Utilizing 3D Digital Design Data in Highway Construction

Final presentation of Case Study Observations, Findings, and Proposed Guidance
Agenda

1. Research Objective and Approach
2. Research Findings
3. Using 3D Design Data in Construction
4. Real-time Verification & Measurement
5. Level of Development in more detail
6. Conclusion
7. Open Discussion
Research Objectives

- Explore advanced uses of AMG, e.g. milling, paving
- Inform optimal investment in survey and 3D modeling
- Practical and actionable guidance for typical STIP projects
- Identify areas for further development in data schemas, technology, and industry standardization
Research Process

**Phase 1**
- Set broad Selection criteria
- Find projects that cover all priority characteristics
- Study projects via interviews and collecting project information
- Identify challenges and opportunities for using 3D data in highway construction
- Interim Report

**Phase 2**
- Analyze processes and policies that led to or constrained 3D data use in construction
- Analyze data uses and data schemas that support those uses to create a LOD designation
- Identify schema gaps and priorities for development
- Create guidance for digital data quality control delivery for construction
- Final Report
Case Study Projects

- I-80 Silver Creek to Wanship Reconstruction
- US 219 Mill & Resurface
- Southern Expressway Section 5 (US 219)
- US 17 Bridge and Safety Improvements
- Route 60 Reconstruction
- I-35 Unbonded Concrete Overlay
Research Findings
## Primary Data Uses

<table>
<thead>
<tr>
<th>Contractor</th>
<th>Resident Engineer/Inspector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-construction quality control</td>
<td>Construction Quality Assurance</td>
</tr>
<tr>
<td>Construction layout and orientation</td>
<td>Measurement of Pay Quantities</td>
</tr>
<tr>
<td>Automated Machine Guidance</td>
<td>Responding to field issues</td>
</tr>
<tr>
<td>Construction Quality Control</td>
<td></td>
</tr>
<tr>
<td>Documenting field issues</td>
<td></td>
</tr>
<tr>
<td>Responding to field issues</td>
<td></td>
</tr>
</tbody>
</table>
Data Types

• All used the same data types:
  – CoGo points
  – Alignments & profiles
  – Original ground surfaces
  – Proposed ground surfaces
  – 3D line strings
  – 2D line strings
  – Field survey points with field codes

There is nothing sophisticated about 3D data used in pavement construction!
Planning for AMG in Construction

Concrete vs Asphalt
Inclusion Criteria for Asphalt Paving

Inclusion criteria for asphalt paving

Inclusion criteria for profile milling
Inclusion Criteria for Real-time Verification

Real-time Verification is beneficial even on mill-and-fill jobs with measured quantities if there is a RTK correction and GNSS Rover available.
Using 3D Design Data in Construction
I worked so hard on this those guys better build it exactly like I designed it, down to the quarter inch!

4/4 projects had great construction outcomes.
Problems with Data Mobility

- None of the case studies had original design data used in construction
- Proprietary formats were challenging
- Designs all required modification because of difference between OG and field conditions
3D Engineered Models are...

- Uncertainty
- Approximation
- Staging
- Risk Management
- Means and Methods
Construction Data Preparation

- Prepare contract plans
  - Digitize contract plans
  - Scale and orient plans to project coordinates
  - Verify scale and orientation are correct
- Prepare 3D data
  - Exchange data from proprietary format #1 to open format
  - Exchange data from open format to proprietary format #2
  - Cut cross-sections at same plan locations
- Compare 3D data to contract plans
- 3D data matches contract plans
- Identify source of difference
- Correct issue with data
- Use 3D data as planned

Flowchart:
- Prepare contract plans
  - Digitize contract plans
  - Scale and orient plans to project coordinates
  - Verify scale and orientation are correct
- Prepare 3D data
  - Exchange data from proprietary format #1 to open format
  - Exchange data from open format to proprietary format #2
  - Cut cross-sections at same plan locations
- Compare 3D data to contract plans
- 3D data matches contract plans
  - True
    - Use 3D data as planned
  - False
    - Identify source of difference
    - Correct issue with data
Data Governance
Level of Development for Highway Data

Also need to communicate uncertainty/confidence
Dual Designation for Level of Development

High detail alone ≠ High LOD
Invest in Design Effort to Match CL

<table>
<thead>
<tr>
<th>MD-1</th>
<th>CL-D</th>
<th>CL-C</th>
<th>CL-B</th>
<th>CL-A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High probability High impact Update control and topo and effect extensive design revisions to resolve transitions and balance material quantities</td>
<td>Moderate probability Moderate impact Update control and topo. Revisions to resolve hard tie-ins and transitions, and/or balance material quantities</td>
<td>Low probability Low impact Minor revisions to hard tie-ins and/or to balance material quantities</td>
<td>Very low probability Very low impact Preconstruction quality control can detect and manage risks</td>
</tr>
<tr>
<td>MD-2</td>
<td>High probability High impact Update control and topo and effect extensive design revisions to resolve transitions and balance material quantities</td>
<td>Moderate probability Moderate impact Update control and topo. Revisions to resolve hard tie-ins and transitions, and/or balance material quantities</td>
<td>Low probability Low impact Design revisions to hard tie-ins to resolve transitions and/or balance material quantities</td>
<td>Low probability Low impact Minor revisions to balance material quantities or accept minor material volume adjustments</td>
</tr>
<tr>
<td>MD-3</td>
<td>High probability High impact Update control and topo and effect extensive design revisions to resolve transitions and balance material quantities</td>
<td>Moderate probability Moderate impact Update control and topo. Revisions to resolve hard tie-ins and transitions, and/or balance material quantities</td>
<td>Low probability Low impact Minor revisions to balance transitions and/or balance material quantities</td>
<td>Very low probability Low impact Minor material quantity discrepancies</td>
</tr>
</tbody>
</table>

Don’t over-refine a design if there is low confidence in the survey
Chapter 7 of Oregon DOT’s Construction Survey Manual requires pre-construction survey verification at or near the bid letting date.
Shifting Final Design Deliverables

- Eliminate field fits, keep control of quantities
- Must have right accuracy at the right place
- Must use parametric models and dynamic plans to propagate change quickly

Facility with 3D Models in Construction

Resident Engineer  Contractor
Construction Partnering
## Areas for Data Schema Development

<table>
<thead>
<tr>
<th>Description</th>
<th>Magnitude of Need</th>
<th>Return on Investment</th>
<th>Likelihood of Success</th>
</tr>
</thead>
<tbody>
<tr>
<td>Governance body for schema development</td>
<td>Critical</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Corridor model parametric relationships</td>
<td>Critical</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Subsurface utility attributes</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Digital signatures and seals</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Internal validation</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Consistent surface implementation</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Enhanced metadata</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Surface data attributes</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Pay item number and specification reference</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Automated code checking</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Real-time Verification and Measurement

in more detail
## Managing Equipment Tolerances

<table>
<thead>
<tr>
<th>Variable</th>
<th>Impact</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D data</td>
<td>Mid-ordinate distances are cumulative.</td>
<td>Use the same 3D data, called a model of record, which has been reviewed and agreed to by Contractor and Resident Engineer. (8)</td>
</tr>
<tr>
<td>Survey instrument</td>
<td>Different instruments will provide different measurements for the same point due to precision differences.</td>
<td>Use the same instrument to check construction that was used to execute it. (29)</td>
</tr>
<tr>
<td>Survey control</td>
<td>Measurements are relative to the truth established by the control. Measurements using different control are not comparable.</td>
<td>Use the same primary and secondary control to check the work that was used to execute it. (29)</td>
</tr>
</tbody>
</table>

![Diagram of apparent construction outcome with lines representing instrument precision and 3D data]

- Inspector’s Solution
- Constructed Grade
- AMG instrument precision
- Inspector instrument precision
- Apparent construction outcome
- 3D data
Real-time Verification and Measurement

- Possible for all projects
- Use as a measuring/documentation tool
- Equipment availability is the biggest challenge
- Provision through Specification/bid items is expensive (but reimbursed with Federal funds)
Building Confidence with 3D Methods

1. Receive 3D Data
   - Review and remedy 3D Data as required to reflect the design intent

2. Receive Survey Equipment
   - Receive training to use Survey Equipment

3. Load Original Ground data onto data collector

4. Practice Real-time Verification methods with Original Ground data

5. Issues with Original Ground data
   - True
     - Practice Topographic Survey methods to collect new Original Ground data
   - False
     - Accept Original Ground data

Image: Berm #8 with topographic data and survey equipment in a field setting.
Processes for Real-time Verification

1. Work is ready to inspect
2. Load 3D Data that represents the design intent onto data collector
3. Select a tool with the appropriate precision to take observations
4. Observe a control point to verify the tool is operating correctly
5. Observe completed work to check tolerances
6. Work is within tolerance
7. Accept work per plan
8. Store as-built observations
9. Regular offsets from flow line to check installation

TABLE 1

<table>
<thead>
<tr>
<th>DIAMETER OR SPAN</th>
<th>&quot;C&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>UP THRU 24&quot;</td>
<td>0</td>
</tr>
<tr>
<td>24&quot; TO 14&quot;</td>
<td>24&quot;</td>
</tr>
<tr>
<td>&gt;24&quot; TO 144&quot;</td>
<td>24&quot;</td>
</tr>
<tr>
<td>144&quot; AND OVER</td>
<td>24&quot;</td>
</tr>
</tbody>
</table>

CIRCULAR PIPE
PIPE ARCHES
SIDE PAYMENT LINES - TRENCH AND CULVERT EXCAVATION (SEE NOTES 5 AND 6)
BACKFILL MATERIAL AS SPECIFIED ON PLANS OR AS SHOWN.
PAYMENT LINES FOR SELECT GRANULAR FILL (SEE NOTE 2)
SUBGRADE OF ROADWAY WHEN UNDER CUT SECTION, GROUND SURFACE OR AS SHOWN.
BOTTOM PAYMENT LINE TRENCH AND CULVERT EXCAVATION (TANGENT TO INVERT)
SEE BEDDING DETAILS AND NOTE 7
PAYMENT LINES FOR SELECT GRANULAR FILL (SEE NOTE 2)

Invert
Flow line
Regular offsets from flow line to check installation

Invert
Processes for Measurement

1. Work is ready to measure
2. Store observations in a work order
3. Compute quantities on the data collector
4. Download the work order, review and annotate
5. Enter quantities into daily report and reference work order

Cross-section for basis of excavation payment per specification

Location of check shots

Actual excavation cross-section

Top of pipe as-built shots

25’ Max apart
Level of Development

*in more detail*
Defining Design Model Tolerances

**Staking**

Stakes at 50-foot intervals on tangents, reduced intervals around curves

**Real-time Verification**

More frequent data points with less interpolation between points
## LOD: Model Density (MD)

<table>
<thead>
<tr>
<th>MD</th>
<th>Definition</th>
<th>Authorized Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>MD-1</td>
<td>Data points are located at regular stations and key geometry points. Transitions are incorporated into the 2D data only.</td>
<td>Preliminary design, ROW engineering, Permit applications</td>
</tr>
<tr>
<td>MD-2</td>
<td>Data points are located at regular stations and key geometry points. Transitions are incorporated into the 3D data. Typical data densities are 25/10/5 (tangents/curves/transitions).</td>
<td>Final design, Bid documents, Quantity take-off</td>
</tr>
<tr>
<td>MD-3</td>
<td>Mid-ordinate distances are small enough to support staking with GNSS or RTS. Typical data densities are 10/2/2 (tangents/curves/transitions).</td>
<td>Quantity take-off, Pre-construction quality control, Construction orientation</td>
</tr>
<tr>
<td>MD-4</td>
<td>Mid-ordinate distances small enough to minimize risk of material overruns. Typical data densities are 5/1/1 (tangents/curves/transitions).</td>
<td>Construction layout, AMG construction, Real-time Verification</td>
</tr>
</tbody>
</table>
| MD-5 | Mid-ordinate distances are small enough to measure quantities within the measurement precision. Typical data densities are:  
• 25-foot point interval for straight or regular features  
• 10-foot point interval in irregular terrain (such as borrow pits)  
• 5-foot point interval in curves  
• Points at horizontal deflections and/or grade breaks | As-built record documentation, Measure pay quantities, Asset inventory |
Confidence Level (CL)

- Must maintain bridge clearance.
- Must tie exactly to the saw cut line.
- Soft tie-ins can easily be adjusted.

Uncertainty varies by feature and location.
# LOD: Confidence Level (CL)

<table>
<thead>
<tr>
<th>CL</th>
<th>Definition</th>
</tr>
</thead>
</table>
| **CL-A** | • Founded on a primary control network of at least 4 monuments with vertical control established by optical leveling AND  
• All control has been recovered or replaced AND  
• Topographic accuracy has been field verified:  
  o For paved surfaces or engineering works is +/- 0.06 foot horizontal and +/- 0.05 foot vertical  
  o For natural ground points is +/- 0.15 foot horizontal and +/- 0.15 foot vertical  
• OR topographic accuracy does not have a material impact on construction outcomes |
| **CL-B** | • Founded on a primary control network of at least 4 monuments with vertical control established by optical leveling AND  
• Topographic accuracy has a high probability:  
  o For paved surfaces or engineering works being +/- 0.06 foot horizontal and +/- 0.05 foot vertical  
  o For natural ground points being +/- 0.15 foot horizontal and +/- 0.15 foot vertical  
• OR topographic accuracy does not have a material impact on construction outcomes |
| **CL-C** | • Complete metadata is available for primary control and topographic survey AND  
• Low probability that field conditions have changed since survey was performed OR  
• Topographic accuracy does not have a material impact on construction outcomes |
| **CL-D** | • Basis of original ground survey is unknown OR  
• Low confidence that original ground survey reflects the field conditions at the time of construction |
Margin of error in topographic accuracy has a larger impact for overlays than for earthwork.

Control needs for static lidar and AMG milling or paving are equivalent.
# Digital Data Manifest

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Features</th>
<th>Station Range</th>
<th>MD</th>
<th>CL</th>
<th>Risks</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utah</td>
<td>Final grade</td>
<td>All</td>
<td>MD-2</td>
<td>CL-C</td>
<td>Inaccurate asphalt milling quantities require import/export of material into/out of the canyon</td>
<td>New topographic survey collected and profiles revised to effect material balance</td>
</tr>
<tr>
<td></td>
<td>CTAB grade (original design data)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utah</td>
<td>Final grade</td>
<td>All</td>
<td>MD-4</td>
<td>CL-A</td>
<td>Inaccurate asphalt milling quantities require import/export of material into/out of the canyon</td>
<td>Successful localized material balances. Good smoothness and yields for concrete paving</td>
</tr>
<tr>
<td></td>
<td>CTAB grade (final AMG data)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virginia</td>
<td>Curb and Gutter</td>
<td>All</td>
<td>MD-4</td>
<td>CL-D</td>
<td>Curbs do not tie to existing roadway after final resurfacing. Cannot maintain 6” reveal. Ponding and drainage issues.</td>
<td>3 week stop work condition, $1m change order, new topographic survey and extensive design revisions.</td>
</tr>
<tr>
<td></td>
<td>(original design data)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virginia</td>
<td>Curb and Gutter</td>
<td>All</td>
<td>MD-4</td>
<td>CL-A</td>
<td>Curbs do not tie to existing roadway after final resurfacing. Cannot maintain 6” reveal. Ponding and drainage issues.</td>
<td>Minimal rework, positive smoothness and drainage outcomes in minimum grade conditions</td>
</tr>
<tr>
<td></td>
<td>(final layout data)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virginia</td>
<td>Final grade</td>
<td>All</td>
<td>MD-4</td>
<td>CL-A</td>
<td>Cannot maintain 4” curb reveal, issues at numerous driveways and curb cuts, positive drainage in minimum grade, smoothness</td>
<td>Successful construction</td>
</tr>
<tr>
<td></td>
<td>Milling profile</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Missouri</td>
<td>Final grade</td>
<td>All</td>
<td>MD-4</td>
<td>CL-A</td>
<td>Overrun concrete quantities</td>
<td>High predictability of concrete yields. No overruns.</td>
</tr>
<tr>
<td></td>
<td>Milling profile</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New York</td>
<td>Final grade</td>
<td>All</td>
<td>MD-2</td>
<td>CL-D</td>
<td>Earthwork, base, and concrete paving quantity discrepancies</td>
<td>New topographic survey after clearing and grubbing and design re-modeled for AMG</td>
</tr>
<tr>
<td></td>
<td>Subgrade (original design data)</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

MD & CL combine into different risk types, probabilities, and impacts
Conclusion
Proprietary schemas are emerging to fill gaps in LandXML. This puts agencies at risk of data security/durability. Data exchange is high skill, low value work.
Conclusion

<table>
<thead>
<tr>
<th>Pre-Design</th>
<th>Early Design</th>
<th>Detailed Design</th>
<th>Pre-construction</th>
<th>Early Construction</th>
<th>Late Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk managed by Designer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Ability to control costs**
- establish control and mapping
- identify footprint
- right-of-way acquisition
- letting
- control verification*
- stakeout or AMG data preparation*

**Cost of design changes**
- Traditional survey effort
- Traditional design effort
- Optimal survey effort
- Optimal design effort

* Contractual model replaces stakeout and AMG data prep
Tell me what you think