Automated Machine Guidance Training

April 23, 28, 29, 2009

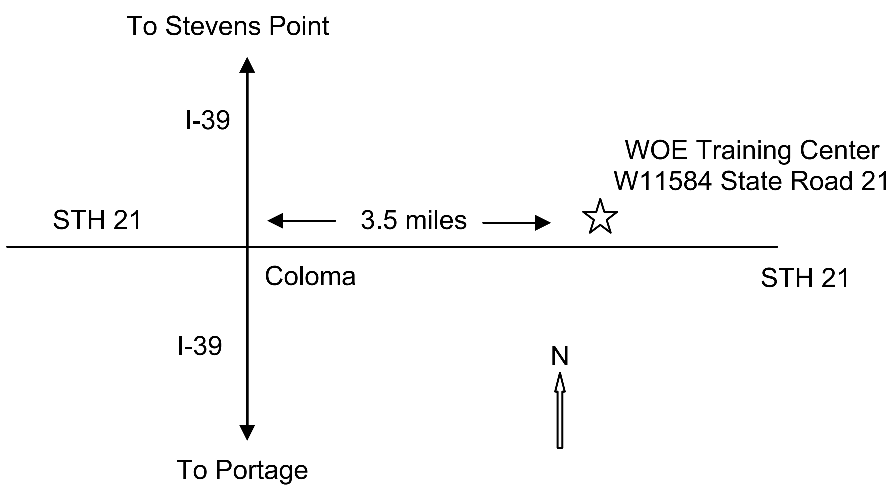
Wisconsin Operating Engineers Training Center
Coloma, WI

Automated Machine Guidance Training for WisDOT and Consultant Personnel
April 23, 28, 29, 2009 (Three One-Day Sessions)
WOE Training Center
Coloma, WI

Objectives:

1. Introduce operational principles of the Global Navigation Satellite System, GPS, and automated machine guidance.
2. Describe the development process for WisDOT's specification for sub grade and CMM language.
3. Examine the final spec and CMM language in detail.
4. Convey practical experiences of pilot project engineers.
5. Conduct field demonstrations and "hands-on" use of the technology.

WOE Training Center: The Wisconsin Operating Engineers Training Center is ideal for in-class and in-field training in automated machine guidance (AMG). Our in-class sessions will be held in one of the second-floor classrooms of the main building. Our field demonstrations will include use of AMG at a construction site on the Center's grounds.



For more information on the Center see http://www.woetrainingcenter.org/

Attire: For field sessions, please bring a hard hat and safety vest. Please also bring a pair of work boots or safety shoes in addition to the shoes you wear indoors. There is a shoe-changing area to keep dirt and mud from being tracked indoors.

Lunch: Lunch will be provided.

Professional Development Hours: A certificate for 7 PDHs will be provided to each participant who successfully completes the training.

Workbook: Handout materials will include a workbook with presentation slides, the sub grade specification and guidance language, and other information.

Instructors: Alan Vonderohe (Construction and Materials Support Center, UW-Madison); Jeff Servi (WOE Training Center); Pilot project engineers (at least one per session): Dan Schneider, Barry Paye, Greg Graf, Doug Weigand, Brett Vissers.

Schedule:

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

8:15-9:45am: GNSS / GPS and how it works; code and carrier phase; differential and RTK; site calibration / localization concepts (Alan Vonderohe)

9:45-10:00am: Break.

10:00-10:45am Automated machine guidance concepts; 3D model concepts; positioning the machine in the model. (Alan Vonderohe / Jeff Servi)

10:45am-12:00pm: WisDOT automated machine guidance program; specification development; pilot projects; final specification and guidance language (CMM) (Alan Vonderohe).

12:00-1:00pm: Lunch.

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

2:30-2:45pm: Break

2:45-4:15pm: Field demonstration; site calibration; grading; sub grade checking (Jeff Servi / Alan Vonderohe).

4:15-4:30pm: Training session evaluation (Trainees).

Automated Machine Guidance Training: WisDOT Program

Wisconsin Operating Engineers' Training Facility, Coloma, WI

April 23,28,29, 2009

Introductions

- Instructors:
  - Alan Vonderohe (Construction and Materials Support Center – UW-Madison).
    - vonderohe@centurytel.net
  - Jeff Servi (WOE Training Facility).
    - Jeff@woetrainingcenter.org
  - Pilot Project Engineers: Dan Schneider, Barry Paye, Brett Vissers, Greg Graf, Jack Laning

Introductions

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

Objectives of the Training

- Introduce operating principles of Global Navigation Satellite System (GNSS), GPS, and automated machine guidance (AMG).
- Describe development process for WisDOT's AMG specification for sub grade and CMM language.
- Examine final spec and CMM language in detail.
- Convey practical experiences of pilot project engineers.
- Conduct field demonstrations and "hands-on" use of GPS and AMG technology.
- Most importantly: Address any questions you might have.

Schedule

- 8:00am-8:15am: Introduction; objectives of training session; overview of training session (Alan Vonderohe).
- 8:15-9:45am: GNSS / GPS and how it works; code and carrier phase; differential and RTK; site calibration / localization concepts (Alan Vonderohe).
- 9:45-10:00am: Break.
- 10:00-10:45am: AMG concepts; 3D model concepts; positioning the machine in the model (Alan Vonderohe / Jeff Servi).
- 10:45am-12:00pm: WisDOT AMG program; specification development; pilot projects; final specification and guidance language (CMM) (Alan Vonderohe).

Schedule

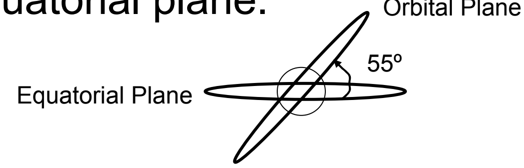
- 12:00-1:00pm: Lunch.
- 1:00-2:30pm: Practical experiences in AMG project management (panel of pilot project engineers).
- 2:30-2:45pm: Break.
- 2:45-4:15pm: Field demonstration; site calibration; grading; sub grade checking (Jeff Servi / Alan Vonderohe).
- 4:15-4:30pm: Training session evaluation (trainees).
- 4:30-6:30pm: 2-hour final exam (graded A-F, no pass / fail) (trainees).

Global Navigation Satellite System (GNSS)

- GPS is considered a component of GNSS which also includes
  - GLONASS (Russia).
  - Galileo (European Union).
  - COMPASS (China).
- The full name of GPS is "Navigation Satellite Timing and Ranging Global Positioning System" (NAVSTAR GPS).

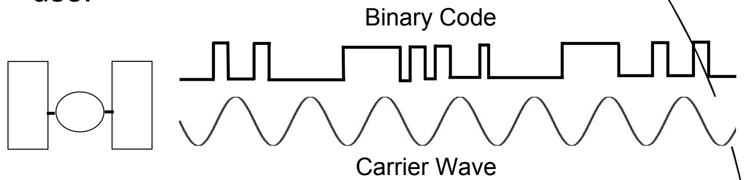
GPS Satellite Constellation

- 24 active satellites (and as many as 7 back ups).
- 20,200km altitudes.
- Four satellites in each of six equally-spaced orbital planes, inclined at 55º to the equatorial plane.



Satellite Radio Signals

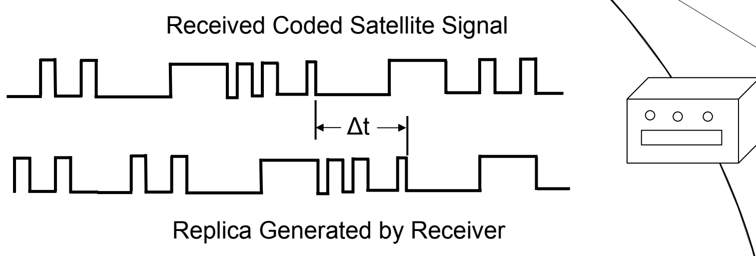
- Each satellite broadcasts as many as five coded signals on as many as three frequencies.
  - Some codes are encrypted and intended for military use.
  - Some codes are open and intended for civilian use.



Coded signals are modulated on higher-frequency carrier waves.

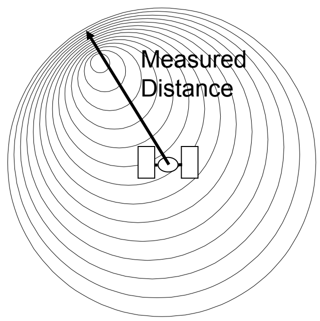
What Does a Receiver Do with the Signals?

- Signals do not explicitly tell the receiver where it is.
- Receiver generates a replica of coded signal.



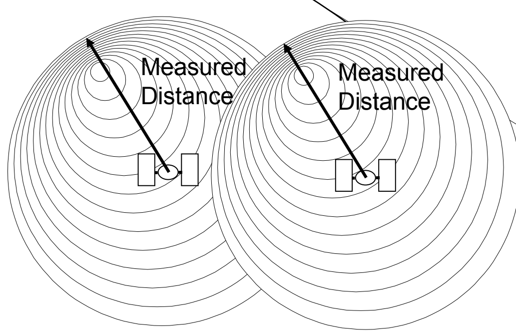
Receiver measures time delay (Δt) between replicated and received signals and multiplies by the speed of light to obtain distance from satellite to receiver antenna center.

Position Computed from Measured Distances (Trilateration)



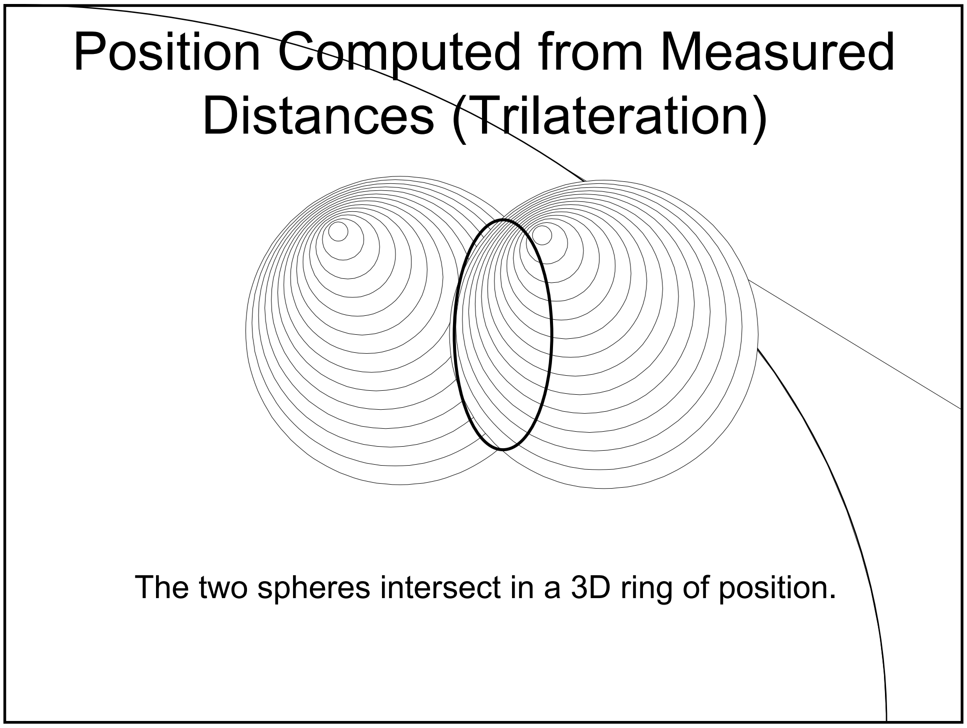
If X,Y,Z coordinates of satellite are known, measured distance defines a sphere of position for receiver's antenna center.

Position Computed from Measured Distances (Trilateration)



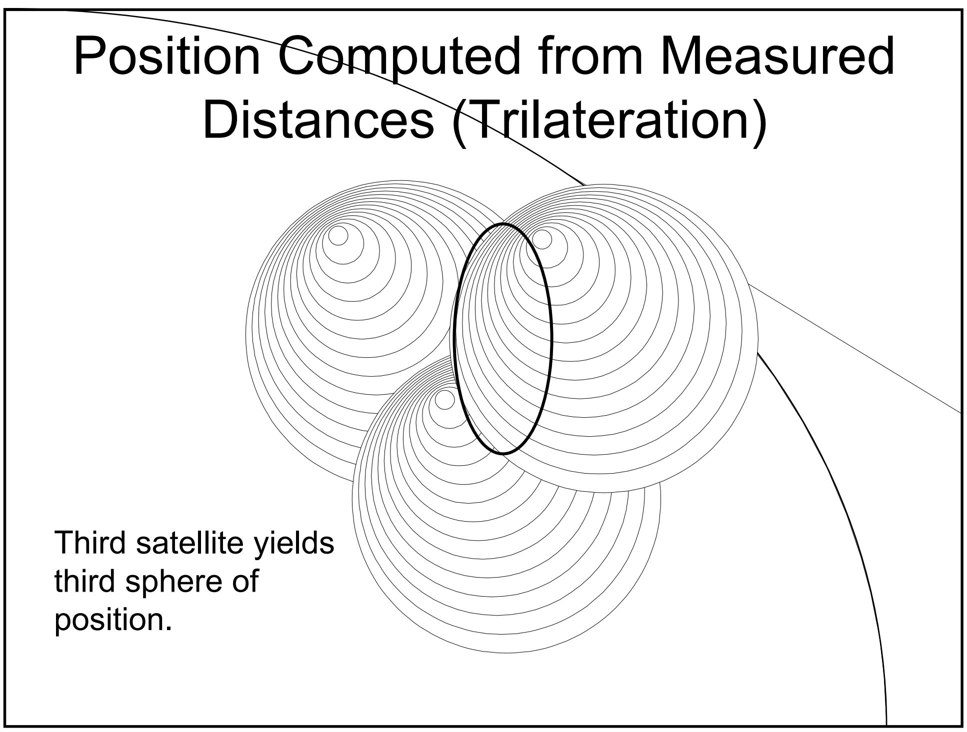
Second satellite and measured distance define second sphere of position.

Position Computed from Measured Distances (Trilateration)



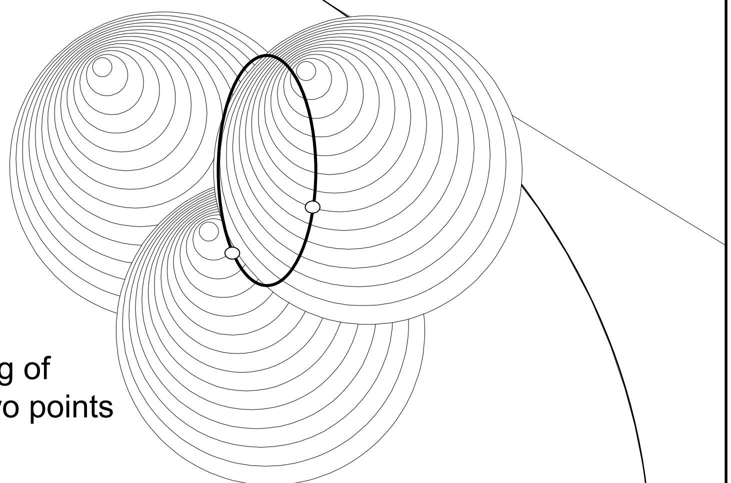
The two spheres intersect in a 3D ring of position.

Position Computed from Measured Distances (Trilateration)



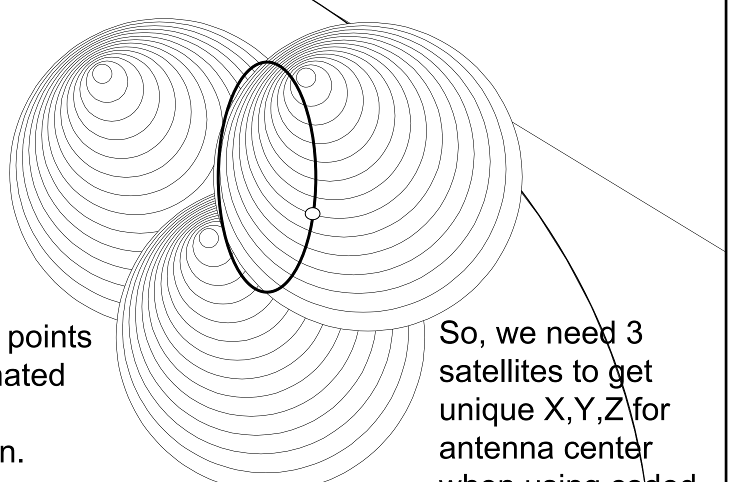
Third satellite yields third sphere of position.

Position Computed from Measured Distances (Trilateration)



Third sphere intersects ring of position at two points in 3D space.

Position Computed from Measured Distances (Trilateration)



One of these points can be eliminated with rough approximation.

So, we need 3 satellites to get unique X,Y,Z for antenna center when using coded signals.

Problem: Δt Must be Measured Very Accurately

- Distance = (Δt)* (speed of light).
- Small error in Δt causes large error in distance.
- Must have excellent clocks.
  - No problem for satellites (have rubidium and cesium atomic clocks). They are even corrected for relativity.
  - But receivers with atomic clocks would cost so much no one could afford to use GNSS.
  - Good, but cheap, clock in receiver has error.
  - If we use a fourth satellite, we can include a receiver clock error term in the equations for computing antenna coordinates, thereby eliminating its effect.
  - So, four satellites are required to get accurate positions with coded signals. More are desired to force redundancy into solution.

How Does the Receiver Know Where the Satellites Are?

- Each satellite's orbital parameters are included in its coded signal (broadcast ephemeris).
- The orbits are irregular, unknown, and changing.
  - Earth's gravitational field is not uniform.
  - Sun and Moon have gravitational effects.
  - Solar radiation pressure.
  - Eclipses (satellite in Earth's shadow).
    - Changes in solar radiation pressure.
    - Solar panels cannot be pointed at Sun. Causes satellite to wobble.

How Do the Satellites Know Where They Are?

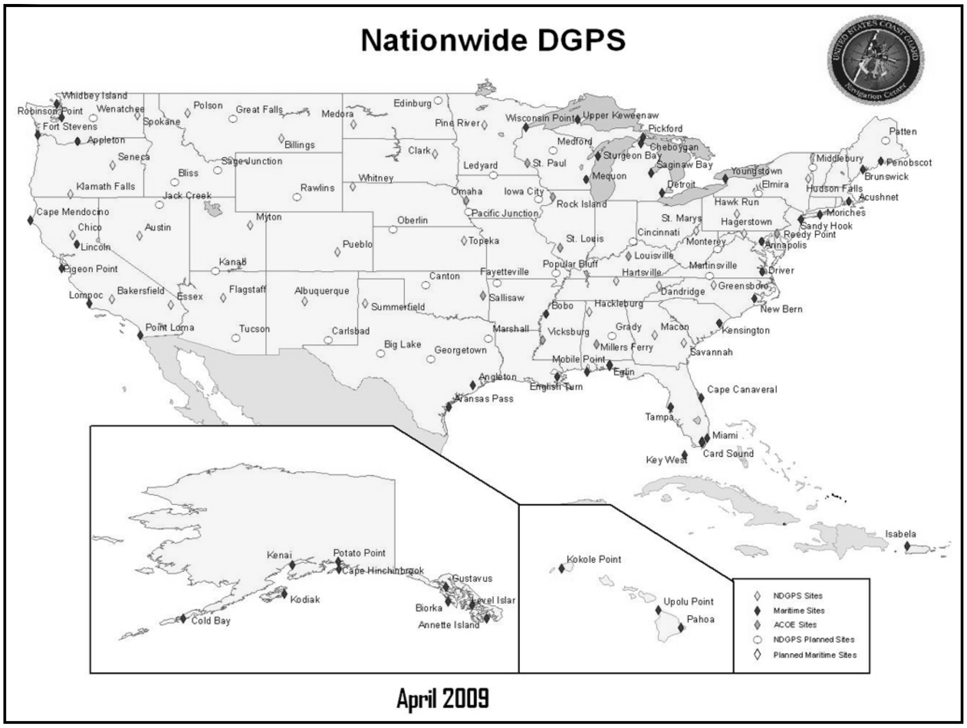
- Periodically (at discrete times), they measure distances among themselves to determine their relative locations.
- Their positions are also monitored by ground tracking stations that can upload data to satellites.
- Broadcast ephemeris must be continuous, so a predictive model is used between measurement epochs.
  - Model degrades with time.
  - Precise ephemeris (from ground tracking stations) can be used in post-processing mode to improve accuracies beyond those that can be realized in real time (using broadcast ephemeris).

Atmospheric Effects

- Measured distances to satellites are affected by atmospheric refraction (speed of light through atmosphere is slower than speed of light in vacuum).
  - Effect is temporally and spatially variable.
  - Atomic-particle-level effects in upper atmosphere (ionosphere).
  - Pressure, temperature, and humidity effects in lower atmosphere (troposphere).
  - Cannot be cancelled by observing more satellites.
  - So severe at low angles above horizon, satellites below 10º-15º are usually “masked out” or ignored.
  - Limits position accuracy to about ±10m or more.

Differential GPS (DGPS)

- Atmospheric effects are fairly uniform over limited areas.
- So, if we know the coordinates of a receiver extremely well (base station), we can use its GPS measured coordinates to determine corrections to satellite distances.
  - These corrections can be applied at other receiver (rover) locations in the area to improve their accuracies.
  - If corrections are broadcast from the base station, a rovers' coordinates can be determined in real time.
  - Accuracies to ±2-5m.

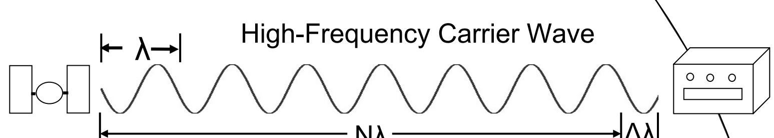


Differential GPS (DGPS)

- DGPS for aviation applications:
  - Wide-Area Augmentation System (WAAS).
    - Corrections broadcast over large areas from WAAS satellites.
    - In-flight navigation.
  - Local-Area Augmentation System (LAAS).
    - Corrections broadcast over local airport areas from ground stations.
    - Landing approach navigation.

Carrier Phase Measurements

- Frequency of the code limits the accuracy of code distance measurements (called "pseudoranges").
- Wave that carries the coded signal has a much higher frequency.
- If we use the carrier wave for distance measurements, we obtain much higher accuracies.



λ is known.

Δλ ("phase shift") is measured by receiver.

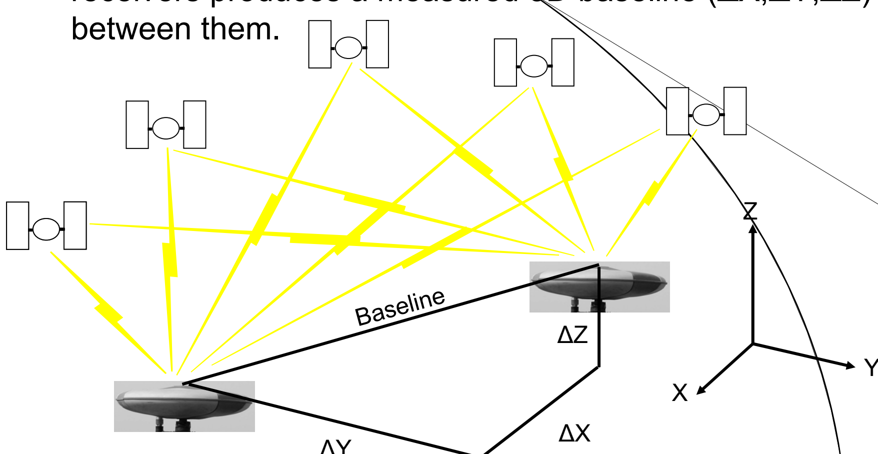
N ("integer ambiguity") is unknown.

Resolving the Integer Ambiguity

- Occupy a known point.
  - Distance to the satellite will be known, so N can be counted.
- Use two receivers observing the same satellites at the same time and take differences between phase shift measurements.
  - Differencing accounts for clock errors, atmospheric effects, and orbital errors, in addition to integer ambiguity.

Relative Positioning

- Differencing phase shift measurements between two receivers produces a measured 3D baseline (ΔX,ΔY,ΔZ) between them.



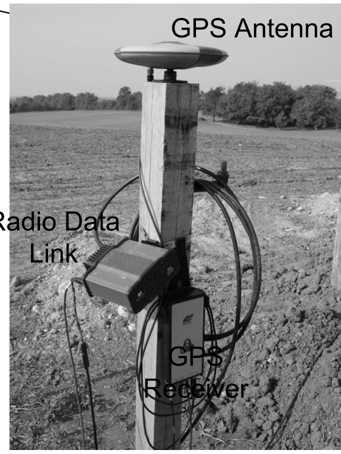
Relative Positioning

- Long occupation times, multiple-frequency receivers, and post-processing with precise ephemerides, yield baselines with accuracies of a few millimeters.
- A well-designed network of baselines connecting unknown and known points yields best possible results.
- What if we want carrier-phase accuracy in real time as we are moving around?

Real-Time Kinematic (RTK) GPS

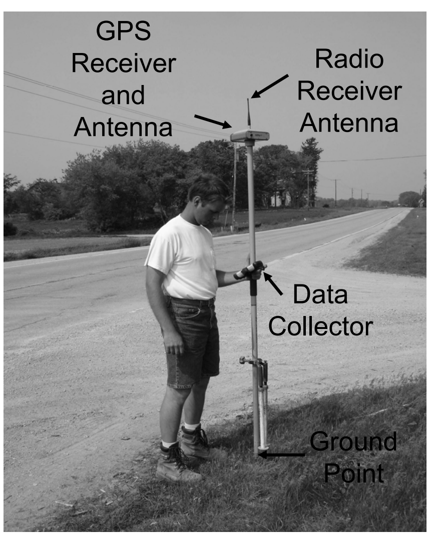
- A base station receiver over a known control point and any number of moving rovers within a 10km radius use carrier-phase measurements to yield accuracies of ±2-3cm in all three coordinates of each rover with 95% confidence in real time (if everything goes right).

RTK Base Station



- Base station antenna at constant fixed height above control point.
- Receiver broadcasts the control point coordinates and either its phase shift measurements from all visible satellites or corrections to its phase shift measurements.
- Radio transmitter has 3-5km range that can be extended with repeaters.

RTK Rover



- Antenna center at fixed height above bottom tip of range pole (ground point).
- Receiver receives both satellite signals and base station signals.
- Receiver differences the phase shifts, accounts for antenna heights, and obtains a baseline (ΔX,ΔY,ΔZ) between the base station control point and the rover ground point.
- ΔX,ΔY,ΔZ are added to the base station control point coordinates to obtain coordinates of ground point (displayed and stored by data collector).

Integer Ambiguities

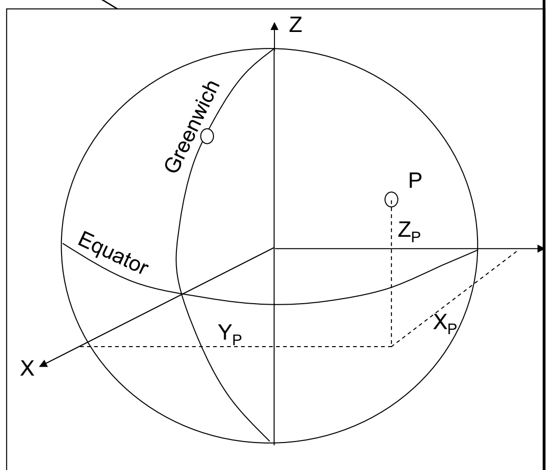
- At the base station:
  - Easily resolved because the coordinates are known.
- At the rover(s):
  - Short “initialization” period at start up and whenever there is “loss of lock”.
    - Requires fifth visible satellite.
  - Sophisticated “on-the-fly” resolution algorithms are running all the time.
    - Computing code pseudoranges and performing regressions and statistical analyses to obtain most reliable value for N (for each satellite).

Coordinate Systems and Datums

- Project control coordinates for design and construction are Northing, Easting, Elevation.
  - N,E are rectangular map projection coordinates (e.g., WISCRS – Dane County; State Plane – Central Zone) usually on NAD 83 (1991) or NAD 83 (1997).
  - Elevation is usually referenced to NAVD 88 or NGVD 29.
  - Horizontal and vertical datums are separate.
- GPS satellite ephemerides and, therefore, all initially-derived coordinates are on a <u>completely different</u> coordinate system.

GPS is Referenced to a 3D Rectangular Geocentric Coordinate System

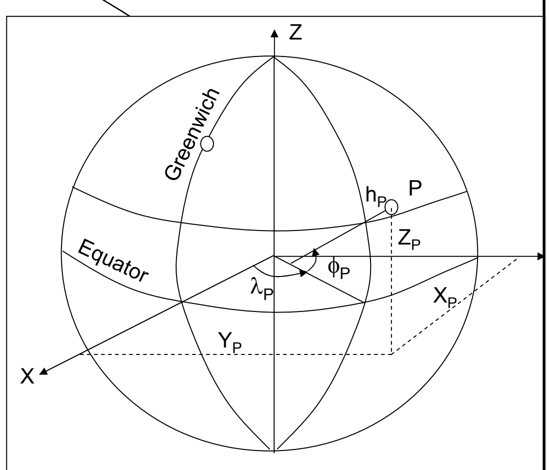
- Geocentric coordinates are based upon a 3D right-handed system with origin at Earth's center.
  - XY plane coincides with equatorial plane.
  - +X axis passes through Greenwich Meridian.
  - Z axis coincides with spin axis.



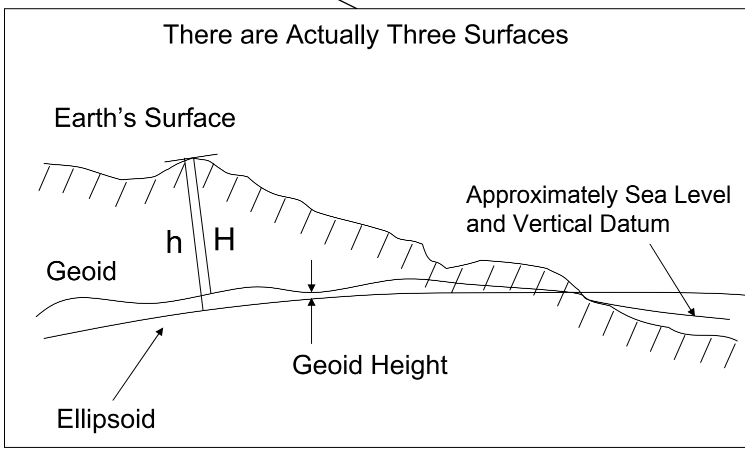
How do we obtain N,E,Elev from X,Y,Z?

Three Coordinate Transformations

- First is from geocentric (X,Y,Z) to geodetic (ϕ = latitude, λ = longitude, h = "ellipsoid" height).
- For any point, there are direct and inverse transformations between X,Y,Z and ϕ,λ,h.
- h is **<u>NOT</u>** elevation. <u>NEITHER IS Z</u>.



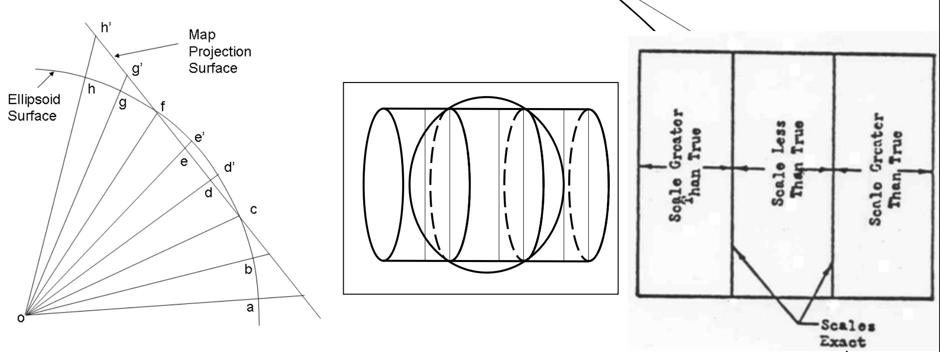
Ellipsoid Height (h) and Elevation (H)



Geoid heights can be obtained by combining GPS and differential leveling or from mathematical models (GEOID03 / GEOID09) stored in the rover's data collector.

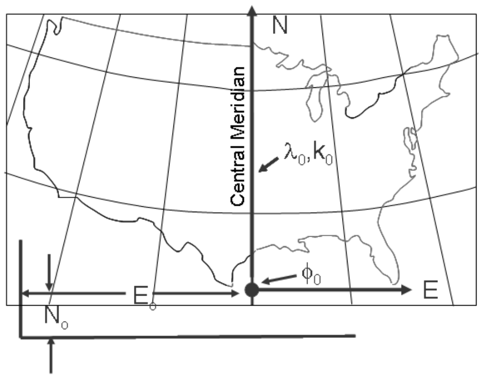
Second Coordinate Transformation

Rover transforms geodetic coordinates (Φ,λ) of ground point into N,E on an arbitrary map projection with its origin at centroid of project control configuration.



Transverse Mercator Projection

Transverse Mercator Projection



Projection Parameters:

λ_0 (longitude of central meridian)

k_0 (scale factor along central meridian)

ϕ_0, E_0,N_0 (latitude, false easting, false northing of the coordinate origin)

• For a highway project, the origin of the arbitrary projection will be local to the project.

• There are direct and inverse functions for $(\Phi,\lambda) \leftrightarrow (N,E)$.

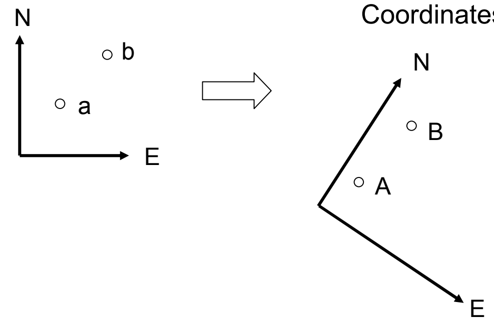
Third Coordinate Transformation

- Rover transforms N,E,Elev of ground point in arbitrary map projection into N,E,Elev in project coordinate system.
- Two step transformation.
  – Horizontal (N,E) by 2D conformal (2 translations, 1 rotation, 1 scale factor).
  – Vertical (Elev) by 1 translation and 2 rotations.
- Transformation parameters computed by visiting well-distributed project control and using differences between measured arbitrary coordinates and known project coordinates.
  – Process is called “site calibration” or “localization”.
  – Critical initial field procedure for RTK and AMG setup.

Horizontal Component (2D Conformal)

Arbitrary Map Projection Coordinates

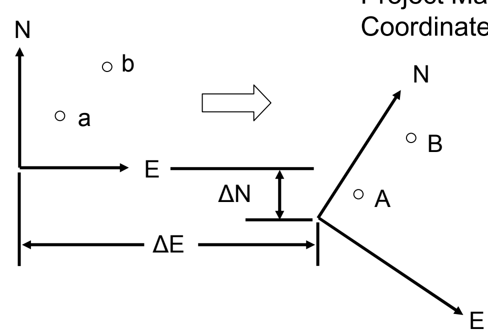
Project Map Projection Coordinates



Horizontal Component (2D Conformal)

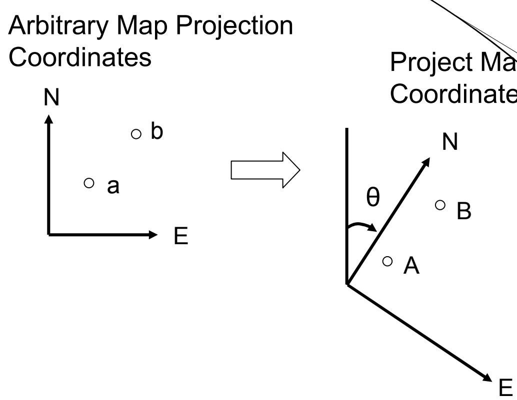
Arbitrary Map Projection Coordinates

Project Map Projection Coordinates



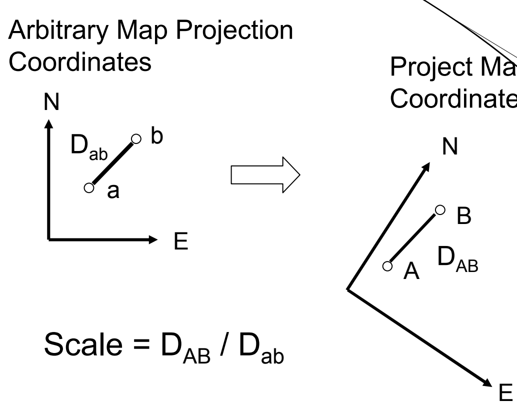
There are two translations.

Horizontal Component (2D Conformal)



There is one rotation.

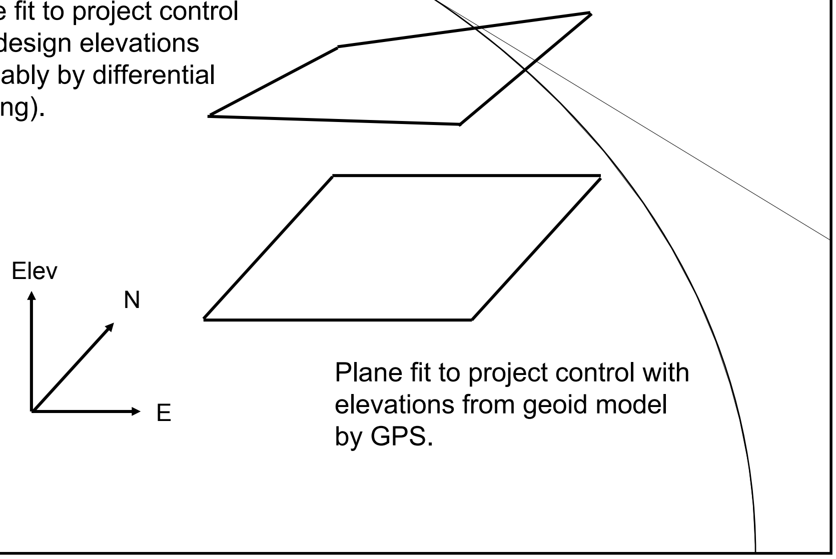
Horizontal Component (2D Conformal)



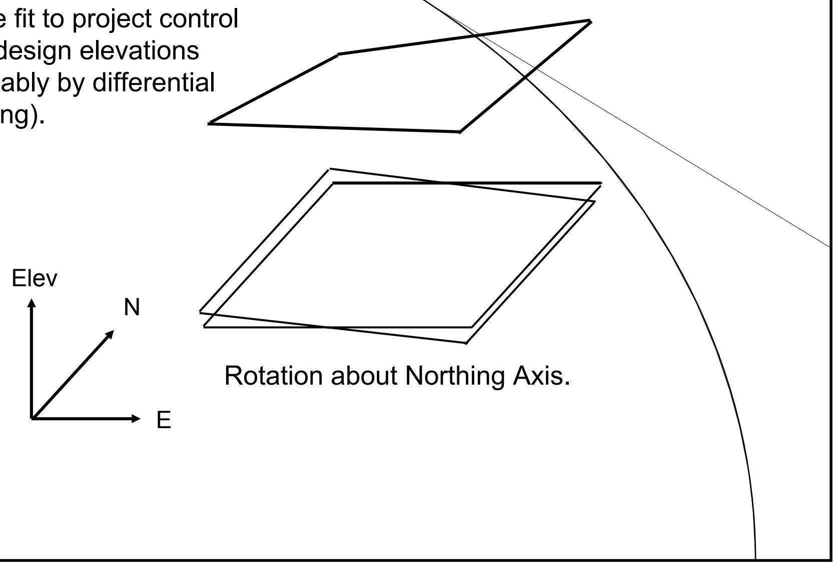
Scale = D_{AB} / D_{ab}

There is one scale factor.

Vertical Component

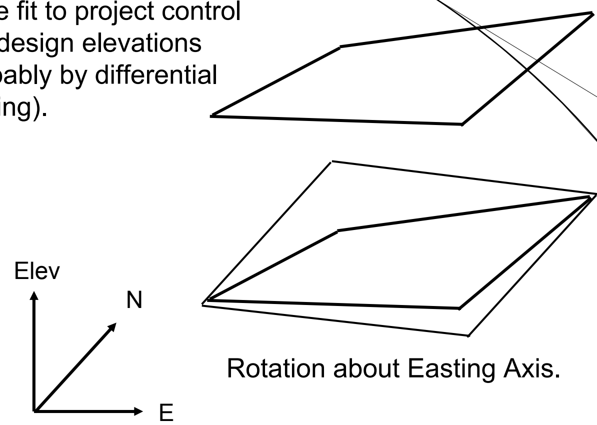


Vertical Component



Vertical Component

Plane fit to project control with design elevations (probably by differential leveling).



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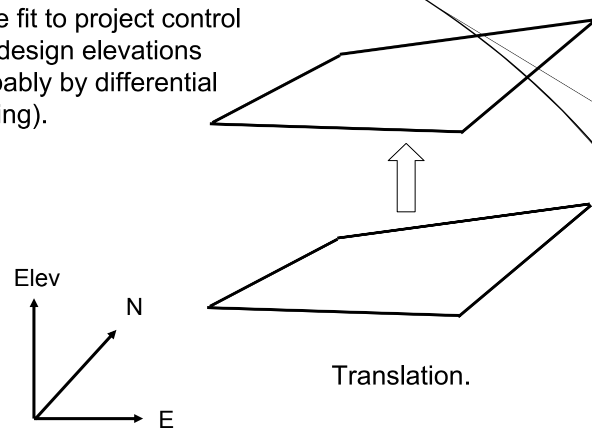
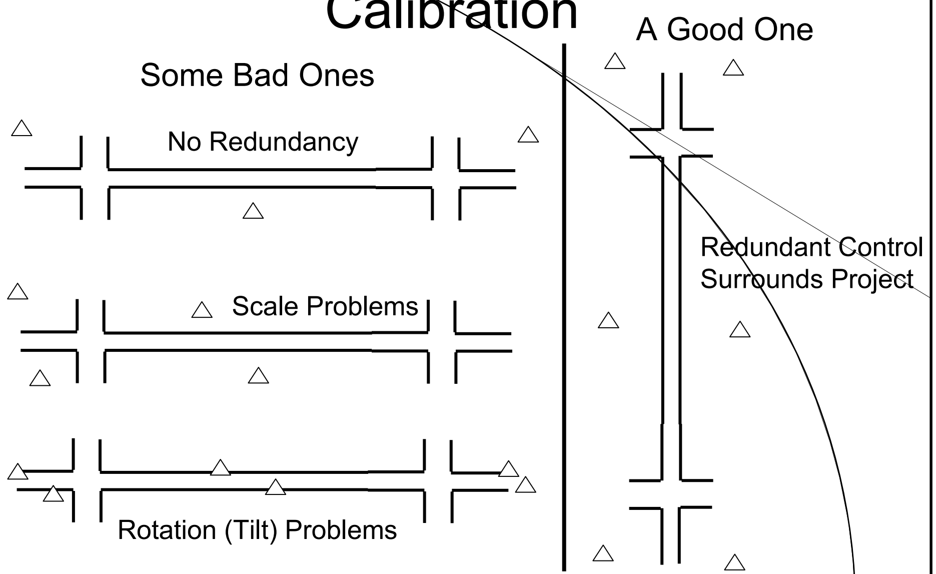


Control Configurations for Site Calibration



The Sum of What Happens

- All transformations needed to obtain N,E,Elev (project) from X,Y,Z (geocentric) are computed on-the-fly in real time by rover.
- All phase shift measurements; broadcasting by base station; differencing of phase shifts; integer ambiguity resolutions; computation of X,Y,Z from baselines; application of geoid model for elevations; and transformations to obtain project coordinates (N,E, Elev) happen in the background and are not apparent to users.

RTK Limitations

- Maximum baseline length = 10km.
  - Assumption of uniform atmosphere breaks down.
  - Integer ambiguities might not be resolvable.
- Satellite signals can be blocked by opaque objects.
- Solar activity disrupts the ionosphere.
- Position Dilution of Precision (PDOP).
  - Index indicates “geometric strength” of solution based upon number and configuration of visible satellites.

RTK Limitations

- “Multipath”.
  - Errors introduced by satellite signals being reflected off nearby hard surfaces.
- Interference with base station radio signal.
  - Power lines parallel with baseline.
  - Non-GPSers on same frequency.
    - Transmitter does channel hopping through multiple open frequencies in unrestricted band.
- Must have good project control to ensure quality site calibration.

GNSS Coming Attractions

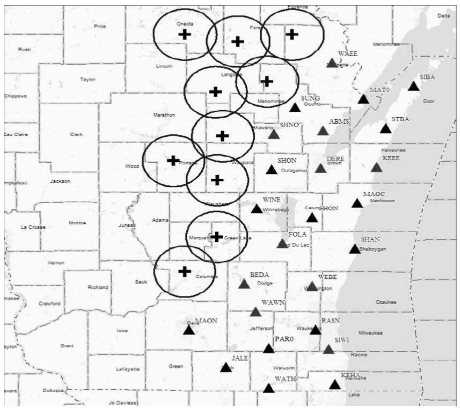
- GPS Modernization.
  - More satellites, more signals, more frequencies, more power.
- GLONASS (Russia) is strong.
  - 17 satellites.
- Galileo (European Union) is shaky.
- COMPASS (China) is ambitious.

What's Happening Locally?

- Wisconsin Continuously-Operating Reference Stations (WisCORS).
  - Under development by WisDOT with fiscal assistance from NOAA.
  - Statewide network of permanent base stations with communication links to central servers.
  - Servers send individualized corrections to rovers by subscribed cellular connection.
  - Supports RTK positioning to ±2-3cm at 95% confidence.
  - Eliminates need for local base station.

WisCORS

Zone 1 went operational in July, 2008.



Triangles: Zone 1 Crosses: Zone 2

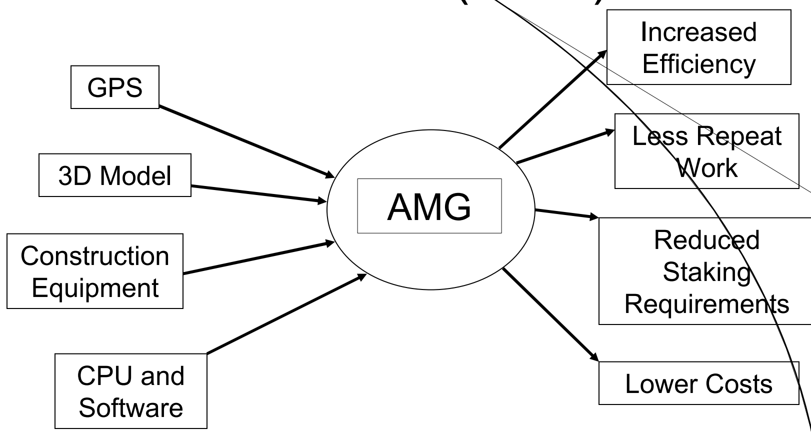
- More than 120 subscribed users as of April, 2009.
- 5-year completion plan for entire state.
- Support for automated machine guidance is being tested.

WisCORS Base Station

- Below ground, the reinforced concrete post is 3 ft in diameter and 12 ft deep.
- This thing is going to stay put.

https://wiscors.wi.gov/

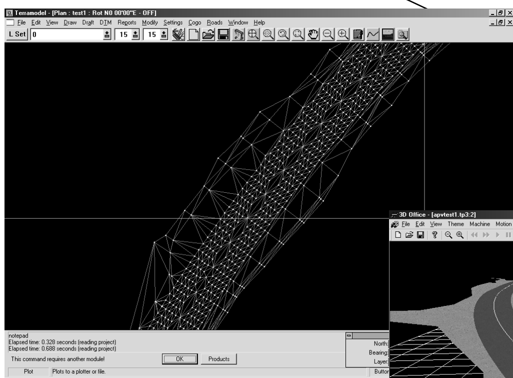
What is Automated Machine Guidance (AMG)?



What is the 3D Model?

- At a minimum, it is a graphic file containing:
  - A representation of the design surface in the project coordinate system.
  - Horizontal alignment tied to project coordinate system.
    - Relates (N,E,Elev) to (Station,Offset,Elev).
- Can also contain:
  - Existing surface (from photogrammetric survey).
  - Line work (centerline, reference line, shoulder breaks, ditch line, etc.)
  - Vertical alignment.
  - Other desired graphic elements.
- Model is continuous across the project.

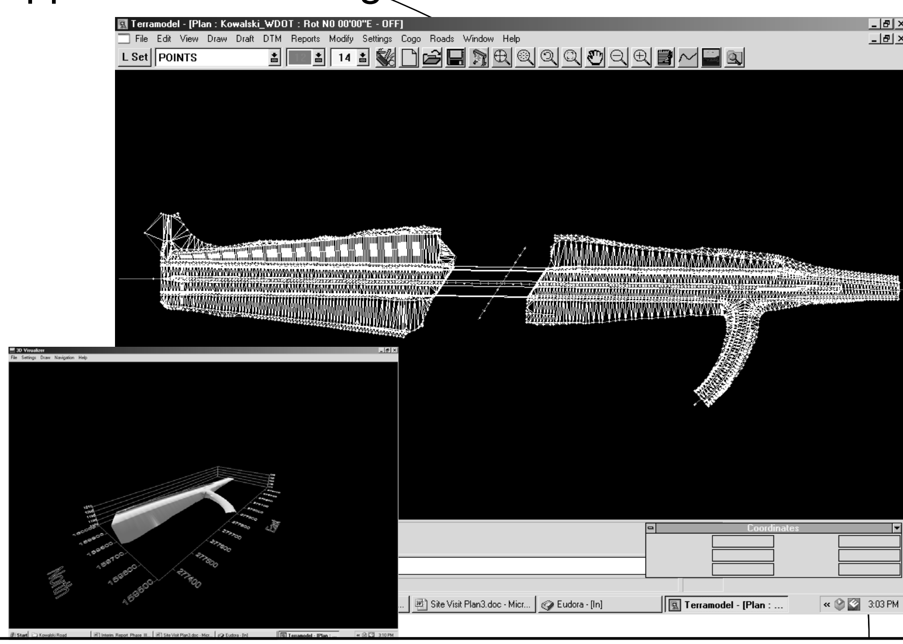
3D Model



Design Surface and Alignment.

Surface is a Triangulated Irregular Network (TIN).

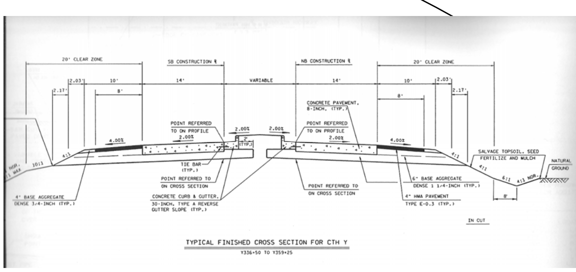
Approaches to Bridge Over I-39 South of Wausau



How is the 3D Design Surface Model Constructed?

- Laboriously, from the plans.
- Break lines and mass points are derived from cross-sections and alignments.
  - Straightaway stretches on mainline are fairly easy.
  - Intersections and superelevation transitions require much more time because necessary information is not on cross-sections.
- Break lines and mass points are “triangulated” to create a “TIN” surface that is continuous across the project.
  - Software does this.

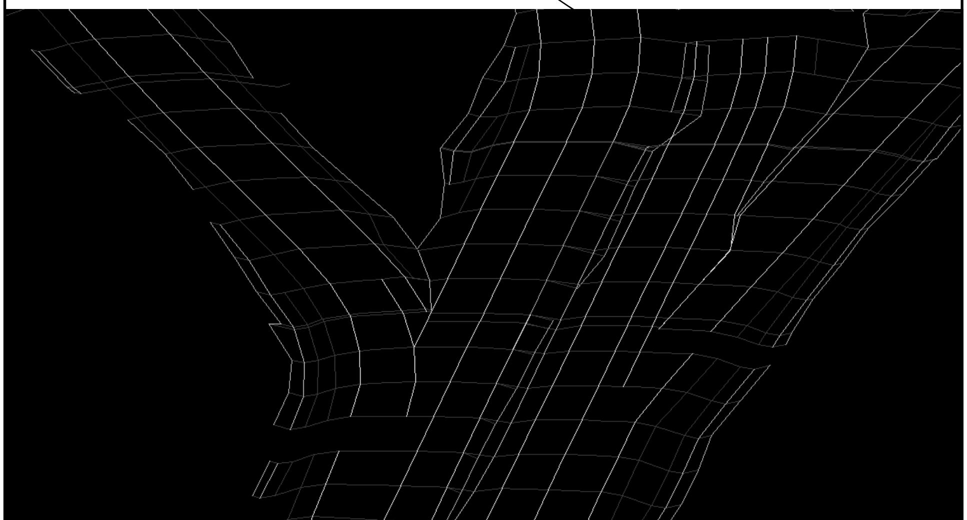
Start with Plans and X-Sect Reports



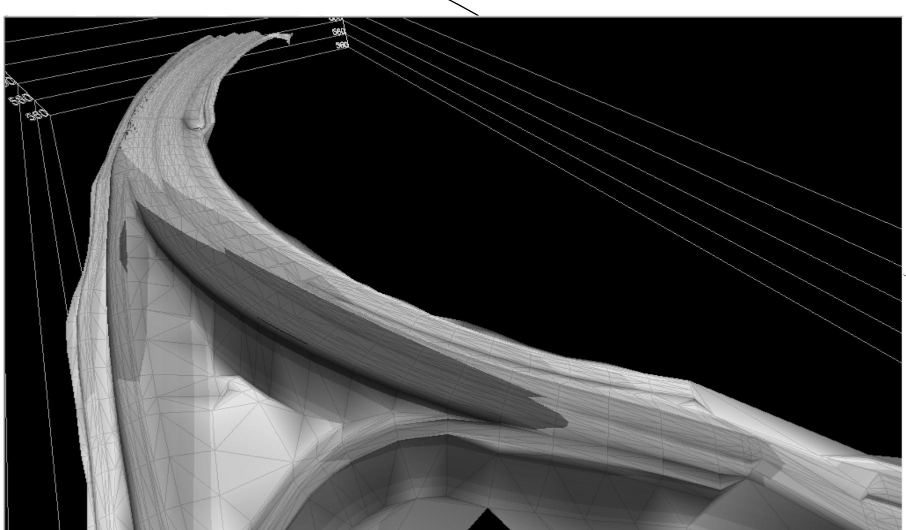
CAiCE Slope Stake Report
Alignment Used for Station and Offset: OLDRL1

STATION	OFFSET	PLAN ELEV	FIELD ELEV	C/F	POINT TYPE	SLOPE
21+00.00	-82.41	828.64			SS	
	-77.41	829.01		F	SIL	1: 4
	-57.09	834.09			SHLD	0.02 ft/ft
	0	835.23				-0.02 ft/ft
	57.09	834.09				1: 4
	61.45	833			DPRT	1: 4
	78.02	837.14		C	SIR	
	83.02	838.4			SS	

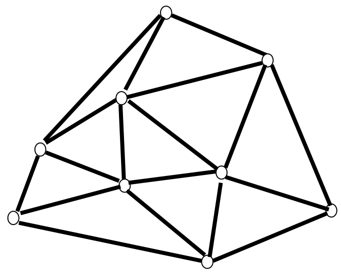
Build Break Lines and Mass Points



Generate TIN



What is This TIN?



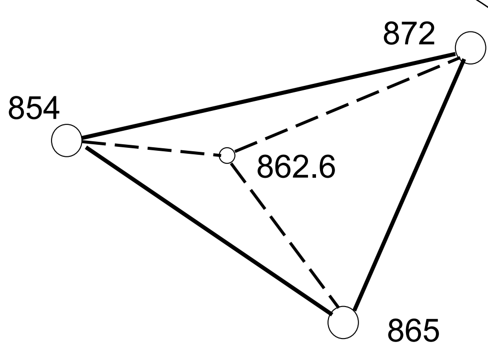
- It is a surface made up of contiguous triangular facets.
- It is not mathematically continuous because there are slope breaks at each edge.

- We know N,E,Elev at each vertex.
- Therefore, we can compute the equation of the plane for each triangle by solving three equations for a,b,c:

$$Elev_1 = a(E_1) + b(N_1) + c$$
$$Elev_2 = a(E_2) + b(N_2) + c$$
$$Elev_3 = a(E_3) + b(N_3) + c$$

What is This TIN?

Elevations can be interpolated at any N,E.



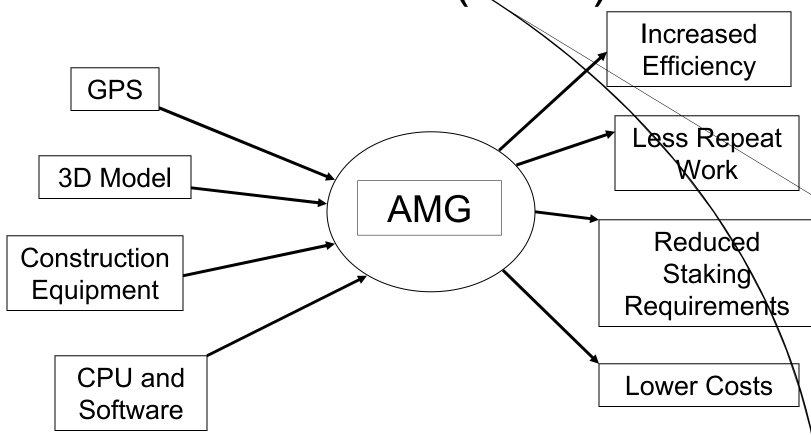
How can we do this?

Because we now know the equation of the plane for each triangle:

Elev = a(E) + b(N) + c.

- Of course, we need to know which triangle contains the point (N,E).
- This is a separate “point-in-polygon” problem.

What is Automated Machine Guidance (AMG)?



How is the Equipment Rigged?

How is the Equipment Rigged?

How is the Equipment Rigged?

Third degree of freedom by tilt sensor, inertial measuring unit (IMU), or computation from sequence of previous positions.

How is the Equipment Rigged?

How is the Equipment Rigged?

Radio Antenna in Cab.

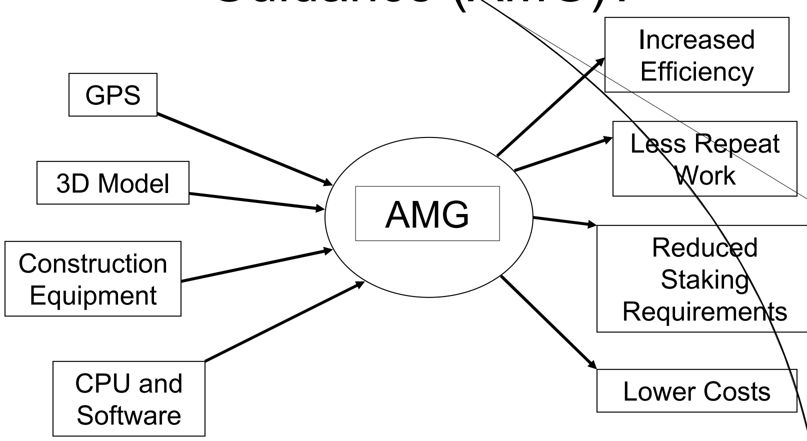
How is the Equipment Rigged?

There is a model of the blade's position with respect to the GPS antennae in the on-board computer's memory.

Periodically, the blade must be checked for wear.

Graders, dozers, scrapers, excavators, rollers, and pavers can all be rigged (even haul trucks).

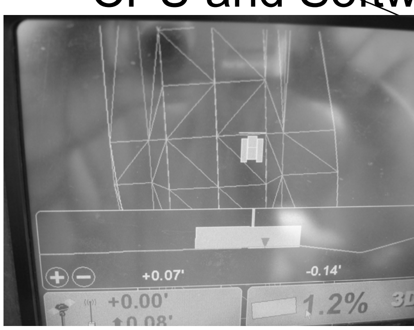
What is Automated Machine Guidance (AMG)?

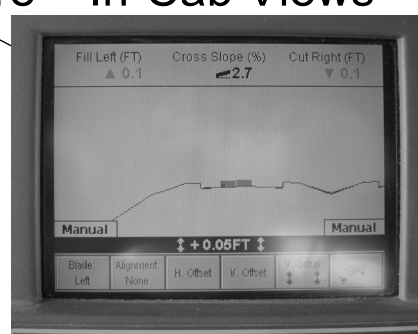


What Do the CPU and Software Do?

- The GPS coordinates and blade model are used to position machine in 3D model at all times.
- Necessary cut or fill at any position (e.g., opposite ends of the blade anywhere on the project) are known at all times.
- Display provides this information to operator in a number of optional views.
- CPU is linked to machine's hydraulics, so blade can be set to correct position automatically as machine moves.
  - Typically done on last few passes.
  - Operator merely steers.

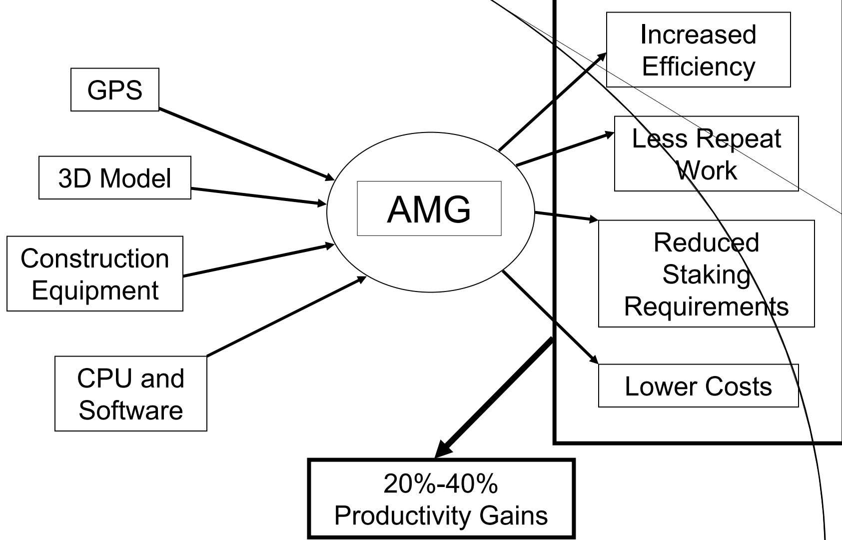
CPU and Software – In-Cab Views





Operator steers the machine but blade can be positioned automatically.

Benefits

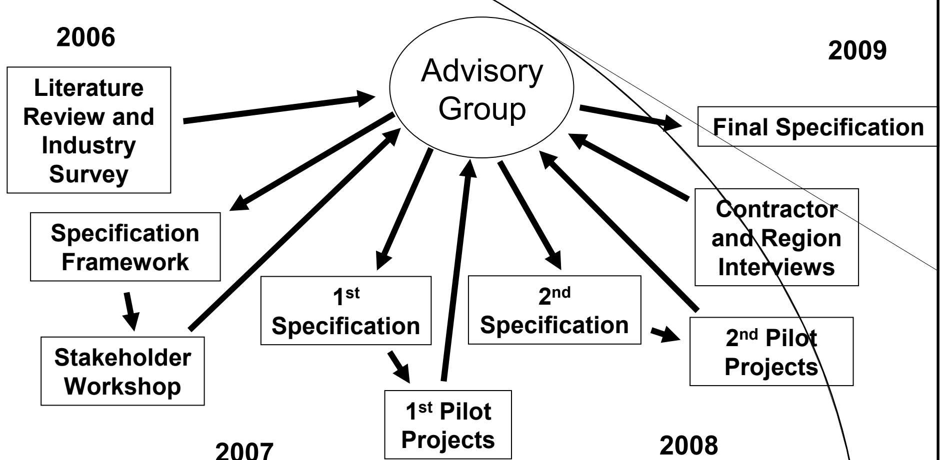


Finished Subgrades, Slopes, and Ditches

Critical Factors

- Site calibration / localization.
- Equipment calibration.
- Development, maintenance, and quality of 3D model.
- Quality assurance of finished sub grade.
- Knowledge, skill, and comfort level of project personnel.

Sub Grade Specification Development Process



Specification Evolution – 1st Spec

- No sub grade stakes required.
- Engineer can require reversion to conventional methods.
- Contractor provides loaner rover and training.
- GPS work plan:
  - Equipment; staff qualifications; project control; site calibration and checks; equipment calibration; sub grade checks.
- 3D model:
  - Dept provides “seed” data; contractor builds model and ensures conformance with plans; Dept checks model; provision for revisions driven by changes to plans; specified data exchange format.

Specification Evolution – 1st Spec

- Site calibration:
  - Greater of 6 control points or 2 per mile; checks every 5 hours at independent control to be within ±0.10 ft. horizontally and ±0.05 ft. vertically.
- Sub grade checks:
  - 20 or more per mile; randomly selected; 4 of any 5 consecutive must be within ±0.10 ft. of plan elevation; Dept makes additional periodic sub grade checks.
- Dept pays for repeat work if GPS machine guidance rejected by engineer for reasons beyond contractor’s control.

Specification Evolution – 2nd Spec

- After two pilot projects using 1st spec.
  - Relaxed frequency of site calibration checks to one per day.
  - Added language to affirm paper plans as contract documents (e.g., sub gade checks to be against elevations shown on plans).
  - Minimum of 20 sub grade checks per roadway mile.
  - Revised formats for data exchange to make more flexible.

Specification Evolution – 3rd Spec

- After three more pilot projects using 2nd spec and interviews with contractors and regions.
  - Removed requirement for loaner rover.
  - Contractor develops 3D model, ensures conformance with plans and provides to Dept. No "seed" data or model checking by Dept.
  - Minimum of 20 sub grade checks per roadway mile, project, or stage. Checks made at full stations. Engineer pre-notified and uses as "sign-off".
  - Repeat work double payment condition eliminated.
- For reports see http://cmsc.engr.wisc.edu/reports.html

Current and Future Expectations

- Specification is an optional special provision that replaces sub grade staking as a bid item on all 2009 projects that include grading.
- Will become component of general specifications for 2010 and beyond.
- WisDOT will monitor performance of sub grade spec while embarking on development of spec for base course, then paving.
- WisDOT deploying 3D design technology – headed towards delivery of 3D models as a design product.

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.

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.

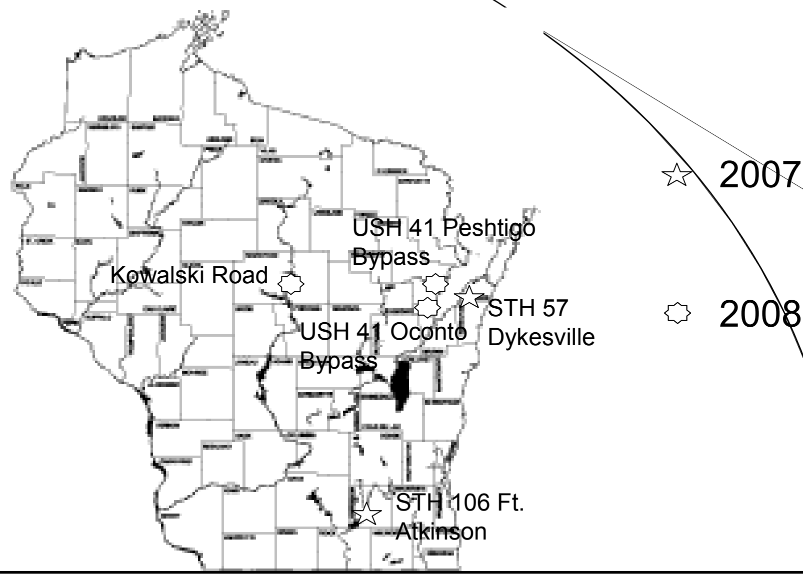
Before conducting the final random checks the engineer may want to direct the contractor to make additional non-random checks in out-of-tolerance areas or areas that otherwise raise concern. The engineer should also be aware of critical points, and have the contractor perform additional checks at these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

WisDOT's AMG Sub Grade Specification Pilot Projects

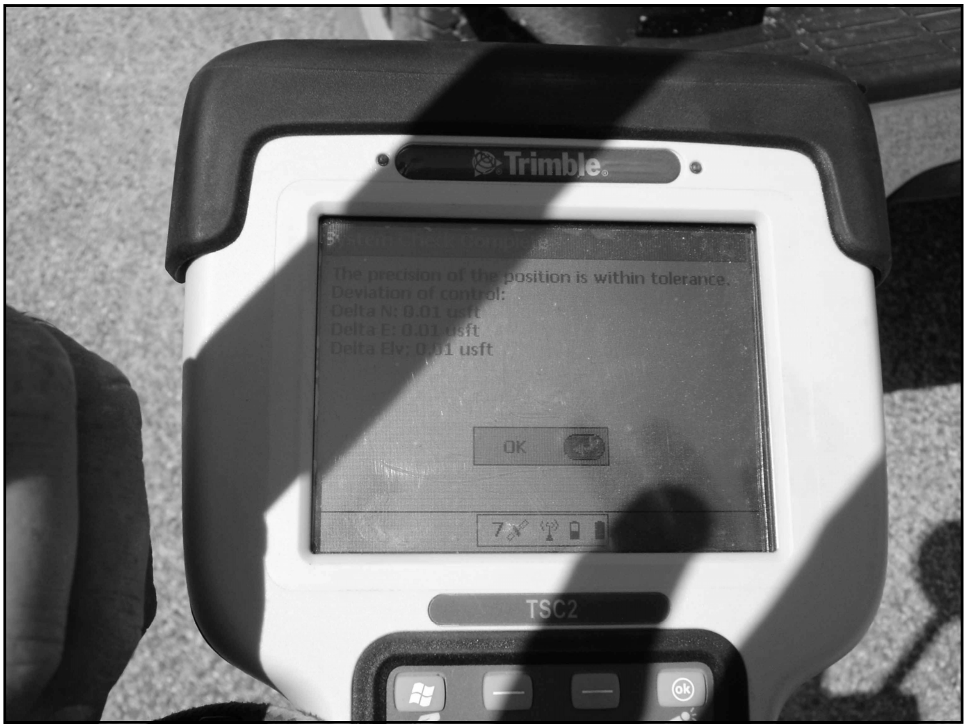


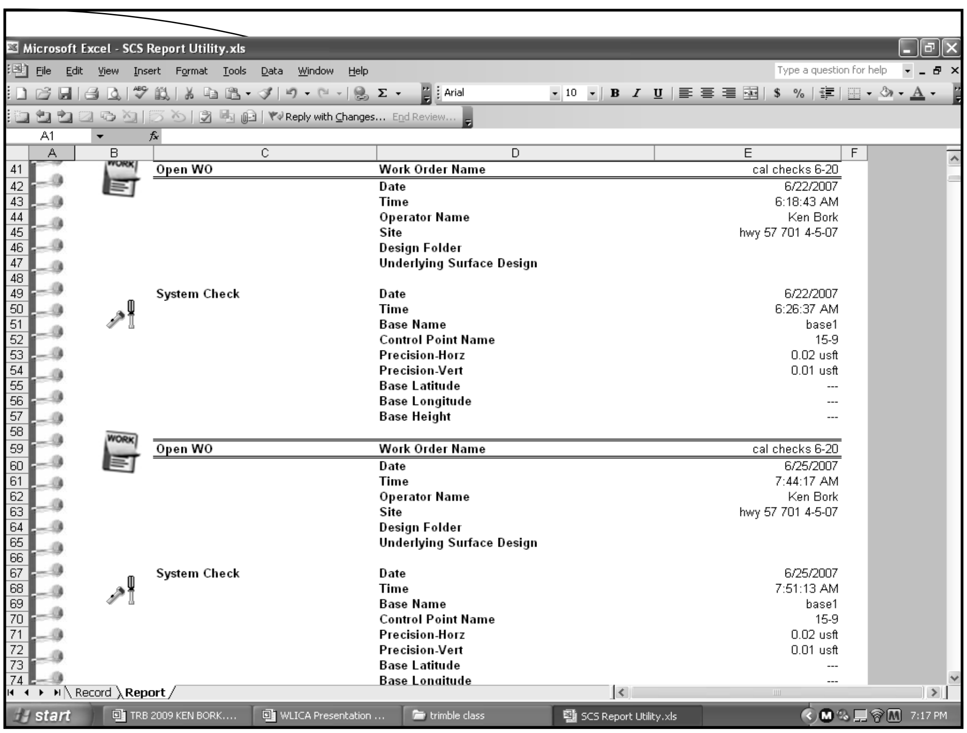
2007 STH 57 Dykesville

- Project engineer: Barry Paye.
- Contractor for sub grade: Hoffman.
- Technology: Trimble.
- Project extent: 5.2 miles of new divided highway.
- Earthwork: Cuts to 39 ft.; Fills to 25 ft.

2007 STH 57 Dykesville

- Both the contractor and the engineer had experience with AMG.
- Region provided 12 newly-monumented control points.
- Contractor provided GPS work plan (near end of workbook), and performed site calibration and site calibration checks with no problems.
- One control point was deficient and not used.



Trimble
The precision of the position is within tolerance.
Deviation of control:
Delta N: 0.01 usft
Delta E: 0.01 usft
Delta Elv: 0.01 usft
OK
TSC2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File Edit View Insert Format Tools Data Window Help
Type a question for help
Arial 10
Reply with Changes... End Review...
A1
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Date 6/22/2007
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Operator Name Ken Bork
Site hwy 57 701 4-5-07
Design Folder
Underlying Surface Design
System Check
Date 6/22/2007
Time 6:26:37 AM
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Control Point Name 15-9
Precision-Horz 0.02 usft
Precision-Vert 0.01 usft
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Base Longitude ---
Base Height ---
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Report
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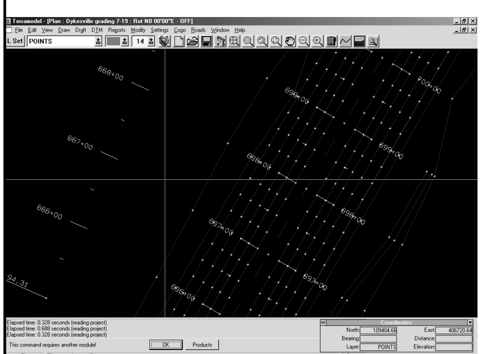
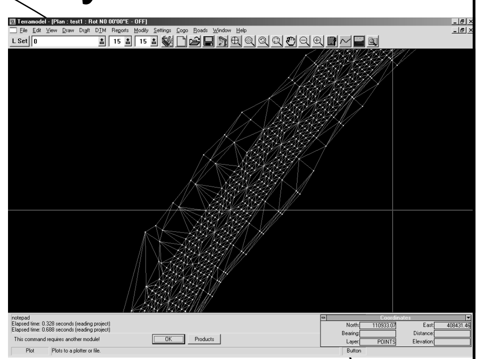
WLICA Presentation ...
trimble class
SCS Report Utility.xls
7:17 PM

2007 STH 57 Dykesville

- Terrain restricted base station radio range to 1.5 miles, boosted to 3 miles with repeater.
- Two base station locations required to cover 5.2-mile extent of project.
- Some minor problems with satellite signal reception on steep back slopes.
- 10-15 minute periods each day of poor satellite geometry (large PDOP).

2007 STH 57 Dykesville

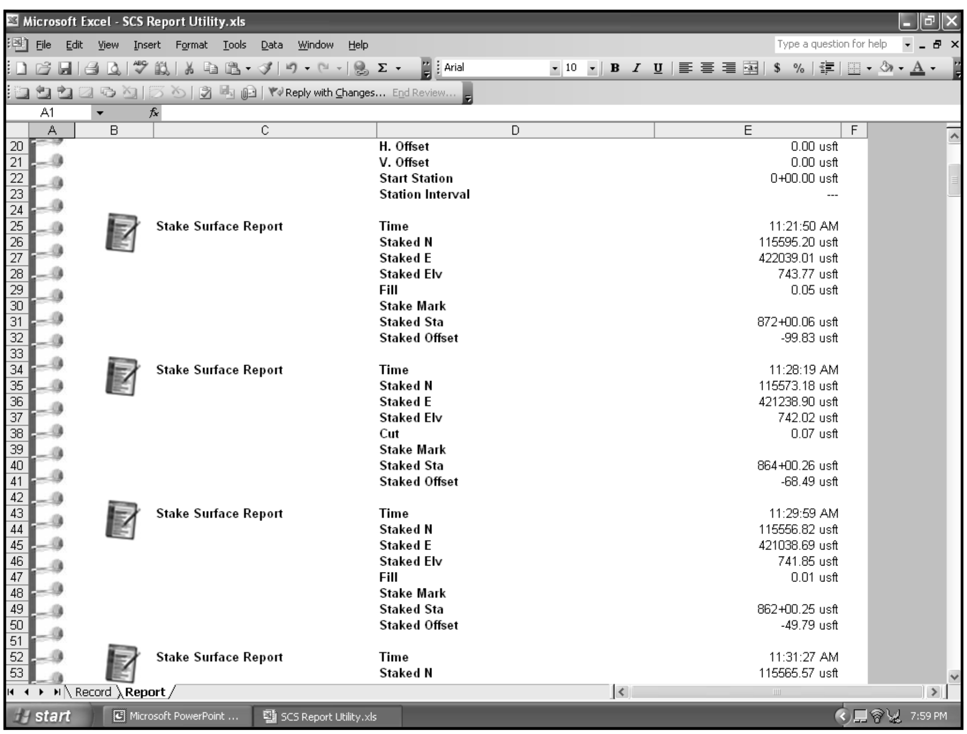




- Specified data exchange format (LandXML) raised issues.
- Department-provided break lines could not be imported.
- Settled on .dwg for exchange format.

2007 STH 57 Dykesville

- Minor design changes not incorporated into 3D model.
- No blue tops were set.
- Slope stakes were set for visual reference and for machines without AMG.
- All but three of 230 sub grade checks met tolerance.



2007 STH 57 Dykesville

2007 STH 106 Ft. Atkinson

- Project engineer: Jeff Kaarto.
- Contractor for sub grade: Wondra.
- Technology: TOPCON.
- Project extent: 9.9 miles of bidirectional highway repaving and reconstruction in six segments.
- Earthwork: Cuts / Fills to 9 ft.

2007 STH 106 Ft. Atkinson

- Contractor had experience with AMG but not on WisDOT projects.
- Engineer had no AMG experience (uses GPS in fishin' boat).
- Spec modified to include some sub grade staking in first 3000 ft.
- Project control was from initial mapping with some supplemental control by region.

2007 STH 106 Ft. Atkinson

- Flat terrain: single base station for full 10-mile project.

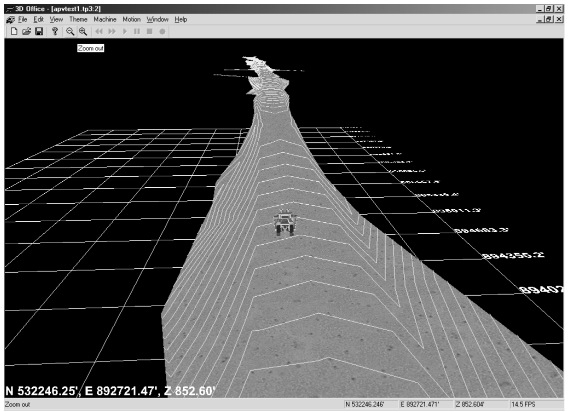
2007 STH 106 Ft. Atkinson

- Separate site calibrations for each of three grading segments.
- No problems with site calibration checks, satellite visibility, or PDOP (used both GPS and GLONASS satellites).

2007 STH 106 Ft. Atkinson

- AMG on dozers only.

2007 STH 106 Ft. Atkinson



- Problems with data exchange format.
- Department-provided data could not be imported.
- Contractor developed 3D model from scratch.
- No data were successfully exchanged and WisDOT did not review 3D model.

2007 STH 106 Ft. Atkinson

- Some blue tops missed in first 1000 ft.
  - Believed to be caused by compaction of soft material in cut areas.
  - Blade offsets usually used for compaction in fill areas but not cut areas.
  - Engineer required centerline blue tops every 500 ft and 3 across at full stations on superelevated curves on rest of project.

2007 STH 106 Ft. Atkinson


2008 Kowalski Road

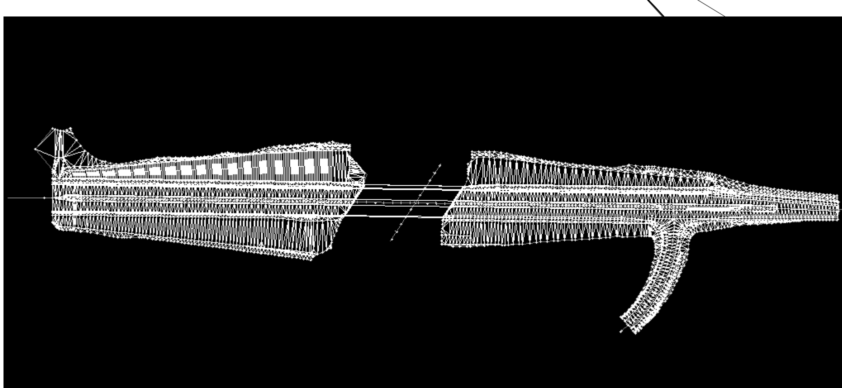
- Project engineer: Greg Graf.
- Contractor for sub grade: River View.
- Technology: Trimble.
- Project extent: 2250 ft. (demolition and reconstruction of bridge over I-39)

2008 Kowalski Road

- Region established six project control points.
- Initially-submitted GPS work plan required some revision.
- No problems with site calibration.
- During construction, staking contractor used benchmark shown on plans – missed project control by 0.10 ft.

2008 Kowalski Road

- Department provided 3D model “seed” data at PS&E in .dwg format.
- Subcontractor was able to use that data when building 3D model.



2008 Kowalski Road

- How is “20 sub grade checks per mile” to be interpreted on a 2250-ft project?
- Engineer generated station and offset for 20 points, asked contactor to measure sub grade elevations, and checked them against elevations on plans.
- All sub grade checks met tolerance.
- Contractor had only one rover and could not spare it to loan to engineer.

2008 Kowalski Road

2008 USH 41 Oconto Bypass

- Project engineer: Doug Wiegand / Dan Schneider.
- Contractor for sub grade: Hoffman.
- Technology: Trimble.
- Project extent: 4.5 miles of new divided highway with at-grade intersections, multiple structures, and ramps.
- Earthwork: 1,000,000 yd^3 at one borrow site.

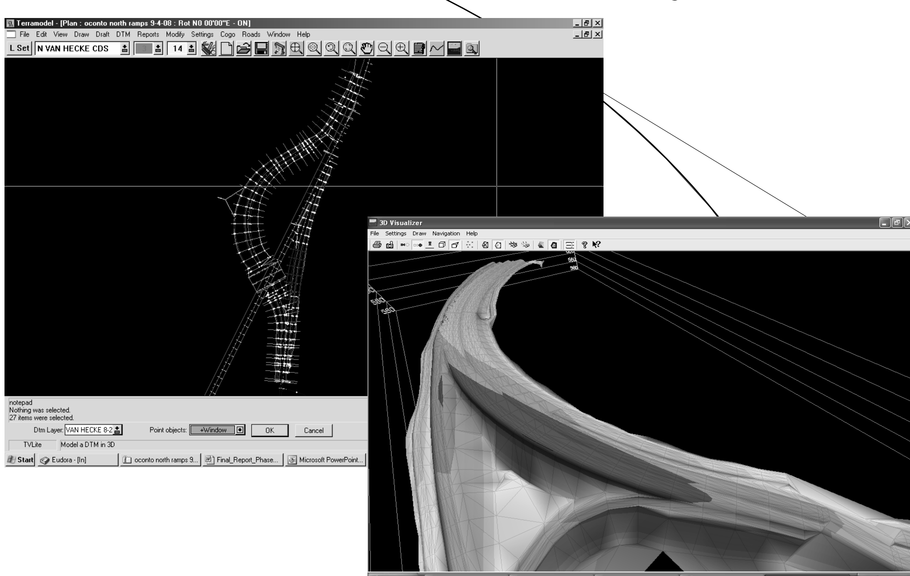
2008 USH 41 Oconto Bypass

- Region provided corridor control.
- Base station set atop HQ building.
- No problems with GPS work plan, site calibration, or calibration checks.
- 13 control points used for site calibration.
- Local radio user experienced interference from contractor's base station.

2008 USH 41 Oconto Bypass

- Department provided 3D model "seed" data at PS&E.
- These data were useful as contractor built model.
- Issue arose during WisDOT review of model.
  - There is no model content standard, so what is necessary level of detail in model to support AMG?

2008 USH 41 Oconto Bypass



2008 USH 41 Oconto Bypass

Initial sub grade checks, made by contractor at two ramps, indicated need for minor re-grading.

rvey ft)				Design Data (US Survey ft)			Difference Data		Alignment Data Station Format 0+00.00			
Measured Elv	Prec. H	Prec. V	Precision Type	Design N	Design E	Design Grade	Cut/Fill	Horiz. Deviation	Design Station	Design Offset	Measured Station	Measured Offset
603.34	0.03	0.05	RTK			603.21	0.13				703+99.99	1.99
613.77	0.03	0.05	RTK			613.92	-0.15				706+99.97	-26.01
624.09	0.03	0.05	RTK			624.38	-0.28				709+99.89	6.02
629.63	0.03	0.05	RTK			629.66	-0.03				714+00.01	-10.99
629.79	0.05	0.08	RTK			629.80	-0.01				714+00.03	-4.01
628.48	0.03	0.05	RTK			628.61	-0.13				717+00.06	-14.04
625.01	0.05	0.08	RTK			625.02	-0.01				719+99.99	0.01
623.17	0.03	0.05	RTK			622.93	0.24				721+99.98	-22.03
624.46	0.04	0.07	RTK			624.43	0.03				721+00.01	-21.03

Final sub grade checks, made by engineer, met tolerance.

2008 USH 41 Oconto Bypass

2008 USH 41 Peshtigo Bypass

- Project engineer: Brett Vissers / Jack Laning.
- Contractor for sub grade: Hoffman.
- Technology: Trimble.
- Project extent: 3.9 miles of new divided highway, 4 at-grade intersections, 10 structures.

2008 USH 41 Peshtigo Bypass

- Region provided corridor control.
- No problems with GPS work plan.
- Site calibration (10 control points) had early problems with checks.
  - Base station antenna on tripod with different height each day.
  - Resolved by mounting antenna on fixed post.
- Ultimately, two base stations were run simultaneously on different frequencies (identical site calibration files).
  - Project extent and terrain conditions.

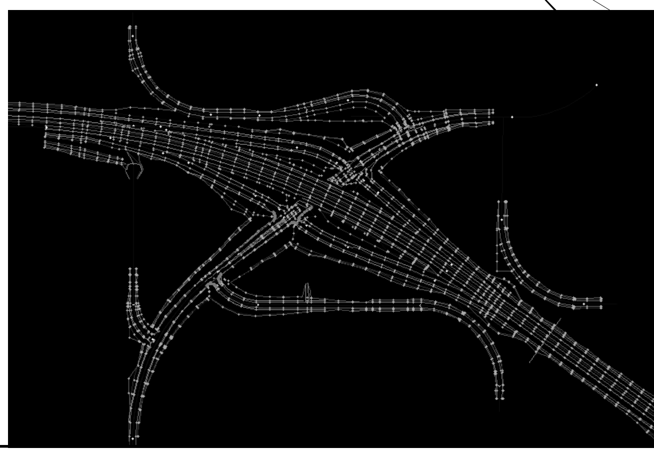
2008 USH 41 Peshtigo Bypass

2008 USH 41 Peshtigo Bypass

- Daily down times of 45-60 minutes due to poor satellite visibility and PDOP. Work doesn't stop…but AMG can't be used.
- Tree canopies caused a few problems near bottoms of steep slopes.

2008 USH 41 Peshtigo Bypass

- Department provided 3D model “seed” data at PS&E.
- Data for slopes and ditches, but not roadways, were useful as contractor built model.



2008 USH 41 Peshtigo Bypass

- First 1000 ft of mainline sub grade was completed with AMG before 3D model was reviewed by WisDOT.
  - This stretch of mainline was blue topped.
- All 64 sub grade checks made after model review were within tolerance.
  - No blue tops.

2008 USH 41 Peshtigo Bypass

HOFFMAN CONSTRUCTION CO.

Work Plan

123 CTH A
Black River Falls, WI 54615
Phone (715) 284-2512 Fax (715) 284-9698
www.hoffmanconstructionco.com

GPS Machine Guidance Specification Pilot

South County Line to Truway Road

Green Bay to Sturgeon Bay Road
STH 57
Door County

Equipment

- Design:
  - Trimble Terramodel v. 10.43
- Staking:
  - Base Station: Trimble SPS750
  - Rover: Trimble SPS780
  - Data Collector: Trimble TSC2
  - Staking Software: Trimble SCS900 v. 2.11
- Machine Control:
  - Caterpillar D6R Dozer
  - Caterpillar 14H Motor Grader
  - System on Machines: Trimble GCS900 v. 6.0

People

Ken Bork
Hoffman Construction Company

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

Twelve 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.

Mike Windsor
Hoffman Construction Company

Two years of grading using Trimble GPS machine control motor graders.
Role in Specification: Operator of Caterpillar 14H Motor Grader equipped with Trimble GCS900.

Dan Stewart
Hoffman Construction Company

Two years of grading using Trimble GPS machine control D6R Dozer.
Role in Specification: Operator of Caterpillar D6R Dozer equipped with Trimble GCS900.

Joe Broullire
Superior Staking

Construction Staking Contractor for the project.
Role in Specification: Create and maintain on-site control points.

Project Control

For this project, the department has provided a list of control (Attachment A) that was established by Coleman Engineering. 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 will not be used in the site calibration; these points will be reserved to be used as 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 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 two control checks per workday. One will be done at the start of work, and the other will be done during the last half of the work 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.

Additional QC Procedures

Machines:

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

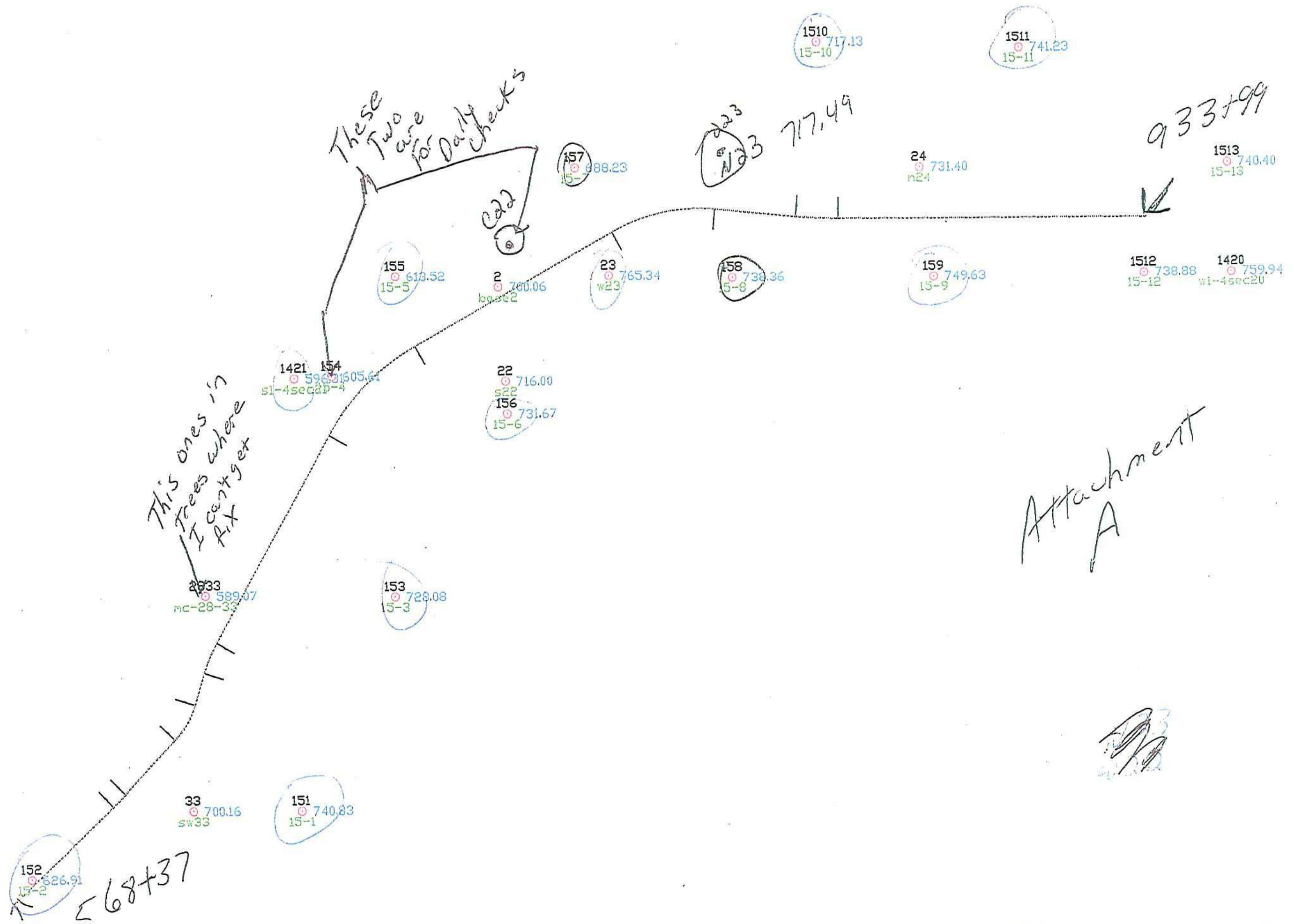
First is the valve calibration. This procedure will be typically done twice per year, or when something changes with the hydraulics of the machine, i.e. replacing of hydraulic fluids, valves, or pumps. This shall be done once before the machine does any finish grading on the project. This procedure requires 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. HCC will notify the engineer when the valve calibration will occur. HCC will document to the engineer that the valve calibration has occurred.

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.



These Two are for Daily checks
This ones in trees where I cant get fix
N23 717.49
933+99
568+37
c22
1510 717.13 15-10
1511 741.23 15-11
1513 740.40 15-13
24 731.40 n24
157 688.23 15-
155 613.52 15-5
2 760.06 bcat2
23 765.34 w23
158 730.36 15-8
159 749.63 15-9
1512 738.88 15-12
1420 759.94 wl-4sec20
1421 596.31 sl-4sec20-4
154 605.64
22 716.00 s22
156 731.67 15-6
2833 589.07 mc-28-33
153 728.08 15-3
33 700.16 sw33
151 740.83 15-1
152 526.91 15-2
Attachment A

15-1	101258.7	406621	740.83
15-2	99675.06	399829.5	626.91
15-3	106448.8	409109.5	728.08
15-4	111861.2	407638.4	605.61
15-5	114275.5	409283.1	613.52
15-6	110879.9	412043	731.67
15-7	116845.8	413872.7	688.23
15-8	114123.3	417800.3	738.36
15-9	114067.1	422874.2	749.63
15-10	119798.2	420022.7	717.13
15-11	119584.8	425119.9	741.23
15-12	114061.3	428189.1	738.88
15-13	116715.4	430352.2	740.4
15-14	114104.7	435639.8	816.86
15-15	118370.1	438256.2	726.31
15-16	121943.7	433525.6	750.98
15-17	124387.9	441023.6	713.55
15-18	127042.6	440930.2	741.87
15-19	127661.5	446291.4	650.57
15-20	131008.2	446296.6	668.42
c22	114321.1	412051.6	704.33
mc-28-33	106556.3	404367.3	589.07
n23	116796.5	417337.4	717.49
n24	116736.9	422562.6	731.4
nesec20	116669.9	435676	788.49
s1-4sec21	111825.8	406697.8	596.31
s1-4sec3	126992.1	443616.1	679.84
s22	111675.6	412019.5	716
sw33	101297.5	403921.2	700.16
swsec9	121968.7	435679.7	752.03
w1-4sec10	124411.7	440975.9	716.08
w1-4sec20	114046.3	430413.7	759.94
w23	114213	414672.8	765.34

Attachment B

Evaluation Form for Training on Automated Machine Guidance for WisDOT and Consultant Personnel

April 23,28,29, 2009
WOE Training Facility, Colomo, WI

NOTE: This evaluation form has two pages.

Circle date: April 23, 28, 29

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 and on the next page.

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

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

3. SA A N D SD — Background material on GPS, RTK GPS, and site calibration / localization was appropriate.

4. SA A N D SD — Material on principles of machine guidance and 3D modeling was appropriate.

5. SA A N D SD — Material on WisDOT's specification and guidance language was appropriate.

6. SA A N D SD — Material on practical experiences on the pilot projects was appropriate.

7. SA A N D SD — Field demonstrations and hands-on work were appropriate.

8. SA A N D SD — Workbook, handouts, and reference materials were appropriate.

Please mark your choice:

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

2. My overall rating of the training is: <u>excellent</u> <u>good</u> <u>average</u> <u>below average</u> <u>poor</u>

3. I am a: <u>WisDOT employee</u> <u>Consultant employee</u> <u>Other (please explain):</u>

Please provide comments on your selections for questions 1-8 or anything else associated with the training (continue on next page if needed).

Please provide suggestions on how the training could be improved.