3D Technology in the Construction Continuum

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Brian E Girouard, Sales Engineer, Milling-Paving-Compaction Specialist
Civil Engineering & Construction – Americas
Trimble Navigation Ltd
Cell: 702-683-4684
Email: brian_girouard@trimble.com

Robert Hutchinson, Sales Representative (Alabama/Florida)
SITECH South
Cell: 334-546-2202
Email: rhutchinson@sitechsouth.com

Scott Bridges, Southeastern Software Sales Account Representative
Civil Engineering & Construction – Americas
Trimble Navigation Ltd
Email: scott_bridges@trimble.com

http://construction.trimble.com/sitech
Notable/Award Winning Projects

- Telluride CO Airport Project with Kiewit (2009)
- New St-George UT Airport Project with Western Rock (2010)
- Port Mann-Hwy 1 Project in Vancouver BC with Kiewit (2011)
- Circuit Of The Americas (COTA) F1 Track in Austin TX with Austin Bridge & Road (2012)
- Western Wake Expressway Raleigh NC with Lane (2012)
- Colorado Springs CO Peterson AFB Runway Project with Kiewit (2013)
- Honolulu HI Reef Runway Project with JAS W Glover (2013)
- Bowling Green KY National Corvette Museum Motorsports Park (Corvette Test Track) with Scotty’s Contracting (2014)
- Quebec Ministry of Transportation (2015)
- Bogota El Dorado International Airport (2016)
- Numerous FHWA/State DOT Intelligent Compaction Projects
- https://www.youtube.com/watch?v=1wxNFYvupFA
- https://www.youtube.com/watch?v=TK6NdvKb8OI
Welcome!

- Construction Challenges
- Construction Continuum
- Construction Connected Site
- Machine Guidance Technology
- The “D”imensions of our Industry
- Machine Guidance Positioning
- Machine Guidance Technology
- 3D Designs to AMG
- Machine Guidance Safety
- Costs and Savings
Construction Challenges
Typical Construction Challenges

- **Material yields**
- **Cost of Materials**
  - Cost of AC
  - Limited aggregate resources
  - Transportation and Production Costs
- **Project Deadlines**
  - Limited access to areas of the project due to roadway or airport traffic control
  - High penalties for going over
- **Project information, data**
- **Additional grading, rework**
- **Additional paving/levelling course**
- **Additional grinding/milling**
  - After paving is completed and to meet smoothness spec
What are the traditional methods?

- Grade stakes
- Placing Stringline or Wire
- Grade paint marks on surface
- Estimating/Guessing?!?
Construction Continuum
Construction Connected Site
Construction Connected Site

Connected Site
Connecting workflows with Technology Solutions

Planning
Feasibility
Estimate
Earthworks and Paving
Build
Maintain &Operate
Design
Earthworks and Paving – New Projects

Data acquisition

Design

Bulk Earthworks

New Projects:
- From initial survey to finish surface

Compact

Pave

Fine/Base Grading

Compact
Earthworks and Paving – Resurfacing

Data acquisition

Resurfacing: From initial survey to finish surface

Design

Mill

Compact

Pave
Construction Connected Site

Machines and Assets
- Earthworks machine guidance solutions
- Milling, paving and compaction solutions
- Local contractor solutions
- Weighing solutions (payload)
- Mixed fleet asset utilization and management
- Remote support

Move to a Digital Site
The Survey Crew and Grade Checker

• Surveyor, survey crews and grade checkers monitor site progress
• Automate site management via work orders for field crews
• Measure stock piles and more
• Ubiquitous high accuracy positioning
• Range of position accuracies to meet all site application needs
Construction Connected Site

The Foreman, Site Engineer, Inspector And All Other Site Staff

- Empower all with project monitoring capabilities
- Accelerate operations via connectivity
- Manage and maximize utilization of equipment, people and materials

Track, Automate and Integrate Seamlessly to QA and Signoff
Machine Guidance Technology
Machine Guidance Technology

- What is Machine Guidance?
  - Machine Guidance is used to accurately position earthwork, milling and paving equipment on a project
  - Uses technology to help maintain grade
    - Rotating Lasers, Sensors, RTK-GNSS, Robotic Total Stations

- Two types of Machine Guidance:
  - Indicate Machine Guidance
    - Technology on machine indicates an on grade, cut/fill or positioning (e.g.: drilling or piling)
    - Operator controls the machine manually
  - Automatic Machine Guidance (AMG)
    - Functions with the hydraulics on the machine
    - Technology on machine displays an on grade or cut/fill
    - Raise or Lower function is controlled automatically to grade
    - Can include horizontal guidance to a line (i.e.: steering)
Machine Guidance Technology

- References:
  - https://www.fhwa.dot.gov/construction/3d/construction.cfm
The “D”imensions of Our Industry
“D”imensions – Science (wiki-answers)

- 0D = A point
- 1D = A line
- 2D = A shape with X and Y lines (square)
- 3D = A shape with X, Y, and Z lines (cube)
- 4D = A 3D shape with the addition of time
- 5D = Another possible reality caused by choice and chance
- 6D = Being able to jump between one reality and another
- 7D = All possible conceivable realities in this universe
- 8D = A different universe in which there are different particles resulting from the big bang
- 9D = Being able to jump from one universe to another
- 10D = An infinite amount of possible universes
- 11D = Being able to jump between the infinite amount of universe and realities
“D”imensions – Engineering

- 0D Point
- 1D Line (no width or height)
- 2D Flat Surface/Plane (has length and width or length and height)
- 3D Surface with Elevation (has length, width and height)
- 4D Time
- 5D Cost
“D”imensions – Construction Machine Guidance

- 1D – Elevation Only (level rotating laser)
- 2D – Elevation and Slope (laser, sensors)
- 3D – Elevation, Slope and Horizontal

In addition, machine guidance technology and machine manufacturers add their own marketing terminology to the dimensions

- 3D+, 3D-MC, mmGPS 3D, etc…
- Auto side-shift, auto steering, laser augmented GNSS, etc…
- These are all extra features
- At the end of the day, 3D is still 3D!
Machine Guidance Positioning
Machine Guidance Positioning

- **1D**
  - Measuring elevation
    - Level Laser

- **2D**
  - Measuring elevation and slope
    - Slope Laser
    - Sonic tracer (s), Averaging Beams
    - Slope sensor
  - Wheel for measuring stationing
  - Material thickness, from ground - up

- **3D**
  - Tracking and measuring of a moving target for x, y and z (Easting, Northing, Elevation) coordinates
    - Optical robotic total station
    - Or a satellite based navigation system
  - Uses an engineer design, from top – down
Machine Guidance Positioning

• 1D

Flat or Level (no slope)

Laser Plane

Laser Transmitter

Reference Elevation
Machine Guidance Positioning

• 2D
Machine Guidance Positioning

• 3D
Machine Guidance Positioning
Machine Guidance Positioning
Machine Guidance Positioning
Machine Guidance Positioning
Machine Guidance Technology
3D Positioning Technologies

- **GPS/GNSS**
  - Satellite based system
  - GPS: Global Positioning System (US DoD)
  - GNSS: Global Navigation Satellite System
    - World’s Satellite Systems used to determine the location of a user’s receiver anywhere on earth

- **Laser Augmented GNSS**
  - Must have RTK GNSS for Horizontal positions
  - Uses a laser to increase the vertical accuracy

- **Robotic Total Stations**
  - Land based system
Three types or grades of GNSS Receivers

- Navigation/Recreational [Autonomous C/A, 10’-50’ (3m-15m)+ H, V?]
- Positioning [Differential C/A or L1 Carrier Phase (Real-Time or Post-Process), 0.5’-10’ (0.1m-3m) H, 2-3x more in V]
- Precise [L1/L2 Carrier Phase. Real-Time Kinematic (RTK) or Post-Process (PP). 0.1’ (30mm) or better, 3D!]
  - RTK is typical for Survey and Construction Applications (Golf Ball Accuracy or better)!
Laser Augmented GNSS

- RTK GNSS for Horizontal positions
- Requires accurate control points for a site calibration
  - Can use State Plane, UTM, etc… coordinate systems
  - Should still have control points to check systems
- Initial setup should be identical to a typical GNSS RTK project
- A laser or series of lasers are used to increase (augment) the vertical accuracy of the GNSS system
- Vertical accuracies will depend on the laser
  - Expectations would be 3mm-5mm or less
- Be aware of any obstructions (e.g.: walls, trees, overpasses, etc…)
  - 100% coverage is expected, if the GNSS system goes down, there is no positioning!
Robotic Total Stations – Land Based

- **Optical measurement system**
  - 1/8” (0.01’, 3mm) accuracy
  - Measures horizontal and vertical angles
  - Measures distances
  - Computes 3D positions for a machine or rover
  - Line of sight required, 100% coverage expected

- **Transmits data via radio link to the rover system**
  - Data Controller
  - Control Box in machine guidance applications
Robotic Total Stations
Using a Rover on a Project

- Checking Elevation Grade behind Mill and/or Paver Screed
- Rover must be accurate
- Can be used to record and store data of compacted areas
3D Design to AMG
Key Components

- 3D Data/Designs
- Survey Control
- Existing and As-Built Data
Historically, contractors provided paper plans or pdf files

CAD files (DXF, DWG, DGN) which lose the geometry

Proprietary files e.g. DTM, ALG, GPK that cannot be read directly into contractors tools

- These are all the least productive for the contractor
- Cannot use for Machine Guidance
- Contractors have to create 3D design
3D Data/Designs – SoftWares

- Several SoftWare Companies
  (Examples)
- AutoDesk
  - Civil 3D
- Bentley
  - MicroStation
  - InRoads
- Trimble
  - Business Center - Heavy Construction Edition®
  - TerraModel®
3D Data/Designs – Types

- Parametric Corridor or Template-Based Corridor Design *
  - Horizontal Alignment (HAL)
  - Vertical Alignment (VAL)
  - Templates (X-Sections)
  - Stationing
  - Superelevations
  - Widening
  - *This is the most accurate way to describe a road

- Triangulated Irregular Network (TIN) Surfaces

- Gridded Surfaces
  - Rectangular (usually square) meshes, not recommended

- CAD LineWork
3D Data/Designs – Formats

- The Most Feature-Rich
  - Design (LandXML, .ttm, Bentley MX, 12D, GENIO, REB, InRoads, NovaPoint, …) Alignments
  - Surfaces
  - Breaklines
  - Points

- 3D model (.icm.dgn, .pro, .vce, .vcl) Breaklines
  - Points
  - Surfaces
  - Alignments
  - Corridors / templates
  - Meshes
  - CAD
3D Data/Designs – Formats Con’t

- Bentley “Infrastructure Consensus Model” (icm.dgn)
- LandXML v1.0 (*.xml)
  - Road Geometry Data
  - 3D Surface (s)
- CAD (*.dwg, *.dxf)
  - Typical LineWork
  - Possible 3D Surface (s)
  - Typically drawings with “no intelligence”
3D Data/Designs – Formats Con’t

- **Trimble Terrain Model, *.ttm**
  - Typical Surface

- **Trimble Business Center-Heavy Construction Edition (BC-HCE), *.vce**
  - Files used with 3D AMG Systems
  - SVD = Design
  - SVL = LineWork

- **Trimble TerraModel®, *.pro**
  - Road Designs
  - 3D Surfaces
  - LineWork
3D Data/Designs – Construction

- Must be Accurate
- Build the design as the project will be constructed
  - Subgrade, Finish Grade, etc…
- Built for Machine Guidance Systems
- Surfaces need to be Optimized or Densified
  - Smoothness for vertical changes
3D Data/Designs – In the Field

- Used for machine guidance and layout
  - Points, lines, alignments, templates, surfaces
- Calculation of quantities
- Mass haul planning
- Sending work orders with subsets of the data to field devices
- Managing the Connected Site
- Project tracking
3D Data/Designs – Demo

- Sample Demo using icm.dgn
3D Data/Designs – Demo
3D Data/Designs – In the Field

- AMG
3D Data/Designs – In the Field

- AMG
3D Data/Designs – In the Field

- Grade Checker Rover
Survey Control

- Project Survey Control must be accurate
- Greater than \( \frac{1}{2} \) the project specifications
- Consider “PROJECT SPECIFIC (i.e.: within the site)” of first order accuracy
  - Highest achievable accuracy of Survey
  - Use a Digital Level system to reduce or eliminate human errors!
- If you are 3D milling or 3D paving, mm accuracy is a must
  - There is no reason for poor survey control accuracy
- Should be no more than 500’ (150m) apart for Total Station Machine Guidance (can be less for Laser type Machine Guidance)
  - You need to know the technology ranges and/or limitations
- Surround the project
Survey Control – Con’t

- Use Digital Level (Vertical)
- Total Station (Horizontal)
Existing or As-Built Data

- Existing or as-built surface data accuracy should be equal or better than the technology being used
  - If the AMG technology can achieve 3mm to 5mm (0.01’ to 0.02’), as-built data accurate at 10mm to +20mm (0.03’ to +0.07’) is not ideal
  - The data can be used for a 3D design and/or to verify was has been graded, milled or placed
There are many safety factors using Machine Guidance

- Reduced need for elimination of string lines for improved worker safety
- Fewer field personnel exposed to heavy equipment and potential back-over/run-over incidents
- Hydraulic Excavators (HEX) can grade without having a grade person in a trench or hole
What are the Contractor's Costs and Savings

- What are the project specifications?
- Is the project a mill and fill?
- Are you being paid by the square area or by volume?
- What are the material overruns? 6%? 8%?
- What is the smoothness pay scale factor?
  - 100% pay or deduction?
  - Ride Bonuses?
- Will you drop the mill in the cut and perform the typical “blow and go”? 
- If the project is still uneven after milling, how do you manage quantities?
- Will you be placing a levelling course before mainline paving?
- How long are you responsible for the project after completion (warranty)?
What are the Costs and Savings

- Project Example:
  - 10 miles long, 25’ wide, 4” thick (compacted)
  - Target Asphalt Density 145 lbs/ft$^3$, 31900 tons placed at $125/tons
  - Asphalt Cost: $3,987,500
  - Placing an additional ¼” of material = $249,219 or +6% (+1994 tons)
What are the Costs and Savings

- Using 3D technology can help you manage quantities
- Quality of the surface typically cannot be achieved using traditional methods
- 3D milled or graded surface is a smooth surface and ready for paving
  - You can control the depth you mill to along the whole project and not just at the end gates or perhaps using an averaging beam
- On a profile 3D mill project, you remove what you require to make the surface smooth
  - Place the desired asphalt thickness on top
- On a variable depth 3D mill project, you control the depth of the drum to meet specifications
  - You will know the amount of asphalt required to fill the project
THANK YOU!