responsibilities
    - 3.2.1 Before
    - 3.2.2 During
    - 3.2.3 After
4. Measurement
5. Payment

### Draft Specification Outline

1. General.
  - \* This specification is a project-specific special provision that modifies 650.3.3 of the Standard Specifications.
  - \* For grading operations.
  - \* For a portion of the project.
  - \* Reserve right to revert to conventional survey should machine control grading tolerances or methods diverge from acceptable practice or accuracy in the opinion of the engineer.
  - \* Slope stakes placed as usual.
  - \* No subgrade stakes to be placed.
  - \* Engineer makes spot checks with rover.
  - \* Machine guidance portion of work must be an agenda item for weekly progress meetings.
  - \* This special provision focuses upon GPS machine guidance and technologies that supplement or augment GPS.
2. Equipment
  - \* List of approved equipment with contractor option to demonstrate that others will meet requirements and receive approval of engineer.
  - \* Contractor provides engineer with rover and a minimum of eight hours of training.
    - \*The department is responsible for loss or damage, beyond normal wear and tear, of the loaned rover while in possession of the engineer.
3. Construction
  - 3.1 Department Responsibilities
    - 3.1.1 Before Construction
      - \* Provide electronic files and other information:
      - \* Survey information: control information, existing surface, etc.
        - \*Utilize existing guidance for contract staking package as noted in CMM, 3-1-10.
          - \*At least two weeks prior to pre-construction conference, provide at least six initial control points or at least two per mile; whichever is greater. All control points shall have horizontal and vertical project coordinates published.

- \*Provide horizontal and vertical datums.
- \* R.O.W. irons, if used as control, as opposed to coordinates off the plat.
- \* Design information: alignments, profiles, and best available design surfaces.
  - \*Utilize existing guidance for DDE contract staking package as noted in FDM, DDE standards.
  - \* Reference 105.6 and 650 for department responsibility for this information.
  - \*At least two weeks prior to pre-construction conference,
    - \*Provide electronic files in a 3-D CAD format for:
      - \*Alignments
      - \*Profiles
      - \*Break lines/Linework ditch bottom line
      - \*ROW
    - \*Provide electronic files in LandXML format for:
      - \*Existing ground surface
      - \*Proposed subgrade surface (for informational purposes only). This surface would be subgrade elevations within pavement structure and finished elevations in topsoiled areas. The department will not have contractual responsibility for this information.
- \* Other
  - \* Need to verify available project control, some concerns that it is not always intact prior to construction.
  - \* ROW irons, if used as control as opposed to coordinates off the plat.
  - \* Obtains, from the contractor, and records a copy of the three-dimensional model to be used for construction.

### 3.1.2 During Construction

- \* Department checking/inspection of earthwork - Qa or Qv
  - \* Perform independent random checking.
  - \* Checks to be made with GPS rover.
- \* Address needed changes/updates to existing and/or design surfaces on a case-by-case basis.
  - \* Review all discrepancies reported by contractor.
  - \* Determines whether Extra Work is needed.
  - \* Determines responsibility for revisions to existing surface DTM.
  - \* Revises design as necessary and provides revised design to contractor.
  - \* Obtains, from the contractor, and records a copy of the revised three-dimensional model.

### 3.1.3 After Construction

- \* Earthwork quantities
  - \* Develop as-built surface model from electronic as-built information provided by contractor.
  - \* Compute quantities but leave payment basis as is.

## 3.2 Contractor Responsibilities

### 3.2.1 Before Construction

- \* Provide information on the qualifications of staff (**NOTE: This is an unresolved issue**).
- \* Provide contract control plan/work plan.
  - \* Include plan for project control list and map of points that will envelop the site.
  - \* Include plan for mechanical calibration of equipment (**NOTE: This is an unresolved issue**).
  - \* Include plan for site calibration.
    - \* Control configuration.
    - \* Calibrate/localize site to tolerances of 0.10' or less horizontally and a precision of 0.05' or less vertically. Calibration results shall be published and reported to engineer prior to the start of staking and grading.
    - \* Frequency of checking calibration.
      - \*Minimum of 1 control point check at start of work and a minimum of one check after each 5 hours of continuous work (**NOTE: This is an unresolved issue**). Document point number, precision, date, and time.
- \* Set project control.
  - \* Utilize existing guidance that contractor provide to match with operations, see supplemental control. Minimum of six control points every mile. **NOTE: This is more than double the requirement in the initial draft outline.**
  - \* Control points shall be set using conventional methods, i.e., total stations and level loops.
- \* Develop 3D model, including design surface DTM, from information provided by department and confirm that the 3D model agrees with the design.
- \* Provide copy of 3D model to project engineer.
- \* Perform field checks of 3D model and inform engineer of problems.
  - \* Could and should use contractor staking specs if at all possible.
  - \* If necessary, revise 3D model based on revised design information provided by department and confirm that the revised 3D model agrees with the revised design.
  - \* Provide copy of revised 3D model to project engineer.
- \* Provide a minimum of eight hours of training on use of rover and 3D model to project engineer.
- \* Perform site calibration according to contract control plan. Report discrepancies to project engineer.
- \* Perform and document checks of all control points supplied by the department. Report any errors/discrepancies to project engineer.

### 3.2.2 During Construction

- \* Use methodologies that properly apply the technology. Spec to reference proper methodologies for use of GPS.
- \* Check calibration according to contract control plan.

- \* Provide information on what is being constructed – Qc.
  - \* Check subgrade at intervals determined by project engineer. WisDOT guidelines for checking surface models suggest a minimum of 20 points per mile.
  - \* Check points on subgrade shall be within 0.06 feet of design (vertically) **(NOTE: This is an unresolved issue)**.
- \* Default parameters, set by the manufacturer for strength of satellite geometry and signals, are not to be modified.
- \* Provide all documentation to project engineer.

### 3.2.3 After Construction

- \* Provide electronic as-builts to project engineer for computation of earthwork.

## 4. Measurement

- \* As noted above, this specification is a special provision modifying the Construction Staking Subgrade bid item, and we would retain the current measurement unit of lineal foot.

## 5. Payment

- \* Payment for Construction Staking Subgrade also includes all costs associated with the use of GPS machine controlled equipment.
- \* An additional item of Rover cost, measured as lump sum, shall be included.
- \* Any contractor's work to revise the 3D model, due to the design not agreeing with field conditions, would be eligible for Extra Work as if they had to redo contractor staking to accommodate a design revision.

## Unresolved Issues and Items of Note

### Qualifications of Staff

- One group suggested that certification should not be required but the contractor should demonstrate staff capabilities on the project. Another group suggested that the contractor needed a foreman or other responsible project person trained by the Machine Control equipment supplier.

### Equipment

- One group suggested machinery should be checked (e.g., for blade wear and pitch sensor calibration) every five hours. Checks should be documented. Another group suggested that machinery checks should be eliminated and the specifications should focus upon results. **NOTE: It is Vonderohe's opinion that the written record of the first group is probably in error and should be referring to the frequency of checking the GPS site calibration. Checking blade wear and pitch sensor calibration every five hours is not necessary.**

### GPS Site Calibration

- One group suggested one control point check at the start of work each day and a minimum of one checkpoint after every five hours of continuous work. Another group

suggested two calibration checks each time a base station is set up (one at the beginning of the session and another at the end of the session).

#### Project Control

- Contractor provides additional project control to a density of 6-10 points per mile.  
**NOTE: This is more than double the requirement in the initial draft outline.**

#### Field Checks

- One group suggested that rover checks of subgrade should have a tolerance of 0.06 ft. for pilot projects. Another group suggested (with some dissension) a tolerance of 0.10 ft.

#### **List of References**

Vonderohe, A., (2007), Interim Report for Implementation of GPS Controlled Highway Construction Equipment, Construction Materials and Support Center, University of Wisconsin – Madison.

## Appendix G.

### Summary of Reviews by Workshop Participants

## Summary of Workshop Participants' Responses To Draft GPS Machine Guidance Specification

Alan P. Vonderohe

March 4, 2007

This document summarizes comments and suggestions made by workshop participants in response to the draft specification for GPS machine guidance. The author has formed the responses into two groups: 1) those that address aspects of the draft specification already considered by the Advisory Group and 2) those that address aspects not yet considered by the Advisory Group. The groups were formed based upon the best recollections and the judgment of the author. Reviewers of this document, who are familiar with the deliberations behind development of the draft specification, are requested to check the author's placement of each response into its respective group.

### Group 1: Comments and Suggestions Already Considered by the Advisory Group.

Reviewer 1:

#### 650.3.3.3.4.3 Managing and Updating Information

(3)The department will determine what revisions may be required. The department will revise the contract plans and existing surface DTM, if necessary, to address errors or discrepancies that the contractor identifies. The department will provide the best available electronic files and other available information related to those contract plan revisions.

COMMENT: Why will the contractor care about the existing surface DTM the department develops? Unless the existing surface is used in a surface to surface calculation of volume for payment or bidding purposes. GPS machine control does not make use of an existing DTM, only the design DTM which will be developed from points and breaklines provided in **650.3.3.3.4.1 (3)**

Reviewer 2:

650.3.3.3.6(2) 0.10 foot from plan seems extreme. It is possible to have a 0.20 foot difference from one test to the next.

Reviewer 3:

#### 650.3.3.3.5 Site Calibration

(2)In addition to the site calibration, perform site calibration checks. Perform these checks at individual control points not used in the initial site calibration. At a minimum, check the calibration at the start of each day and at least once for every 5 hours of continuous subgrade construction work. Report out-of-tolerance checks to the engineer.

COMMENT: Out-of-tolerance is reported, but should there be guidance on what should be done if this occurs? What corrective action is necessary?

Reviewer 4:

6.50.3.3.3.4.5 (3) - tolerance for vert less than that for horiz (or is the intent to make sure the vert component is really tight)?

6.50.3.3.3.4.5 (4) - is the 0.10 for both horiz and vert?

Reviewer 5:

#### **650.3.3.3.4 Geometric and Surface Information**

##### **650.3.3.3.4.1 Department Responsibilities**

(2) The department will provide data to the contractor that include the following:

When is this data being supplied? Prior to let? So they know what they have – would make it easier for the contractor and bidding purposes.

##### **650.3.3.3.4.3 Managing and Updating Information**

(4) *Who? Contractor or Department?* Revise the design surface DTM as required to support construction operations and to reflect any contract plan revisions the department makes. Perform checks to confirm that the revised design surface DTM agrees with the contract plan revisions. Provide a copy of the resultant revised design surface DTM to the engineer for archiving. The department will pay for costs incurred to incorporate contract plan revisions as extra work.

##### **650.3.3.3.5 Site Calibration**

(2) Calibrate the site by determining the parameters governing the transformation of GPS information into the project coordinate system. Provide the resulting **site calibration file** to the engineer before beginning subgrade construction operations.

*What format, and what are they actually getting back?*

Reviewer 6:

##### **650.3.3.3.1 General**

(3) Provide GPS rover equipment to department staff as requested to check the work. This equipment is not intended for exclusive use of the department and may be used by the contractor as needed on the project. Provide training for department staff designated to use the GPS rover. Training shall include but not be limited to hardware, software, setup and operation of GPS rover equipment. Provide a copy of the user manual for the rover equipment



supplied. Provide routine maintenance of equipment provided for department use. The department is responsible for loss of, or damage (beyond normal wear and tear) to, the rover while in the engineer's possession.

COMMENTS: Insert "for daily operations" at the end of the second sentence, above. Insert "setup," between "software," and "and operation" in the fourth sentence, above.

#### **650.3.3.3.2 GPS Work Plan**

- (2) The GPS work plan should discuss how GPS machine guidance technology will be integrated into other technologies employed on the project. Include, but do not limit the contents to, the following:
  1. Describe the manufacturer, model, and software version of the GPS equipment.
  2. Provide information on the qualifications of contractor staff. Include formal training and field experience. Designate a single staff person as the primary contact for GPS technology issues.
  3. Describe how project control is to be established. Include a list and map showing control points enveloping the site.
  4. Describe site calibration procedures. Include 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 as well as how the site calibration and checking information is to be documented.

COMMENTS: Insert "machine and rover" between "GPS" and "equipment" at the end of the sentence in item 1, above. Insert "the" between "showing" and "control" in item 3, above. Insert "the" between "site" and "calibration" in the first sentence in item 4, above.

#### **650.3.3.3.5 Site Calibration**

- (3) In addition to the site calibration, perform site calibration checks. Perform these checks at individual control points not used in the initial site calibration. At a minimum, check the calibration at the start of each day and at least once for every 5 hours of continuous subgrade construction work. Report out-of-tolerance checks to the engineer. The measured position must match the established position at each individual control point within the following tolerances:
  - Horizontally to 0.10 feet or less.
  - Vertically to 0.05 feet or less.

COMMENT: Insert "as well as the number of satellites in view during said check" between "checks" and "to the engineer" in the fourth sentence, above.

## **Group 2: Comments and Suggestions Not Yet Considered by the Advisory Group.**

Reviewer 7:

On a separate note, we do not really address payment for work completed. There may need to be some construction guidance and maybe even some spec guidance. I assume we would still pay for "subgrade staking" by the station, but in reality, they would not be performing that work. This will probably create some confusion for project staff (and contractors) unless guidance is provided.

Reviewer 8 in response to above comment from Reviewer 7:

From my perspective the spec gives the contractor the option of using GPS machine guidance or conventional staking to do the subgrade staking, and we're paying for it on a lineal foot basis. My sense is that most projects will be a combination of the two so the contractor will have to bid blended price. The nice thing about getting a lineal foot price is we have a starting point for CCO's in case the length of the project or sideroads change.

Reviewer 7 in response to above comment from Reviewer 8:

Maybe I'm wrong, but staff may get the idea that if the subgrade staking is not performed from x to y, that you would not pay the subgrade staking item from x to y. Maybe just a sentence under the Payment heading that says: Machine control grading will be paid at the same unit price as subgrade staking.

Reviewer 9:

### **650.3.3.3.4.2 Contractor Responsibilities**

- (2) Provide design surface DTM information to the department in LANDXML format. The department will review the contractor's initial design surface model and subsequent updates for compatibility with the contract plans.

NOTE: Delete "in LANDXML format" from the end of the first sentence in the above paragraph.

- (3) Provide an electronic as-built design surface DTM to the department in LANDXML DTM format upon completion of subgrade construction.

NOTE: Revise this paragraph to read: "Provide an electronic as-built surface DTM of the finished roadway to the department."

COMMENT: Providing a finished as-built DTM of the subgrade developed from a topo would not be very cost effective or efficient. On projects where the graveling operation is caught up to the subgrade grading operations this would require extra time to topo each small piece of subgrade before gravel was placed. Unless you accept the DTM surface file that was used as an as-built model in which you would already have this file(s) from para.(2).

Reviewer 10:

650.3.3.1(2) Does "reasons beyond the contractor's control" include faulty equipment or software? If they 'choose' to revert to conventional staking methods for reasons of faulty equipment, etc. can they claim additional cost of extra work?

650.3.3.3.2(1) Is there a lead time required for submitting updates to the GPS work plan?

650.3.3.3.2(2)2. Does contractor staff qualifications pertain only to the surveyors/stakers or also the machine operators?

650.3.3.3.4.3(1) How long before the planned start of construction should we get the design surface model?

650.3.3.3.5(3) Should the 'checks' be more frequent when out of tolerance is detected?

650.3.12(3) Is it necessary to stake 'each cross-section location shown on the plans.' Some plans have sections at places which would not necessitate staking.

Reviewer 11:

#### **650.3.3.3.2**

(1) Submit a comprehensive written GPS work plan for department review at least 10 business days before affected grading operations begin.

COMMENT: Does the department/engineer approve or accept this plan? What if the engineer wants revisions?

#### **650.3.3.3.4.2 Contractor Responsibilities**

(3) Provide design surface DTM information to the department in LandXML format. The department will review the contractor's initial design surface model and subsequent updates for compatibility with the contract plans.

COMMENT: Should there be guidance on what to do if the contractor and department do not agree on these models?

#### **650.3.3.3.6 Construction Checks**

(2) Ensure that at least 4 of any 5 consecutively-tested subgrade points are within 0.10 foot vertically of the plan elevation. Notify the engineer if more than one of any five consecutively-tested subgrade points differ by more than 0.10 feet from the plan elevation.

COMMENT: Should there be guidance on what is done if this is exceeded?? What corrective action is required/necessary.

### 650.3.12 Initial Layout

(3) Verify the existing ground elevations as shown for all roadways on cross-section sheets for accuracy. If the elevation at the slope intercept is off by more than 0.4 foot (120 mm), notify the engineer.

COMMENT: What corrective action is necessary? Provide guidance on what should be done if required accuracy is exceeded?

Reviewer 12:

The areas I see as being of some concern are as follows: The use of LANDXML software is foreign to our staff. The DOT provided DTM information will take a lot of training of our current staff. The use of GPS will also require a lot of training of our staff, supposedly done by the contractor, but I see some of the onus falling on the survey unit. Who is checking calibrations and control to know if there are issues? Again PDS staff are not knowledgeable in these things and the survey unit may be called upon. Checks are being proposed using the same equipment, calibration and control that the contractor is using. But is that really an independent check? Basically my concerns involve the survey unit being given a lot of extra work when we are already overworked, understaffed and been taken off of the construction jobs with the implementation of contractor staking. Also, I know some of the capabilities of our PDS staff and this seems to be stretching that to possibly unreasonable limits at this time.

Reviewer 13 in response to above comments from Reviewer 12:

Apparently, SW survey staff hasn't done a lot with GPS survey to date, within a staking environment, nor have they done a lot to exchange digital data with contractors. I explained that LandXML is not software, but simply a file format that gets generated from the software they're already using.

I also explained our commitment for XXXX to help with producing the initial file of design surface points and breaklines; and then again, during construction if changes are required.

In light of SW's concerns, they will likely revise our spec to indicate that some reduced frequency/key location subgrade staking will be required (rather than none) on the first area they do as a "test section". If things go well, they may change these requirements for next area.

Reviewer 14 in response to above comment from Reviewer 12:

As I see it, the machine control grading should ultimately relieve some of the burden from survey crews and take advantage of GPS technology to accomplish work more efficiently and generate time and cost savings. The Department will still provide project control and some checks as the project gets underway and as needed, but responsibilities for checking control and calibrations will be on the contractor. We are hoping to draw Construction Engineers that have some familiarity with GPS and they will receive some training on the machine control

equipment. I think there will still be some need to call on our regional survey staff that have been using this technology for a number of years and can provide some expertise for construction engineers as needed.

I understand we will be getting some assistance from Bureau of Project Development in developing XML files and XXX will assist project design staff in getting that information together. Northeast Region is also proposing to try a pilot and we will be meeting with design, construction and survey folks prior in order to identify our roles and responsibilities.

This item will also be discussed at our upcoming survey conference and training.

Reviewer 15:

#### **650.3.3.3.1 General**

(3) Provide GPS rover equipment to department staff as requested to check the work. This equipment is not intended for exclusive use of the department and may be used by the contractor as needed on the project. Provide training for department staff designated to use the GPS rover. Training shall include but not be limited to hardware, software, and operation of GPS rover equipment. **Provide a copy of the user manual for the rover equipment supplied.** *Reword to ... Provide a copy of the user manual for the supplied rover equipment. Original sounds a little clumsy.*

#### **650.3.3.3.2 GPS Work Plan**

(2) The GPS work plan should discuss how GPS machine guidance technology will be integrated into other technologies employed on the project. Include, but do not limit the contents to, the following:

*Will there be a standardized, DOT form for the contractor to fill out? Would be easier... for contractor and department personnel that will be reviewing it.*

1. Describe the manufacturer, model, and software version of the GPS equipment.
2. Provide information on the qualifications of contractor staff. Include formal training and field experience. Designate a single staff person as the primary contact for GPS technology issues.

#### **650.3.3.3.3 Equipment**

(1) Use GPS machine guidance equipment to meet the requirements of the contract.

*Again... a DOT log form? To be filled out during the life of the project?*

#### **650.3.3.3.5 Site Calibration**

(1) Designate a set of control points, including a total of at least 6 horizontal and vertical points or 2 per mile, whichever is greater, for site calibration for the portion of the project employing GPS machine guidance. Incorporate the

department-provided control framework used for the original survey and design. *Is this enough? And with GPS, the control wouldn't even need to be on the project... but... if an inspector wanted to check anything – with conventional survey – would there be project control available so they can do this?*

#### **650.3.3.3.6 Construction Checks**

- (3) The department will conduct periodic independent subgrade checks using the contractor supplied **GPS rover or conventional survey methods**. When using the GPS rover, the department will use the same calibration files and other hardware and software settings the contractor uses for subgrade checking. The department will notify the contractor if any individual check varies more than 0.10 feet from the design. *I would suggest both – GPS and Conventional... at least until the GPS accuracy has been proven on the specific project. If only using GPS, your going to get the same results as the contractors GPS... so what is the check? If you also check with a total station, your doing an alternate way of measuring, not based on the calibrations... would be a better check to the “system”. Would also make sure the department is checking to the PLAN info... not the digital data within the GPS collector – to ensure the design surface (digital/machine controlled) matches to the intent of the plan – which matches to the grades/alignment in the field.*

#### **650.3.12 Initial Layout**

- (2) For the portion of the project using GPS machine guidance, set and maintain supplemental control points sufficient to ensure that there are a minimum of 6 established control points per mile. Ensure that these control points are consistent with third-order, class I horizontal and third-order vertical accuracy. Establish vertical control by differential leveling. *Control points should be spelled out... to be within the project limits. Like I mentioned above, GPS points can be boxed out, not near the actual roadway... I believe your intent is for control along the project so inspectors can use this control with conventional equipment? I've had this problem on plans in the past...consultants saying they supplied control in a plan... but it isn't even near the project. Doesn't do much good for conventional work.*

Reviewer 16:

I have been construction staking on WisDOT projects for 17 years, and exclusively using GPS for approximately 7-8 years. It has been my experience that most of the problems due to staking with or without GPS arise from control point issues; either improperly labeled on the plan, improperly or not checked in the field, or incorrectly re-established during construction. I feel a licensed land surveyor should be required to perform the control establishment for the GPS work, similar to being required to do

the row plat and initial plan control in the plan design phase. This will insure that a qualified individual will establish the ground work for all others to work off of. Without the requirement, I fear any GPS savvy technician could establish a 2-3 point localization, shoot new points with that GPS localization, and reshoot the points again labeling them as a control point (i.e. set project control with the GPS and use the points set as control in lieu of using traditional total station traverse methods), which will create obvious problems compounded by each base setup. I fear this could happen quite easily due to the time constraint demands of the construction schedule, and feel a non-professional individual may give in to that pressure in lieu of procedure and accuracy. The establishment of a proper and accurate network of ground control points for the GPS to orient and localize to is critical for GPS staking, grading, and layout to occur within the required tolerances on a consistent basis. I have routinely checked the GPS system we operate with differential leveling and total station traversing on several projects and consistently obtain sub ½-inch accuracies. Requiring a licensed land surveyor to establish the control will ensure that proper checks and balances are in place for the establishment of the GPS control network.

#### **650.3.3.2 Subgrade Staking**

- (1) Set construction stakes or marks at a minimum 100-foot (40 m) intervals for rural sections and a minimum 50-foot (20 m) intervals for urban sections, including additional stakes each cross-section to match the plan cross-section as necessary to achieve the required accuracy, and support the method of operations.

COMMENTS: Insert “a minimum of three” between “Set” and “construction” , above. Replace “including” with “and” between “sections” and “additional” , above. Insert “at” between “stakes” and “each cross-section” , above.

#### **650.3.3.3.2 GPS Work Plan**

- (2) The GPS work plan should discuss how GPS machine guidance technology will be integrated into other technologies employed on the project. Include, but do not limit the contents to, the following:
  1. Describe the manufacturer, model, and software version of the GPS equipment.
  2. Provide information on the qualifications of contractor staff. Include formal training and field experience. Designate a single staff person as the primary contact for GPS technology issues.
  3. Describe how project control is to be established. Include a list and map showing control points enveloping the site.
  4. Describe site calibration procedures. Include 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 as

well as how the site calibration and checking information is to be documented.

COMMENT: Insert the following between the first and second sentences in item 3, above: "New, additional, or replacement of project control points; beyond those illustrated in the plan, shall be set, verified and incorporated into the work consistent with third-order, class I horizontal and third-order vertical accuracy, and under the direct supervision of a licensed land surveyor."

#### **650.3.3.3.5 Site Calibration**

- (3) In addition to the site calibration, perform site calibration checks. Perform these checks at individual control points not used in the initial site calibration. At a minimum, check the calibration at the start of each day and at least once for every 5 hours of continuous subgrade construction work. Report out-of-tolerance checks to the engineer. The measured position must match the established position at each individual control point within the following tolerances:
- Horizontally to 0.10 feet or less.
  - Vertically to 0.05 feet or less.

COMMENT: Insert the following at the end of paragraph 3, above: "Provide the previous week's daily calibration check results to the engineer at the weekly progress meeting for monitoring the GPS work. Information to include, the GPS base setup point, the control point(s) validated and checked from that base setup, the resultant horizontal and vertical measured positions for each checked point, and the individual performing said calibration/checks. This information can be provided in either a hard copy format or a raw data file for viewing through word, notepad, or other text editor program."

- (4) The department will use the same calibration file the contractor uses and perform calibration checks using the same set of control points the contractor uses.

COMMENT: Insert the following at the end of paragraph 4, above. "The department's calibration checks shall be stored in a hardcopy format or the raw data file for archiving and viewing by the contractor in a text format via word, notepad, or other text editor. The information shall include the GPS base setup point, the control point(s) validated and calibrated/checked from that setup point, the resultant horizontal and vertical measured positions for each calibration/checked point, and the person performing said checks."

#### **650.3.12 Initial Layout**

- (1) Set and maintain construction marks as required to support the method of operations consistent with third-order, class I horizontal and third-order vertical accuracy. Validate the department-provided horizontal and vertical



control information and notify the engineer of any discrepancies. Provide marks to establish and maintain intermediate vertical and horizontal control for reference line alignment, side road alignments, radius points, bench level circuits, slopes on the ground, and offsetting the horizontal roadway alignment. These marks constitute the field control used to govern and execute the work.

COMMENT: Insert the following at the end of the paragraph above: "Control establishment and verification shall be done under the direct supervision of a licensed land surveyor."

Reviewer 17:

#### 650.3.3.2

The specifications have 100 ft (40 m). 100 feet is closer to 30 m. Also the 50 ft (20 m) conversion should be closer to 15 m.

#### 650.3.3.3.4.2

(2) The sub-title for this is Contractor Responsibilities. Why is the department responsible for checking the surface model for compatibility with the contract plans. **This should be the contractors responsibility. This moves the workload and risk to the departments side. This responsibility should remain with the contractor.**

(3) Where does the electronic as-built design surface end? Will the limits be subgrade shoulder points, slope intercept, etc..

#### 650.3.3.3.4.3

(1) **Remove the first sentence entirely.** Similar to (2) under 650.3.3.3.4.2, it is the contractors responsibility to come up with an accurate surface model.

(2) Does the existing surface discrepancies need to be defined?

#### 650.3.3.5

(1) Designate a set of control points, including a total of at least 6 horizontal and vertical points or 2 per mile **or as directed by the engineer**, whichever is greater, for site calibration for the portion of the project employing GPS machine guidance.

We may want to check the contractor's work with a total station instead of the rover which may require more control points. Not sure what advantage checking the grade with a rover using the "same calibration files and other hardware and software setting" has. Using a total station you have a check that does not rely on satellite technology and purposely is not calibrated with the other equipment. It is a more independent and possibly more reliable check.

Other notes:

- Consultants should be prepared for the department seeking compensation through errors and omissions if their DTM data is not correct.
- Some of our designers aren't sure what land XML DTM format is. Is such a file easily created in CAiCE and the new software that will be selected?

## Appendix H.

# Specification and Guidance for 2007 Pilot Projects

**Specification and Guidance for 2007  
Wisconsin Department of Transportation  
GPS Machine Guidance Pilot Projects**

**NOTE: This document is intended for use on only the 2007 pilot projects for GPS machine guidance. The specification and guidance language are subject to change for the 2008 and later construction seasons. In addition, this document is subject to possible modification by WisDOT regions with 2007 pilot projects.**

**2007 PILOT PROJECT SPECIFICATION**

Construction Staking Subgrade, Item 650.4500; Construction Staking Initial Layout, Item 650.9900  
Conform to standard spec 650 as modified in this special provision.

*Replace standard spec 650.3.3 with the following:*

**650.3.3 Subgrade**

**650.3.3.1 General**

- (1) Use global positioning system (GPS) machine guidance or conventional subgrade staking on designated portions of the contract as follows:

<u>GPS Machine Guidance</u>	<u>Subgrade Staking</u>

- (2) The engineer may require the contractor to revert to conventional subgrade staking methods for all or part of the work at any point during construction if, in the engineer's opinion, the GPS machine guidance is producing unacceptable results. If the engineer revokes approval to use GPS machine guidance on all or part of the work for reasons beyond the contractor's control, the department will measure the additional subgrade staking required to successfully complete the work in those areas as specified in 650.4(2) of this special provision.

**650.3.3.2 Subgrade Staking**

- (1) Set construction stakes or marks at intervals of 100 feet, or more frequently, for rural sections and at intervals of 50 feet, or more frequently, for urban sections. Include additional stakes at each cross-section as necessary to match the plan cross-section, achieve the required accuracy, and to support construction operations. Also set and maintain stakes as necessary to establish the horizontal and vertical positions of intersecting road radii, auxiliary lanes, horizontal and vertical curves, and curve transitions. Locate stakes to within

0.25 feet (75 mm) horizontally and establish the grade elevation to within 0.03 feet (10 mm) vertically.

### **650.3.3.3 GPS Machine Guidance**

#### **650.3.3.3.1 General**

- (1) No subgrade stakes are required for work approved for GPS machine guidance.
- (2) Coordinate with the engineer throughout the course of construction to ensure that work performed using GPS machine guidance conforms to the contract tolerances and that the methods employed conform to the contractor's GPS work plan and accepted industry standards. Address GPS machine guidance issues at weekly progress meetings.
- (3) Provide GPS rover equipment to department staff as requested to check the work. This equipment is not intended for exclusive use of the department and may be used by the contractor as needed on the project. Provide training for department staff designated to use the GPS rover. Training shall include but not be limited to hardware, software, and operation of GPS rover equipment. Provide a copy of the user manual for the supplied rover equipment. Provide routine maintenance of equipment provided for department use. The department is responsible for loss of, or damage (beyond normal wear and tear) to, the rover while in the engineer's possession.

#### **650.3.3.3.2 GPS Work Plan**

- (1) Submit a comprehensive written GPS work plan for department review at least 10 business days before affected grading operations begin. The engineer will review the plan to determine if it conforms to the requirements of this special provision.
- (2) Construct the subgrade as the contractor's GPS work plan provides. Update the plan as necessary during construction of the subgrade.
- (3) The GPS work plan should discuss how GPS machine guidance technology will be integrated into other technologies employed on the project. Include, but do not limit the contents to, the following:
  1. Describe the manufacturer, model, and software version of the GPS equipment.
  2. Provide information on the qualifications of contractor staff. Include formal training and field experience. Designate a single staff person as the primary contact for GPS technology issues.
  3. Describe how project control is to be established. Include a list and map showing control points enveloping the site.
  4. Describe site calibration procedures. Include 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 as

well as how the site calibration and checking information are to be documented.

5. Describe the contractor's quality control procedures. Describe procedures for checking, mechanical calibration, and maintenance of equipment. Include the frequency and type of checks performed to ensure that the constructed subgrade conforms to the contract plans.

**650.3.3.3.3 Equipment**

- (1) Use GPS machine guidance equipment to meet the requirements of the contract.
- (2) Perform periodic sensor calibrations, checks for blade wear, and other routine adjustments as required to ensure that the final subgrade conforms to the contract plans.

**650.3.3.3.4 Geometric and Surface Information**

**650.3.3.3.4.1 Department Responsibilities**

- (1) The department will provide to the contractor the best available electronic files of survey and design information as described here in 650.3.3.3.4.1 and in CMM 3-1-10. The department incurs no additional liability, beyond that specified in standard spec 105.6 or standard spec 650, by having provided this additional information.
- (2) The department will provide data to the contractor that include the following:

<b>Data Type</b>	<b>Format</b>
Reference Line Data	LandXML
Design Profile Data	LandXML
Proposed Cross Section Data	Land XML
Existing Surface DTM Data	LandXML DTM
Existing Topographic Data (excluding utilities)	LandXML
Superelevation Data	LandXML
Graphical Information	DGN or DWG

- (3) The department will provide design surface data in the form of points and break lines derived from the cross sections in the contract in LandXML format. The points and break lines will be on the subgrade surface between the subgrade shoulder points, and will be on the finished surface in topsoiled areas. The department provides design surface data for information only, and has no contractual liability for it.

#### **650.3.3.3.4.2 Contractor Responsibilities**

- (1) Develop and maintain the initial design surface DTM for areas of the project employing GPS machine guidance consistent with information the department provides. Confirm that the design surface DTM agrees with the contract plans.
- (2) Provide design surface DTM information to the department in LandXML or other engineer-approved format.

#### **650.3.3.3.4.3 Managing and Updating Information**

- (1) The department and contractor will agree on the design surface model before using it for construction. Provide a copy of the resultant design surface DTM to the engineer at least two business days before using that design surface DTM for construction.
- (2) Notify the department of any errors or discrepancies in department-provided information. Provide information regarding errors or discrepancies in the existing surface DTM, identified in the field, to the department in LandXML format if a revision to the contract plans is required. If surveying work beyond that required to slope stake is required to re-define the existing surface, the department will pay for costs of that additional surveying as extra work.
- (3) The department will determine what revisions may be required. The department will revise the contract plans and existing surface DTM, if necessary, to address errors or discrepancies that the contractor identifies. The department will provide the best available electronic files and other available information related to those contract plan revisions.
- (4) Revise the design surface DTM as required to support construction operations and to reflect any contract plan revisions the department makes. Perform checks to confirm that the revised design surface DTM agrees with the contract plan revisions. Provide a copy of the resultant revised design surface DTM to the engineer. The department will pay for costs incurred to incorporate contract plan revisions as extra work.
- (5) The department will maintain the existing surface DTM by incorporating needed revisions. The department will make the current existing surface DTM available, in LandXML DTM format, to the contractor throughout construction.

#### **650.3.3.3.5 Site Calibration**

- (1) Designate a set of control points, including a total of at least 6 horizontal and vertical points or 2 per mile, whichever is greater, for site calibration for the portion of the project employing GPS machine guidance. Incorporate the department-provided control framework used for the original survey and design.

- (2) Calibrate the site by determining the parameters governing the transformation of GPS information into the project coordinate system. Provide the resulting site calibration file to the engineer before beginning subgrade construction operations.
- (3) In addition to the site calibration, perform site calibration checks. Perform these checks at individual control points not used in the initial site calibration. At a minimum, check the calibration at the start of each day and at least once for every 5 hours of continuous subgrade construction work. Report out-of-tolerance checks to the engineer. The measured position must match the established position at each individual control point within the following tolerances:
  - Horizontally to 0.10 feet or less.
  - Vertically to 0.05 feet or less.
- (4) Provide the previous week's daily calibration check results to the engineer at the weekly progress meeting for monitoring the GPS work.
- (5) The department will use the same calibration file the contractor uses.

#### **650.3.3.3.6 Construction Checks**

- (1) Conduct calibration checks daily conforming to 650.3.3.3.5 of this special provision and consistent with the contractor's GPS work plan. Use a GPS rover to check the subgrade at 20 or more randomly selected locations per mile. Document all GPS rover subgrade checks and any auxiliary checks made using other technologies. Provide all documentation to the engineer.
- (2) Ensure that at least 4 of any 5 consecutively-tested subgrade points are within 0.10 foot vertically of the plan elevation. Notify the engineer if more than one of any five consecutively-tested subgrade points differs by more than 0.10 feet from the plan elevation.
- (3) The department will conduct periodic independent subgrade checks using the contractor supplied GPS rover or conventional survey methods. When using the GPS rover, the department will use the same calibration files and other hardware and software settings the contractor uses for subgrade checking. The department will notify the contractor if any individual check differs by more than 0.10 feet from the design.

Replace standard spec 650.3.12 with the following:

#### **650.3.12 Initial Layout**

- (1) Set and maintain construction marks as required to support the method of operations consistent with third-order, class I horizontal and third-order vertical accuracy. Validate the department-provided horizontal and vertical control information and notify the engineer of any discrepancies. Provide



marks to establish and maintain intermediate vertical and horizontal control for reference line alignment, side road alignments, radius points, bench level circuits, slopes on the ground, and offsetting the horizontal roadway alignment. These marks constitute the field control used to govern and execute the work.

- (2) For the portion of the project using GPS machine guidance, set and maintain supplemental control points sufficient to ensure that there are a minimum of 6 established control points per mile. Ensure that these control points are consistent with third-order, class I horizontal and third-order vertical accuracy. Establish vertical control by differential leveling.
- (3) Verify the existing ground elevations as shown for all roadways on cross-section sheets for accuracy. If the elevation at the slope intercept is off by more than 0.4 foot (120 mm), notify the engineer. Take and document a minimum of 3 shots per roadway section. Set and maintain slope stakes on each side of the road at each cross-section location shown on the plans. Stake additional clearing and grubbing, and marsh excavation limits at locations where they vary from the slope stakes.
- (4) Document and provide to the engineer complete descriptions and reference ties for the control points, alignment points, and benchmarks to allow for quick reestablishment of the plan data at any time during construction and upon project completion.

Replace standard spec 650.4 with the following:

**650.4 Measurement**

- (1) The department will measure the Construction Staking bid items for base, concrete pavement, resurfacing reference, and initial layout by the linear foot acceptably completed, measured along each roadway centerline. The department will not measure construction staking for base underlying concrete pavement.
- (2) The department will measure Construction Staking Subgrade by the linear foot of subgrade acceptably completed, measured along each roadway centerline. The department will base measurement on the length of acceptably completed subgrade whether that subgrade was constructed using GPS machine guidance or using conventional construction staking. The department will include the length of subgrade where GPS machine guidance is initially employed but subsequently suspended by the engineer for reasons beyond the contractor's control. The department will measure this work twice, once for the suspended GPS work and once for the conventional subgrade staking required to successfully complete the work. If the department suspends GPS work for reasons within the contractor's control, the department will measure work in the affected area only once.

- (3) The department will measure Construction Staking Curb Gutter and Curb & Gutter by the linear foot acceptably completed, measured along the base of the curb face. The department will measure Construction Staking Concrete Barrier by the linear foot acceptably completed, measured along the base of the barrier. The department will not measure these bid items if abutting concrete pavement.
- (4) The department will measure Construction Staking Storm Sewer System as each individual inlet catch basin, manhole, and endwall acceptably completed.
- (5) The department will measure Construction Staking Pipe Culverts by each individual pipe culvert staked and acceptably completed.
- (6) The department will measure Construction Staking Structure Layout as a single lump sum unit for each structure acceptably completed. The department will measure Construction Staking Electrical Installations as a single lump sum unit for all electrical installations acceptably completed on each project.

**GUIDANCE FOR 2007  
WISCONSIN DEPARTMENT OF TRANSPORTATION  
GPS MACHINE GUIDANCE PILOT PROJECTS**

**GENERAL CONSTRUCTION AND PROJECT SELECTION**

The candidate project should first be reviewed for suitability for GPS use; for example, projects with dense tree canopy or large vertical cuts may not prove suitable. The region surveyor would assist in this preliminary evaluation with the construction engineer. It may also be determined that only certain project segments would be suitable. Recommended pilot projects should be communicated to the region's project manager and forwarded to Ken Brockman, Bureau of Project Development (BPD) for final approval.

On the pilot projects, the item of machine control grading will be used to replace subgrade staking on the whole project or segments of selected roadway sections. The project or segments should be reviewed and agreed upon by the engineer and contractor. A no-cost change order would then be submitted to allow the machine control grading. The item for Staking Subgrade would be paid for in all segments where machine control is attempted.

It is recommended that projects using machine control grading would also include contractor staking items such as initial layout.

**DESCRIBING PROJECT EXTENTS**

The GPS machine guidance pilot project specification allows some or all of the construction project to be done with GPS machine guidance. If the entire project is to be done with GPS machine guidance, then the following location description table can be used:

<u>GPS Machine Guidance</u>	<u>Subgrade Staking</u>
Entire Project	None

If segments of the project are to be done with GPS machine guidance and the remaining segments are to be done using conventional construction methods, the segments using conventional methods must be subgrade staked. The extents of each GPS machine guidance segment and each subgrade staking segment need to be described. There are a number of methods for describing the extents of segments. Examples include project stationing (preferred), cross street (intersection) naming, and bridge identification.

The following location description table combines some of these methods to describe the extents of four segments:

<u>GPS Machine Guidance</u>	<u>Subgrade Staking</u>
From Sta 0+00 to Sta 56+50	From Sta 56+50 to the intersection with CTH N.
From the intersection with CTH N to the Elm Street overpass (B-05-151)	From the Elm Street overpass (B-05-51) to EOJ

## **ROLES AND RESPONSIBILITIES**

### **Designer**

The project designer is responsible for overall design and any subsequent changes.

The designer provides normal digital data exchange data including DTM information and would work with the Methods Development Unit (MDU) engineer to prepare XML format information to be used by the contractor. Some additional field verification of models and digital terrain models (DTMs) may be required as a quality assurance of this information.

The designer would make the necessary design changes in case of errors and work with the MDU engineer to provide changed DTMs.

### **Construction Engineer**

#### Project Selection

For the pilot projects, the construction engineer would assist in the determination of the applicability of the use of machine control. The engineer should work with the region surveyor to evaluate the suitability of GPS technology and the availability of project control for the proposed project. The engineer, contractor, and region surveyor should agree on usage and limits of machine control grading, and a recommendation should go to regional & BPD management as noted above.

The engineer would lead the coordination of department-provided items and be the focal point for communication with the contractor.

#### Data and Surface Model Coordination

In order to prepare project data, DTMs, and surface model information for use by the contractor, there needs to be close coordination between the construction engineer, the designer, and the methods development unit (MDU) engineer. A meeting as noted below could help facilitate this.

#### Initial Coordination Meeting

Integral DOT/consultant staff that will provide information and guidance to the project should meet to discuss roles and responsibilities. This should include the design engineer, construction engineer, regional surveyor, methods development engineer, appropriate management, and may include contractor survey personnel. Some of the items to be addressed include provision of models and their formats, survey data and support, and project communications.

### Pre-Construction Survey Meeting

Before the start of construction survey, it is recommended that a coordination meeting be held to aid in the passing of survey information to the contractor and discuss the contractor's GPS work plan.

### Pre-Survey Meeting

This meeting includes the contractor, contract surveyor, construction engineer, methods development engineer, and regional surveyor. At this meeting, the contractor should share and discuss their GPS work plan, project schedule, and survey schedule. The department should identify key personnel and methods for handling changes on the model, etc.

### During Construction

Calibration checks are the responsibility of the contractor, but should be reviewed with the region surveyor to verify they are in reasonable tolerances and format.

The engineer should work with the region surveyor to develop a plan to perform construction checks. It is essential to provide some checks at project start-up to ensure contractor methods are meeting necessary tolerances. These checks can be performed using contractor-supplied GPS rover, independent GPS equipment, or conventional survey methods, and should meet specified tolerances. It is anticipated that once initial methods are working, construction checks could be performed using contractor-supplied rover. The department reserves the right to do added checks as needed.

### After Construction

The contractor, construction engineer, and surveyor should meet to review the effectiveness of the machine control grading operations and identify benefits and issues to be addressed.

The construction engineer should prepare a final report evaluating the machine control usage. Evaluation items could include overall project impacts, specification improvements, construction administration issues and other pertinent items. This evaluation should be submitted to the machine control grading steering team; Ken Brockman in the Bureau of Project Development is the designated lead for submittals.

### **Region Surveyor**

The region surveyor is responsible for providing control points and technical support on the project.

### Control Points

For the pilot projects, the region's survey unit would provide a minimum of 6 control points or 2 points per mile for use during the project. These points should be constructed or located outside the anticipated construction footprint. They should be type 1 or equivalent and should be set 15 degrees clear to the horizon with 360-degree access desirable at 6 foot height.

Control points should have horizontal and vertical project coordinates published. These points should be available two weeks before the preconstruction conference.

### Technical Support

The region surveyor should assist in initial evaluation of the project for potential GPS use. The surveyor could also assist in the development of a plan for providing construction checks.

The contractor is required to do their own project calibrations and check their work as it progresses. However, there may be questions that arise from the construction engineer

related to GPS operations and calibrations. It is expected that the regional surveyor would be available to lend technical guidance as warranted.

The surveyor should assist in evaluation of the pilot and provision of specific feedback on issues to be resolved, etc.

## **EARTHWORK QUANTITIES**

The region surveyor should work with the construction engineer and contractor to obtain as-built data and/or construction surface models for computing final quantities. The surveyor would work with the MDU engineer and the construction engineer to develop informational quantities for comparison to conventional quantity computations.

## **SITE CALIBRATION AND CHECKS**

The contractor performs site calibration and site calibration checks. The contractor provides data collected during these activities to the construction engineer. The following is intended for both the contractor and the construction engineer as guidance in configuring the control points used for site calibration, interpretation of site calibration and check data, and appropriate procedures to follow if either of the specified site calibration check tolerances is exceeded. The construction engineer can also consult with the regional surveyor on these matters.

### **Site Calibration**

Site calibration, sometimes referred to as “localization”, for GPS machine guidance is a process that results in computation of parameters for transforming measured GPS coordinates into the coordinate system of the project control points. Good site calibration and checking are vital to the success of GPS machine control operations.

#### Control Point Configuration

The GPS machine guidance pilot project specification requires that a minimum of six control points be used for site calibration and that the site calibration be periodically checked at control points not used in the calibration itself. The control points used for site calibration should envelop the project and be well distributed around its perimeter. Control points in close proximity to one another should be avoided. Long, narrow configurations of control points should be avoided. There should be control points near the corners of the project and approximately midway along its boundaries.

#### Error Estimates

Horizontal and vertical tolerances are specified for the site calibration checks but not for the site calibration itself. Once the site calibration measurement process is complete, the RTK GPS software will report estimates for the horizontal and vertical errors at each of the site calibration control points. A majority of the horizontal error estimates should be 0.10 feet or less in magnitude. A majority of the vertical error estimates should be 0.05 feet or less in magnitude. If any horizontal error estimate is greater than 0.15 feet, or if any vertical error estimate is greater than 0.08 feet, it is indicative (but not conclusive) that there might be later difficulties in meeting the site calibration check tolerances at the independent control points. These tolerances are 0.10 feet (horizontal) and 0.05 (vertical).

### **Site Calibration Checks**

If any site calibration check exceeds the specified tolerances (i.e., 0.10 horizontally or 0.05 feet vertically), there is a sequence of steps that should be followed:

1. The check should be re-measured at the same independent control point to ensure there is no problem with the check measurement.

2. A second and, perhaps, a third independent control point should be used to check the site calibration. If tolerances are met at these additional independent control points, then a problem is indicated with the first check control point.
3. If check tolerances are not met at two or more independent control points, then a problem is indicated with the site calibration and the site calibration measurement and computation procedure should be repeated to ensure that there is no problem with the initial site calibration measurements. If site calibration problems persist, vendor supplied manuals or guidance might also need to be consulted.
4. If the repeated site calibration measurements are in close agreement with the initial site calibration measurements, then a problem is indicated with one or more of the site calibration control points. The site calibration should then be performed while excluding the control point with the largest horizontal and / or vertical error estimate. It is likely that such error estimates will be larger than 0.10 feet horizontally or 0.05 feet vertically.
5. If a problem with a site calibration control point is identified in step 4, that control point should be replaced by another, and the site calibration procedure and checking should be repeated. The above control point configuration guidelines should be followed in selecting replacement control points.

## **CHANGES/ERRORS**

Specifications direct the contractor to immediately notify the engineer of any errors during staking and construction. Noted errors should be investigated as quickly as possible and may result in changes to the project model. The machine control specifications give guidance on handling model changes. It will be necessary to coordinate with the design engineer and the MDU engineer to make model changes.

In cases of significant errors and changes, further consideration may have to be given to the continued use of the machine control operations on the project. Current pilot specifications provide that should the machine control technology prove to be unworkable, the engineer would pay the item of subgrade staking for the section attempted and revert back to conventional staking.