NCHRP Research Report 831: Civil Integrated Management for Departments of Transportation

NCHRP Project 10-96
NCHRP is a State-Driven Program

• Sponsored by individual state DOTs who
  - Suggest research of national interest
  - Serve on oversight panels that guide the research

• Administered by TRB in cooperation with the Federal Highway Administration
Practical, ready-to-use results

- Applied research aimed at state DOT practitioners
- Often become AASHTO standards, specifications, guides, syntheses
- Can be applied in planning, design, construction, operations, maintenance, safety, environment
Today’s Speakers

• CIM: Moving Forward with Implementation
  - Dr. Paul Goodrum, P.E.
    ▪ University of Colorado at Boulder
  - Dr. William O’Brien, P.E.
    ▪ University of Texas at Austin

• Webinar Moderator
  - Richard Hewitt, P.E.
    ▪ Florida Department of Transportation
TRB Webinar

Civil Integrated Management (CIM): Moving Forward with Implementation

NCHRP 10-96 Project Team

Wednesday, April 26th, 2017
NCHRP 10-96 Project Team

• The University of Texas at Austin
  – Bill O’Brien – Principal Investigator
  – Fernanda Liete – Co-Principal Investigator
  – Nabeel Khwaja – Co-Principal Investigator
  – Bharathwaj Sankaran – Graduate Student

• The University of Colorado at Boulder
  – Paul Goodrum – Co-Principal Investigator
  – Keith Molenaar – Co-Principal Investigator
  – Guillermo Nevett – Graduate Student
  – Joshua Johnson – Graduate Student
Why use CIM?

• CIM can have great benefits in cost and time savings on projects

• CIM can improve information flow
  – Transparency among project stakeholders
  – Improve outreach to the public

• CIM can increase the effectiveness of agency professionals and service providers
  – Breach traditional silos
  – Improve information quality and availability
  – Increase productivity
  – Improve interfaces with contracted professionals
What is CIM?

“Civil Integrated Management (CIM) is the technology-enabled collection, organization, managed accessibility, and the use of accurate data and information throughout the life cycle of a transportation asset. The concept may be used by all affected parties for a wide range of purposes, including planning, environmental assessment, surveying, construction, maintenance, asset management, and risk assessment.”

-FHWA, AASHTO, ARTBA (2012)
Agenda

- **National Surveys**
  - What are agencies using?

- **Case studies**
  - Detailed interview of projects that demonstrated successful utilization of one or more CIM practices
  - Identify practical strategies, lessons learned, and recommendations

- **Implementation Guide**
  - Identify practical strategies for increasing reliance on digital project delivery and asset management.
AGENCY SURVEY - DATA ANALYSIS
Survey participants

64 respondents from 42 state transportation agencies

38% of respondents were involved in design

30% of respondents were involved in construction

32% were involved in operations, maintenance, or another area.
What is CIM?

**2D**
- 2D Plan sets in the field during construction

**3D / nD**
- 3D Visualization during construction (e.g. isometric drawings, physical models, etc.)
- 3D CADD 4D Modeling Analysis (3D + schedule)
- 5D/nD Modeling Analysis (model-based quantity takeoff/model-based cost estimating)
- Work Packaging Software / Advanced scheduling

**Sensing**
- 3D Imaging (e.g. LiDAR, photogrammetry)
- Geographical Information Systems (GIS)
- Global Positioning Systems (GPS)
- Intelligent Transportation Systems (ITS)
- Field Sensors (e.g. RFID, ground penetrating radar, ultrasonics)
- Intelligent Compaction
- Automated Machine Guidance and Control (AMG)
- Utility Engineering / Clash Detection / Coordination

**Data Management**
- Electronic archival and updating of plans
- Digital Asset Management
- Materials Management System (e.g. Spreadsheets and RFIDs)
- Mobile Digital Devices for onsite applications (tablets, smart phones, etc.)
- Data Connectivity Other than Cellular Towers
- Digital Signatures
Survey results— 3D/nD usage level at DOTs

- 4D and 5D modeling appears to be emerging areas of applications (likely to increase in future)
- CIM for visualization is gaining significance; more agencies in favor of it.
- (Interestingly) 3D CADD came to be the highest (implementation of CAD/DGN electronic data)
Survey results– \textbf{Sensing} usage level at DOTs

\begin{center}
\begin{tabular}{l|c}
\hline
\textbf{Sensing Technology} & \textbf{Responses} \\
\hline
Utility Coordination & 39\% \\
Intelligent Compaction & 45\% \\
Field Sensors & 66\% \\
AMG & 68\% \\
3D Imaging & 84\% \\
ITS & 89\% \\
GIS & 92\% \\
GPS & 95\% \\
\hline
\end{tabular}
\end{center}

\textbf{Inferences from responses}:
- CIM for utility coordination and Intelligent Compaction recorded low usage levels (likely to increase in future)
- GIS and GPS recorded highest usage levels (as per expectations since they have numerous applications)
- LiDAR recorded significant usage levels (need to investigate application areas)
- AMG shows encouraging trend (necessary to study AMG application for individual activities)
Survey results– Data Management usage level at DOTS

**Inferences from responses:**

- Data connectivity (other than cellular towers) recorded the lowest usage (need to study further as RTN/CORS GPS networks are more common)
- Material management systems and digital signatures appears to be emerging applications
- Electronic updating and archiving of plans recorded highest usage (may relate to actual base/master files or 2D plans sheets)
Use of CIM by Project Phase

Phase-wise usage of CIM technologies

- Planning
- Survey
- Environmental
- Design
- Bidding
- Construction
- Traffic safety
- O&M

Legend:
- 2D Category
- 3D/nD Category
- Sensing category
- Data Management Category
Cumulative CIM Technologies Usage

Map showing the cumulative usage of CIM technologies across the United States, with states color-coded based on their CIM Score:
- **1-6**: Limited usage of CIM tools
- **7-12**: Intermediate usage of CIM tools
- **13-15**: Advanced usage of CIM tools

States with **No Data** are not color-coded.

Alaska and Hawaii have their own inset maps for clarity.
How does the cumulative use of CIM vary by DOT?

State DOT Budget
Level of Design In-House
Use of Alternative Contracts
ROI Research
Agency Budget vs. CIM Usage

Budget Divided by Quartiles

<table>
<thead>
<tr>
<th>Quartile</th>
<th>CIM Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>8</td>
</tr>
<tr>
<td>2nd</td>
<td>9</td>
</tr>
<tr>
<td>3rd</td>
<td>7</td>
</tr>
<tr>
<td>4th</td>
<td>10</td>
</tr>
</tbody>
</table>

Significance | 0.366
F            | 1.086
Percentage of Design Conducted in House vs. CIM Usage

![Bar chart showing percentage of design conducted in house vs. CIM usage. The chart indicates a significance of 0.807 and an F value of 0.06.](chart.png)
Usage of Design/Build as Delivery Method vs. CIM Usage

<table>
<thead>
<tr>
<th>CIM Usage</th>
<th>DB</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO</td>
<td>8</td>
</tr>
<tr>
<td>YES</td>
<td>10</td>
</tr>
</tbody>
</table>

Significance: 0.565

F: 0.337
Usage of Public-Private Partnership (P3) vs. CIM Usage

**Significance**: 0.002

<table>
<thead>
<tr>
<th></th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NO</strong></td>
<td></td>
</tr>
<tr>
<td><strong>YES</strong></td>
<td></td>
</tr>
</tbody>
</table>

**F**: 11.041

**Increase (%)**: 37.5
Usage of Contractual Language involving CIM vs. CIM Usage

<table>
<thead>
<tr>
<th>Contractual Language</th>
<th>NO</th>
<th>YES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significance</td>
<td>0.006</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>8.331</td>
<td></td>
</tr>
<tr>
<td>Increase (%)</td>
<td>39.7</td>
<td></td>
</tr>
</tbody>
</table>
ROI Research vs. CIM Usage

ROI Research Conducted

CIM Usage

<table>
<thead>
<tr>
<th></th>
<th>NO</th>
<th>YES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significance</td>
<td>0.078</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>3.277</td>
<td></td>
</tr>
</tbody>
</table>
Summary Thus Far...

- **Wide variability** in use of CIM
- Increased use of CIM related to:
  - Use of *Alternative Delivery Methods*
  - *Contractual Language* to support use
  - Measure of **ROI**
CASE STUDIES
# Case studies

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Project</th>
<th>Project Delivery Method</th>
<th>Approx. Project Cost ($M)</th>
<th>CIM Topics examined</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rotary upgrade to modern roundabout (CTDOT)</td>
<td>D-B-B</td>
<td>1.45</td>
<td>Electronic Engineering Data</td>
</tr>
<tr>
<td>2</td>
<td>Kiewit case study on I-70 project (CDOT)</td>
<td>D-B-B</td>
<td>18</td>
<td>3D modeling for visualization</td>
</tr>
<tr>
<td>3</td>
<td>Relocation of KY7 in Elliott County (KYTC)</td>
<td>D-B-B</td>
<td>26.5</td>
<td>Contract precedence to 3D models</td>
</tr>
<tr>
<td>4</td>
<td>I-96 Livonia construction project (MDOT)</td>
<td>D-B-B</td>
<td>124.1</td>
<td>E-construction initiative</td>
</tr>
<tr>
<td>5</td>
<td>Fore River bridge replacement project (MassDOT)</td>
<td>D-B</td>
<td>300</td>
<td>3D modeling for steel bridge</td>
</tr>
<tr>
<td>6</td>
<td>Kosciuszko Bridge project (NYSDOT)</td>
<td>D-B</td>
<td>555</td>
<td>4D/5D modeling for project monitoring and control</td>
</tr>
<tr>
<td>7</td>
<td>Crossrail Ltd. (UK)</td>
<td>Various</td>
<td>42,000</td>
<td>CIM Lifecycle integration practices</td>
</tr>
</tbody>
</table>

**Agency interviews**

1. Oregon DOT’s CIM Practices (3-D design models for AMG)
   Ron Singh (Ranvir.SINGH@odot.state.or.us)
2. Wisconsin DOT CIM Practices (Integrated Surveying for 3-D design)
   Lance Parve (Lance.Parve@dot.wi.gov)
Lessons learned– Organizational

– Technology implementation planning for CIM vital at organizational level (phased and detailed)
  • Vision and mission statement
  • Leads and responsibilities
  • Funding and regulations / other constraints
  • Plan to involve relevant stakeholders (vendors, utility companies)
  • Executive management buy-in
  • 3-D Design and construction (QA/QC) training requirements for agencies

A few Examples
  • WisDOT’s 3-D Technologies Implementation Plan (TIP, 2013)
  • Utah DOT’s 3-D TIP (2014)
  • Oregon DOT’s Engineering Automation Plan (2008)
  • UK Government’s BIM strategy (Crossrail)
  • Singapore’s e-BIM submission system (regulations)
Lessons learned– CIM and work processes

3D design
- Common for roadway design (terrain models) over structures
- Integrated surveying important for collecting data (LiDAR/Robotic TS/Aerial imagery/Photogrammetry)
- Major issues: LOD, pilot projects, training, managing design changes, Electronic Engineering Data (EED) specifications

4D/5D
- Complex interchanges, bridges, staged construction
- LOD model vs schedule (consistency), linking (automation)
- 5D - emerging application; few reported instances in practice (NYSDOT’s Kosciuszko Bridge project)

Advanced Surveying Methods (LiDAR/UAVs)
- Rapid data collection for assisting 3-D design
- High initial investment (Mobile / Airborne) – greater returns on a “system” perspective
- DOTs of Wisconsin, Oregon, CalTrans, Washington (Examples)
Lessons learned– CIM and work processes

Automated Machine Guidance (Machine controls)

- Used for grading/excavation, emerging application for finished surface (asphalt/concrete); Specs of Iowa, Michigan, Wisconsin and NYSDOT
- Increased productivity and safety on site;
- Contract clauses – explicitly mentioning AMG-related activities
- “Information only” models, QA/QC checks using rovers/RTS

Utility engineering

- Risks/uncertainties have to justify investments
- Issues: Initial investment (GPR/GPS/EMI/Rovers), skilled labor-force
- Clash detection with other design entities – major application
- Extending current standards (UCMs) to accommodate 3D Geospatial data
- Request as-built utility data from contractors (specs.)

Data/Information management

- e-bidding and submittals, electronic document management (common)
- ProjectWise, AASHTO Project Suite, Microsoft SharePoint (software tools)
- Workflow mainly document-based (challenges for model-based workflow)
- Different variants of data for O&M – 2D as-builts (pdfs, electronic), 3D CAD, 3D point clouds (challenge)
# Lessons learned – ROI analysis

<table>
<thead>
<tr>
<th>Organization</th>
<th>Focal point for analysis</th>
<th>Brief description</th>
</tr>
</thead>
</table>
| Michigan DOT          | e-document management systems (ProjectWise) (Farr 2013).      | Agency-wide implementation of electronic document management systems and digital signatures  
  – Monetary benefits through paper-less work process and efficiency improvements  
  **(APPROX. $185,000 SAVINGS IN LATSON ROAD PROJECT ($32M))**                                                                                           |
| Wisconsin DOT         | 3D design (Clash detection) (Parve 2012/2015).                | clash detection processes on SE Freeways Mitchell Interchange, Zoo IC projects  
  -- Reported considerable reduction in RFIs, change orders, and design issues  
  **(3%+/- RFI/CCOS REDUCTION IN ZOO IC & MITCHELL IC PROJECTS)**                                                                                       |
| CalTrans, and         | Mobile LiDAR (Yen et al. 2014).                               | examined different strategies of deploying a mobile LiDAR for agencies’  
  -- Purchasing and operating surveying grade mobile LiDAR emerged as least cost option  
  **($ 6.1 MILLION DOLLARS LESS FOR 6 YEARS LIFECYCLE)**                                                                                                 |
| Washington DOT        |                                                               |                                                                                                                                                                                                                  |
| TxDOT                 | 3D design and ProjectWise (TxDOT 2014).                       | TxDOT conducted a preliminary NPV analysis for agency-wider implementation of 3D design on its projects and ProjectWise to support the 3D workflow.  
  -- *(ESTIMATED TO BE $ 70-95 MILLION DOLLARS OVER 5 YEARS.)*                                                                                         |
| Oregon DOT            | Information Technology Benefit-Cost Evaluation report (Hagar 2011). | ODOT evaluated the benefits and costs of nine IT systems that included GIS infrastructure, environmental analysis tools, electronic document management systems, engineering tools, work zone analysis tools, among others  
  -- Reported time savings (converted to labor-costs through hours saved), workflow and efficiency improvements in information management  
  **(B/C RATIO ESTIMATED TO BE 2.1)**                                                                                                                  |
IMPLEMENTATION GUIDE
Impact of CIM on Project Workflow

CIM Functions  Project Phases  Facility lifecycle
Proposed Implementation Framework

• Three-stage process

Stage 1: Planning from current capabilities
- Action steps for functional needs – maturity levels
- CIM Implementation Plan (Integration of action steps and business needs)

Stage 2: Assessment of future capabilities
- Identification of investments (tools and functions)
- Identification of benefits (functions)
- Synthesizing results (Implementation documents)

Stage 3: Implementation considerations
- Project delivery strategies
- Standards and specifications
- Training and cultural shift
- Governance and policy
- Information management

Communicating lessons learned, best practices, and updating CIM objectives
Stage I CIM Implementation – Maturity Model

- NCHRP 10-96 provides an implementation maturity model to help assess current capabilities and next steps

- Use the maturity model to plan and better connect CIM initiatives across the agency
Stage II CIM Implementation
Investment and Benefits

- Identification of investments – major category

- Identification of benefits
  - Direct: perceivable/measurable improvements for CIM functions
  - Indirect: coordination, long-term program improvements

<table>
<thead>
<tr>
<th>CIM Tools</th>
<th>C*</th>
<th>Investment Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D digital design</td>
<td>S</td>
<td>Generally, none, additional investment can be towards producing digital deliverables (for integrating geospatial information).</td>
</tr>
<tr>
<td>ND modeling tools</td>
<td>S</td>
<td>Discipline-specific needs for digital design (structures, utilities, roadway, drainage, and others) in 3D Procuring software tools that enable geospatial integration of design can be an added advantage.</td>
</tr>
<tr>
<td>Traffic simulation tools</td>
<td>S</td>
<td>Tools that enable microsimulation and macroscopic capabilities to perform traffic analysis at required granularity.</td>
</tr>
<tr>
<td>Information management systems</td>
<td>S</td>
<td>Information management systems (documents, CAD files, databases, models, geospatial data). Efforts to integrate agency’s Enterprise Resource Planning system with project information systems.</td>
</tr>
<tr>
<td>GIS</td>
<td>S</td>
<td>GIS-enabled software platforms to serve across all CIM functions. Capabilities of such applications include ability to perform spatial querying and analyses, geospatial data integration, and providing geo-referenced base maps for several other functions.</td>
</tr>
<tr>
<td>Digital signatures</td>
<td>S</td>
<td>Digital identification (encryption technology) from Certified Authorities for the agency personnel requiring them. Investments for ensuring compatibility with information management systems in place.</td>
</tr>
<tr>
<td>Airborne, mobile, and terrestrial LiDAR</td>
<td>S</td>
<td>Software platforms to process, analyze, visualize, and use the resulting point clouds and the imagery. Innovative applications to extract 3D models.</td>
</tr>
<tr>
<td>Laser scanner (total station)</td>
<td>E</td>
<td>Laser scanner (total station)—terrestrial LiDAR. Seniors (need-based), GPS equipment (supporting data), inertial measurement units, external wheel encoders, data loggers (mobile and airborne).</td>
</tr>
<tr>
<td>GPS</td>
<td>E</td>
<td>GPS tool for installation on a variety of equipment as required for surveying, design, construction automation, and as-built verification using rovers. Augmentation with total stations to improve vertical accuracy.</td>
</tr>
<tr>
<td>GPR</td>
<td>S</td>
<td>Software tools to process the collected data (nametag) and extract the utility information, construct 3D images, and integrate them with other design entries.</td>
</tr>
<tr>
<td>RFID</td>
<td>E</td>
<td>RFID equipment (optional integration with GPS and electromagnetic induction technology to improve efficiency).</td>
</tr>
<tr>
<td>RFID markers, with tags and readers, preloaded with necessary geospatial and project-based information.</td>
<td>E</td>
<td></td>
</tr>
</tbody>
</table>
Stage III CIM Implementation Considerations

- Implementation factors learned from past experience or research
  - Project delivery strategies
    - ATCs, 3D models pre-bid, performance specs.
  - Standards and specifications
    - Level of detail (LOD), as-built data, QA/QC for 3D models, priority of formats (3D/2D)
  - Training and cultural shift
    - Just-in-time and on-field training, cross-disciplinary, learning curve, supply chain
  - Governance and policy
    - Risk and liability of errors, digital signatures (utility and encryption guidelines)
  - Information management
    - Data requirements analysis, version and access control, digital archive efforts,
• Identifies CIM tools and related functions for project delivery, their uses and benefits

• Proposes a three-stage framework for integrating CIM with agency workflow

• Compiles illustrative and case examples to demonstrate the framework

Introduction: • Overview of CIM tools and functions

CIM workflow: • Impact of CIM on project delivery

Framework: • Planning of current capabilities (maturity model)
  • Assessment of future needs (costs-benefit analysis)
  • Implementation considerations (best practices)

Resources: • Literature review
  • Current state of practice (Surveys)
  • Case studies (lessons learned)

Appendix: • CIM resources/references
Additional Suggested Resources

- NCHRP 831: Guide for Civil Integrated Management in Departments of Transportation
- NCHRP 20-68A: Scan 13-02, Advances in Civil Integrated Management
- FHWA-IF-05-025, Innovation in Vertical and Horizontal Construction: Lessons for the Transportation Industry
- CIM 3D Technologies Implementation Plan
- FHWA – HIF – 12 – 014, Identifying existing and emerging technologies in the area of Intelligent Construction of highways
- NCHRP Synthesis 372, Emerging technology in construction delivery
- FDOT CIM Workshop 2012, FTBA 2015 CIM presentations
- Digital project delivery presentations, IHEEP 2014 and 2015
Thank You & Q&A

Dr. Bill O’Brien, P.E.
The University of Texas at Austin
wjob@mail.utexas.edu

Dr. Paul Goodrum, P.E.
The University of Colorado – Boulder
Paul.goodrum@Colorado.edu

University of Colorado Boulder