IMPLEMENTATION OF GPS CONTROLLED HIGHWAY CONSTRUCTION EQUIPMENT – PHASE III

Project 02-13
February 2009

National Center for Freight & Infrastructure Research & Education
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Implementation of GPS Controlled Highway Construction Equipment Phase III

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Final Report

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16. Abstract

Beginning in 2006, WisDOT and the Construction Material and Support Center (CMSC) at UW-Madison worked together to develop the specifications and the QA/QC procedures for GPS machine guidance on highway grading projects. These specifications and procedures were the basis for the 2007 Pilot Program using GPS machine control grading on two projects. A phase II contract with CMSC was developed to monitor and analyze the 2007 pilot projects. The end result of this contract was the refinement of the specifications and procedures to be used in the 2008 pilot program.

Currently there are five (5) grading contracts that were selected by the regions as good candidates for GPS machine guidance and will be let with specifications that will permit the use of GPS machine guidance in lieu of setting blue tops. In addition, there is one (1) more project that is in the process of doing a no cost contract change order to use GPS machine guidance and will be part of the 2008 pilot program. Because five (5) of these projects will permit and not require the use of GPS machine guidance, we are uncertain at this time of the exact number for our 2008 pilot program. We are anticipating 2 – 4 projects in the 2008 pilot program. The allocation of hours by CMSC staff in the section on Tasks, below, assumes three pilot projects.

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Final Report

Implementation of GPS Controlled Highway Construction Equipment Phase III

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1. Background

During 2006, WisDOT and the Construction and Materials Support Center (CMSC) at UW-Madison worked together to develop a specification and guidance language for GPS machine guidance on highway construction grading operations. The specification was incorporated by change order in contracts on two pilot projects during the 2007 construction season. A third project also contributed information to the effort in 2007. Based upon the experiences of these projects, the specification and guidance language were modified in preparation for a second round of pilot projects during 2008. Following the 2008 pilot projects, further adjustments were made to the specification and guidance language. These are steps in a phased implementation plan whose ultimate goal is adoption of the final specification and guidance language into standard WisDOT documents and statewide implementation of optional GPS machine guidance for grading. 2008 was the final year for pilot projects.

During 2008, CMSC assisted WisDOT with evaluation of the specification and guidance language on three selected pilot projects on which GPS machine guidance for grading was included in the bidding process. The goal of the work was identifying and making any necessary modifications in a timely manner so that revised versions were in place for bidding on all 2009 projects involving grading. To meet this goal, a strategy was developed for structured data collection and analysis of experiences on the pilot projects. This strategy included a pair of site visits to each of the pilot projects. There was one pilot project in the WisDOT North Central Region and two pilots in the Northeast Region. An additional project in the Southeast Region provided information and assistance, although it was not designated as an “official” pilot project. The project team also visited an I-94 Illinois Tollway project on which GPS machine guidance was being used in conjunction with TOPCON’s Continuously-Operating Reference Stations (CORS).

In addition to the pilot projects, and as part of the information gathering process, the project team interviewed a number of construction contractors, their representatives, and a number of WisDOT region staff to obtain breadth and depth of opinion and perspective on the specification and guidance language.

Training of project engineers and other WisDOT staff in basic principles and techniques of GPS machine guidance is recognized as critical for successful implementation of the technology. During April, 2008, a two-day training session was conducted for engineers and staff expecting to participate in this year’s pilot projects. Evaluation of the training provided insights to improvements for future offerings. Associated recommendations appear within this report and three on-day training sessions are planned for April, 2009.

This report is a synopsis and summary of all 2008 activities and findings to date. The document concludes with descriptions of the final specification and guidance language. The final specification will be included as an option for bidding in all 2009 construction projects that include grading.

2. 2008 Specification and Guidance Language

The three 2008 pilot projects adopted, by special provision, the specification and guidance language as they appear in Appendix A of this report and as published in the final report from last year (Vonderohe (2008)).

3. Training Session

A training session on GPS machine guidance was conducted April 2-3, 2008 for WisDOT staff and consulting engineers. The training was hosted by the Wisconsin Operating Engineers' (WOE) Training Facility at Coloma, Wisconsin. Trainers were Alan Vonderohe (representing UW-Madison), Ken Bork and Jeff Servi (WOE Training Facility), Adam Patrow (FABCO), and Shane Behlendorf and Tom Walrath (Positioning Solutions). The roster of 24 trainees appears in Appendix B of this report.

Objectives of the training were to familiarize the trainees with GPS concepts and principles; machine guidance concepts and principles; 3D models and their role in GPS machine guidance; Trimble's and TOPCON's implementation of the technology; and WisDOT's pilot program, specification, and guidance language; and to address any questions the trainees might have had.

3.1. Session Content

The training session schedule appears in Appendix C. The first morning was devoted to introductions and objectives, GPS and machine guidance concepts and principles, and Trimble's implementation of the technology. During the first afternoon, trainees spilt into two groups, the first of which performed field exercises (with Trimble technology) on site calibration and sub grade checks. The second group received instruction on 3D model building and manipulation with Trimble technology. Midway through the afternoon, the groups switched roles and exercises.

The second morning was devoted to WisDOT's pilot program, specification, and guidance language, and TOPCON's implementation of the technology. During the second afternoon, the trainees once again split into two groups with the first performing field exercises with TOPCON technology and the second receiving instruction on 3D model building and manipulation using TOPCON technology. Once again, midway through the afternoon, the groups switched roles and exercises.

Figure 1 shows a number of views of the training class in session. Vonderohe's presentation slides, constituting a portion of each morning session, appear in Appendix D.

3.2. Evaluation by Trainees

The last 30 minutes of the training session were devoted to answering any additional questions the trainees had and to evaluation of the session by the trainees. An evaluation form was prepared in advance, distributed to the trainees during the closing session, and collected from them as they left the room. The evaluation questions, average rating received on each question, and comments furnished by the trainees appear in Appendix E. Table 1 summaries the responses to questions 1-8 for which the trainees had five choices: a) strongly agree = 1, b) agree = 2, c) neutral = 3, d) disagree = 4, e) strongly disagree = 5. An additional question on pace of the training was rated 1.89 with too slow = 1, about right = 2, too fast = 3. Overall rating of the training was 1.78 with excellent = 1, good = 2, average = 3, below average = 4, poor = 5.

Figure 1.
Classroom and Field Views of the Training Session

Table 1.
Average Ratings for Questions 1-8 on the Training Session Evaluation Form
(SA=1, A=2, N=3, DA=4, SDA=5)

Question	**Average Rating**
Met Needs?	1.72
About what expected?	1.78
Background material appropriate?	1.83
Material on vendors' implementation appropriate?	1.94
Field exercises appropriate?	2.06
3D model and data collector material appropriate?	2.06
Material on specification and guidance language appropriate?	1.83
Handouts and reference material appropriate?	2.06

Constructive comments provided by the trainees included:

1. Take less time in the classroom and more time in the field explaining features of each manufacturer’s product.
2. There should be an inspection check, such as an inspector would do in the field, as a field exercise.
3. Lengthen to include more hands-on.
4. Make handouts of all presentation material.
5. Have computer workstations for each trainee to do their own models.
6. Focus on inspector needs and how to document specs.
7. More time on spec and pilot program – less on GPS equipment specifics.

In addition to the feedback from the evaluations, received immediately after the training, the author interviewed three of the trainees later during pilot project site visits. These interviews came after the trainees had gained practical experience with both GPS machine guidance and the specification and could provide a more retrospective view of the training and how it could be improved.

3.3. Recommendations for Future Training

All of the evaluation information obtained as described above, and the personal experience of the author, lead to the following recommendations:

1. Each year, 2-3 days of training on GPS machine guidance and the specification should continue to be provided to WisDOT personnel and consulting engineers until there is a more general level of comfort throughout the community and the trained can begin to train the untrained. Formal training should be provided for at least the next 2-3 years.

2. WisDOT and UW-Madison should seek to maintain their relationship with the Wisconsin Operating Engineers, as the WOE training facility and staff are very high quality. The site is ideal for the needed training.

3. If possible, a computer workstation should be made available to each trainee (or pair of trainees) during indoor hands-on sessions. The WOE facility currently does not have enough computers for this.

4. Field exercises need more structure, with written step-by-step instructions that trainees can use for future reference.

5. A manual of training materials should be developed so students have a more complete set of consistent documentation for future reference.

6. Instruction on extended functionality and deep details on use of software and data collectors are not needed. Exercises and materials should be kept simple, focused upon basics, and upon what engineers need to know and do to oversee construction projects.

7. A panel of project engineers on past pilot projects should constitute part of the training. The panel would provide practical perspective on project oversight under the GPS machine guidance specification.

8. The FHWA / NHI has recently made available a no-cost, 1-2 hour, web-based introductory course on GPS for construction (FHWA-NHI-134078 TCCC GPS Technology) (see www.nhi.fhwa.dot.gov). The author has taken this course and finds it to be useful. Future trainees should be encouraged to take the course before enrolling in WisDOT-sponsored training sessions.

3.4. Planned 2009 Training

Since development of the recommendations in Section 3.3, major revisions to the specification were made (see Section 14**)**. These include elimination of provision of 3D model "seed" data by WisDOT, review of the contractor's 3D model by WisDOT, loaning of contractors' GPS rovers to project engineers, and use of those rovers by project engineers for acceptance measurements. Consequently, the detail on 3D model construction, provided in the 2008 training, is not as significant and, more importantly, project engineers need not actually use rovers in the field, reducing the need for "hands-on" field exercises.

Given these developments, three one-day training sessions, to be delivered during April, 2009 have been planned. The 2009 training session schedule appears in Appendix F. Contents include basic principles of GPS and GPS machine guidance, emphasis on the 2009 specification and guidance language, a panel of past pilot project engineers, and filed demonstrations. The 2009 training sessions will be conducted at the Wisconsin Operating Engineers Training Facility in Coloma.

4. Questions to be Addressed on the Pilot Projects

Among the questions initially expected to be addressed by the pilot projects were:

1. Does the specification need revision to make it more "bidder friendly".

2. What are the impacts of using the CORS network on GPS machine guidance?

3. What are the impacts of using GLONASS and other components of the Global Navigation Satellite System (GNSS) on GPS machine guidance?

4. What are the obstacles to use of "last pass" information for creation of a final DTM for final quantity measurement? "Last pass" refers to data collected during the machine's "last pass" over an area. Some feel that these data have potential to be used, in full or in part, to create a final DTM to measure earthwork. Others feel that problems associated with the data would be prohibitive because of needs for significant editing and additional survey information to supplement the data. Because this is not part of the specification, this might not be determined by the pilot program unless a contractor requests to use it and willingly participates in the research.

5. What is the experience of contractors with bidding projects with the option of using GPS machine guidance (e.g., bidder familiarity, cost, and procedural issues)?

6. What are the contractors’ expectations of WisDOT in regard to furnishing design surface data necessary to develop the DTM? If WisDOT did not furnish these data, how would that affect a contractor’s decision to use GPS machine guidance on a project and how would that affect the cost of the contract? Are current data exchange standards and rates sufficient for updating models during construction?

7. Are there parts of the specification that are too restrictive?

8. What is the required frequency or intervals of slope stakes; who uses slope stakes; what they are used for in addition to constructing ditches, slopes and sub grade; and what information is still needed on slope stakes if the contractor uses GPS machine guidance?

9. Is GPS machine guidance being used for base course? What should be its future use for base course on WisDOT projects? There have been some reported past projects that have used GPS-controlled motor graders to do finish grading on base course. Recommendations for implementation or further studies would be intended as a starting point for discussion with the industry and not the basis for immediate implementation.

10. What are the necessary knowledge and skill levels for project engineers and surveyors to administer contracts involving GPS machine guidance and what are effective means for acquiring these skills and knowledge?

11. Can project control requirements be reduced? Does availability of the CORS network reduce the need for project control?

12. Is there a need to specify the maximum geographic extent of a single site calibration?

13. Are there issues with GPS machine guidance in urban areas that are not apparent in rural areas?

5. Information Gathering Methods for the Pilot Projects

Information from the pilot projects was gathered by the following means:

1. Project plans and schedules.
2. Telephone and face-to-face interviews with project personnel (WisDOT staff, consulting engineers, and contractor staff).
3. Attendance at some pre-construction and selected weekly progress meetings.
4. Two rounds of site visits to the three pilot projects and site visits to two additional projects.
5. Acquisition of project data, including 3D models, GPS work plans, project engineer diary entries, contractor reports, and completed spreadsheets containing measurements. Spreadsheet templates (see Appendix G) were developed by the author and distributed to project engineers and foremen. These spreadsheets were intended for recordation of site calibration, site calibration checks, and sub grade checks.

6. Sets of questions and talking points, distributed to project personnel prior to the second site visit to each pilot project (see Appendices H, J, and L). These were used to generate discussion during interviews.

6. Pilot Projects

6.1. Kowalski Road - Project ID 1166-01-70

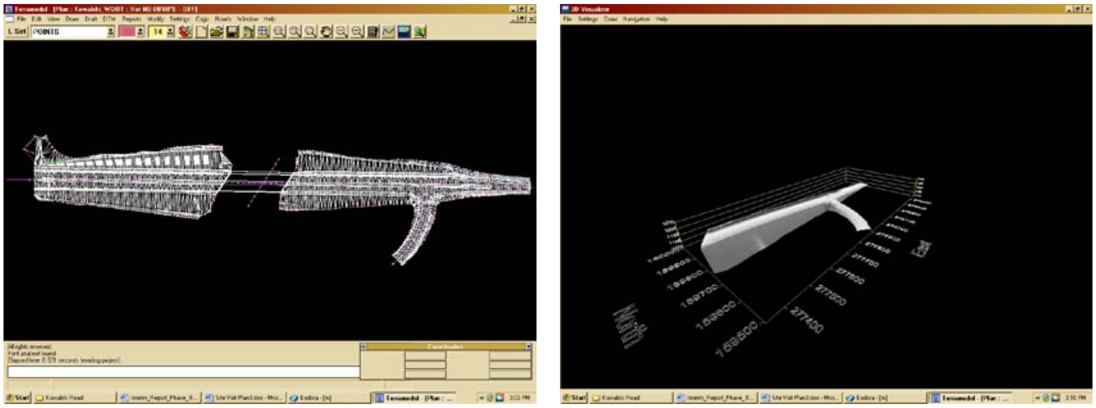
Region Project Development Supervisor: Matt Bronson
Region Project Manager: Mark Steidl
Region Survey Coordinator: John Kedrowski
Region Surveyor: Norm Jensen
Project Engineer: Greg Graf (Earthtech)
Prime Contractor: Lunda Construction
Grading Subcontractor: River View Construction (John Stone, Project Manager)

This project involved demolition and reconstruction of a bridge over I-39 on Kowalski Road, to the south of Wausau, near the Village of Kronenwetter. The full project was 2250 feet in length and included approaches to the bridge and the intersection of Kowalski Road and Kronenwetter Drive. The project included a number of vertical curves and a substantial volume of fill.

The first project weekly meeting was held on May 1. The author used this opportunity to conduct the first site visit to the project. Notably, the project was staged with the north half of the roadway and bridge to be completed before the south half. There were two separate grading operations for one roadway. The second site visit was conducted on August 20, just after sub grade checks for the north half of the project had been completed.

Earthtech served as project engineer, Lunda Construction wais the prime contractor, and River View Construction was the grading subcontractor. WisDOT included breaklines and mass points, developed from the plans, in the PS&E package and REI developed those data into a 3D model that was provided to River View, Earthtech, and WisDOT. A number of design changes were made as the model was being built and REI was in close contact with the design engineers to determine intent. REI used LANDXML for data exchange and did not report any problems. Methods Development Unit staff reviewed the initial model. Twelve person-hours were required for model review with about half that time devoted to learning aspects of WisDOT's new design software. REI reported that the review process took 2-3 weeks from the time of submittal. One revision, concerning a temporary lane, was made to the model after initial review. The revision was not reviewed. Figure 2 shows a plan view of the full model and a perspective view of the eastern half of the model. The bridge itself is not included in the model.

After some clarification on roles and responsibilities associated with provision of geodetic control, the Region Surveyor established six control points for the project, four to the north and two to the south, well off the right-of-way. RTK GPS was used for horizontal control and differential leveling was used for vertical control. Horizontal and vertical positions were tied to a number of existing control points. Due to the expected completion of grading on the project before the winter season, and to its limited geographic extent, capped reinforcing rods were used for control point monumentation. Horizontal coordinates were referenced to the Wisconsin County Coordinate System, Marathon County and elevations were referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). During construction, a staking subcontractor used a benchmark from the design control shown on the project plans. This benchmark disagreed with project control by 0.10 ft.



a) Plan View of Full Model b) Perspective View of East Half
Figure 2.
Kowalski Road 3D Model

River View's initial GPS work plan was reviewed by the project engineer and some changes were suggested to include more detailed information required by the specification. The necessary revisions were easily made. The revised GPS work plan appears in Appendix I. River View used Trimble technology on two GPS machine guidance dozers on the project. River View has been using GPS machine guidance for grading since 2001.

River View established an RTK base station atop a permanent post (see Figure 3) and completed its site calibration using all six WisDOT-provided control points. One of the same control points was used for periodic checks of the site calibration. These checks could not be made every day because River View had only one rover that was needed on more than one job. Most site calibration checks were within tolerance.

River View has a number of QA/QC procedures that they follow and document on every GPS machine guidance project. For example, a temporary benchmark is established at a PK nail in asphalt pavement, and each morning operators place the dozers' blades on the benchmark to verify that correct elevations of the blades are being obtained. Periodic adjustments are made for blade wear and the antennae posts on the equipment are checked frequently for signs of impact deformation or cracking from fatigue. River View also made sub grade checks over and beyond the 20 per mile required by the specification.

For sub grade checks, the project engineer used a random number generator to determine station and offset for 20 points (5 in each quadrant of the project). He then used software that he had previously written to determine the plan elevation at each of the check points. The contractor was asked to measure the elevation of the finished sub grade at each of the 20 check points and document the results. The engineer was in the field with the contractor as the measurements were being made. Therefore, on this small project, it was not necessary for the contractor to loan the rover to the engineer. The engineer was satisfied with using the 20 specified check points as verification of the sub grade. As mentioned previously, the contractor made additional sub grade checks for further assurance. This was because the random checks were not uniformly distributed across the sub grade. The random number generator had tended to group them. Sub grade checks for the north half of the project appear in Table 2. The sub grade checks meet the specified tolerance even though two of them were measured in wheel ruts. The field work for making the sub grade checks shown in Table 2 was completed in 30-45 minutes.

Figure 3.
River View's Base Station atop a Permanent Post

Table 2.
Sub Grade Checks for North Half of Kowalski Road Project

Station	Offset (ft)	Plan Elev (ft)	Measured Elev (ft)	Difference (Meas – Plan) (ft)
30+45	36 L	1183.77	1183.80	+0.03
31+35	12 L	1187.07	1187.02	-0.05
30+22	18 L	1183.41	1183.41	0.00
29+08	13 L	1179.95	1179.95	0.00
29+27	32 L	1180.16	1180.16	0.00
45+46	20 L	1185.76	1185.65	-0.11*
40+57	22 L	1198.72	1198.66	-0.06*
45+70	11 L	1185.24	1185.18	-0.06
44+00	10 L	1190.26	1190.16	-0.10
42+26	30 L	1194.93	1194.90	-0.03
40+99	30 L	1197.83	1197.86	+0.03

* Measurement taken in wheel rut

Figure 4 shows views of the construction site prior to and after grading of the north half (i.e., first stage).

a) Prior to Construction b) After Gravel Placement

c) Finished Slope and Ditch d) Finished Slope and Ditch

Figure 4.
Western Approach to Kowalski Road Bridge Prior to Construction and after Grading of the North Half (Stage 1)

Record-keeping forms and examples that appear in Appendix G were given to the contractor and the engineer. However, Trimble data collectors can download reports that contain the same information.

6.1.1. Discussion Points Raised on the Project

1. For small projects of this extent, the requirement for six control points for site calibration, plus a seventh (not used in the calibration) for checking, could potentially be reduced. Three 3D control points yield a unique solution for site calibration (no check). Four control points provide some redundancy. Five control points add statistical confidence to the solution. It might be feasible to reduce the control requirements for site calibration on small projects to as few as four (one in each corner of the project) with a fifth control point withheld for checking. However, both the contractor and the project engineer on this pilot project felt that the current requirement of a minimum of six control points for site calibration was appropriate. They did not recommend reducing the number.

2. For small projects of this extent (less than a mile), how is the specification of 20 or more sub grade checks per roadway mile to be interpreted? The contractor

and engineer on this project made 20 sub grade checks together, with the engineer specifying random locations. The contractor made additional sub grade checks that were more uniformly distributed.

3. For staged projects that have a single reference line but temporally distinct grading operations, basing the number of sub grade checks on roadway miles is inadequate. The specification was revised for 2209 and beyond to read “Conduct at least 20 random checks per stage, per project, or per roadway mile whichever results in the most tests” to account for both small projects and staged projects (see Section 14 and Appendix N).

4. For projects expected to be completed in one season, without need for project control to carry over into the next year, it might not be necessary to pour concrete monuments for the control points. This project used capped reinforcing rods.

5. What is the basis for payments to the contractor for expenses incurred in making 3D model revisions as a result of revisions to the project plans?

6. Project control for construction should be referenced to the control used for design if at all possible. As the WisDOT CORS network gradually becomes the basis for both design control and construction control, this issue will become moot.

7. Communication between 3D model builders and design engineers is important to determine design intent when developing detail in the model. This is an issue if the designer is not available or not obligated to provide additional information once the design is complete.

8. WisDOT review of the 3D model is important, especially if a third party does the model building. Review of the model provides a level of comfort for everyone.

9. Field staff need software and skills to make model revisions in near real time.

10. If the design product is a 3D model, tracking model revisions and providing data security as a project progresses will be an issue.

11. Slope stakes are necessary, but slope stake markings can be reduced to station and offset. On this pilot project, slope stakes markings included station, offset, and elevation (see Figure 5), but the elevation information was not necessary.

6.2. Oconto Bypass (USH 41) - Project IDs 1154-01-73 and 1154-01-74

Region Project Development Supervisor: Steven Noel (both projects)
Region Survey Coordinator: Dennis Keyzer (both projects)
Project Engineer: Doug Wiegand (south project); Dan Schneider (STS) (north project)
Prime Contractor: Lunda Construction (south project); Hoffman Construction (north project)
Grading Subcontractor: Hoffman Construction (south project)
Grading Foreman: Ken Bork (both projects)

Figure 5.
Kowalski Road Slope Stake Lath Marked with Station, Offset, and Elevation.

The USH 41 bypass around Oconto was actually two projects treated as one for purposes of this study. The southern component of the project involved 1.33 miles of new, rural, divided roadway and ramps. It included an at-grade intersection and five structures. Lunda Construction was the prime contractor and Hoffman Construction was the grading subcontractor. The northern component of the project involved 3.13 miles of new, rural, divided roadway and ramps. It included two at-grade intersections and ten structures. Hoffman Construction was the prime contractor. An initial site visit was made to correspond with weekly project meetings for both components. At the time of the first site visit, grading had not yet begun because there were 20 feet of fill / haul on the south component and the erosion control plan and haul road permits were waiting approval (see Figure 6). It was expected that grading would operate 24 hours per day once it was initiated. Hardcopy and electronic versions of the record-keeping forms in Appendix F were provided to the project engineer.

Figure 6.
Initial Excavation, Haul, and Fill on Oconto Bypass Project

The second site visit was on November 11. A set of questions and talking points were sent to the project engineer and the contractor prior to the second site visit (see Appendix J). A top-soiled borrow pit had been recently re-opened to bring in 70-80 truck loads to finish the sub grade. The marshy soil had been mixed with borrowed sand and sub grade had been found to consistently 0.1 ft too low due to consolidation and compaction. Checks of the final finished sub grade were beginning to be made at the time of the second site visit.

According to the project plans, the horizontal coordinate system for the Oconto Bypass project was the Wisconsin County Coordinate System, Oconto County and the vertical datum for was NGVD 29. Geodetic control for the Oconto Bypass project, as well as for the Peshtigo Bypass project (see Section 6.3), was established by Coleman Engineering Company under contract with the Northeast Region. The vertical datum for construction control was NAVD 88. To control both bypass projects, Coleman constructed 39 control point monuments and provided coordinates and elevations for them as well as for six other existing control point monuments. Rapid static GPS methods were used for horizontal control measurements and ties were made to at least five existing control points. Differential leveling was used for vertical control measurements and ties were made to at least two existing benchmarks.

The base station for the Oconto Bypass was on the roof of the project headquarters building and was not easily accessible for photography. Hoffman's site calibration was controlled with 13 of the points set by Coleman. Six additional supplemental project control points were set by Hoffman and were used for daily site calibration checks, among other things. Hoffman's GPS work plan for the project appears in Appendix K. For the duration of the project, site calibration checks were consistently within specified tolerances, with a few exceptions. A local commercial Internet service provider experienced interference from Hoffman's base station radio signals and alerted the regional supervisor. After checking with the technology vendor it was confirmed that Trimble base station use open frequencies in the 900 megahertz range and that no parties are granted exclusive use of these frequencies.

Break lines and mass points, derived from the plans, were included by WisDOT in the PS&E packages for both components of the Oconto Bypass project. Hoffman reported that each of the two initial models took one week of office time to build. Model building was complex because there were many horizontal and vertical curves and two reference lines (one northbound and one southbound). Locations of super elevation transition points, and their cross sections, had to be computed from profiles shown on the plans. In addition, super elevations had to be carried from one reference line to the other through station equations. The roadway design included gradual slope changes into and out of super elevation start and end points as opposed to a constant slope / crown leading to no crown at supers (NOTE: This is not typical and these all had to be computed to build the 3D model). The 3D model was undergoing review at the time of the first visit and a number of issues had been raised (see Section 6.2.1 on discussion points raised on the project). Sixty percent of the design was done in-house by WisDOT and the remaining 40% was contracted to consulting engineers. As a result, many designers developed cross sections for the plans. At the time of the first site visit, the project engineer was inquiring if the designers could generate cross sections not shown in plans for the purpose of 3D model building. Ultimately, the model was completed by Hoffman and agreed to by WisDOT. Figure 7 shows views of the 3D model at ramps.

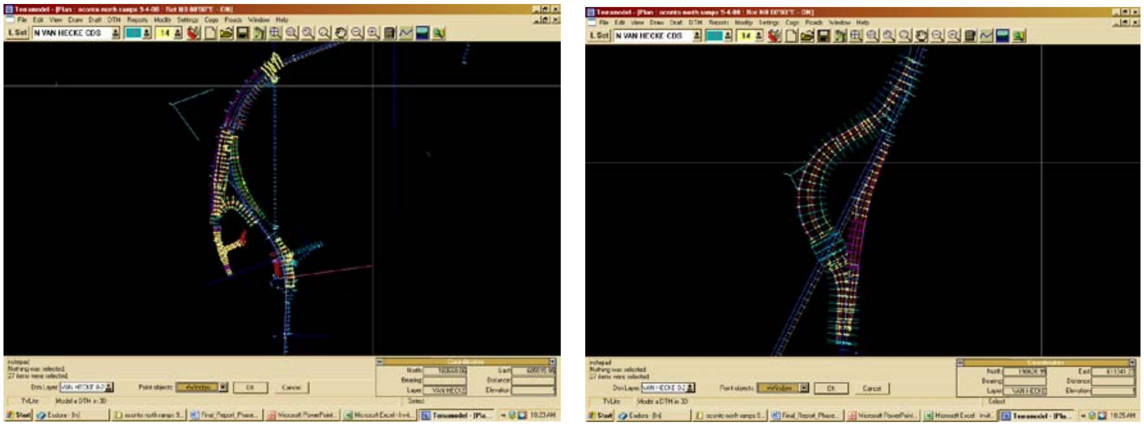


Figure 7.
Oconto Bypass 3D Model at Ramps

The contractor and the project engineer stated that slope stakes are needed for reference at every station for reference. The project engineer frequently finds the project reference line by offsets with a tape from the slope stakes. Besides visual reference for grading, slope stakes are used for clearing and grubbing, silt fence placement, and any other operation that needs station and offset locations. Slope stakes on the project are marked with an identifier, station, and offset. No cut / fill or elevation is included in the markings (see Figure 8). Project personnel suggested that there is a need for a different slope staking bid item and payment on projects that use GPS machine guidance. The existing slope stake specification for checking the original ground is out of date if an original ground DTM is available.

Figure 8.
Oconto Bypass Slope Stake Lath Marked with Identifier, Station, and Offset

Initial sub grade checks made by the contractor and engineer on two ramps indicated some re-grading needed to be done. The final sub grade checks, made by the project engineer, on one of these ramps appear in Table 3. All the final checks meet the specification. The project engineer used the rover loaned by the contractor to make the final checks.

The contractor made 54 sub grade checks along 6000 feet of northbound and southbound main line (12000 feet of roadway). Of these 54 checks, all met the specified tolerance with one exception where two consecutive checks were 0.11 ft and 0.18 ft below design elevations. Checks were made at full stations, chosen with a random number generator with additional stations designated by the project engineer where the random number generator left 200-300 ft gaps. A few blue tops were set on some side roads.

Table 3.
Final Sub Grade Checks made by the Project Engineer on a Ramp

Station	Offset (ft)	Plan Elev (ft)	Measured Elev (ft)	Difference (Meas – Plan) (ft)
704+00	2R	603.21	603.27	+0.06
706+00	25L	610.30	610.36	+0.06
708+00	17L	617.36	617.38	+0.02
710+00	6R	624.38	624.40	+0.02
712+00	1L	628.30	628.31	+0.01
715+00	4L	629.79	629.77	-0.02
718+00	0	627.92	627.88	-0.04
721+00	10L	628.83	623.80	-0.03

Figure 9 shows views of finished slopes, ditches, sub grade on mainline and an aerial view of main line and the bridge over the Oconto River.

a) Finished Slopes and Ditch

b) Finished Mainline Sub Grade

c) Aerial View of Mainline and Bridge

Figure 9.
Views of the Oconto Bypass

6.2.1. Discussion Points Raised on the Project

1. During 3D model review, WisDOT requested refinements and inclusion of details that were not shown on the plans (e.g., 50 ft cross sections and cross sections at super elevation transition points). The contractor felt that WisDOT should provide the same detail in the plans that they are going to require in the 3D model. An alternative would be for WisDOT to provide station, offset, and elevation for points on cross sections that are needed in the 3D model but do not appear in the plans.

2. Cross sections at full stations, as they appear in plans, cause chords to appear along curved ditches in the 3D model. WisDOT requested that more detail be included in the model to reduce the chord lengths. Hoffman's position is that the machine operators will build curved ditches not chords. That is, the operators will build what was intended in the design, not what is exactly in the model.

3. Locations of super elevation transition points and their cross sections, that have to be computed from profiles, cannot be verified against the plans because they are not in the plans. The specification requires the contractor to ensure that the 3D model conforms to the plans.

4. Intended uses of the 3D model and the plans are different. Plans are used for estimating and 3D models are used for construction.

5. The current slope staking specification, applied to checking the original ground, is insufficient if an original ground DTM is available.

6.3. Peshtigo Bypass (USH 41) – Project ID 1154-01-75

Region Project Development Supervisor: Steven Noel
Region Survey Coordinator: Dennis Keyzer
Project Engineer: Brett Vissers (Mead and Hunt)
Prime Contractor: Hoffman Construction
Project Foremen: Mark Miles (south) and Jene Pientok (north)
Grading Foreman: Al Johnson

This project also consisted of two separate contracts being treated as one project for the purposes of this study. The project involved 3.90 miles of new, rural, divided roadway and ramps, forming a bypass of USH 41 around the City of Peshtigo. Four at-grade intersections and ten structures were included. Hoffman Construction was the prime contractor.

The project was let in May and the first site visit took place in July to coincide with a project weekly meeting. Hardcopy and electronic versions of the record-keeping forms in Appendix F were given to the project engineer and the grading foreman. The second site visit took place in November as sub grade checks were beginning to be made. A set of questions and talking points were sent to the project engineer and the contractor prior to the second site visit (see Appendix L).

According to the project plans, the horizontal coordinate system for the Peshtigo Bypass project was the Wisconsin County Coordinate System, Marinette County and the vertical datum for the project was NAVD 88. Geodetic control for the project was established by Coleman Engineering Company under the same contract with the Northeast Region that was used for establishing control on the Oconto Bypass project (see Section 6.2).

Hoffman's GPS work plan appears in Appendix M. Ten of the geodetic control points established by Coleman were used in the site calibration. Some of these same points are being used for site calibration checks. At the time of the first site visit, approximately 80% of the site calibration checks were within specified tolerances. It was determined that those exceeding tolerances were probably attributable to the base station being set up on a tripod and the antennae height having to be entered each morning. This situation was soon remedied by establishing a fixed base station on the roof of the project headquarters building. A second fixed base station was also established atop a post on the project site (see Figure 10). Both base stations used the same calibration file but they broadcast corrections on separate channels. Two base stations were necessary because of the extent of the project and the terrain conditions.

Hoffman's Two Fixed Base Stations
Figure 10.

The staking subcontractor's (POB) site calibration was different than that of the contractor. The two site calibrations had some common control points, but they were not identical. Both Hoffman and POB had some initial difficulty tying into one of the high-accuracy reference network (HARN) stations - Peshtigo GPS. It is likely that this station was not included in Coleman's geodetic control work. Also, a level loop tied to a project benchmark misclosed on another project control point by 0.10 ft. Misclosures of this magnitude are not unusual for control points whose initial measurements have undergone separate adjustments. Issues with control point misclosures should be resolved before construction begins. Railroad bridge clearance was critical on this project and consistent project control for design, model building, and construction was an issue. Hoffman added project benchmarks within the right-of-way to better tighten the control for grading.

The early construction process experienced significant GPS downtime (1-2 hours per day) for more than a week due to weak satellite geometry (only five visible satellites). At the time of the second site visit, the downtime window was about 45 minutes each day. On some ramps, there were steep side slopes with tree-canopied areas near the bottoms (see Figure 11). Satellite signals are sometimes blocked under similar conditions.

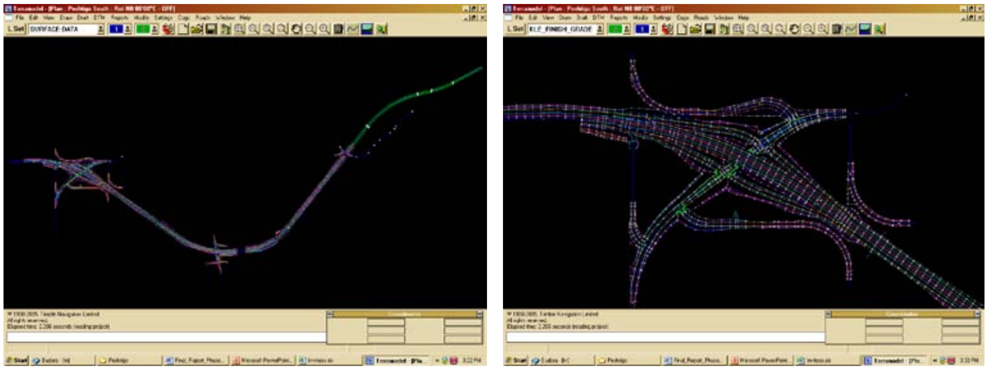
Figure 11.
Dozer Spreading Topsoil on Steep Slope near Tree Canopy

Break lines and mass points, derived from the plans, were included by WisDOT in the PS&E package for one of the two components of the Peshtigo Bypass project. At the time of the first site visit, the 3D model was still being built. It had not yet been reviewed but parts of it were being used for construction. A short section of mainline sub grade had been completed with GPS machine guidance, and, because the model had not been reviewed, that section of mainline was blue topped (see Figure 12). The grading foreman believed from his experience with model building that it is better to use WisDOT break line data for slopes and ditches, discard the roadway break line data, and either enter the roadway from scratch or use a template. This is because WisDOT break lines do not include data for vertical curves and super elevations. Two views of the final 3D model appear in Figure 13.

Figure 12.
A Segment of Main Line Sub Grade that was Blue Topped because the Model had not yet been Reviewed.

Table 4 shows some of the 64 sub grade checks made by Hoffman before the close of construction in late November. All the checks met specification. The project engineer accompanied the contractor as the checks were being made, so there was no need for the contractor to loan a rover to the engineer. Figure 14 shows finished slopes and ditches, and work underway on the northbound mainline.

The project engineer stated that slope stakes are needed but their frequency can be reduced to every 200-300 feet. The only necessary markings are station and offset.



Two Views of the Peshtigo Bypass 3D Model
Figure 13.

Table 4.
Sub Grade Checks Made by the Contractor on Three Roadways

Segment Station	Offset (ft)	Plan Elev (ft)	Measured Elev (ft)	Difference (Meas – Plan) (ft)
Ramp				
55+00	4R	623.40	623.39	-0.01
56+00	12L	621.11	621.14	+.0.03
58+00	22R	614.32	614.28	-0.04
59+00	0	610.99	611.03	+0.04
NB Mainline				
1494+00	12R	641.45	641.47	+0.02
1495+00	12L	639.99	639.97	-0.02
1496+00	33R	638.90	638.93	+0.03
1497+00	16R	637.91	637.95	+0.04
1498+00	12L	636.01	635.96	-0.05
1499+00	32R	635.92	635.96	+0.04
1500+00	15R	633.49	633.49	+0.00
1501+00	9L	630.76	630.73	-0.03
1502+00	7L	629.45	629.48	+0.03
1503+00	37R	629.25	629.25	+0.00
1504+00	12R	626.48	626.44	-0.04
1505+00	9L	623.87	623.88	+0.01
1506+00	33R	623.91	623.99	+0.08
1507+00	16R	621.48	621.45	-0.03
1510+00	9R	616.02	616.03	+0.01
SB Mainline				
1510+00	85.7L	615.21	615.15	-0.06
1511+00	63.5L	614.47	614.47	+0.00
1512+00	88.5L	611.74	611.65	-0.09
1513+00	75.5L	610.62	610.57	-0.05
1514+00	52.4L	609.92	609.91	-0.01
1515+00	95.0L	606.44	606.40	-0.04
1516+00	70.3L	605.86	605.86	+0.00
1517+00	74.0L	604.29	604.31	+0.02

a) Finished Slope and Ditch b) Work on Northbound Main Line

Figure 14.

Grading Work on the Peshtigo Bypass

6.3.1. Discussion Points Raised on the Project

1. There is a need for consistent project control that is used by all parties.

2. WisDOT-provided break lines and mass points are a good starting point for model building but much detail often needs to be added. It might be best to use WisDOT data for side slopes and ditches, and develop mainline data from the plans or by using a template.

3. Partial models can be used for construction before the full 3D model is built. There can be bottleneck issues associated with model review by WisDOT when construction needs to be expedited.

4. There were some lengthy downtimes (1-2 hours) on this project due to poor satellite geometry. Perhaps some post investigation of satellite orbits and visibility for this project site is warranted. Downtimes of this duration have not been experienced elsewhere.

5. Fixed base stations eliminate problems with daily measurement and input of antenna heights.

7. Other Site Visits

7.1. Burlington Bypass (SB STH 36 to SB STH 83) - Project ID 3180-11-70

This project was 2.7 miles of bypass around the city of Burlington. The project was originally slated as a candidate 2008 GPS machine guidance pilot project, but the contractor (H. James and Sons) elected not to participate in the pilot program. A site visit was made to the project to discuss the contractor's decision and to learn their perspective on the specification and GPS machine guidance in general.

The contractor stated that they did not participate in the pilot program because, from past experience, they expected the design for the project to contain a significant number of errors. The effort to make plan and 3D model revisions and the process of coordinating the final model changes with WisDOT for review would be too much additional burden. The majority of design errors had to do with drainage.

The contractor still prefers to set blue tops when using GPS machine guidance with motor graders. This is a good way to assure quality control and for the operator to know immediately if something is wrong. There is no significant savings in eliminating blue tops because the surveying firm that is contracted to set blue tops will unbalance their bid by putting very little cost in this and increasing cost for other staking. The total cost for sub grade staking is about the same with or without setting blue tops. There is a level of comfort with the blue tops. As time goes by, the number of blue tops could be reduced, and perhaps they could be eliminated. At this point in time, any savings in the cost of blue topping is not a major consideration for H. James and Sons to use GPS machine guidance. The significant savings is in reduced time and effort to complete grading.

The requirement for sharing a GPS rover with WisDOT staff was discussed. The contractor has two rovers and four of its own crews use them. Contractors and WisDOT staff do not have a clear understanding on utility of the loaned GPS rover. Some WisDOT staff feel that the rover is available to them for any staking or other use during the entire duration of the project. Others believe it is to be used only for supplemental sub grade checks. The contractor stated that, ultimately, WisDOT should provide its own equipment for checking the sub grade. It would not be necessary for each project engineer to have a WisDOT-owned rover. Rather one- or two-person crews could be assigned to small groups of projects in proximity to one another and then schedule sub grade checks among the projects according to project progression rates.

H. James and Sons uses TOPCON technology. One motor grader is equipped for GPS machine guidance. No dozers are equipped. Therefore, machine guidance is used for roadway sub grade only, not slopes and ditches. However, the contractor's 3D models include slopes and ditches in addition to roadway because the models are used for staking and layout. H. James and Sons constructs all of their 3D models. They have developed a method for importing CaCIE slope stake reports into a spreadsheet sheet and subsequently into TOPCON's 3D Office software. Consequently, construction of the framework for the 3D model is straightforward. Intersections and other detail missing from the slope stake reports must then be added to the model.

It was noted that most contractors who are adopting GPS machine guidance are in a state of transition where some equipment is rigged and some is not. Project-wide use of the technology might be limited as a result. We are in a period of change in which a mix of construction technologies and methods will be the norm on many projects.

The contractor is very supportive of efforts in the pilot program and they are dedicated to continued use of GPS machine grading. Savings in time and effort are quite significant. The quality of the work is greatly increased. H. James and Sons is also anticipating using GPS machine grading on sections of base course.

7.2. Illinois Tollway (I-94)

WisDOT is building and implementing a statewide network of continuously-operating reference stations (CORS) to support RTK GPS positioning. The CORS network in the eastern 1/3rd of Wisconsin became operational and publically available in July, 2008.

CORS is designed to provide a network solution that eliminates the need for a local RTK base station. CORS consists of a network of fixed-position receivers that are continuously receiving satellite signals and transmitting data to a central server. The server develops a baseline network solution and an atmospheric correction model for any individual rover that is subscribed to its service. Carrier-phase corrections are sent by the server to individual rovers by cellular connection.

The Wisconsin CORS uses Trimble technology. For GPS machine guidance applications, the Trimble CORS server sends cellular corrections to a single project-based device that re-broadcasts them, via radio signal, to all GPS machine guidance construction equipment. FABCO (Caterpillar / Trimble distributor) and Trimble are currently testing the operational component of the Wisconsin CORS network for GPS machine guidance applications.

On the other hand, TOPCON CORS technology for GPS machine guidance sends corrections from the central server directly to the individual machines by cellular connection. There is no re-broadcast radio. However, the machines need to be rigged for cellular reception rather than radio reception.

TOPCON CORS was used during 2008 for GPS machine guidance on reconstruction of the I-94 Tollway in Illinois, from the Wisconsin border to the south. The project team made a site visit to the Tollway project to observe TOPCON CORS-based GPS machine guidance in operation (see Figure 15). At the time of the site visit, TOPCON CORS provided a single baseline solution referenced to the nearest CORS station, not a network solution referenced to multiple stations. Consequently, TOPCON reference stations need to be more densely spaced, because no rover can be further from the nearest reference station than it would be from its own base station if CORS was not being used. TOPCON and Positioning Solutions (distributor) are in the process of extending their reference station network into Wisconsin.

Figure 15.
A Motor Grader Using TOPCON CORS-Based GPS Machine Guidance on I-94 Illinois Tollway Reconstruction (Corrections are being Received by Cellular Connection to a Central Server)

8. Summary of Discussion Points from the Pilot Projects and Other Site Visits

1. For small projects, the requirement for six control points for site calibration, plus a seventh (not used in the calibration) for checking, could potentially be reduced. Three 3D control points yield a unique solution for site calibration (no check). Four control points provides some redundancy. Five control points add statistical confidence to the solution. It might be feasible to reduce the control requirements for site calibration on small projects to as few as four (one in each corner of the project) with a fifth control point withheld for checking. However, both the contractor and the project engineer on the Kowalski Road Project felt that the current requirement of a minimum of six control points for site calibration is appropriate. They did not recommend reducing the number.

2. For small projects (less than a mile), how is the specification of 20 or more sub grade checks per roadway mile to be interpreted? The contractor and engineer on the Kowalski Road Project made 20 sub grade checks together, with the engineer specifying random locations. The contractor made additional sub grade checks that were more uniformly distributed.

3. For staged projects that have a single reference line but temporally distinct grading operations, basing the number of sub grade checks on roadway miles is inadequate. The specification should be revised to account for individual grading operations over time.

4. For projects expected to be completed in one season, without need for project control to carry over into the next year, it might not be necessary to pour concrete monuments for the control points.

5. What is the basis for payments to the contractor for expenses incurred in making 3D model revisions as a result of revisions to the project plans?

6. Project control for construction should be referenced to the control used for design if at all possible. There is a need for consistent project control that is used by all parties. As the WisDOT CORS network gradually becomes the basis for both design control and construction control, this issue should become moot.

7. Communication between 3D model builders and design engineers is important to determine design intent when developing detail in the model. This is an issue if the designer is not available or not obligated to provide additional information once the design is complete.

8. Some contractors feel that WisDOT review of the 3D model is important, especially if a third party does the model building. Review of the model provides a level of comfort for everyone.

9. Field staff need software and skills to make model revisions in near real time.

10. If the design product is a 3D model, tracking model revisions and providing data security as a project progresses will be an issue.

11. Slope stakes are necessary, but slope stake markings can be reduced to station and offset if GPS machine guidance is used to construct the entire roadway width. Slope stake spacing could potentially be reduced to 200-300 feet.

12. During 3D model review, WisDOT sometimes requests refinements and inclusion of detail that are not shown on the plans (e.g., 50 ft cross sections and cross sections at super elevation transition points). Some contractors feel that WisDOT should provide the same detail in the plans that they are going to require in the 3D model. An alternative would be for WisDOT to provide station, offset, and elevation for points on cross sections that are needed in the 3D model but do not appear in the plans.

13. Cross sections at full stations, as they appear in plans, cause chords to appear along curved ditches in the 3D model. Some contractors assert that this is sufficient and that machine operators will build curved ditches not chords. That is, operators will build what was intended in the design, not what is exactly in the model.

14. Locations of super elevation transition points and their cross sections, that must be computed from profiles, cannot be verified against the plan cross sections because they are not in the plans. The specification requires the contractor to ensure that the 3D model conforms to the plans.

15. WisDOT-provided break lines and mass points are a good starting point for model building but much detail often needs to be added. It might be best to use WisDOT data for side slopes and ditches, and develop main line data from scratch or by using a template.

16. Partial models can be used for construction before the full 3D model is built. There can be bottleneck issues associated with model review by WisDOT when construction needs to be expedited.

17. There were some lengthy downtimes (1-2 hours) on the Peshtigo Bypass Project due to poor satellite geometry. Perhaps some post investigation of satellite orbits and visibility for this project site is warranted. Downtimes of this duration have not been experienced elsewhere.

18. Fixed-height, permanent project base stations eliminate problems with daily measurement and input of antenna heights.

19. Some contractors have QA/QC procedures that go beyond the current specification (e.g., some do blue topping by choice).

20. Expectations of significant design errors and consequent bottlenecks with model review cause hesitation by some contractors to operate under the 2008 specification.

21. Sharing a GPS rover can be an issue. Some contractors do not have enough rovers to be able to provide one to WisDOT staff. There is also some confusion over the intended use of the shared rover.

22. GPS machine guidance is being used in Wisconsin for base course placement. There currently is no corresponding specification.

23. Use of the WisDOT CORS in support of GPS machine guidance is currently being tested.

9. Interviews with Contractors

During the period July 23-30, 2008, five construction contractors were interviewed by teleconference and a meeting with four others and the Executive Director of the Wisconsin Earth Movers' Association was conducted. The purpose of these activities was to obtain contractor perspectives on seven key questions concerning the GPS machine guidance specification for sub grade construction that is ultimately expected to become part of WisDOT's standard specifications.

Those participating in the teleconferences were 1) the interviewee (each of Jeremy Craven – Edgerton Construction; John Stone – Riverview Construction; Russ Chrisman – RC Excavating; Tom Dobberthein – Mashuda Construction; Tom Kluck – Mann Brothers); 2) Alan Vonderohe (representing UW-Madison); and 3) Ken Brockman (WisDOT). Jerry Zogg (WisDOT) participated in two of the teleconferences and Jack Arseneau (WEMA) participated in one of them.

Those participating in the meeting were Jack Arseneau, Randy Henkel (H. James and Sons), Brad Ottum (Relyco), Chris Goss (Hoffman Construction), Tim Peterson (J. Peterson Sons), Alan Vonderohe, Ken Brockman, Jerry Zogg, and Jonathan Ciche (UW-Madison note taker).

9.1. Questions and Responses

1. Under the current specification, WisDOT provides initial digital data, primarily in the form of break lines, for development of the 3D design model by the contractor. Are these data of value to you as a contractor? If you needed to develop the 3D models directly from the plans, without the initial data provided by WisDOT, would this affect your decision to bid under the specification?

- Yes, the data are of value. The Marquette interchange required one month of model-building from scratch and would have taken one week if preliminary data had been available. There is an expectation of saving 50-75% on model building if preliminary data are available.

- A savings of about $15,000 on a 4-5 mile job is realized with the survey data package (40-50 hours with the data, 100-120 hours without the data). NOTE: The survey data package is furnished with all contracts. It is not the more enhanced break lines and mass points provided by MDU for the pilot projects. Others assert the survey data are important but not for model building. Rather, it is the break lines data that are of assistance in model building.

- The additional break lines and points that WisDOT provided for the pilot projects (in addition to the survey data) saves about 3-5 hours per mile in model building. If this information is not available, it would not affect the decision to bid or the overall cost of the project.

- Model building troubleshoots the plans before running into much higher costs if problems with plans are found during construction. Some consultants feel that checking the complete set of plans is appropriate if one problem is found.

- Sometimes the MDU-provided data do not match the plans due to last minute revisions in the plans after the data have been developed or have started to be developed.

- Lack of preliminary data would not influence some contractors' decisions to bid under the specification, but at least one other is more hesitant because not having the preliminary data incurs more liability because WisDOT assures that the preliminary data conform to the plans.

- Productivity gains from GPS machine guidance outweigh costs of model building from scratch. Building the model requires less effort than setting stakes. At least one contractor is going to use GPS machine guidance on every job. Others assert that each job is looked at differently. If a job warrants building a model then they will do it. Non-availability of preliminary data might affect at least one contractor's decision to use GPS machine guidance on smaller jobs, but not on large jobs.

- One contractor is experienced a significant number of design changes during 2008, some of which were discovered as a result of model building.

- Some contractors' greatest concerns are model building and model accuracy. The sub grade will be built according to the model, so it must be correct.

- Model building on the part of contractors will become moot once a full transition to 3D design has been made. NOTE: Civil 3D is scheduled for deployment by WisDOT in 2009, but the move to full 3D design and possible adoption of models as contract documents is expected to take longer because of the normal 3-5 year lead time needed to develop plans prior to bid lettings.

<u>2. If WisDOT continues to provide initial digital data, for 3D model building by the contractor, does having these data available in the PS&E package assist you significantly in the bidding process? Would the bidding process be more difficult if the data were instead made available at a later date?</u> (NOTE: GPS machine guidance is optional, so having data available at PS&E involves wasted MDU effort if the contractor elects not to use GPS machine guidance on the project.)

- Some stated that having the data at PS&E helps to know the costs of model building and makes the bidding process easier, but the general opinion was that there would be no real difference in price if the data were made available at a later date. Model building costs go into overhead.

- If the data come later than PS&E, they must be in time to build the model before it is needed for construction (this would include any necessary review time). "Early enough" is 2-3 weeks prior to construction.

- Some would use the data, if available at PS&E, to assist in other aspects of bidding (NOTE: this could be a reference to the survey data package). For one of the 2008 pilot projects, MDU-provided data were used to build a model prior to bid. The information is of assistance, but it is not critical.

- The more information the better. At a bare minimum the survey data file is needed.

3. Does the requirement for review of the 3D design model by the department, and for the department and the contractor to agree on the 3D model to be used for grading operations, place an undue burden on you as a contractor? NOTE: Departmental review procedures are the same as those used for photogrammetric map checks. Random spot elevations are derived from plans and overlaid with contractor's model.

- Some contractors prefer departmental review of the model as this spreads responsibility and liability. At least one contractor stated that departmental review is essential. "The more eyes the better" for quality assurance of the model. Model accuracy is the most important factor in GPS machine guidance. Ideally, departmental review makes everyone feel comfortable, but, practically, updates incur costs.

- Some feel that departmental review is important but secondary to checking the model in the field and that, if it is a matter of allocation of departmental resources, then priority should placed on the field side.

- Some aspects of WisDOT checking are better before projects begin, other elements might be better checked during construction.

- Alignment checks are critical, whether they be done by WisDOT or the contractor. The alignment must register to the plan for sub grade checks to be made at the correct places.

- On the other hand, some stated that departmental review is unnecessary and that contractors should have control over the model they use, thereby absorbing the risk. If it is the contractor's responsibility to ensure that the model conforms to the plans, then why have the department review it? Model checking by the department causes a false sense of security.

- If WisDOT continues to review models, there needs to be some standard for model content, level of detail, and accuracy.

- Delays during construction are a concern. Reviews of model revisions, caused by plan revisions, must be timely to prevent construction delays. At least one contractor is comfortable with taking the risk and using a revised model for construction while it is being reviewed. One contractor stated that reviews of revisions during construction are not a concern as long as work can progress on other areas of a project (e.g., side slopes are no problem, but having a paving machine on line is a different matter). Changes near the end of construction are more likely to cause problems than early and midstream changes.

- Design changes should be factored into project completion dates and time extensions should be granted for things beyond the contractor's control. The standard specification has a list of excusable delays. This should be revisited for GPS machine guidance considerations.

- Sometimes it might be faster to stake revisions than to revise and review models. Some contractors depend upon third parties for model building and revisions. Getting the overall job done requires flexibility. Changes can be dealt with on a job-by-job basis. Every situation is different. Some changes are easy, some are complex.

- It would be wonderful to have capacity for the project engineer to review model changes in the field. NOTE: Should this be a longer-term goal?

4. What approach would you recommend that the Department use to assure the accuracy of the 3D model:

a. A detailed check of the model and all model revisions, by the Department, prior to construction. In addition, sufficient sub grade checks would be made to assure that the finished sub grade conforms to the plan lines and grades. (This is the method used in the pilot program)

b. No review of the 3D model or model revisions by the Department. The Department would do sufficient checks of the finished sub grade to assure conformance with plan lines and grades. (The full responsibility for compliance to the plan lines and grades would rest on the contractor)

c. No review of the 3D model or model revisions by the Department. Continue to set blue tops to assure conformance to the plan lines and grades. (This is the method that is used on conventional grading projects)

d. Other approaches?

- Some contractors prefer choice (a), the method of the current specification. One stated that (a) is the consensus choice throughout the company. Others feel that (a) is ideal but might become impractical.

- Concerning (a) and (b), it might be desirable to have the project engineer present when the contractor is doing sub grade checks. They could be done at the same time.

- Concerning supplemental sub grade checks made by the engineer, some contractors feel that these should be done with an independent technology.

- One of the contractors interviewed by teleconference and the group at the meeting strongly preferred choice (b). One suggested that model review by the department be made optional.

- No one selected choice (c) but it was stated that any parts of a job that are not done by GPS machine guidance must be fully staked.

- Concerning choice (c), contractors can elect to set some blue tops for assurance. The specification does not have to be modified, but there is a need for guidance language that blue tops are not prohibited and might be desirable under some circumstances.

5. Does the current requirement to make a GPS rover available to the project engineer for supplemental sub grade checks, and to provide training on use of the rover to the engineer, place an undue burden on you as a contractor?

- Larger contractors do not feel that loaning of a rover is a burden and in some cases have loaned a rover for the full project. However, it is an issue with some smaller operators because these companies might own only one or two rovers. In one case, a small company is shuttling its single rover back and forth between jobs and there is no spare time to lend it to the engineer. In such cases, these companies would either have to buy another rover or lease one to be able to comply with the specification.

- Contractors do not want to have to educate engineers on GPS and GPS machine guidance. Engineers should already have an understanding of the technology. Training by the contractors should be limited to providing a user's manual or showing the engineer which buttons to push to get the information they need (e.g., sub grade checks).

- Some contractors stated the rover has the same information in it as the earth-moving equipment, so how is it that the engineer is making independent checks? Engineer's checks should be made with conventional technology or an independent rover and base station. NOTE: This issue was adamantly addressed on the other side by a large Midwest contractor who was interviewed during 2006. That contractor stated that the engineer and the contractor should be using the same model and site calibration file.

6. What level of effort do you associate with the requirement to provide a GPS work plan?

- Most contractors feel the GPS work plan is a good idea and not an undue burden, especially in the early stages of technology adoption. The work plan reinforces QA/QC procedures and what is to be done. It gets everyone on the same page.

- Most critical components are the control configuration and the site calibration procedures. Everyone should be using the same project control.

- The group at the meeting stated that item 5) sub grade checks should be deleted (see additional notes on this issue in question 7, below).

- It would be good to have a template and / or examples of what is expected in the GPS work plan.

- Concerning staff qualifications, should we be certifying people to use GPS?

- A reduction in the amount of control required for site calibration should be allowed if there is mutual agreement.

- Just when is the GPS work plan due? What is meant by “affected grading operations” in the specification?

7. After completion of the 2008 pilot program, WisDOT will be revising the special provisions for the 2009 construction season and the standard specifications for 2010 and beyond. The intent would be to require these specifications on all contracts that use GPS machine guidance. Are there any modifications to the current specification that you would deem necessary before it could be required on all projects that use GPS machine guidance for grading?

- One contractor interviewed by teleconference, and the group at the meeting, felt strongly about the requirement for contractor sub grade checks. Some did not want to be required to make checks; others seemed to object only to having to document and report the checks. At least one contractor felt that sub grade checks were not something a grading foreman should be doing and these should be done by surveyors if at all. In addition, if sub grade checks continue to be required, this will cause bids to be higher (2-3 person-hours per mile). (NOTE: If contractor sub grade checks are eliminated from requirements, then there must be highly-increased scrutiny of the finished sub grade on the part of the project engineer, including detail on how and where to make measurements.) (NOTE: The point was made that there is no need for interaction between the contractor and WisDOT (on the model or field checks) before the sub grade is finished and the engineer needs to check it. Does this also mean eliminating the requirement for site calibration checks and reporting?)

- On the other hand, some of the contractors interviewed by teleconference thought the requirement for sub grade checks was not burdensome and that they hoped their foremen were actually doing more than 20 per mile. One stated that the machine operators wanted the contractor to make sub grade checks.

- One contractor always uses independent technology to do their own sub grade checks, stating that rover checks are not sufficient. They once experienced a 4-foot horizontal discrepancy in their site calibration and now err on the side of caution. They go so far as to set check hubs and bring the rigged machines to them. They stated that it is easy to get too comfortable with GPS.

- The point was made that WisDOT is looking to reduce field staff. The current specification is similar to materials sampling and testing in the standard specification, wherein WisDOT does about 10% of QA/QC. However, if contractors want to manage the risk, WisDOT should listen. The counterpoint was made that QA/QC for sub grade is different than that for materials which can degrade over time. Guidance language should contain a list of things that can go wrong during a day. Some people do not know what can go wrong. What are the most likely things to go wrong and what can be done about them?

- There was some discussion of having a line item for model building. The current price of doing blue tops does not cover the costs of making a model. Perhaps it is preferable to bid either or both of staking or GPS machine guidance. Prices from surveying and model building must be known at bid time (NOTE: Contrast this with the earlier statement that model building costs are absorbed in overhead). Others felt that a separate bid item was not necessary. Savings are realized in increased efficiency, not in elimination of staking.

- It should be the contractor, not WisDOT, who decides what parts of a project will be done with GPS machine guidance and what parts will be done with conventional methods. The contractor could identify the appropriate project segments in the GPS work plan.

- One contractor mentioned that WisDOT should set all project control and require everyone to use it. There have been problems with sub-contractor control points.

- Can the requirement for the contractor to maintain the loaned rover be eliminated?

9.2. Additional Information Obtained During the Interviews and Meeting

- There could be information added to the plans that would facilitate model building. Project horizontal coordinates (Northing and Easting) are needed at station equations. They are also needed at the beginnings and ends of reference lines.

- It would be best to have any given project on only one coordinate system, but if county boundaries are crossed, the design will be on different systems. Therefore, station equations, with coordinates for both counties, are needed at county boundaries. Also, separate coordinate systems require separate models and separate site calibrations.

- Contractors are using GPS machine guidance for base course placement. This is being done on the Burlington bypass this summer and was done last year on 11 miles of the STH 57 pilot projects. The base course contractor (RC Excavating) built an independent model from the ones that had been built by Hoffman and Mashuda for sub grade. One month was required for data preparation and another month was required to build and check the model. Hoffman's and Mashuda's models were not used directly, but RC Excavating made sure their model agreed with the others. RC Excavating did grading around the clock using GPS machine guidance automatics. They turned on the machines' lights merely to see where they were going. Most checks of the base course were within 0.04 ft. No check was worse than 0.08 ft. Base course placement and sub grade construction used separate site calibrations.

- On projects that are using GPS machine guidance, but not operating under the pilot specification, project engineers are developing their own methods for quality assurance. For example on a project in Portage County only super elevations were blue topped. This was supplemented by some additional random checks. On a project in Fond du Lac County, everything was blue topped.

- It is highly desirable to move towards 3D models as design products. This eliminates construction-side model building and the issues surrounding review of the model.

- Some contractors feel it is important to have existing ground information.

- At least one contractor has both TOPCON and Trimble technology. There is considerable interest in CORS solutions for GPS machine guidance.

- Field checks are critical and should be independent of equipment and models used for construction.

- Grades must be checked against the plan and not the model. It was suggested that the best use of Department resources, in an effort to assure quality, be in sub grade checks rather than model checks.

9.3. Summary

- Contractors place value on preliminary model data provided by the Department, but a lack of it in the future would not typically affect decisions to use GPS machine guidance, especially on larger jobs. The preliminary data can save as much as 50-75% of the costs of model building. Although having the preliminary data as part of PS&E is useful, it is not critical. The data need to be in hand in time to build the model for construction, perhaps 2-3 weeks prior (NOTE: it is not clear if this includes enough time for departmental review).

- There is disagreement among contractors as to whether or not WisDOT should review models. Some feel it is critical, other feel that no review should be required. There is consensus that construction delays need to be avoided if models are revised and re-reviewed after work in underway. A number of ways for avoiding such delays were suggested.

- There is also disagreement on the requirement for a minimum of 20 sub grade checks per mile on the part of the contractor. Some feel this is not a burden because they are doing more than that anyway. Others feel they should not be required to make a certain number of checks. More seem to object to having to document and report the checks as opposed to making them.

- Rover loaning and training are not a problem for the larger contractors as long as training is limited and they do not also have to provide education. On the other hand, rover loaning and training are a serious problem for smaller contractors who have only a few machines rigged and own only one or two rovers.

- The GPS work plan is a good idea, but clarification of when it is due is needed.

- Some feel that all project control should be provided by WisDOT and that all parties should be required to use the same control.

- Contractors want flexibility in deciding what parts of a project will be done by GPS machine guidance and what parts will be done by conventional methods.

- Model building can be facilitated by merely including horizontal coordinates at station equations and county boundaries on plans.

- GPS machine guidance is being used in Wisconsin for base course placement with acceptable results.

- Quality assurance on projects using GPS machine guidance for sub grade, but not under the current specification, is being done in a number of ways at the discretion of the project engineer.

10. Interviews with Region Staff

During the period July 29-August 13, 2008, WisDOT staff in the Northeast, Southeast, and Southwest Regions were interviewed to obtain a regional perspective on five key questions concerning the GPS machine guidance specification for sub grade construction that has been under development for the past two years and is ultimately expected to become part of WisDOT's standard specifications.

Those participating in the interviews were: Doak Christensen and Jeff Kaarto (SW Region); Kevin Derenne, Barry Paye, Doug Wiegand, Forrest Van Asten, and Eric Gwidt (NE Region); Allen Gilbertson, Julie Jenks, Rafat Jamaleddin (R.A. Smith National) (SE Region); Alan Vonderohe (representing UW-Madison); and Ken Brockman (WisDOT).

10.1. Questions and Responses

<u>1. Do you feel that the current GPS machine guidance pilot specification requires resources or incurs costs to the region that exceed benefits to the department that are realized by contractors' use of the technology? If so, please identify these excessive costs or resources.</u>

- Work and time for field staff for grade verification and model changes (NOTE: It is expected that these costs do not outweigh benefits).

- Regions do not have the right tools and training. Regional surveyors cannot respond in a timely manner. There is a need for departmental equipment and training standards. If the department had rovers, scheduling and sharing of them between projects could become an issue. How about having leasing (not purchase) of a rover for the project engineer as a bid item? (NOTE: There are problems with federal funds if equipment is purchased – can be used only on that project).

- Model review is burdensome. Two reviews of the Oconto model were required.

- There are no significant field costs, but slope stake maintenance is an issue. Once the contractor uses slope stakes as visual reference for rough grading, they tend to get knocked out and not replaced. However, slope stakes are used for a number of things other than grading and project engineers find themselves needing to maintain the stakes. Slope stakes are needed up to and through landscaping phases of projects. This enables field staff to adequately reference and measure items such as top soil, seeding, mulching, silt fence, etc. Slope stakes should be marked, at a minimum, with station and offset.

2. Is the current pilot guidance language for GPS machine guidance helpful and complete? If not, how could it be improved?

- No pilots in SE Region, so guidance language was not used.

- There is very little experience with use of the guidance language at this point in the Northeast Region. Barry has extensive experience with GPS machine guidance and Doug has a lot of experience with GPS, so they have not had need to fall back on the guidance language.

3. Do you feel that training and educational materials on the technology, the specification, and the guidance language might help alleviate concerns, within the regions and engineering community, with their use?

- Field exercises with “cheat sheets” during training sessions would be helpful. Have an education session on who is responsible for what…execution of a project under the specification (NOTE: This was also emphasized in the evaluation of this year’s training session….there was a session on the specification, but practical implications and procedures could have been more emphasized). Develop a panel of pilot project engineers for the training sessions.

- In the Southeast Region, Julie participated in the April, 2008 training. She thought the background material was appropriate, but she wanted step-by-step, “how-to” documentation on field exercises that she could take with her for later reference. The field exercises need to be more structured. Do site calibration and sub grade checks.

- In the Northeast Region, Doug participated in the April, 2008 training session. He felt that the experience was good but that the material and presentations could be more focused. The component on background knowledge and basic principles is very important, but the details of how to use extended functionality of both vendors’ technology were too much to absorb. Would be good to follow session on basics and principles with a virtual field exercise using a virtual, generic rover and software….this to be followed by open-ended field work on site calibration and sub grade checking….need emphasis that sub grade is to be checked against plans, not model…maybe prepare a spreadsheet of plan elevations to be carried in the field (Note: Could this be derived from the PS&E “survey” package for future projects?).

- Recommend that WisDOT continue to provide "just-in-time" training as was provided in Coloma this year. This training should be provided for the next few years until everyone is familiar with GPS machine guidance.

4. After completion of the 2008 pilot program, WisDOT will be revising the special provisions for the 2009 construction season and the standard specifications for 2010 and

beyond. The intent would be to require these specifications on all contracts that use GPS machine guidance. Are there any modifications to the current specification that you would deem necessary before it could be required on all projects that use GPS machine guidance for grading?

- There should be a “stop work” clause in case of site calibration problems.

- Independent checks of the sub grade are needed. WisDOT does not have the field staff. Is photogrammetry an option? What about third party checks being part of the contract? What about WisDOT contracting separately for third party checks…there has been discussion of “master contracts” over the years and this idea has met resistance.

- Contractors are production-oriented and reluctant to do sub grade checking. On the Moorland Road interchange (construction by Musson Bros.) an independent staking contractor was hired to do sub grade checks. They used independent site calibration and not necessarily the same control as the contractor for site calibration. They did not have the contractor’s model and they did not need it…sub grade was being checked against plan elevations. Could this be the way to specify supplemental sub grade checks? The contractor would not have to document and report sub grade checks. It eliminates the need for loaning and training on a rover. Could this be melded with model building as a bid item (would still need separate item for blue topping)? This would require a rigorous, detailed standard / specification on how the final sub grade checks were to be made (spatial frequency / accuracy / tolerances)…perhaps these details would need to be worked out with ACEC / WSLS. This would be an interim specification for the next few years until WisDOT has its own GPS equipment and staff trained in the use of GPS technology.

- Double measurement of work for problems beyond contractor control should go away. Contractor absorbs risk….contractor needs a contingency plan (maybe part of GPS work plan?) …need a list of excusable delays.

- Check tolerances are adequate. Need standards for model content and procedures. How much detail is necessary in models?

- We need a specification that contractors will follow (NOTE: No contractors on SE Region projects wanted to do pilots.) While using the technology, the GPS machine guidance specification should be required. The current standard specification should not be used on projects that employ the technology.

5. The current pilot specification requires the contractor to make a GPS rover available to department staff for purposes of supplemental sub grade checks. Do you feel that regions can perform the necessary supplemental sub grade checks by some other cost-effective method? If so, please identify the method.

- Loaning of a rover by the contractor to WisDOT will not work. Contractors do not have spare rovers. They need all their rovers all the time. Engineer needs exclusive use of rover during time of sub grade checks…contractor that does not have rover to loan should lease one.

- Time and personnel to make sufficient supplemental sub grade checks is an issue.

- WisDOT should have its own technology (RTK GPS or otherwise). Checks should be independent of the contractor's technology.

- Could use level if ties and benchmarks were maintained. Rover is a convenience item; more a luxury than a need. It is valuable for laying out pipes, especially if slope stakes and / or benchmarks are knocked out. Could project engineer use contractor's rover for slope stake maintenance? Sub grade can be checked with conventional equipment, but rover does save some time.

- What if WisDOT had its own rovers? How would technology upgrades and compatibility with contractor's technology (e.g., software version) be managed? Who loads the model onto the WisDOT rover?

- What if there was a "traveling" WisDOT rover among several projects? Might be a coordination issue…timing of needs on given projects…would require multiple projects / models / site calibrations in rover memory or uploading of models and site calibrations on as-needed basis…need to be able to use conventional methods also.

10.2. Additional Information Obtained During the Interviews

- There is a need for data security on revised models and a need for model revision history. Greatest fear is field changes and associated delays with model.

- There is a need to use common sense. Don't build exactly to model. Slope edges need to be rounded. Ditches must drain and meet pipes.

- The specification will be revised over time. It should be regarded as a living document.

- Design control is often destroyed, either prior to or during construction.

- Slope stakes are needed for the duration of a stage. Moorland Road interchange, slope stakes used for lay out and measurement of erosion control and clearing and grubbing. Slope stakes should be marked with station and offset…sometimes need elevation because there are not enough project benchmarks. Need benchmarks every 300 feet or slope stakes unless field crews are well equipped (NOTE: Currently, the Southeast Region field staff are not well-equipped…old survey equipment for $22M interchange).

- On one project, there was a problem with the antenna height on an adjustable-height rover being wrong. Perhaps a constant height pole on the rover should be required.

- GPS machine guidance has not yet been used for base course placement in the Southeast Region. Urban curb and gutter can have issues. Suggest doing rural base course first.

- Utilities in the model help prevent problems like paving over man holes.

- Project engineers have been using their own discretion in QA/QC on GPS machine guidance projects under the standard specification. There are issues with practical risk management. If you trust the technology and a finished sub grade is in place Friday afternoon (with storms forecast for the week end), do you wait for blue topping until some time next week or do you go ahead and cover the sub grade with gravel? (NOTE: Is this dilemma addressed by having the independent staking contractor do final sub grade checks (as suggested above) or would there still be problems with potential delays?) It is possible to develop a false sense of security. That is why it is important to follow a good set of specifications.

- Model building reveals problems with plans prior to construction – construction delays for plan revisions are avoided.

- How is the contractor paid for model revisions? Is this an administrative item?

- There are design-side vs construction-side trade-offs.

- The Northeast Region and Mashuda had differences in volumes last year because of DTM-to-DTM vs average-end-area.

- Conventional slope stakes are still needed. They need to be maintained for the duration of the job for Department staff and subcontractors to use as a location reference. If a contractor fails to maintain slope stakes and project control, they must be willing to let the Department and subcontractors use a rover for purposes other than checking sub grade.

- Projects must establish and maintain enough control (X,Y, and Z) for all the other work, besides grading, that is required on a project and still needs to use conventional survey methods for layout / control.

- It is important that control for the construction of the project be tied to the same control that was used for design of the project.

10.3. Summary

- Slope stakes with station and offset notation are critical throughout a project. Slope stake maintenance is an issue when GPS machine guidance is being used.

- Little has been learned about the effectiveness of the pilot guidance language because very few people have used it.

- Regions lack staff and equipment to do sub grade checks. Loaning of rovers does not work with small contractors because they have single rovers and they are always in use. There is a need for independent sub grade checks. Options include having one-person survey crews serve projects in proximity, requiring smaller contractors to lease rovers for Department use, and contracting for third parties to do independent checks. Ultimately, it is desirable for WisDOT to have its own equipment and adequate field staff.

- Model review is burdensome and there is considerable concern about impact on the construction schedule of plan revisions, followed by model revisions, followed by model re-review.

- Training is important. Basic principles are critical. Structured field exercises with "take-home", "how-to" instructions are needed. There is a need to emphasize roles and responsibilities for project execution under the specification. A session with a panel of pilot project engineers is desirable.

- We need a specification that contractors will follow. When using GPS machine guidance on future projects, the GPS machine guidance specification, not the current standard specification, should be used.

- If WisDOT continues to review models, there is a need for standards on model content and level of detail.

- After the pilot projects, the specification for double measurement for sub grade staking needs to be replaced with a list of excusable delays. Contractors should absorb any risk of using the technology.

- Construction should involve common sense and not merely building exactly to the model.

- Consistency in geodetic control for a project is a must.

11. Summary of Issues Intended to be Addressed by the 2008 Pilot Projects

Here, the general questions identified in Section 4 are repeated along with notes on their statuses as a result of the 2008 pilot projects and interviews:

1. Does the specification need revision to make it more "bidder friendly".

    A number of such revisions were identified, including eliminating the requirements for:
    - Departmental review of 3D models.
    - Contractors to loan a GPS rover to the project engineer and provide training.
    - Contractors to provide documentation on site calibration checks and sub grade checks to the engineer.

2. What are the impacts of using the CORS network on GPS machine guidance?

    As of this writing, the Wisconsin vendor for Trimble-based GPS machine guidance technology is testing the viability of the WisDOT CORS network to support it use in construction (NOTE: WisDOT's CORS is Trimble-based). A successful demonstration has not yet been made. The TOPCON CORS network in Illinois was observed to be operational in support of GPS machine guidance, but TOPCON CORS does not currently provide a network-based solution. Rather, corrections are obtained from only the nearest CORS station (i.e., single baseline).

3. What are the impacts of using GLONASS and other components of the Global Navigation Satellite System (GNSS) on GPS machine guidance?

    All three 2008 pilot projects used technology that received signals from only the GPS satellites. One of the pilots experienced significant downtime (e.g., as much as 1-2 hours on some days) due to weak satellite geometry and visibility issues arising from terrain and tree canopy conditions. Downtimes of 15-20 minutes per day are more typical. One of the 2007 pilot projects used technology that received both GPS and GLONASS satellite signals. That project experienced very little downtime (Vonderohe, 2008).

4. What are the obstacles to use of "last pass" information for creation of a final DTM for final quantity measurement? "Last pass" refers to data collected during the machine's "last pass" over an area.
    - When operating in topographic mode, the machines collect data points without indication of the blade's position with respect to the ground (i.e., "up" or "down").
    - Data are collected even if the machine is turning or backing up.
    - Break lines cannot be inserted as the data are being collected, so the result is a collection of unrelated data points that would need interpretation and editing.
    - It is very difficult to capture critical features, such as edge-of-slope, with construction equipment.
    - This is not an effective or efficient use of the technology or the operator's skills. It is better to follow up construction with an as-built survey using rovers and field personnel familiar with DTM data collection procedures.

5. What is the experience of contractors with bidding projects with the option of using GPS machine guidance (e.g., bidder familiarity, cost, and procedural issues)?

    The pilot project contractors did not report any problems with the bidding process. This was also true for the 2007 pilot projects.

6. What are the contractors' expectations of WisDOT in regard to furnishing design surface data necessary to develop the DTM? If WisDOT did not furnish these data, how would that affect a contractor's decision to use GPS machine guidance on a project and how would that affect the cost of the contract? Are current data exchange standards and rates sufficient for updating models during construction?

Contractors would appreciate having WisDOT continue to provide design surface data as a starting point for model building. However, if these data were not available, the contractor's decision to use GPS machine guidance would not be affected. The benefits of using the technology outweigh the costs of model building. The impact of WisDOT not providing design surface data would be minor on the costs of contracts. None of the models on the pilot projects had to be updated and re-reviewed as a result of design changes, so the third question was not addressed.

7. Are there parts of the specification that are too restrictive?

   The control requirements for site calibration and tolerances for site calibration checks are appropriate as are the tolerances and frequencies for sub grade checks. However, there are aspects of the specification that some contractors believe place an undue burden upon them (see answer to question 1 in this list, above).

8. What is the required frequency or intervals of slope stakes; who uses slope stakes; what they are used for in addition to constructing ditches, slopes and sub grade; and what information is still needed on slope stakes if the contractor uses GPS machine guidance?

   There is consensus among contractors and project engineers that slope stakes are necessary, although some feel that their intervals could be relaxed to 200-300 feet. Slope stakes are used for visual reference on the project in general and for referencing many kinds of routine measurements, for example, locating utilities, pipe inverts, silt fences, and reference lines. Slope stakes are used for these and other purposes by contractors, subcontractors, project engineers, and others such as utility personnel. The only information required on slope stakes is station and offset.

9. Is GPS machine guidance being used for base course? What should be its future use for base course on WisDOT projects?

   GPS machine guidance is being used successfully in Wisconsin for base course placement, although there is no corresponding specification. During 2009, WisDOT expects to undertake development and testing of such a specification.

10. What are the necessary knowledge and skill levels for project engineers and surveyors to administer contracts involving GPS machine guidance and what are effective means for acquiring these skills and knowledge?

    Project engineers and surveyors should understand the basic operational principles of GPS and GPS machine guidance, to the level of being able to address issues that might arise on projects. They should have an understanding of WisDOT's specification and guidance language and what to expect on projects in terms of roles and responsibilities. Surveyors should have in-depth knowledge of how to use GPS technology, but, under the revised (2009) specification such in-depth knowledge is not as important for project engineers. WisDOT provided in-class and field-based training during 2008 and expects to do so again in 2009 (see Section 3.4).

11. Can project control requirements be reduced? Does availability of the CORS network reduce the need for project control?

    There is consensus that project control requirements should not be reduced. Use of CORS will still require project control for site calibration to account for local effects of the geoid.

12. Is there a need to specify the maximum geographic extent of a single site calibration?

    This question was not explicitly addressed on the pilot projects. The vendors of RTK GPS technology typically recommend maximums on geographic extents for site calibrations.

13. Are there issues with GPS machine guidance in urban areas that are not apparent in rural areas?

    This question was not addressed on the pilot projects because all of them were rural.

12. Recommendations for Revisions to Specification

1. Eliminate the section where segments of the project that use GPS machine guidance are specified in the contract and add a requirement for the contractor to identify those segments in the GPS work plan.

2. Eliminate the section on loaning a GPS rover and providing training to WisDOT staff.

3. Eliminate the requirement for WisDOT to provide design surface data.

4. Eliminate the requirement for the contractor and WisDOT to agree on the design surface model before it is used for construction.

5. Eliminate the requirement for review of revisions to the design surface model.

6. Revise the due date for submittal of the GPS work plan from prior to affected grading operations to prior to the preconstruction conference.

7. Eliminate the requirement for the contractor to document and report all sub grade checks.

8. Replace the section on supplemental WisDOT sub grade checks with a section on independent verification to be provided by the contractor.

9. Eliminate the section on double measurement if GPS machine guidance is revoked by the engineer for reasons beyond the contractor's control.

13. Further Considerations

1. Consider making the contractor staking packet available at contract award time instead of the preconstruction conference.

2. Consider clarifying the requirement of 20 sub grade checks per roadway mile for the case of staged projects.

3. Consider clarifying the requirement of 20 sub grade checks per roadway mile for the case of projects less than a mile in extent.

4. Consider relaxing the requirement for robust control point monumentation for projects of short duration and / or limited extent.

5. Consider requiring staking contractors to verify and check sub grade until WisDOT has GPS equipment available and staff trained in use of the equipment.

14. 2009 Specification and Guidance Language

The project advisory group considered the information and recommendation provided above in this report and made revisions to the specification and guidance language. The 2009 specification appears in Appendix N. Significant changes from the 2008 specification include:

- Elimination the section where segments of the project that use GPS machine guidance are specified in the contract and addition of a requirement for the contractor to identify those segments in the GPS work plan.

- Requiring the GPS work plan to be submitted at least five days prior to the pre-construction conference.

- Elimination of the section on loaning a GPS rover and providing training to WisDOT staff.

- Elimination of the requirement for WisDOT to provide design surface data and review the contractor's model. The contractor develops the 3D model and provides it to WisDOT.

- Addition of language allowing the contractor to request the contractor staking packet anytime after the contract is awarded and requiring WisDOT to provide the packet within five business days of the request.

- Elimination of the requirement for the contractor to document and report all sub grade checks. The contractor is now required to notify the engineer prior to making sub grade checks. The intent is to allow the engineer to observe the process and take its results into consideration during acceptance.

- Revision of the language on the required minimum number of sub grade checks to account for roadway mile, stage, or project.

- Elimination of the section on double measurement if GPS machine guidance is revoked by the engineer for reasons beyond the contractor's control.

The 2009 specification is to be included as a special provision in all 2009 construction season lettings that have the construction staking sub grade item. The specification is expected to be adopted in the standard specifications for 2010. Under the specification, use of GPS machine guidance is optional for grading. WisDOT expects to continue to monitor the performance of the specification and make future refinements as necessary.

The 2009 guidance language appears in Appendix O. It has become Chapter 7, Section 18 of the Construction and Materials Manual. It contains subsections on general information, initial coordination, 3D model development and exchange, site control and calibration, site calibration checks, and sub grade checks.

15. Maryland's and New York's GPS Machine Guidance Specifications for Base Course Placement

WisDOT expects to develop and test a GPS machine guidance specification for base course placement during 2009. A number of state DOTs were previously queried for information on base course specification development.

15.1 Maryland

The Maryland State Highway Administration (MDSHA) has a special provision for projects that use machine guidance either by GPS or robotic total station (Vonderohe, 2007). These technologies may be used for the placement of sub grade, sub base, base course, and other roadway materials.

The contractor develops the 3D model, using contract documents and MDSHA digital terrain data if available, and submits it to the project engineer for review. 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. RTK GPS used to control equipment must be within tolerances of ±0.1 ft. Robotic total station control is used where grade tolerances are less than ±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.

15.2 New York

The New York State Department of Transportation (NYSDOT) is a strong advocate for GPS machine guidance. They have recently updated their specification on survey operations, row and survey markers, and GPS inspection units which contains subsections on GPS machine guidance (referred to more commonly and in the NYSDOT specification as "automated machine guidance") (NYSDOT, 2009). Automated machine guidance can be used on many aspects of construction including excavation, fill, material placement, and grading.

NYSDOT provides three-dimensional model data for automated machine guidance as part of the contract documents. The final, updated three-dimensional model can be used for pay item quantities. All electronic data is shared, exchanged, and kept current between the contractor and the project engineer.

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. Use of the NYSDOT CORS network is strongly encouraged.

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

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List of References

NYSDOT, (2009), "Revision to Standard Specifications: Section 625, Survey Operations, ROW and Survey Markers, and GPS Inspection Units", Engineering Instruction EI 08-03X.

Vonderohe, A.P., (2007), "Implementation of GPS Controlled Highway Construction Equipment", Final Report submitted to the Wisconsin Department of Transportation, Construction and Materials Support Center, University of Wisconsin – Madison, April.

Vonderohe, A.P., (2008), "Implementation of GPS Controlled Highway Construction Equipment – Phase II", Final Report submitted to the Wisconsin Department of Transportation, Construction and Materials Support Center, University of Wisconsin – Madison, January.

Appendix A.
Specification and Guidance Language for 2008 Pilot Projects
(As Presented in Vonderohe (2008))

Construction Staking Subgrade, Item 650.4500; Construction Staking Supplemental Control, Item 650.9910
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) The contractor may use either global positioning system (GPS) machine guidance or conventional subgrade staking on designated portions of the contract as follows:

______________________	______________________
______________________	______________________
______________________	______________________

Use conventional subgrade staking on the remainder of the contract.

(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:

Data Type	Format [1]
Reference Line Data	LandXML
Design Profile Data	LandXML
Proposed Cross Section Data	Land XML or DWG
Existing Surface DTM Data	LandXML DTM or DWG
Existing Topographic Data (excluding utilities)	LandXML
Superelevation Data	LandXML
Graphical Information	DGN or DWG

[1] The department will provide data in whichever listed format the contractor chooses.

(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 or DWG format at the contractor's option. 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. Use the resulting design surface DTM to ensure that the work conforms to the plans, but the department's approval of the design surface DTM does not supercede the lines, grades, and cross-sections the plans show.

(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 under the Construction Staking Slope Stakes bid item, 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 in LandXML or other engineer-approved format. 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 or DWG 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. Use the full set of control points, designated under 650.3.3.3.5 (1), for the initial site calibration. 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. 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 against the plan elevation at 20 or more randomly selected locations per roadway 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 Supplemental Control

(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. Check 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, 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) 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. Document additional control on forms described as a part of the contractor staking packet in CMM 3-1-10.

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 slope stakes 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. The department will measure Construction Staking Supplemental Control as a single lump sum unit for all control marks acceptably completed on each contract.

GUIDANCE FOR 2008
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. Be sure to coordinate with Ken Brockman to make sure the appropriate special provisions are inserted because the bid items will change with the December 2007 let.

On the pilot projects, the item of GPS machine guidance 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. On a select number of projects, the GPS machine guidance will be bid. In other cases, a no-cost change order would be submitted to allow the use of GPS machine guidance. The item for Staking Subgrade would be paid for in all segments where machine guidance is attempted.

It is recommended that projects using GPS machine guidance would also include contractor staking items.

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:

GPS Machine Guidance	Subgrade Staking
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:

GPS Machine Guidance	Subgrade Staking
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 (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 or DWG format information to be used by the contractor. Some additional field verification of models and digital terrain models (DTMs) may be required as 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 modified DTMs.

Construction Engineer

Project Selection

For the pilot projects, the construction engineer would assist in determination of the applicability of machine guidance. 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 GPS machine guidance, and a recommendation should go to regional and 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

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 who will provide information and guidance to the project should meet to discuss roles and responsibilities. These should include the design engineer, construction engineer, regional surveyor, methods development engineer, and 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 to 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 in the model and related matters.

During Construction

Site calibration checks are the responsibility of the contractor, but should be reviewed with the region surveyor to verify they are within specified tolerances.

The engineer should work with the region surveyor to develop a plan to perform construction checks. It is essential to provide some independent checks at project start-up to ensure contractor methods are meeting necessary tolerances. These checks should be performed using independent GPS equipment or conventional survey methods (e.g., total station or level), and should meet specified tolerances. It is anticipated that once initial methods are working and checked using independent technology, construction checks could be performed using a contractor-supplied rover. The department reserves the right to do added checks as needed. The number of site calibrations performed by the contractor should be limited. It is preferred that a single site calibration be used for the duration of the project, but there might be circumstances under which follow-up site calibrations are necessary. In such cases, independent construction checks should be made after each site calibration.

The engineer is responsible for maintaining an archive of DTM revisions and dates for future reference. The archive should include the DTM files and the time period for which each was active on the project.

After Construction

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

The construction engineer should prepare a final report evaluating the machine guidance usage. Evaluation items could include overall project impacts, specification improvements, construction administration issues and other pertinent items. This evaluation should be submitted to the GPS machine guidance 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 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 region 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.

DATA DEVELOPMENT AND EXCHANGE

Model Development

The processes for model development are outlined below.

1. WisDOT Methods Development will provide the breaklines and points to assemble a proposed model for all of the 2008-targeted GPS machine guidance projects. The design breaklines and points will be created from the best available digital design data. This information will not include details such as side road radii, entrances, gore areas, and other areas not easily extracted from normal plan and cross section information. It will include information necessary to build a subgrade surface, as well as information needed to build the surface out to the slope intercepts.
2. The proposed model information will be given to the region project staff early in the construction season. If the region project staff does not feel comfortable sharing the data with the contractor, they can request the contractor work directly with the Methods Development engineer assigned to their project.
3. The contractor must supplement the proposed model information provided to them to fill in those areas missing from the Methods Development-provided proposed model. The contractor must verify their proposed model.
4. The contractor must pass the complete and verified proposed model to the region project staff. Region project staff will pass the proposed model information to the assigned Methods Development engineer. If the region project staff does not feel comfortable sharing the data with the contractor, they can request the contractor work directly with the Methods Development Engineer assigned to their project.
5. The Methods Development engineer assigned to the project will review the contractor's proposed model. They will do spot checks by projecting known points generated from the plan cross sections (station / offset / elevation converted to northing / easting / elevation) onto the proposed model and generate an error report.

   It is expected the Methods Development engineer will check five points per mile in the blue top areas and random points on the outside slope areas. The error report will be shared with the contractor and region project staff. If significant errors occur, the Methods Development engineer will notify the region project staff and contractor of the problem areas. Steps 3 - 5 must be repeated until the model is verified.

6. If there are plan errors and plan changes necessary, steps 1-5 must be followed once the updated plan information has been created for those affected areas.

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 site calibration checks but not for site calibration itself. Once the site calibration measurement process is complete, the RTK GPS software will report estimates for 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 site calibration check tolerances at independent control points. These tolerances are 0.10 feet (horizontal) and 0.05 (vertical).

Site Calibration Checks

If any site calibration check exceeds 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 foot horizontally or 0.05 foot 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.

SUBGRADE CHECKS

The machine guidance specification requires the contractor to perform 20 or more randomly-selected subgrade checks per roadway mile against plan elevations. According to the definition of roadway in standard spec 101.3, a divided highway has two or more roadways.

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 guidance specifications give direction on handling model changes. It will be necessary to coordinate with the design engineer and the MDU engineer to make model changes.

Appendix B.
April 2008 Training Session Roster

Class Roster
GPS Machine Guidance Grading
Course Number 8740013

Session: April 2-3, 2008

Location: WOE Training Facility, Coloma, WI

Instructors: Shane Behlendorf (Positioning Solutions, behls23@yahoo.com); Ken Bork (WOE, kenneth_bork@yahoo.com); Adam Patrow (FABCO, aap@fabco.com); Jeff Servi (WOE, jeff@woetrainingcenter.org); Alan Vonderohe (Vonderohe Consulting, LLC, vonderohe@centurytel.net); Tom Walrath (Positioning Solutions, tomw@1psc.com)

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20. Keith Process, Mead & Hunt, keith.process@meadhunt.com
21. Mark Mitchell, STS, mark.mitchell@sts.aecom.com
22. Matt Geurts, STS, matt.geurts@sts.aecom.com
23. Tom Willmarth, REI, twillmarth@reiengineering.com
24. David Renaud, REI, drenaud@reiengineering.com

NOTE: For outdoor work, odd numbers above will be in Group 1 and even numbers above will be in Group 2.

Appendix C.
April 2008 Training Session Schedule

GPS Machine Guidance
Training Schedule for WisDOT and Consultant Personnel
April 2-3, 2008
WOE Training Facility
Coloma, WI

<u>Wednesday, April 2</u>

8:30am-9:00am: Introduction; objectives of the training session; overview of the training session. (Alan Vonderohe)

9:00am-10:00am: GPS and how it works; code and carrier phase; differential and RTK; site calibration / localization concepts; GPS machine guidance concepts; 3D model concepts; positioning the machine in the model. (Adam Patrow - FABCO)

10:00am-10:15am: Break.

10:15am-11:15am: Trimble's implementation: Machine guidance / data collectors and how they work; site calibration; stakeout functions (surface, alignment, points); recording data; retrieving data from the data collector. (Patrow).

11:15am-12:15pm: Field exercise: Site calibration with Trimble technology (Ken Bork, Jeff Servi, Patrow, Vonderohe)

12:15pm-1:00pm: Lunch.

Immediately after lunch divide into two groups.

1:00pm-2:45pm: Group 1 is outside doing stake out and subgrade checks with Trimble technology. Group 2 is inside using Trimble software, manipulating 3D models, and examining data collector files. (Bork, Servi, Patrow, Vonderohe)

2:45pm-3:15pm: Break.

3:15pm-5:00pm: Group 2 is outside doing stake out and subgrade checks with Trimble technology. Group 1 is inside using Trimble software, manipulating 3D models, and examining data collector files. (Bork, Servi, Patrow, Vonderohe)

<u>Thursday, April 3</u>

8:00am-9:30am: WisDOT's GPS machine guidance specification and guidance language; responsibilities; reporting; 2008 pilot projects. (Vonderohe)

9:30am-9:45am: Break.

9:45am-11:00am: TOPCON's implementation: Machine guidance / data collectors and how they work; localization; stakeout functions (surface, alignment, points); recording data; retrieving data from the data collector. (Tom Walrath and Shane Behlendorf – Positioning Solutions)

11:00am-12:00pm: Field exercise: Localization with TOPCON technology (Bork, Servi, Walrath, Behlendorf, Vonderohe)

12:00pm-12:45pm: Lunch.

Immediately after lunch divide into two groups.

12:45pm-2:30pm: Group 1 is outside doing stake out and subgrade checks with TOPCON technology. Group 2 is inside using TOPCON software, manipulating 3D models, and examining data collector files. (Bork, Servi, Walrath, Behlendorf, Vonderohe)

2:30pm-2:45pm: Break.

2:45pm-4:15pm: Group 2 is outside doing stake out and subgrade checks with TOPCON technology. Group 1 is inside using TOPCON software, manipulating 3D models, and examining data collector files. (Bork, Servi, Walrath, Behlendorf, Vonderohe)

4:15pm-4:30pm: Training session evaluation.

Appendix D.
Vonderohe's Slides from Morning Portions of the Training Session

GPS Machine Guidance Training: WisDOT Program

Wisconsin Operating Engineers' Training Facility, Colomo, WI

April 2-3, 2008

Introductions

- Instructors:
  - Alan Vonderohe (Construction Materials and Support Center – UW-Madison).
  - Ken Bork and Jeff Servi (WOE Training Facility).
  - Adam Patrow (FABCO).
  - Shane Behlendorf and Tom Walrath (Positioning Solutions).

Introductions

- Trainees:
  - Please introduce yourselves, tell us your job position, and what you hope to learn during this training session.

Objectives of the Training

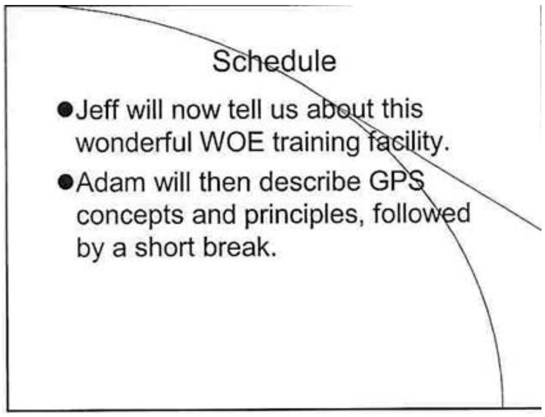
- Familiarize you with:
  - GPS concepts and principles.
  - Machine guidance concepts and principles.
  - 3D models and their roles in machine guidance.
  - Trimble's and TOPCON's implementation of the technology (hands-on and field exercises).
  - WisDOT's pilot program, specification, and guidance language.
- Most importantly:
  - Address any questions you might have.
  - To meet this objective, the training schedule is flexible.

Schedule

- Weds morning:
  - Introductions, GPS and machine guidance concepts and principles, Trimble's implementation, site calibration field exercise.
- Lunch provided.
- Weds afternoon:
  - Continue use of Trimble technology.
  - Break into two groups (see roster) that switch between:
    - 3D modeling and data collector downloads (indoors).
    - Stake out and subgrade checks (outdoors).

Schedule

- Thurs morning (Note 8:00am start time):
  - WisDOT's pilot program, specification, and guidance language; TOPCON's implementation, localization field exercise.
- Lunch provided.
- Thurs afternoon:
  - Continue use of TOPCON technology.
  - Break into two groups (see roster) that switch between:
    - 3D modeling and data collector downloads (indoors).
    - Stake out and subgrade checks (outdoors).
  - Training evaluation.


Schedule
Jeff will now tell us about this wonderful WOE training facility.
Adam will then describe GPS concepts and principles, followed by a short break.

GPS Machine Guidance Training: WisDOT Program

WisDOT's Pilot Program, Specification, and Guidance Language

April 2-3, 2008

Pilot Program

- Three-Year Objective:
  - Collaboratively develop a consensus-based specification and guidance language, leading to eventual adoption of GPS machine guidance as a statewide bidding option for subgrade.

Pilot Program

- Year 1 (2006-2007):
  - Form Advisory Group.
  - Develop background information.
  - Develop specification structure and issues.
  - Conduct stakeholder workshop.
  - Develop specification and guidance for first round of pilot projects.

Pilot Program

- Year 2 (2007-2008):
  - Select pilot projects and incorporate specification by contract change order.
  - Two pilots:
    - STH 57, Door County, (Hoffman Construction).
      - 5 miles of new divided highway.
      - Trimble technology.
    - STH 106, Fort Atkinson, (Wondra Excavating).
      - 10 miles of bi-directional pavement replacement and alignment change.
      - TOPCON technology.
  - Evaluate performance of specification and guidance language.
  - Make revisions for second round of pilot projects.

Pilot Program

- Year 3 (2008-2009):
  - Select potential pilot projects and include specification as option in PS&E.
  - Six candidates; hoping for three pilots.
    - NC, SE, NE Regions.
  - Provide this training.
  - Evaluate performance of specification and guidance language.
  - Make final revisions.

Specification for 2008 Pilots

- GPS machine guidance is an option.
- Sections on which GPS machine guidance is to be used must be identified.
- No blue tops required for work approved for GPS machine guidance.
- Engineer may require reversion to blue tops if results are unacceptable.
- Contractor loans GPS rover to WisDOT staff and provides training.

Specification for 2008 Pilots

- Contractor submits GPS work plan, describing hardware and software, qualifications of staff, project control, site calibration, quality control measures.
- 3D model:
  - Department provides existing surface DTM and initial design surface data, derived from plans – with plans remaining as the contract documents. LandXML or DWG format.
  - Contractor develops and maintains 3D model including design surface, confirms that it conforms to plans, and provides to WisDOT.
  - Contractor and WisDOT agree on 3D model.

Specification for 2008 Pilots

3D model:
- Contractor informs WisDOT if errors in department-provided information are detected in the field.
- WisDOT determines if revisions are necessary, then makes them and provides to contractor.
- Contractor revises 3D model and ensures conformation with revised plans.
- Contractor provides revised 3D model to WisDOT.
- WisDOT pays for incorporation of plan revisions.
- WisDOT maintains existing surface DTM and makes available to contractor throughout project.

Specification for 2008 Pilots

Site Calibration / Localization:
- Contractor designates which project control points are to be used for site calibration.
  - Six total or two per mile, whichever is greater.
- Contractor performs site calibration and provides site calibration file to engineer.
- WisDOT uses same calibration file as contractor.
- Contractor checks site calibration at start of each day (minimum);
  - Checks at control points not used in calibration.
  - Tolerances: ±0.10 ft (horizontal), ±0.05 ft (vertical).
  - Check results are provided to engineer at weekly meetings.

Specification for 2008 Pilots

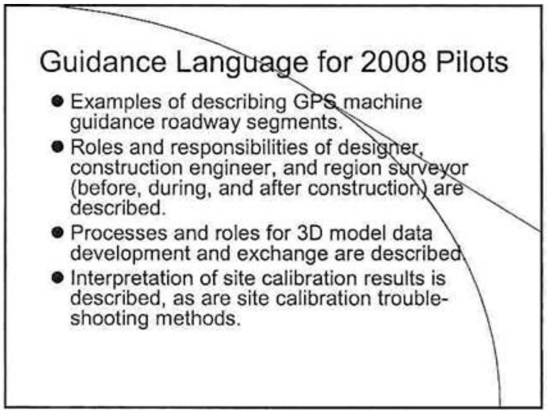
Construction Checks:
- Contractor performs subgrade checks at 20 or more randomly-selected locations per roadway mile.
- Checks must be made at full stations or other locations where cross-sections are shown on plans.
  - Checks are against plan elevations, not 3D model.
- Four out of any five consecutive subgrade checks must be within 0.10 ft of plan elevations.
  - If not, engineer must be notified.
- Engineer can make additional subgrade checks.
  - Notifies contractor if any check differs by more than 0.10 ft from plan elevation.

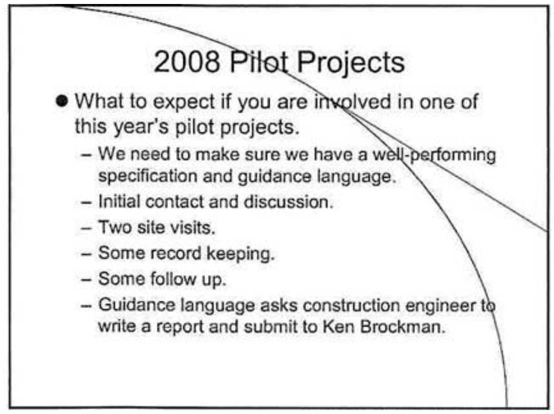
Specification for 2008 Pilots

Supplemental Control:
- WisDOT provides initial geodetic control according to standard specification.
- Contractor provides supplemental control to ensure at least six control points per mile.
- Vertical control by differential leveling.

Specification for 2008 Pilots

Measurement:
- Construction staking base, concrete pavement, resurfacing reference, slope stakes by linear foot.
- Construction staking subgrade by linear foot, whether constructed by GPS machine guidance or conventional construction staking.
  - If GPS machine guidance suspended for reasons beyond contractor's control, repeat work will be measured twice (once if suspension is for reasons within contractor's control).
- Construction staking curb gutter, curb & gutter, and concrete barrier by linear foot.
- Structures and other bid items measured as in standard specification.


Guidance Language for 2008 Pilots
Examples of describing GPS machine guidance roadway segments.
Roles and responsibilities of designer, construction engineer, and region surveyor (before, during, and after construction) are described.
Processes and roles for 3D model data development and exchange are described.
Interpretation of site calibration results is described, as are site calibration trouble-shooting methods.


2008 Pilot Projects
What to expect if you are involved in one of this year's pilot projects.
– We need to make sure we have a well-performing specification and guidance language.
– Initial contact and discussion.
– Two site visits.
– Some record keeping.
– Some follow up.
– Guidance language asks construction engineer to write a report and submit to Ken Brockman.

Appendix E.
2008 Training Session Evaluation Summary

Summary of Evaluation Form Responses

On Training on GPS Machine Guidance for WisDOT and Consultant Personnel
April 2-3, 2008
WOE Training Facility, Coloma, WI

Please mark SA (strongly agree), A (agree), N (neutral), D (disagree), SD (strongly disagree). Please provide associated comments in the space near the bottom of the page.

For analysis, SA=1, A=2, N=3, D=4, SD=5

1. SA A N D SD This training session met my needs.

Score = 1.72

2. SA A N D SD This training session was about what I expected.

Score = 1.78

3. SA A N D SD Background material on GPS, machine guidance, and 3D modeling (Weds morning) was appropriate.

Score = 1.83

4. SA A N D SD Material on how Trimble and TOPCON have implemented the technology (Weds and Thurs mornings) was appropriate.

Score = 1.94

5. SA A N D SD Site calibration / localization field exercises were appropriate.

This question was not applicable, as these field exercises were not done.

6. SA A N D SD Stake-out and subgrade check field exercises were appropriate.

Score = 2.06

7. SA A N D SD Indoor material and exercises on data collector downloads and 3D modeling were appropriate.

Score = 2.06

8. SA A N D SD The material on WisDOT's specification and guidance language (Thurs morning) was appropriate.

Score = 1.83

9. SA A N D SD Handouts and reference materials were appropriate.

Score = 2.06

Please mark your choice:

1. The overall timing and pace of the training was: too slow about right too fast

With too slow = 1, about right = 2, and too fast = 3, score = 1.89

2. My overall rating of the training is: excellent good average below average poor

With excellent = 1, good = 2, average = 3, below average = 4, poor = 5, score = 1.78

3. I am a: WisDOT employee Consultant employee Other (please explain):

18 total responses, 9 each from WisDOT employees and consultant employees.

Please provide suggestions on how the training could be improved (Use back of form if you run out of space):

Please provide comments on your selections for questions 1-9 or anything else associated with the training (Use back of form if you run out of space):

Summary of comments:

1. Ken is knowledgeable and I enjoyed how much information he shared.
2. Take less time in the classroom explaining features of each manufacturer and more time to show the features in the field.
3. I didn't feel it was necessary to hand out addresses and emergency contacts to the entire class.
4. There should be a check like an inspector would do in the field as a field exercise.
5. I think the training should be lengthened to include more hands-on training with the instrumentation. In-class instruction was good. Thank you.
6. Good work! Thanks again!
7. Could put more emphasis on stakeout and subgrade checks (field work aspect).
8. Don't hand out everyone's emergency contact information – should be kept private.
9. Enjoyed the hands-on training.
10. Powerpoint slide print outs for all presentations would be helpful.

11. Have a computer station to have students set up subgrade models.

12. Overall good. Since this was directed towards engineer, may want to give overview then focus on specific needs, like documenting. But it was good.

13. Specs section most useful.

14. Less sales.

15. I would focus on inspector needs. How to document specs.

16. Training should be an awareness training, not necessarily a hands-on. As a DOT project leader, my role has increased over the years, yet staff has been reduced. My suggestion to management is to give duties for RTK to our survey crews. There will never be a time when GPS will be on every project. Our survey crews only cross section borrow sites. Would be nice to have them rotate between several sites to do the checking.

17. I realize Alan is on the implementation committee for the specifications. Yet, I think that Jerry Zogg or Mike Hall could better answer specific questions on the specs.

18. The outside training could be combined. Both days were too similar only showing the difference between TOPCON and Trimble.

19. Kenny Bork needs a raise!

20. Too many sales pitches.

21. Too much time was spent on GPS equipment specifics rather than discussions about the spec and how the pilot programs will work.

22. Instructors / presenters need to remember the group is made up of civil engineers, not operating engineers.

23. Handing out of the simulators would help greatly.

24. Sometimes seemed like sales pitch.

25. Engineers would likely not be doing the stake out and subgrade checks.

26. Did not learn much from just watching the indoor exercises / demonstrations – too technical.

27. The proprietary information and training could have been condensed. If scheduled correctly, the class should have only taken 1-1.5 days.

28. Food sucked.

Appendix F.
2009 Training Session Schedule

GPS Machine Guidance
Training Schedule for WisDOT and Consultant Personnel
April 23, 28, 29, 2009
WOE Training Facility
Coloma, WI

8:00am-8:15am: Introduction; objectives of the training session; overview of the training session. (Alan Vonderohe)

8:15-9:30am: GPS and how it works; code and carrier phase; differential and RTK; site calibration / localization concepts (Alan Vonderohe)

9:30-9:45am: Break.

9:45-10:30am GPS machine guidance concepts; 3D model concepts; positioning the machine in the model. (Alan Vonderohe)

10:30am-12:00pm: WisDOT GPS machine guidance program; specification development; pilot projects; 2009 specification and guidance language (CMM) (Alan Vonderohe).

12:00-1:00pm: Lunch.

1:00-2:30pm: Practical experiences in GPS machine guidance project management (Panel of pilot project participants).

2:30-2:45pm: Break

2:45-4:45pm: Field demonstration; site calibration; grading; subgrade checking (Ken Bork / Jeff Servi / Alan Vonderohe).

4:45-5:00pm: Training session evaluation (Trainees).

Appendix G.
Record-Keeping Forms
and Examples Distributed to Pilot Project
Engineers and Foremen

Site Calibration / Localization Form

Project ID =

Date =

Table of Control Point Error Estimates

NOTE: Under "Control Point Type", enter H for horizontal, V for vertical, or B for Both.

NOTE: Enter error estimates corresponding with control point types (e.g., do not enter a vertical error estimate for a horizontal control point)

Control Point ID	Control Point Type	Horizontal Error Estimate (ft)	Vertical Error Estimate (ft)

Site Calibration / Localization Form

Project ID = 14-691234

Date = 5/22/08

Table of Control Point Error Estimates

NOTE: Under "Control Point Type", enter H for horizontal, V for vertical, or B for Both.

NOTE: Enter error estimates corresponding with control point types (e.g., do not enter a vertical error estimate for a horizontal control point)

Control Point ID	Control Point Type	Horizontal Error Estimate (ft)	Vertical Error Estimate (ft)
22A	H	0.05	
3	V		0.04
BILL	H	0.02	
5C7	H	0.04	
445	B	0.02	-0.03
15CARL	B	0.01	0.02
MMM	B	0.02	-0.04
142	V		0.01

Site Calibration / Localization Check Form

Project ID =

Table of Control Point Checks

NOTE: Under "Control Point Type", enter H for horizontal, V for vertical, or B for Both.

NOTE: Enter check values corresponding with control point types (e.g., do not enter a vertical check value for a horizontal control point)

Date	Control Point ID	Control Point Type	Horizontal Check Value (ft)	Vertical Check Value (ft)

Site Calibration / Localization Check Form

Project ID = 14-691234

Table of Control Point Checks

NOTE: Under "Control Point Type", enter H for horizontal, V for vertical, or B for Both.

NOTE: Enter check values corresponding with control point types (e.g., do not enter a vertical check value for a horizontal control point)

Date	Control Point ID	Control Point Type	Horizontal Check Value (ft)	Vertical Check Value (ft)
5/24/2008	5123	B	0.03	-0.04
5/25/2008	5123	B	0.01	-0.02
5/26/2008	5123	B	0.02	-0.02
5/27/2008	5123	B	0.03	0.00
5/28/2008	JAMES	H	0.04	
5/28/2008	MIKE	V		0.04
5/29/2008	JAMES	H	0.02	
5/29/2008	MIKE	V		0.02
5/30/2008	143	B	0.00	-0.03
5/31/2008	143	B	0.01	-0.02

Subgrade Check Form								
Project ID =								
Table of Subgrade Checks								
Date	**Station**		**Offset**			**Subgrade Check Value (ft)**		

Subgrade Check Form								
Project ID = 14-691234								
Table of Subgrade Checks								
Date	**Station**		**Offset**			**Subgrade Check Value (ft)**		
6/22/2008	300+00.02		55.36L			-0.06		
6/22/2008	301+00.05		32.56R			0.03		
6/22/2008	301+99.98		10.99R			0.08		
6/22/2008	302+00.00		11.44L			0.05		
6/22/2008	304+00.03		25.78L			-0.07		
6/22/2008	305+00.01		8.27R			0.05		
6/23/2008	305+99.93		5.33R			-0.03		
6/23/2008	305+99.98		22.82L			-0.06		

Appendix H.
Questions and Talking Points for
Second Site Visit to Kowalski Road Project

Talking Points for Second Site Visit
To Kowalski Road (RiverView)

NOTE: This document is a list of questions and talking points for the second site visit during August, 2008. It is not a questionnaire to be filled out and returned. The questions and talking points focus upon selected, specific aspects of the specification and guidance language for the pilot project.

1. The specification allows the engineer to require conventional subgrade staking if GPS machine guidance is producing unacceptable results. In such cases, if the GPS problems are beyond the contractor's control, WisDOT will measure the additional subgrade staking for payment.

    Is this a good idea? Was there a need to revert to conventional staking on the pilot project? Does this part of the spec need any modification?

2. No subgrade stakes are required for work approved for GPS machine guidance.

    Does this part of the spec need any modification?

3. The spec requires coordination throughout the course of construction between the contractor and engineer to ensure that GPS machine guidance conforms to contract tolerances and that methods conform to the contractor's GPS work plan. This includes addressing GPS machine guidance issues at weekly progress meetings.

    What was your experience with this coordination on the pilot project? Does this part of the spec need any modification?

4. The spec requires provision by the contractor of a GPS rover, along with training, to the project engineer for use as needed on the project.

    What was your experience with this aspect of the spec on the pilot project? Does this part of the spec need any modification?

5. The spec requires periodic sensor calibrations, checks for blade wear, and other routine adjustments.

    How often were these equipment checks and sensor calibrations performed? What was checked? What was calibrated? Does this part of the spec need any modification?

6. The spec requires WisDOT review of changes to the 3D model that result from changes to the plans. We understand that this project had a number of plan revisions.

    What was your experience with plan revisions, subsequent model revisions, and required WisDOT reviews of the revised models? What about the timeliness of information flows and departmental reviews during this process? Were there any construction delays because of these requirements?

7. For site calibration / localization, the specification requires at least 6 horizontal and vertical control points, or two per mile, whichever is greater.

   For projects of smaller extent, like this one, is the number of points over-specified? Can the number of required control points for site calibration be reduced for smaller projects?

8. Site calibration checks are required at the start of each day. Horizontal tolerance is 0.10 ft or less. Vertical tolerance is 0.05 ft or less.

   Is this frequency appropriate for site calibration / localization checking? Are the tolerances appropriate? Did any site calibration / localization check fail to meet tolerance? If so, what was done? Does this part of the spec need any modification?

9. Daily site calibration / localization checks results are to be provided to the engineer at weekly progress meetings.

   Does this part of the spec require any modification?

10. A GPS rover is to be used by the contractor to check the subgrade at 20 or more randomly selected locations per mile. At least 4 of any 5 consecutively-tested subgrade points must be within 0.10 ft (vertically) of the plan elevation. If otherwise, the engineer must be notified. The engineer makes periodic independent subgrade checks and notifies the contractor if any individual check differs by more than 0.10 ft from design.

    How did the contractor select the check points? Were there any failures of the 4-out-of-5 0.10 ft tolerance? If so, what was done? Did any of the engineer's checks fail the 0.10 ft tolerance? If so, what was done? Does this part of the spec require any modification?

    For projects less than one mile in extent, such as this one, how did you interpret the requirement of at least 20 checks per mile?

11. WisDOT provided initial project control points.

    Was the control provided by WisDOT sufficient in number and configuration? Did the contractor need to establish supplemental project control?

12. Can the number (frequency) of slope stakes be reduced? How long do slopes need to be maintained…in other words, at what point in the construction process are they no longer needed?

13. What are the necessary knowledge and skill levels for project engineers to administer contracts involving GPS machine guidance?

14. Is there any other aspect of the specification that needs attention? Are there unnecessary redundancies in the specification? Is there anything left out of the specification? What else can be done to improve the specification?

15. Have you reviewed the guidance language? Was it necessary to rely upon any of the guidance language during the pilot project? If so, did you find it useful? Even if you did not need to use the guidance language on the pilot project, do you think it is useful in its current form? Is there anything missing from the guidance language? Are there any unnecessary redundancies in the guidance language? Is there anything that is unclear or confusing in the guidance language? What else can be done to improve the guidance language?

Appendix I.
GPS Work Plan for Kowalski Road

GPS Work Plan

Mosinee – Wausau

Kowalski Road Overpass and Approaches 37-407

River View Construction Inc. has been using Trimble Machine Control since 2001. We have worked with several versions of Trimble Software including beta versions and are now using 5.01. All of our Dozer Operators are highly trained having many hours of in house training provided by Trimble Navigation and Fabco and have 5+ years of experience.

Base Station Model

- MS 750 Receiver
- 13” Rugged antenna
- Site-Net 900 Radio

Rover Model

- 5700 Receiver
- Zepher antenna
- Internal Radio

Dozer Model

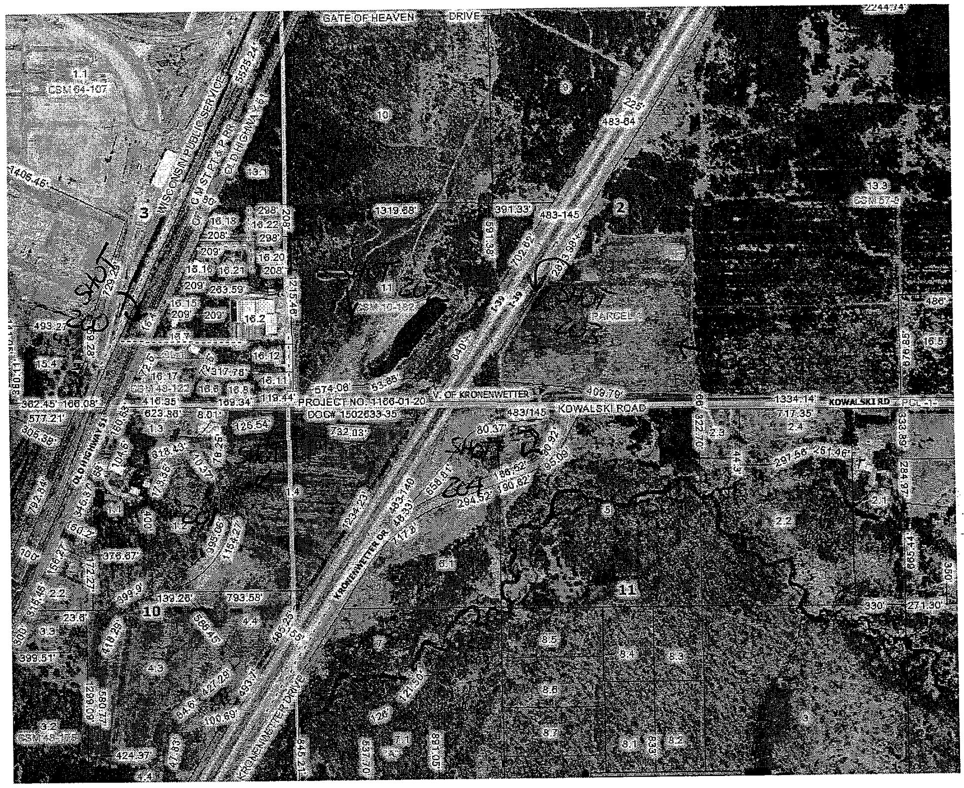
- MS 860 Receiver
- 13” Rugged antennas
- Site-Net 900 Radio

John Stone will be the contact for any GPS technology issues. He is one our Project Managers and a Registered Land Surveyor for the State of Wisconsin.

The project control is being furnished by the DOT, a map and list of coordinates (attachment A and B)

Site calibration will consist of the 6 points provided by the DOT and one point will be checked on a daily basis. A printout of the checks will b provided to the Engineer at the weekly construction meetings. Four bench marks will be set by River View (one in each quadrant of the bridge) to check the dozer blades. The dozer operator will check their blade with this reference mark each day. Sub-grade checks will be made at 100’ to 200’ intervals. Other checks will be made through out the project.

Attachment A



Appendix J.
Questions and Talking Points for Second Site Visit to Oconto Bypass Project

Talking Points for Second Site Visit
To Oconto Bypass (Hoffman)

NOTE: This document is a list of questions and talking points for the second site visit during November, 2008. It is not a questionnaire to be filled out and returned. The questions and talking points focus upon selected, specific aspects of the specification and guidance language for the pilot project.

16. The specification allows the engineer to require conventional subgrade staking if GPS machine guidance is producing unacceptable results.

    Is this a good idea? Was there a need to revert to conventional staking on the pilot project?

17. No subgrade stakes are required for work approved for GPS machine guidance.

    Does this part of the spec need any modification?

18. The spec requires coordination throughout the course of construction between the contractor and engineer to ensure that GPS machine guidance conforms to contract tolerances and that methods conform to the contractor's GPS work plan. This includes addressing GPS machine guidance issues at weekly progress meetings.

    What was your experience with this coordination on the pilot project? Was a GPS work plan submitted? If so, can I obtain a copy?

19. The spec requires provision by the contractor of a GPS rover, along with training, to the project engineer for use as needed on the project.

    What was your experience with this aspect of the spec on the pilot project?

20. The spec requires periodic sensor calibrations, checks for blade wear, and other routine adjustments.

    How often were these equipment checks and sensor calibrations performed? What was checked? What was calibrated? Does this part of the spec need any modification?

21. The spec requires WisDOT review the 3D model and changes to it that result from changes to the plans. On this project, there were initial issues with model review.

    How were these issues resolved? Can I obtain a copy of the final model in .pro (Terramodel) format?

22. For site calibration / localization, the specification requires at least 6 horizontal and vertical control points, or two per mile, whichever is greater.

Is this requirement appropriate? Should there be more control? Should there be less control?

23. Site calibration checks are required at the start of each day. Horizontal tolerance is 0.10 ft or less. Vertical tolerance is 0.05 ft or less.

    Is this frequency appropriate for site calibration / localization checking? Are the tolerances appropriate? Did any site calibration / localization check fail to meet tolerance? If so, what was done? Does this part of the spec need any modification?

24. Daily site calibration / localization checks results are to be provided to the engineer at weekly progress meetings.

    Does this part of the spec require any modification?

25. A GPS rover is to be used by the contractor to check the subgrade at 20 or more randomly selected locations per mile. At least 4 of any 5 consecutively-tested subgrade points must be within 0.10 ft (vertically) of the plan elevation. If otherwise, the engineer must be notified. The engineer makes periodic independent subgrade checks and notifies the contractor if any individual check differs by more than 0.10 ft from design.

    How did the contractor select the check points? Were there any failures of the 4-out-of-5 0.10 ft tolerance? If so, what was done? Did any of the engineer's checks fail the 0.10 ft tolerance? If so, what was done? Does this part of the spec require any modification?

26. WisDOT provided initial project control points.

    Was the control provided by WisDOT sufficient in number and configuration? Did the contractor need to establish supplemental project control?

27. Can the number (frequency) of slope stakes be reduced? How long do slope stakes need to be maintained…in other words, at what point in the construction process are they no longer needed?

28. What are the necessary knowledge and skill levels for project engineers to administer contracts involving GPS machine guidance?

29. Is there any other aspect of the specification that needs attention? Are there unnecessary redundancies in the specification? Is there anything left out of the specification? What else can be done to improve the specification?

30. Have you reviewed the guidance language? Was it necessary to rely upon any of the guidance language during the pilot project? If so, did you find it useful? Even if you did not need to use the guidance language on the pilot project, do you think it is useful in its current form? Is there anything missing from the guidance language? Are there any unnecessary redundancies in the guidance language?

Is there anything that is unclear or confusing in the guidance language? What else can be done to improve the guidance language?

Appendix K.
GPS Work Plan for Oconto Bypass

GPS Machine Guidance Specification Pilot
Oconto - Peshtigo
Mill Street – CTH S
USH 41
Oconto County

Equipment

Design:

Trimble Terramodel v. 10.50

Staking:

Base Station: Trimble SPS750

Rover: Trimble SPS780

Data Collector: Trimble TSC2

Staking Software: Trimble SCS900 v. 2.12

Machine Control:

Caterpillar D6N Dozer

Caterpillar D6R Dozer

Caterpillar 14H Motor Grader

Caterpillar D8N Dozer

System on Machines: Trimble GCS900 v. 6.0 or newer

People

Ken Bork

Hoffman Construction Company

Seven years of grade staking and data preparation using robot total stations, GPS instruments, and design/survey software.

Seven years of teaching grade staking classes using total stations and GPS instruments at Local 139 Union School in Coloma.

Role in Specification: Primary contact for GPS Pilot Spec. He will be on-site daily, and will be handling data flow and field operations for the pilot.

Chris Goss

Hoffman Construction Company

Thirteen years of construction layout, data preparation, and property surveying using total stations, GPS instruments, design/survey software, and cad software.

Role in Specification: Oversight and support to field and data operations.

Operators: Mike Windsor gps blade
Don Severson gps dozer
Brian Pecher gps dozer

Joe Broullire

Superior Staking

Construction Staking Contractor for the project.

Role in Specification: Create and maintain on-site control points.

<u>Project Control</u>

For this project, the department has provided a list of control that was established by the Wis D.O.T . This control shall be used as the primary control for this project. Hoffman Construction Company ("HCC") will use these points in the site calibration. All of the points were used in the calibration file since the Oconto north and south jobs were calibrated together. Joe Broullire and Superior Staking set out extra control to use for daily checks.

<u>Site Calibration</u>

Site calibration will be performed using the calibration function in Trimble SCS900. The points used in the site calibration will envelope the site. The entire project will be included in one site calibration. Each point in the calibration will be observed statically for 15 seconds. The resulting precision of the site calibration shall fall within 0.10 ft. horizontally and 0.05 ft. vertically. A hard copy of the resulting site calibration data from SCS900 will be given to the engineer.

HCC will perform control checks daily. HCC's typical workweek will be 5 days per week, 50 hours per week. HCC will perform one control checks per workday. Those checks shall fall within 0.10 ft. horizontally and 0.05 ft. vertically. Those control checks will be recorded using SCS900.

<u>Additional QC Procedures</u>

Machines:

GCS900 v. 6.0 has two equipment checks that shall be done:

First is the valve calibration. This procedure will be typically done twice per year, or when something changes with the hydraulics of the machine, i.e. replacing of hydraulic fluids, valves, or pumps. This shall be done once before the machine does any finish grading on the project. This procedure requires the machine to be stationary. The machine will go through a series of lifts and drops of the blade to calibrate the valves. The valve calibration shall be done after the machine has been operated. The calibration shall not be done at first start-up.

Second is the blade wear check. Blade wear is a series of simple measurements that are taken along the cutting edge of the blade. There will be three measurements taken along the blade (quarter points). Those three measurements will be averaged and entered into GCS 900. This measurement shall be done at a minimum of once per workweek during finish grade operations. The measurements will be documented to the engineer. If the measurements vary by 0.08 ft. then HCC will make efforts to true up the cutting edge or replace it.

Grade Checks:

HCC will perform random grade checks on the subgrade (between shoulder points) at a rate of 20 checks per mile. The checks will be done on even stations to allow for ease in the verification with the plans. The point data will be recorded using SCS900. A hard copy of the recorded data and precision will be given to the engineer on a weekly basis when finish grade operations are occurring.

As in the past, HCC grade foremen will be continually working and checking with the crews to ensure that the grade is being constructed to the plan lines and grades. This everyday checking will not be recorded, but it will aid in the accuracy of the grade.

Appendix J.
Questions and Talking Points for Second Site Visit to Peshtigo Bypass Project

Talking Points for Second Site Visit
To Peshtigo Bypass (Hoffman)

NOTE: This document is a list of questions and talking points for the second site visit during November, 2008. It is not a questionnaire to be filled out and returned. The questions and talking points focus upon selected, specific aspects of the specification and guidance language for the pilot project.

31. The specification allows the engineer to require conventional subgrade staking if GPS machine guidance is producing unacceptable results.

    Is this a good idea? Was there a need to revert to conventional staking on the pilot project?

32. No subgrade stakes are required for work approved for GPS machine guidance.

    Does this part of the spec need any modification?

33. The spec requires coordination throughout the course of construction between the contractor and engineer to ensure that GPS machine guidance conforms to contract tolerances and that methods conform to the contractor's GPS work plan. This includes addressing GPS machine guidance issues at weekly progress meetings.

    What was your experience with this coordination on the pilot project?

34. The spec requires provision by the contractor of a GPS rover, along with training, to the project engineer for use as needed on the project.

    What was your experience with this aspect of the spec on the pilot project?

35. The spec requires periodic sensor calibrations, checks for blade wear, and other routine adjustments.

    How often were these equipment checks and sensor calibrations performed? What was checked? What was calibrated? Does this part of the spec need any modification?

36. The spec requires WisDOT review the 3D model and changes to it that result from changes to the plans.

    What was your experience with WisDOT review(s) of the 3D model? Can I obtain a copy of the final model in .pro (Terramodel) format?

37. For site calibration / localization, the specification requires at least 6 horizontal and vertical control points, or two per mile, whichever is greater.

    Is this requirement appropriate? Should there be more control? Should there be less control?

38. Site calibration checks are required at the start of each day. Horizontal tolerance is 0.10 ft or less. Vertical tolerance is 0.05 ft or less.

    Is this frequency appropriate for site calibration / localization checking? Are the tolerances appropriate? Did any site calibration / localization check fail to meet tolerance? If so, what was done? Does this part of the spec need any modification?

39. Daily site calibration / localization checks results are to be provided to the engineer at weekly progress meetings.

    Does this part of the spec require any modification?

40. A GPS rover is to be used by the contractor to check the subgrade at 20 or more randomly selected locations per mile. At least 4 of any 5 consecutively-tested subgrade points must be within 0.10 ft (vertically) of the plan elevation. If otherwise, the engineer must be notified. The engineer makes periodic independent subgrade checks and notifies the contractor if any individual check differs by more than 0.10 ft from design.

    How did the contractor select the check points? Were there any failures of the 4-out-of-5 0.10 ft tolerance? If so, what was done? Did any of the engineer's checks fail the 0.10 ft tolerance? If so, what was done? Does this part of the spec require any modification?

41. WisDOT provided initial project control points.

    Was the control provided by WisDOT sufficient in number and configuration? Did the contractor need to establish supplemental project control?

42. Can the number (frequency) of slope stakes be reduced? How long do slope stakes need to be maintained…in other words, at what point in the construction process are they no longer needed?

43. What are the necessary knowledge and skill levels for project engineers to administer contracts involving GPS machine guidance?

44. Is there any other aspect of the specification that needs attention? Are there unnecessary redundancies in the specification? Is there anything left out of the specification? What else can be done to improve the specification?

45. Have you reviewed the guidance language? Was it necessary to rely upon any of the guidance language during the pilot project? If so, did you find it useful? Even if you did not need to use the guidance language on the pilot project, do you think it is useful in its current form? Is there anything missing from the guidance language? Are there any unnecessary redundancies in the guidance language? Is there anything that is unclear or confusing in the guidance language? What else can be done to improve the guidance language?

Appendix M.
GPS Work Plan for Peshtigo Bypass

GPS Machine Guidance Specification Pilot
Oconto - Peshtigo
CTH Y – Schacht Rd SP1154-01-75/82/85
USH 41
Marinette County

Equipment

Design:
- Trimble Terramodel v. 10.50

Staking:
- Base Station: Trimble SPS750
- Rover: Trimble SPS780
- Data Collector: Trimble TSC2
- Staking Software: Trimble SCS900 v. 2.12

Machine Control:
- Caterpillar D6N Dozer
- Caterpillar D6R Dozer
- Caterpillar 14H Motor Grader
- Caterpillar 140H Motor Grader
- Caterpillar D8N Dozer
- System on Machines: Trimble GCS900 v. 6.0 or newer

People

Allen Johnson
Hoffman Construction Company
Eight years of grade staking. Five years of staking with GPS instruments along with two years of data preparation using design/survey software.
Role in Specification: Primary contact for GPS Pilot Spec. He will be on-site daily, and will be handling data flow and field operations for the pilot.

Chris Goss
Hoffman Construction Company
Thirteen years of construction layout, data preparation, and property surveying using total stations, GPS instruments, design/survey software, and cad software.
Role in Specification: Oversight and support to field and data operations.

Kim Zajec
Hoffman Construction Company
Two years experience using Trimble GPS machine control.
Role in Specification: Heavy Equipment Operator

Travis Kurth
Hoffman Construction Company
One year experience using Trimble GPS machine control.
Role in Specification: Heavy Equipment Operator

Brian Carlson
Hoffman Construction Company
Two years experience using Trimble GPS machine control.
Role in Specification: Heavy Equipment Operator

Daryl Beneke
Hoffman Construction Company
Three years experience using Trimble GPS machine control.
Role in Specification: Heavy Equipment Operator

Eugene Kilcher
Hoffman Construction Company
Two years experience using Trimble GPS machine control.
Role in Specification: Heavy Equipment Operator

Donald Severson
Hoffman Construction Company
Two years experience using Trimble GPS machine control.
Role in Specification: Heavy Equipment Operator

Michael Kurth
Hoffman Construction Company
One year experience using Trimble GPS machine control.
Role in Specification: Heavy Equipment Operator

Steven Wolfe
Hoffman Construction Company
Three years experience using Trimble GPS machine control.
Role in Specification: Heavy Equipment Operator

Jack Taylor
Hoffman Construction Company
Three years experience using Trimble GPS machine control.
Role in Specification: Heavy Equipment Operator
Ray Mahr
Hoffman Construction Company
One year experience using Trimble GPS machine control.
Role in Specification: Heavy Equipment Operator

Brian Pecher
Hoffman Construction Company
One year experience using Trimble GPS machine control.
Role in Specification: Heavy Equipment Operator

James Melton
Hoffman Construction Company
Two years experience using Trimble GPS machine control.
Role in Specification: Heavy Equipment Operator

Harold Waters
Hoffman Construction Company
Two years experience using Trimble GPS machine control.
Role in Specification: Heavy Equipment Operator

Jeffrey Lien
Hoffman Construction Company
Two years experience using Trimble GPS machine control.
Role in Specification: Heavy Equipment Operator

Mike Windsor
Hoffman Construction Company
Three years experience using Trimble GPS machine control.
Role in Specification: Heavy Equipment Operator

Fred Ramp
Hoffman Construction Company
Two years experience using Trimble GPS machine control.
Role in Specification: Heavy Equipment Operator

Project Control

For this project, the department has provided a list of control (Attachment A) that was established by WisDOT. This control shall be used as the primary control for this project. Hoffman Construction Company ("HCC") will use these points in the site calibration. Some points may not be used in the calibration due to accessibility or deficient correlation with the rest of the control. If six or less points are used in the calibration, a seventh point not used in the calibration will be reserved for daily checks throughout the duration of the project.

Site Calibration

Site calibration will be performed using the calibration function in Trimble SCS900. The points used in the site calibration will envelope the site. The entire project will be included in one site calibration. Each point in the calibration will be observed statically for about 15 seconds. The resulting precision of the site calibration shall fall within 0.10 ft. horizontally and 0.05 ft. vertically. A hard copy of the resulting site calibration data from SCS900 will be given to the engineer.

HCC will perform control checks daily. HCC's typical workweek will be 5 days per week, 50 hours per week. HCC will perform at least one control check per workday. That check will typically be done at the start of work each day. Those checks shall fall within 0.10 ft. horizontally and 0.05 ft. vertically. Those control checks will be recorded using SCS900. A hard copy of that record will be reported weekly to the engineer.

A list of points used in the site calibration and used as checks, and their location can be found in Attachment B.

<u>Additional QC Procedures</u>

Machines:

GCS900 v. 6.0 has two equipment checks that shall be done:

First is the valve calibration. This procedure is typically done twice per year, or when something changes with the hydraulics of the machine, i.e. replacing of hydraulic fluids, valves, or pumps. It may also be done when the operator notices erratic machine control of the blade. This procedure requires the machine to be stationary. The machine will go through a series of lifts and drops of the blade to calibrate the valves. The valve calibration shall be done after the machine has been operated. The calibration shall not be done at first start-up. HCC will notify the engineer if/when a valve calibration will occur.

Second is the blade wear check. Blade wear is a series of simple measurements that are taken along the cutting edge of the blade. There will be three measurements taken along the blade (quarter points). Those three measurements will be averaged and entered into GCS 900. This measurement shall be done at a minimum of once per workweek during finish grade operations. The measurements will be documented to the engineer. If the measurements vary by 0.08 ft. then HCC will make efforts to true up the cutting edge or replace it.

Grade Checks:

HCC will perform random grade checks on the subgrade (between shoulder points) at a rate of 20 checks per mile. The checks will be done on even stations to allow for ease in the verification with the plans. The point data will be recorded using SCS900. A hard copy of the recorded data and precision will be given to the engineer on a weekly basis when finish grade operations on the subgrade are occurring. This data will be double-checked versus the paper plan elevations.

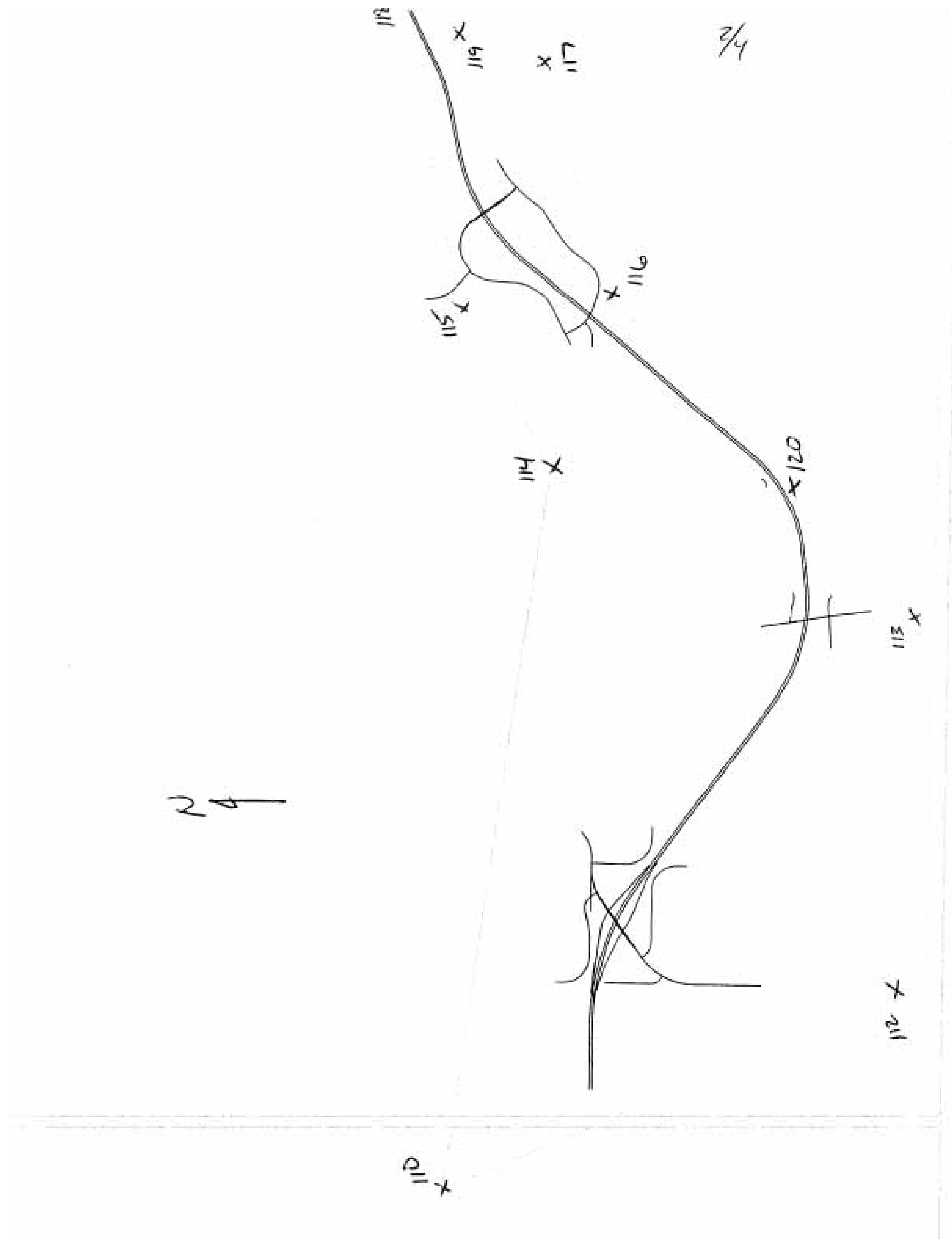
As in the past, HCC grade foremen will be continually working and checking with the crews to ensure that the grade is being constructed to the plan lines and grades. This everyday checking will not be recorded, but it will aid in the accuracy of the grade.

ATTACHMENT A 1/4

Marinette County Coordinates

(NAD 83(1991), NAVD 88, US feet)

North	East	Elevation	Description
109032.361	741160.288	648.05	Mon. 100
108793.617	749462.028	617.35	Mon. 101
111689.368	750869.619	615.44	Mon. 102
114362.033	745920.596	642.11	Mon. 103
119656.089	755752.880	623.84	Mon. 104
119637.612	748473.544	640.21	Mon. 105
124876.124	749093.358	644.60	Mon. 106
124657.009	755727.540	634.29	Mon. 107
129985.523	752414.081	640.28	Mon. 108
132452.828	754784.001	630.55	Mon. 109
134493.370	760785.707	625.63	Mon. 110 ✓
133236.941	765455.130	616.63	Mon. 111
124503.602	765483.198	610.44	Mon. 112 ✓
124237.512	773904.676	606.98	Mon. 113 ✓
132501.533	776960.034	605.24	Mon. 114 ✓
134581.146	780314.528	611.50	Mon. 115 ✓
131340.732	780722.063	608.65	Mon. 116 ✓
132962.589	785758.338	609.46	Mon. 117 ✓
136235.642	787098.428	615.01	Mon. 118 ✓
134816.479	786331.615	610.83	Mon. 119 ✓
127152.157	776668.621	602.96	Mon. 120 ✓
132666.683	770949.457	611.70	Peshtigo GPS(1027)
131725.782	778958.916	---	T218
134111.903	783338.118	---	T219



119
117
115
116
120
114
113
112
110
N

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Calibration	Date	10/1/2005
Calibration	Time	10:45:13 AM
Calibration	Control Point Name	113
Calibration	Calibration Horizontal Residual	0.04 usft
Calibration	Calibration Vertical Residual	0.06 usft
Calibration	Latitude	45°01'56.65884" N
Calibration	Longitude	87°44'46.71713" W
Calibration	Height	487.50 usft
Calibration	Control Point Name	120
Calibration	Calibration Horizontal Residual	0.03 usft
Calibration	Calibration Vertical Residual	-0.04 usft
Calibration	Latitude	45°02'25.44650" N
Calibration	Longitude	87°44'08.24393" W
Calibration	Height	483.53 usft
Calibration	Control Point Name	114
Calibration	Calibration Horizontal Residual	0.03 usft
Calibration	Calibration Vertical Residual	0.05 usft
Calibration	Latitude	45°03'18.26381" N
Calibration	Longitude	87°44'04.20787" W
Calibration	Height	485.76 usft
Calibration	Control Point Name	112
Calibration	Calibration Horizontal Residual	0.06 usft
Calibration	Calibration Vertical Residual	-0.02 usft
Calibration	Latitude	45°01'59.23409" N
Calibration	Longitude	87°46'43.98273" W
Calibration	Height	491.31 usft
Calibration	Control Point Name	116
Calibration	Calibration Horizontal Residual	0.02 usft
Calibration	Calibration Vertical Residual	-0.04 usft
Calibration	Latitude	45°03'06.81043" N
Calibration	Longitude	87°43'11.80203" W
Calibration	Height	489.33 usft
Calibration	Control Point Name	117
Calibration	Calibration Horizontal Residual	0.06 usft
Calibration	Calibration Vertical Residual	-0.04 usft
Calibration	Latitude	45°03'22.82287" N
Calibration	Longitude	87°42'01.65025" W
Calibration	Height	489.81 usft
Calibration	Control Point Name	119
Calibration	Calibration Horizontal Residual	0.05 usft
Calibration	Calibration Vertical Residual	-0.03 usft
Calibration	Latitude	45°03'41.12654" N
Calibration	Longitude	87°41'53.65915" W
Calibration	Height	491.16 usft
Calibration	Control Point Name	118
Calibration	Calibration Horizontal Residual	0.04 usft
Calibration	Calibration Vertical Residual	0.03 usft
Calibration	Latitude	45°03'55.13629" N
Calibration	Longitude	87°41'42.97307" W
Calibration	Height	495.27 usft
Calibration	Control Point Name	115
Calibration	Calibration Horizontal Residual	0.04 usft

4/4

Calibration	Calibration Vertical Residual	0.05 usft
Calibration	Latitude	45°03'38.80370" N
Calibration	Longitude	87°43'17.48362" W
Calibration	Height	491.93 usft
Calibration	Control Point Name	110
Calibration	Calibration Horizontal Residual	0.02 usft
Calibration	Calibration Vertical Residual	-0.02 usft
Calibration	Latitude	45°03'37.82208" N
Calibration	Longitude	87°47'49.53914" W
Calibration	Height	506.73 usft
Calibration	Precision-Horz	0.04 usft
Calibration	Precision-Vert	0.04 usft
Calibration	H Scale Factor	1.00000163
Calibration	Slope North	-0.05 ft per mile.
Calibration	Slope East	0.16 ft per mile.
Calibration	Stored File Name	Peshtigo.dc

Appendix N.
2009 Specification

Construction Staking Subgrade, Item 650.4500
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) Under the Construction Staking Subgrade bid item the contractor may substitute global positioning system (GPS) machine guidance for conventional subgrade staking on all or part of the work. 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.

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 completed using 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.

650.3.3.3.2 GPS Work Plan

(1) Submit a comprehensive written GPS work plan for department review at least 5 business days before the preconstruction conference. 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. Designate which portions of the contract will be done using GPS machine guidance and which portions will be done using conventional subgrade staking.
2. Describe the manufacturer, model, and software version of the GPS equipment.
3. 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.
4. Describe how project control is to be established. Include a list and map showing control points enveloping the site.
5. 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.
6. 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) At anytime after the contract is awarded the contractor may request the contractor staking packet. The department will provide the packet within 5 business days of receiving the contractor's request.

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. 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) Notify the department of any errors or discrepancies in department-provided information. The department will determine what revisions may be required. The department will revise the contract plans, if necessary, to address errors or discrepancies that the contractor identifies. The department will provide the best available information related to those contract plan revisions.

(2) 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 in LandXML or other engineer-approved format. The department will pay for costs incurred to incorporate contract plan revisions as extra work.

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. Use the full set of control points designated under 650.3.3.3.5 (1) for the initial site calibration. Provide the resulting site calibration file to the engineer before beginning subgrade construction operations.

650.3.3.3.6 Construction Checks

650.3.3.3.6.1 Daily Calibration Checks

(1) 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 as described in the contractor's GPS work plan. 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.

(2 Discuss the previous week’s daily calibration check results at the weekly progress meeting for monitoring the GPS work.

650.3.3.3.6.2 Final Subgrade Elevation Checks

(1) Check the subgrade against the plan elevation at randomly selected points on cross sections located at stations evenly divisible by 100. Conduct at least 20

random checks per stage, per project, or per roadway mile whichever results in the most tests. Also check the subgrade at additional points as the engineer directs. Notify the engineer at least 2 business days before making subgrade checks so the engineer can observe the process.

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

(3) The department may conduct periodic independent subgrade checks. The department will notify the contractor if any individual check differs by more than 0.10 feet from the design.

Appendix O.
2009 Guidance Language

Construction and Materials Manual

Wisconsin Department of Transportation

Chapter 7 Construction Surveying

Section 18 GPS Machine Guidance

GENERAL

The GPS machine guidance provision allows the contractor to substitute GPS machine guidance for all or part of the subgrade staking work under the contract. The extents of each GPS machine guidance segment and each subgrade staking segment need to be described in the contractor's GPS work plan. It is the contractor's option whether they will use GPS machine guidance or conventional methods.

The provisions will be in place by special provision with the item of subgrade staking 2009 construction season. Not all projects are suitable for GPS use. Projects with dense tree canopy, large vertical cuts, or limited survey control may not prove suitable. On these projects, subgrade staking would continue to be performed using conventional methods.

INITIAL COORDINATION

The contractor needs to provide the GPS work plan as described in the provision to the engineer before the preconstruction conference so the engineer can evaluate the proposed plan. The design engineer, construction engineer, region surveyor, methods development engineer, appropriate management, and contractor survey personnel should be present at the preconstruction meeting to discuss the following points regarding grading with machine guidance:

- GPS work plan
- Project and survey schedules
- Key personnel, roles and responsibilities
- Methods for handling changes in the model and related matters
- Handling of survey data and support
- 3-D models and their formats

The project engineer should be in close contact with the region surveyor throughout the course of the project.

3-D MODEL DEVELOPMENT AND EXCHANGE

The contractor must develop and maintain the design model for use with the GPS machine guidance equipment, based on the initial survey information provided in the contractor staking packet, as discussed in CMM 7.10. The department recognizes that the contractor will need time to develop the model. To accommodate this, after the contract is awarded the contractor may request available survey and design information. The department will provide available information within 5 business days of receiving the request. If the contractor does not make the request to get survey information early, the department will provide survey information in the contractor staking packet at the preconstruction conference.

The contractor is responsible for ensuring the model agrees with the contract plans. If a plan error is discovered, the contractor must notify the engineer. The department will make necessary plan revisions and updates to the existing surface DTM, but the contractor is still responsible for updating the model and sending the revised version back to the department in LandXML format or other engineer-approved format.

The engineer should review the contractor's proposed model and perform spot checks by projecting known points generated from the plan cross sections onto the proposed model, and generate an error report. The engineer is responsible for maintaining an archive of DTM revisions and dates. The archive should include the DTM files and the time period for which each was active on the project.

SITE CONTROL AND CALIBRATION

The department is responsible for providing control from the initial survey. The contractor is responsible for verifying, supplementing, and maintaining the project control. 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.

The GPS machine guidance specification requires that a minimum of 6 control points or 2 points per mile be used for site calibration and that the site calibration be checked daily at control points not used in the calibration. The horizontal and vertical coordinates of all control points must be documented and presented to the engineer. These points should be constructed or located outside the anticipated construction footprint, and they should be available 2 weeks before the preconstruction conference.

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.

The number of site calibrations performed by the contractor should be limited. It is preferred that a single site calibration be used for the duration of the project, but there might be circumstances under which follow-up site calibrations are necessary. In these cases, independent construction checks should be made after each site calibration.

CONSTRUCTION CHECKS

The engineer should work with the region surveyor to develop a plan to perform construction checks. It is essential to provide some independent checks at project start-up to ensure contractor methods are meeting necessary tolerances. These checks should be performed using independent GPS equipment or conventional survey methods (e.g., total station or level), and should meet specified tolerances. The department reserves the right to do added checks as needed.

Daily Site Calibration Checks

Site calibration checks are the responsibility of the contractor, but should be reviewed with the region surveyor to verify they are within specified tolerances.

Horizontal and vertical tolerances are specified for site calibration checks but not for site calibration itself. Once the site calibration measurement process is complete, the RTK GPS software will report estimates for horizontal and vertical errors at each of the site calibration control points. The tolerances are 0.10 feet horizontal and 0.05 vertical for the site calibration checks. If any site calibration check exceeds specified tolerances, follow these steps:

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.
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.

Final Subgrade Checks

On completion of the subgrade the contractor must perform 20 or more randomly-selected subgrade checks per stage, per project, or per roadway mile, whichever is greater, against plan elevations. According to the definition of roadway in standard spec 101.3, a divided highway has two or more roadways. These points should be adjusted to the nearest practical project stations.

Before conducting the final random checks the engineer may want to direct the contractor to make additional non-random checks in out-of-tolerance areas or areas that otherwise raise concern. The engineer should also be aware of critical points, and have the contractor perform additional checks at these locations. Critical points include the following:

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

The specification requires the contractor to notify the engineer at least 2 business days before making the random subgrade checks. It is very important for the engineer to be present during the subgrade checks, and to make note of each check in the field diary.

If more than 1 of any 5 consecutively tested random subgrade points differs by more than 0.10 feet from the plan elevation, the grade is not suitable, and the contractor must make corrections to the grade. Random subgrade checks should then be performed again until 4 out of 5 consecutively tested points are within 0.10 feet of plan elevation.

The Construction and Materials Support Center (CMSC) is housed in the Department of Civil and Environmental Engineering on the University of Wisconsin-Madison campus. The CMSC was formed in partnership with the Wisconsin Department of Transportation (WisDOT) to focus on implementing research findings within the department and other local, state, and federal transportation agencies. In addition, the CMSC functions as a service and applied research group to deliver timely solutions to construction management and materials engineering problems for a variety of organizations. The mission of the Center is to develop research implementation strategies and tools to help WisDOT, public agencies, and industry rapidly implement new and relevant technologies throughout the project development process. The Center draws upon university expertise to collaborate with department personnel and the private sector to find solutions to problems, minimize delays to construction, and improve the quality and efficiency in which materials are used throughout the construction process. Emphases areas for the Center are:

- Accelerated construction techniques
- Construction project management
- Innovative project delivery processes
- Materials performance and production

The Center is staffed to conduct research, develop tools and techniques to enhance project cost-control and minimize scheduling delays in project construction, identify methods and processes to accelerate project delivery and construction activities, create strategies for departments of transportation and others to implement new techniques and technologies, assess new construction materials and create project specifications.

Services include training staff on new techniques and processes, developing application guidance tools for inclusion in manuals, and holding workshops and seminars. Academic staff incorporate the field applications and lessons learned into undergraduate and graduate level engineering courses taught at the UW-Madison.

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