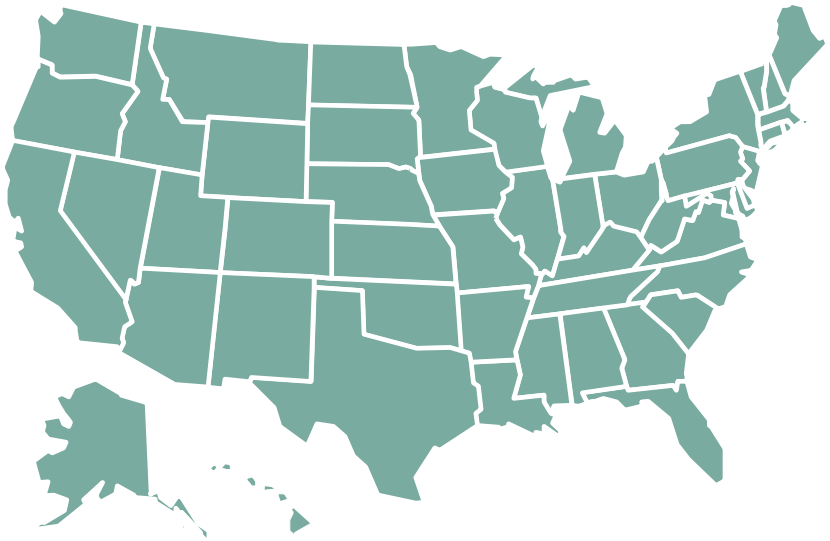
NCHRP Research Report 831:

Civil Integrated Management for Departments of Transportation

NCHRP Project 10-96

NCHRP is a State-Driven Program

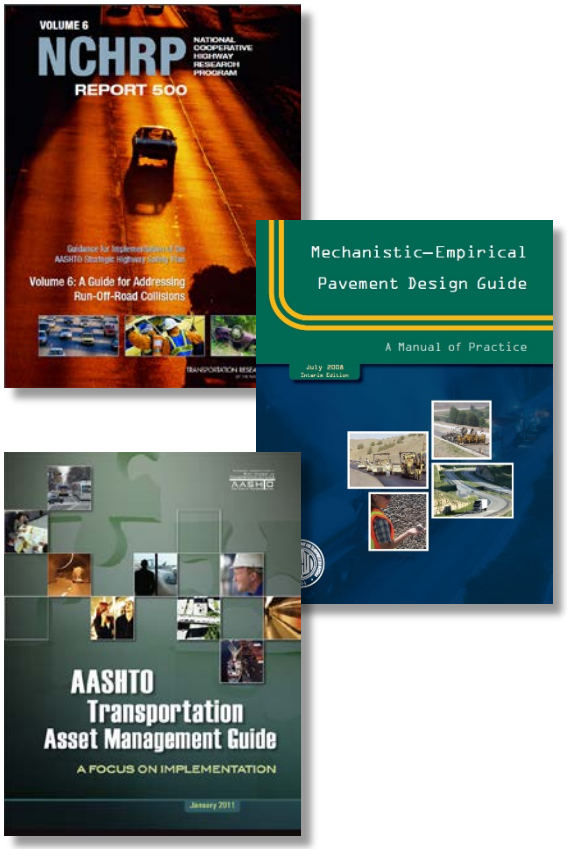
- Sponsored by individual state DOTs who
  - Suggest research of national interest
  - Serve on oversight panels that guide the research



- 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

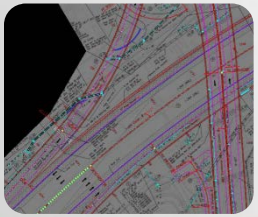
30% of respondents were involved in construction

32% were involved in operations, maintenance, or another area.

What is CIM?

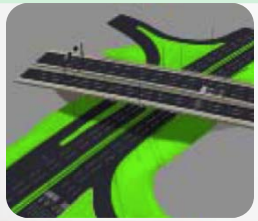
2D

- 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



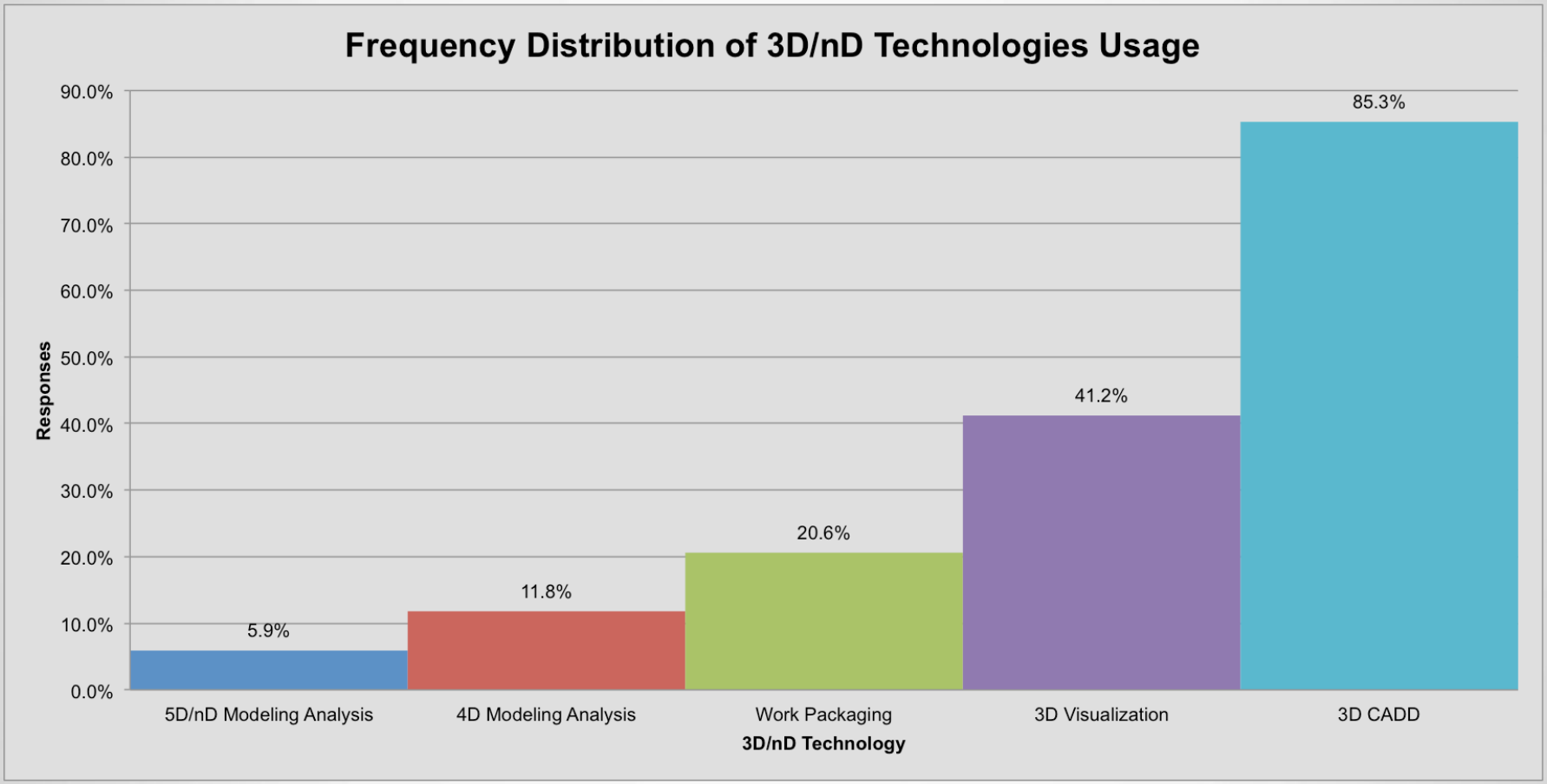
Sensing

- 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

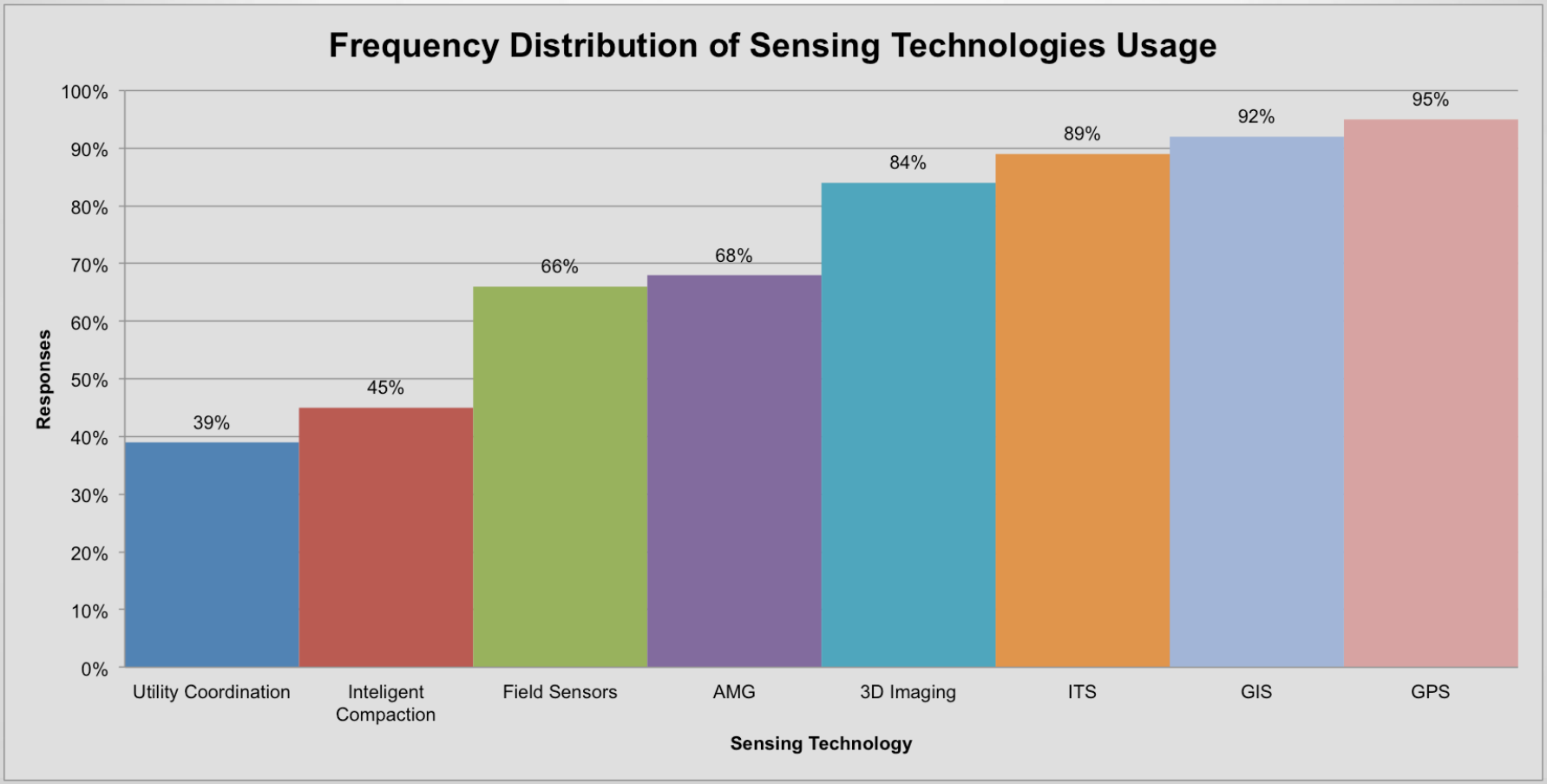
Survey results– 3D/nD usage level at DOTs



Inferences from responses:

- 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)

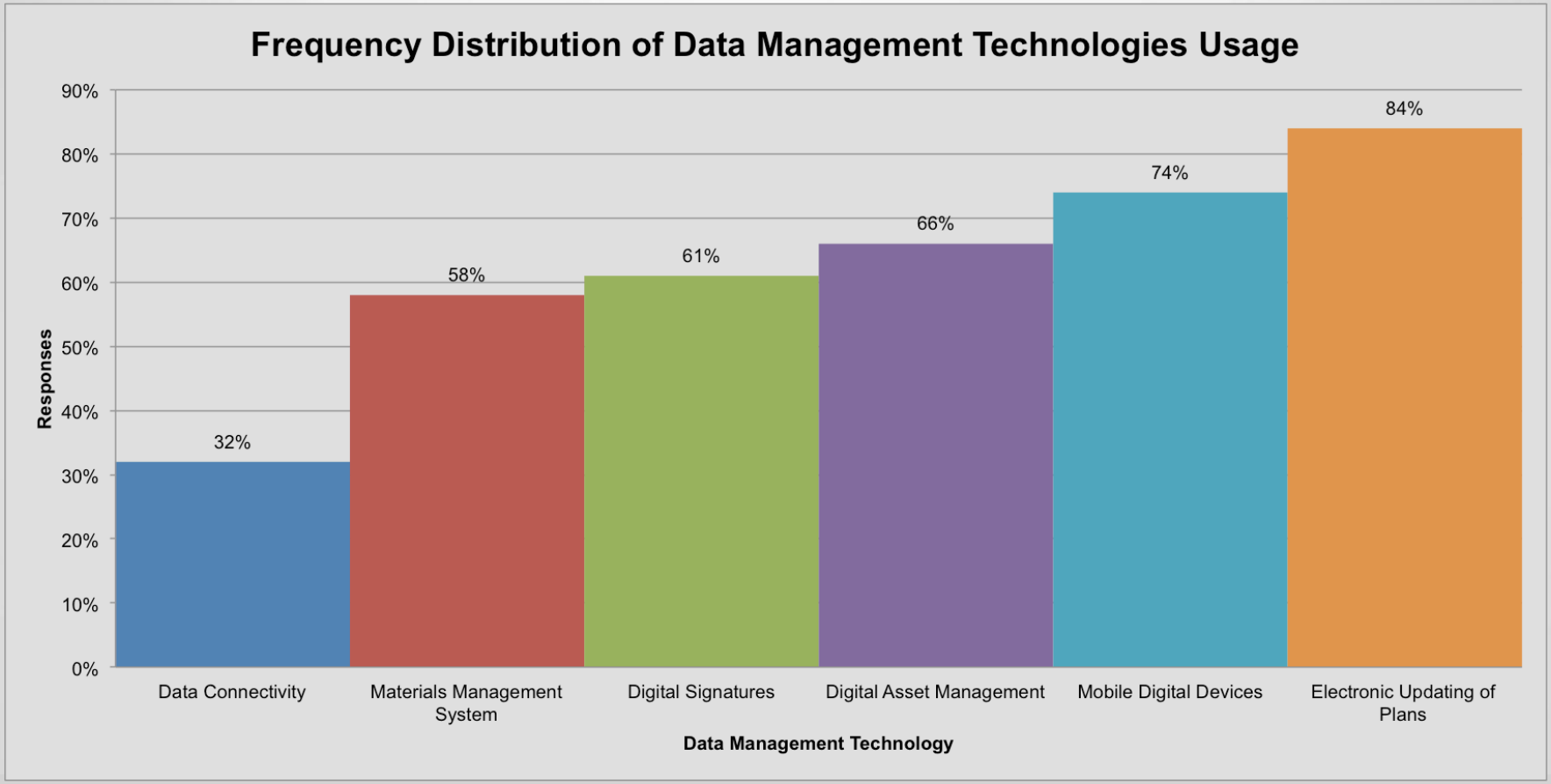
Survey results– Sensing usage level at DOTs



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)

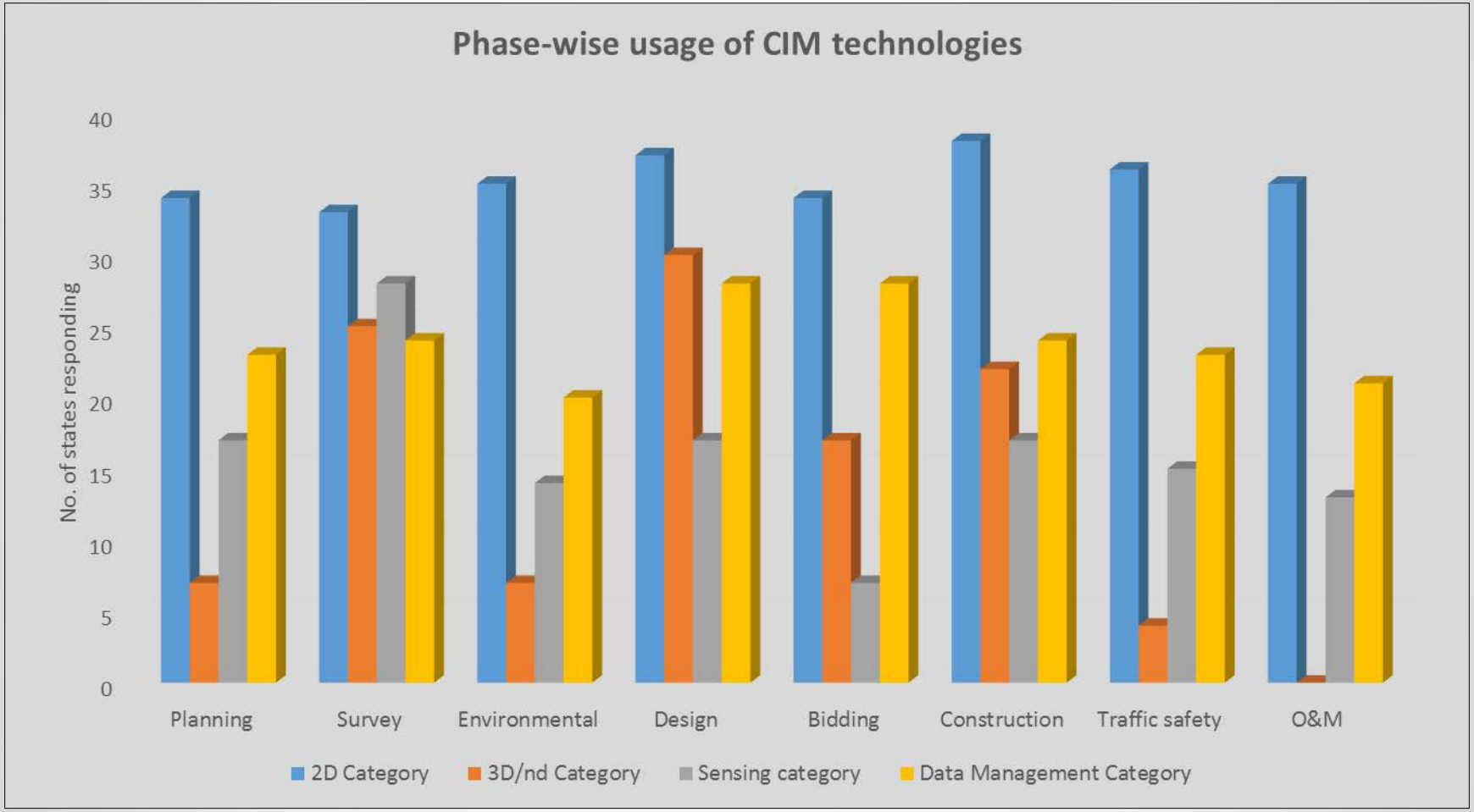
Survey results– Data Management usage level at DOTS



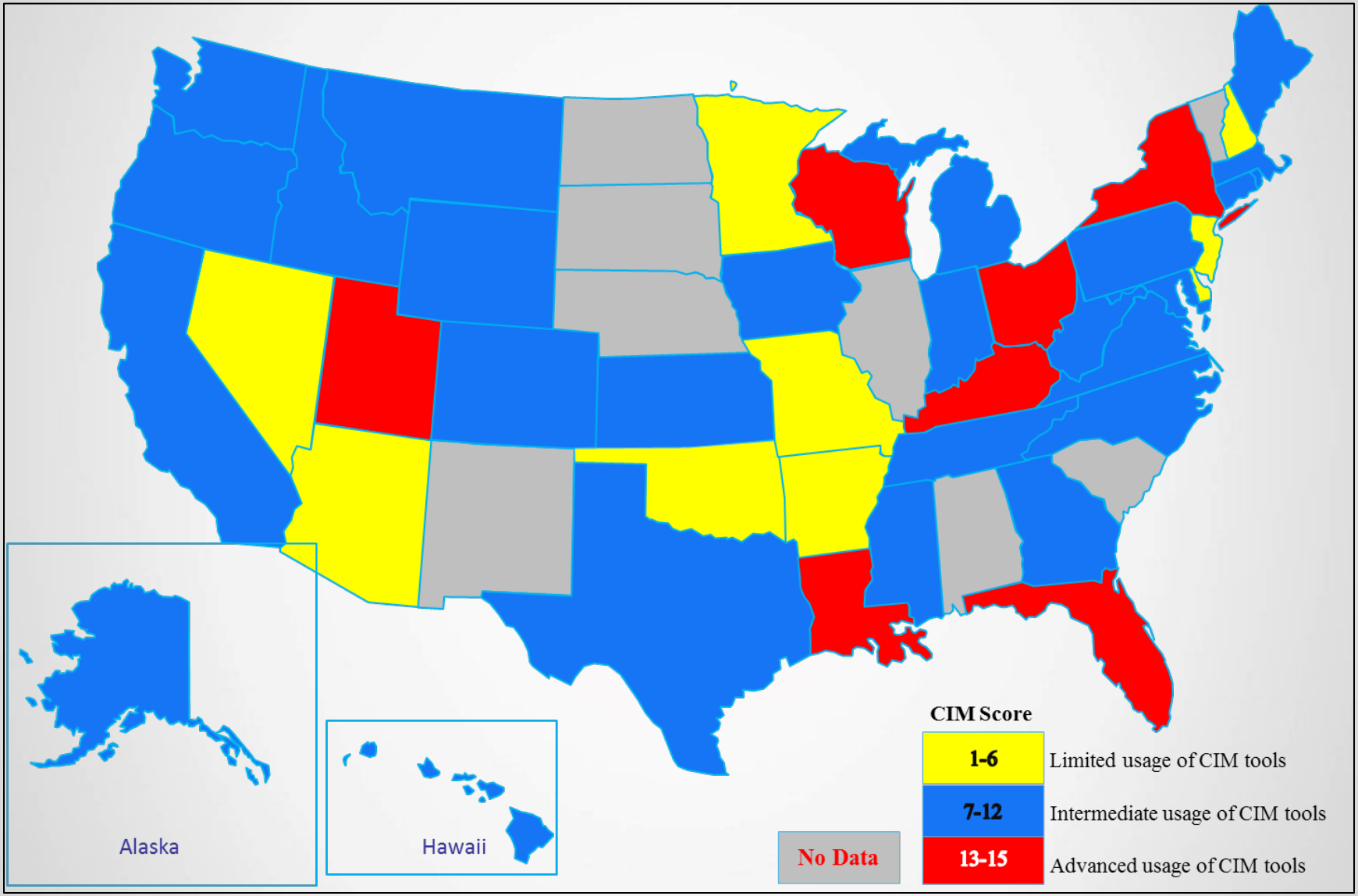
Inferences from responses:

- 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



Cumulative CIM Technologies Usage



How does of the cumulative use of CIM vary by DOT?

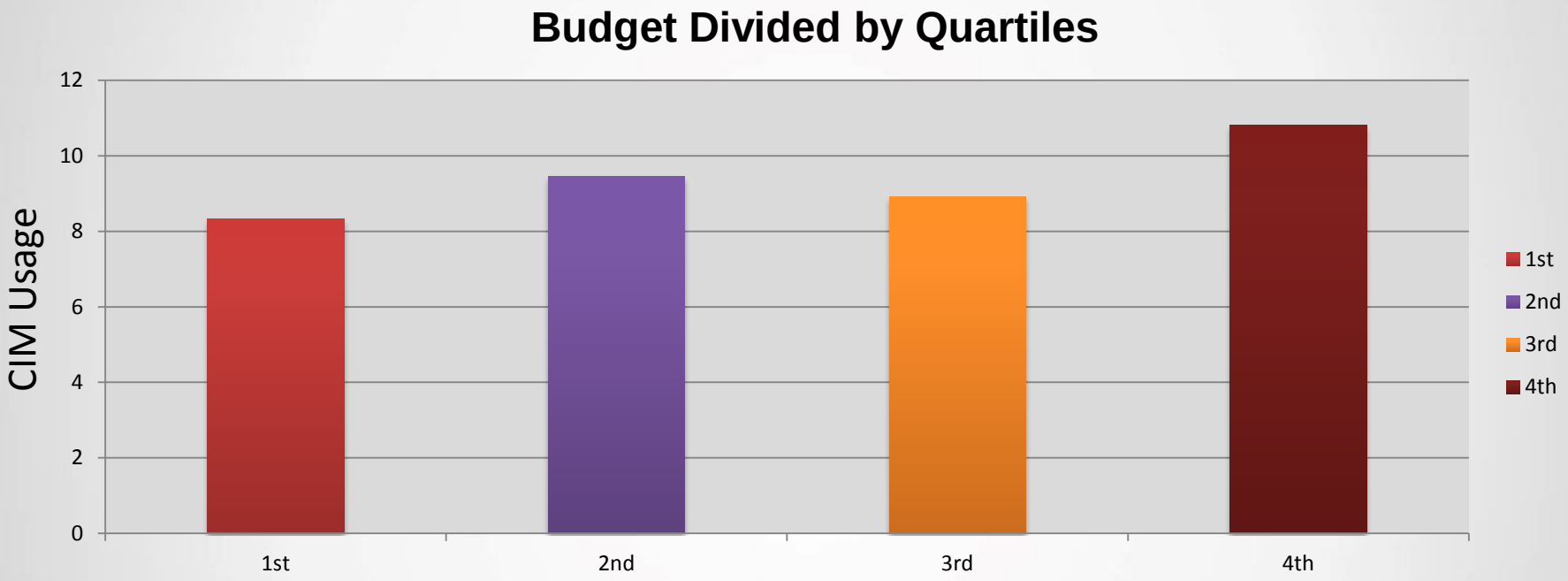
State DOT Budget

Level of Design In-House

Use of Alternative Contracts

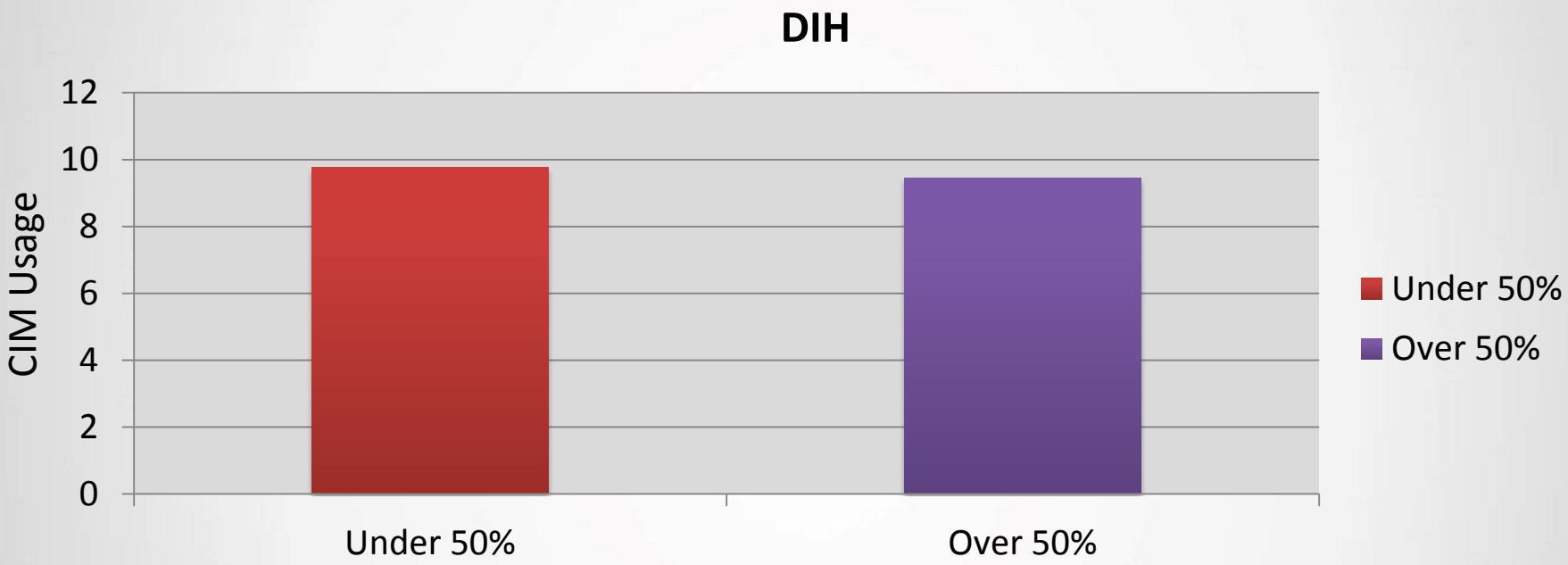
ROI Research

Agency Budget vs. CIM Usage



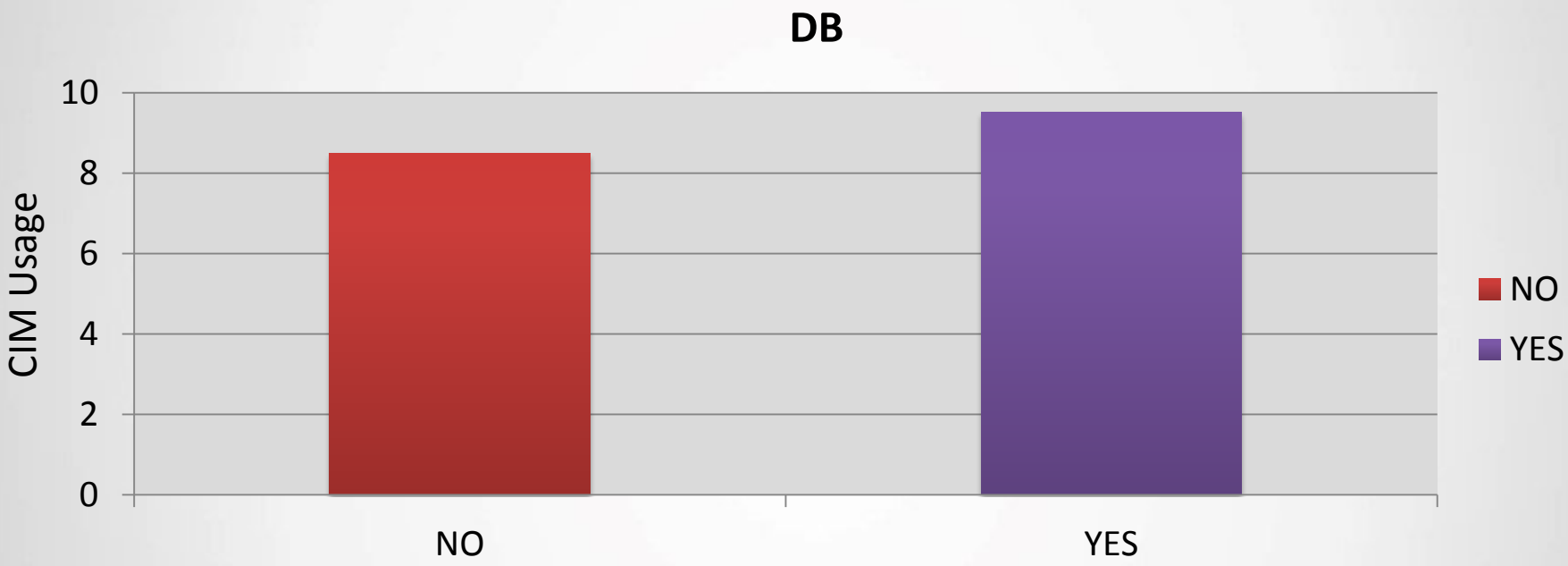
Significance	0.366
F	1.086

Percentage of Design Conducted in House vs. CIM Usage



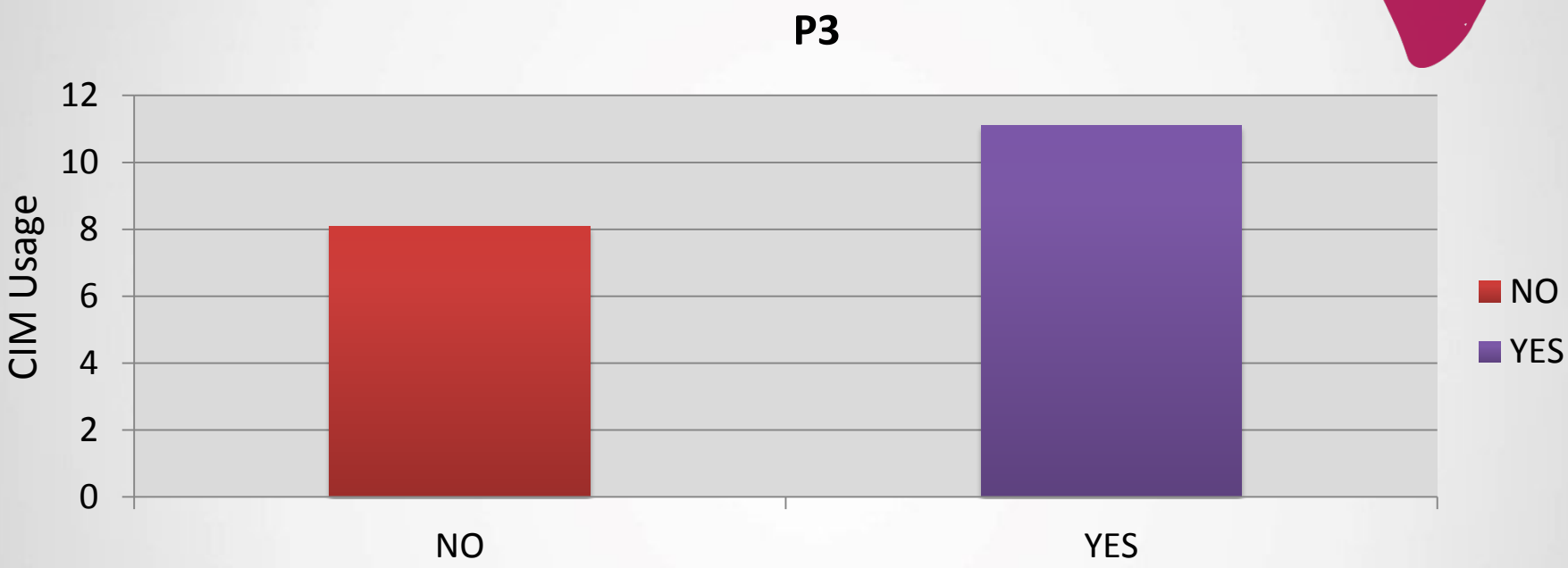
Significance	0.807
F	0.06

Usage of Design/Build as Delivery Method vs. CIM Usage



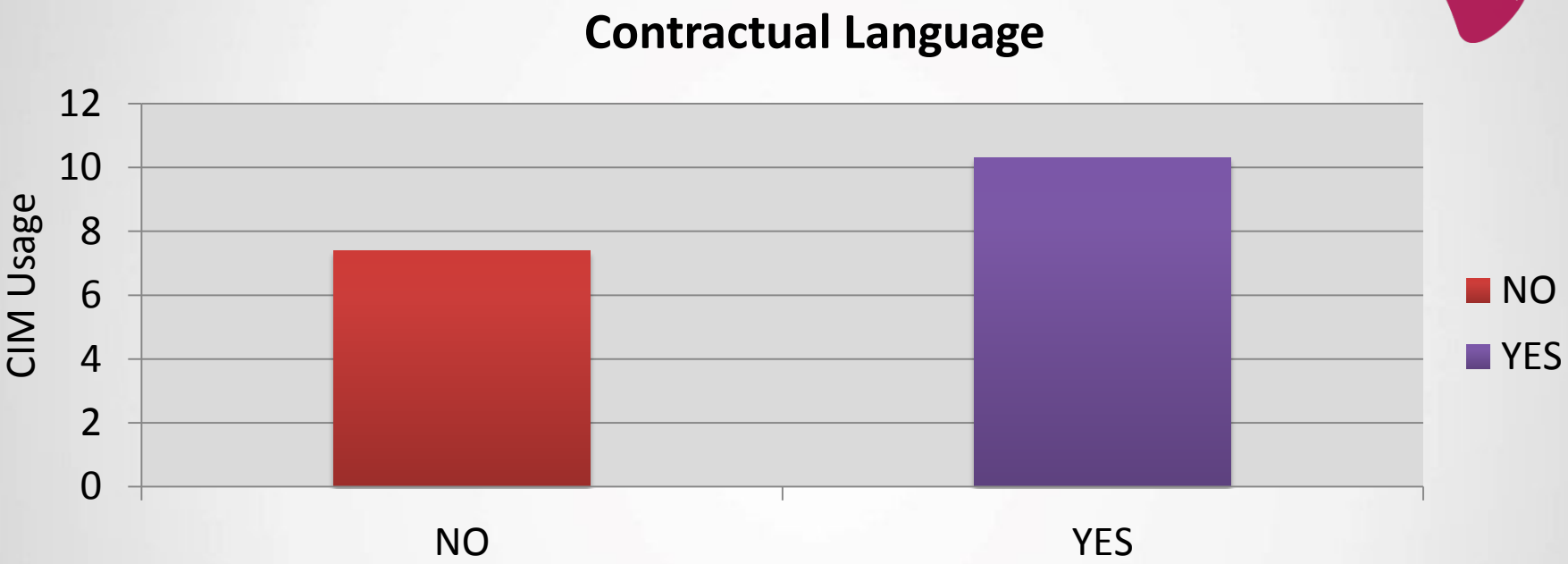
Significance	0.565
F	0.337

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



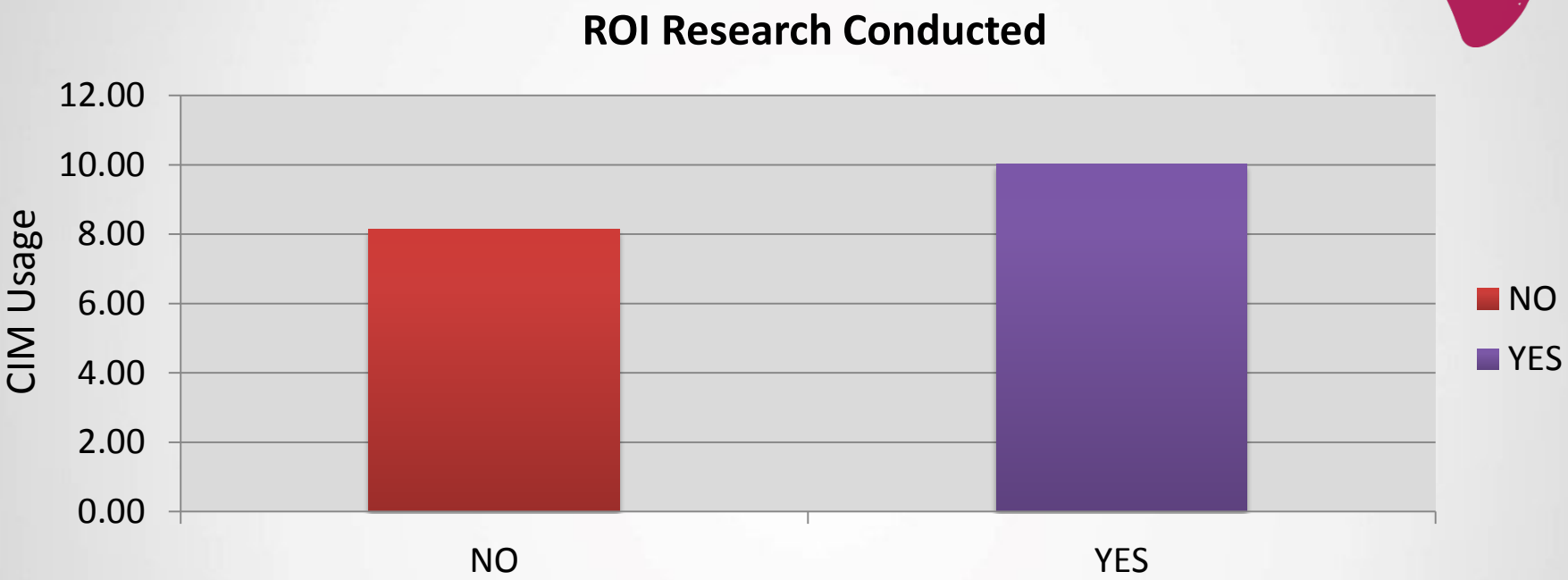
Significance	0.002
F	11.041
Increase (%)	37.5

Usage of Contractual Language involving CIM vs. CIM Usage



Significance	0.006
F	8.331
Increase (%)	39.7

ROI Research vs. CIM Usage



Significance	0.078
F	3.277

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

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

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)

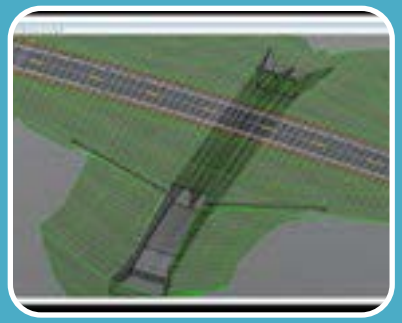
Lessons learned– Organizational

- **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

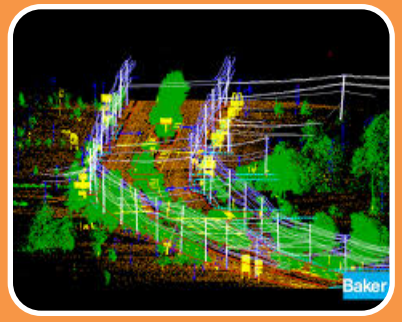


3D **design**

- **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*)



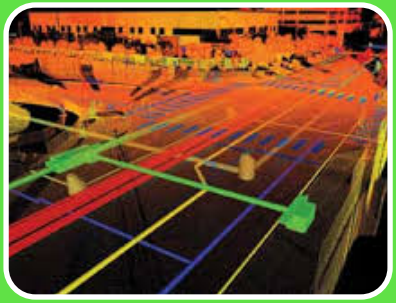
Advanced Surveying Methods(LiDAR/UAVs)

- **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)

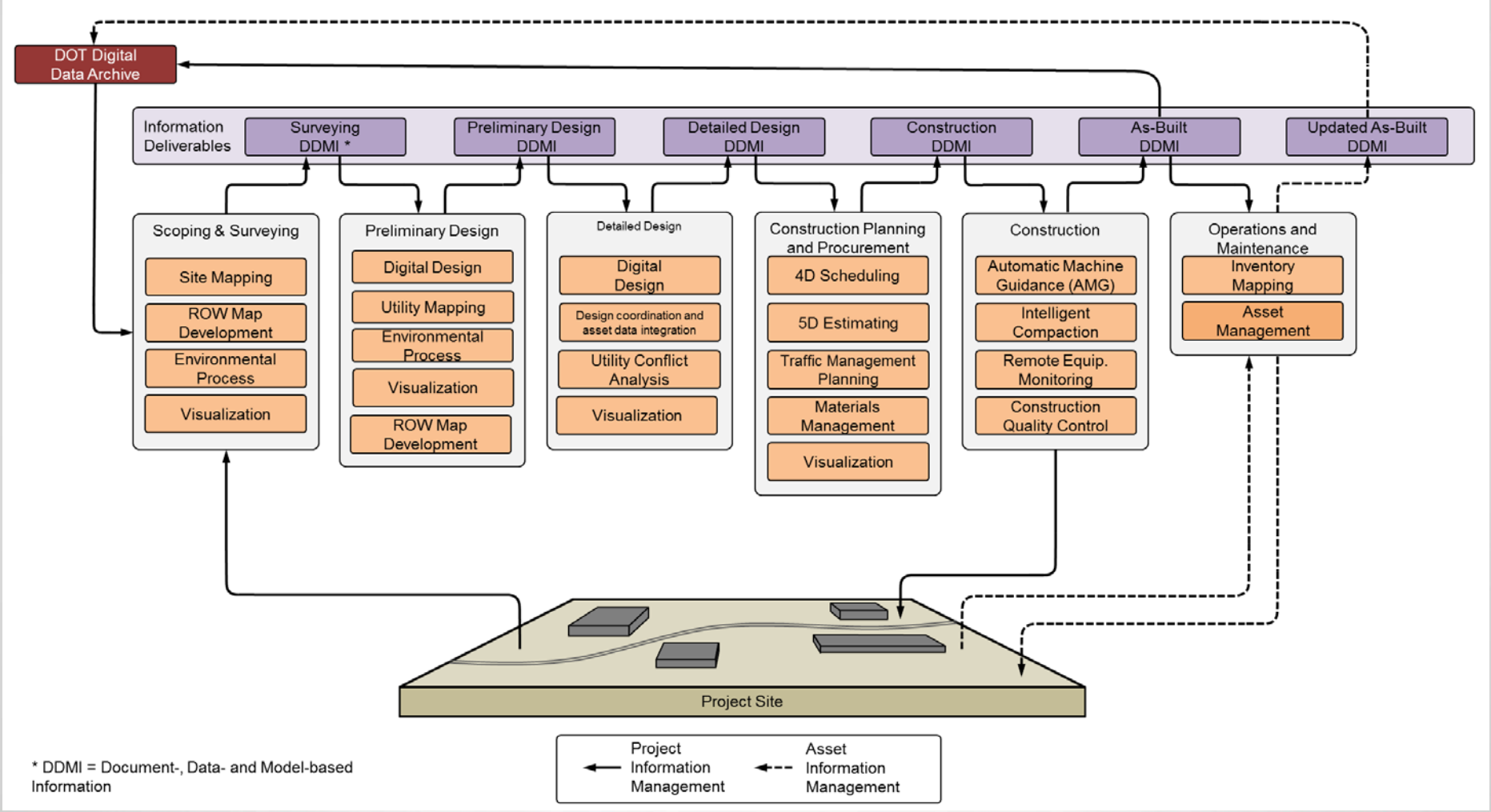
Lessons learned – ROI analysis

Organization	Focal point for analysis	Brief description
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 ($32M))***
Wisconsin DOT	3D design (Clash detection) (Parve 2012/2015).	clash detection processes on SE Freeways Mitchell Interchange, Zoo IC projects --Reported considerable reduction in RFIs, change orders, and design issues (3***%+/- RFI/CCOS REDUCTION IN ZOO IC & MITCHELL IC PROJECTS***)
CalTrans, and Washington DOT	Mobile LiDAR (Yen et al. 2014).	examined different strategies of deploying a mobile LiDAR for agencies' -- Purchasing and operating surveying grade mobile LiDAR emerged as least cost option ***($ 6.1 MILLION DOLLARS LESS FOR 6 YEARS LIFECYCLE)***
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

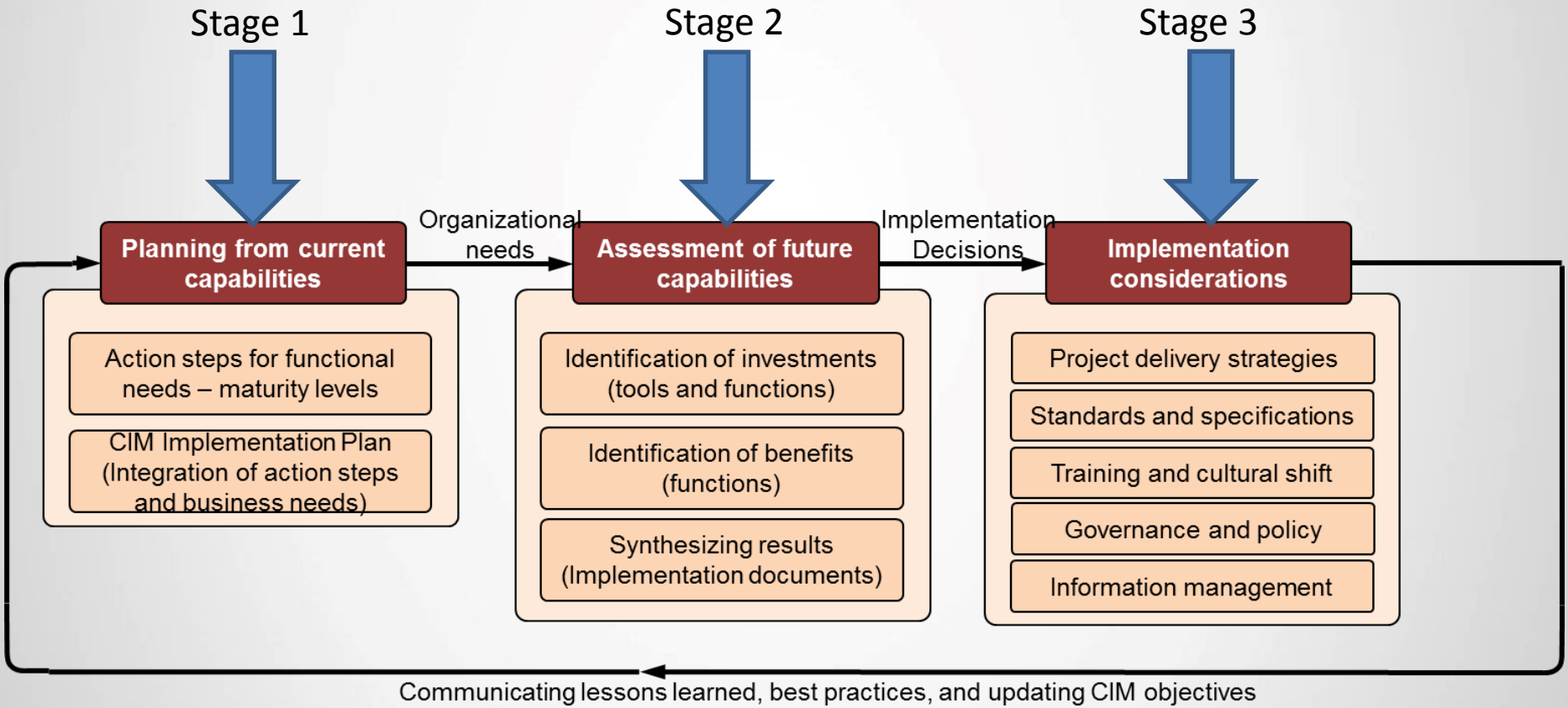
Impact of CIM on Project Workflow

CIM Functions → Project Phases → Facility lifecycle



Proposed Implementation Framework

- Three-stage process



Stage 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

	Initial Level Most of the functions and deliverables are non-CIM with limited/no utilization of CIM technologies; information integration across phases is limited	Intermediate Level Usage of model-based tools for performing certain functions. information deliverables are matured with points of integration across phases	Advanced Level A matured approach for project delivery where CIM-based functions dominate the project workflow with full information integration across phases
Scoping & Surveying Phase	• GIS-based platforms with basic capabilities for project development activities (e.g. ROW map development, and environmental processes); • Use of traditional surveying methods together with static LiDAR for project-level data collection.	• GIS-based platforms with basic capabilities for project development activities; • Basic use of visualization (GIS layers) • Increased use of advanced surveying methods for project-level data collection; • 3D geospatial data for design may not be an outcome.	• Geospatial and cloud-based tools for project development activities; • Extensive use of visualization for concept design and approval (GIS layers, conceptual 3D models) • Extensive use of advanced surveying methods to produce 3D data (integrated surveying with LiDAR/GPS/RTN/Robotic Total stations).
Preliminary & Detailed Design Phase	• Terrain model design performed in 3D, but detailing is in 2D (e.g. gore areas, intersections); • All other design disciplines work in 2D environments; • PS&E documents are delivered in 2D; • Use of traditional utility location methods for project-level data collection; • Design coordination/reviews and utility conflict analysis performed in 2D.	• Terrain model design and detailing performed in 3D; • All other design disciplines work in 2D but produce representative 3D CAD models; • PS&E delivered in 2D; limited use of modern SUE technologies (e.g. GPR, EMI, RFID) for project-level data collection; A 3D geospatial model may not exist; • Design coordination and utility conflict analysis performed in both 2D and 3D.	• Collaborative design by all disciplines in 3D; structures designed to the required LOD (detailing in 2D) with O&M data IDs / needs • PS&E delivered in 2D and 3D (wherever required); • Extensive use of modern SUE technologies to produce 3D geospatial data for project-level data collection; • Design coordination and utility conflict analysis in 3D.
Construction Planning & Procurement Phase	• Traditional (paper-based) scheduling and estimating methods; traditional materials management; • Traffic Control Plans (TCPs) developed and visualized in 2D - temporary construction, lane closures, crash barriers, variable message signs, barricades, and other traffic control devices	• Use of 4D/5D models for visualization purposes only; • Real-time tracking of materials using CIM tools (such as RFID) and web-based solutions; • TCPs developed in 2D, but visualized in 3D.	• Use of 4D/5D models for visualization, constructability analyses, progress monitoring, and cost control (i.e. model-based project controls); • real time tracking of materials using RFID and cloud-based tools; • TCPs developed in 2D and visualized in 3D with real-time traffic data.
Construction Phase	• Use of AMG for excavation and grading operations (dirtwork); • Use of mobile digital devices for field verification (using 2D plan sheets). • Limited/No use of rovers for QA/QC checks • No use of Intelligent Compaction Technologies • As-built checks and record creation not very frequent	• Use of AMG extended to finished surfaces (e.g. asphalt or concrete pavements); • Use remote site monitoring (equipment telematics). • Use of intelligent compaction; • Use of mobile digital devices for field verification (2D plans and 3D models for pavements); • Use of Rovers/RTS for QA/QC checks and	• Extensive use of AMG (including. concrete barriers, retaining walls); • Use of remote site monitoring and active control (design updates); • Use of intelligent compaction • Use of mobile digital devices for field verification (3D models); • Use of Rovers/RTS for QA/QC checks, drones for inspection; accurate and frequent

CIM Implementation Maturity Model: NCHRP 10-96 Guidebook

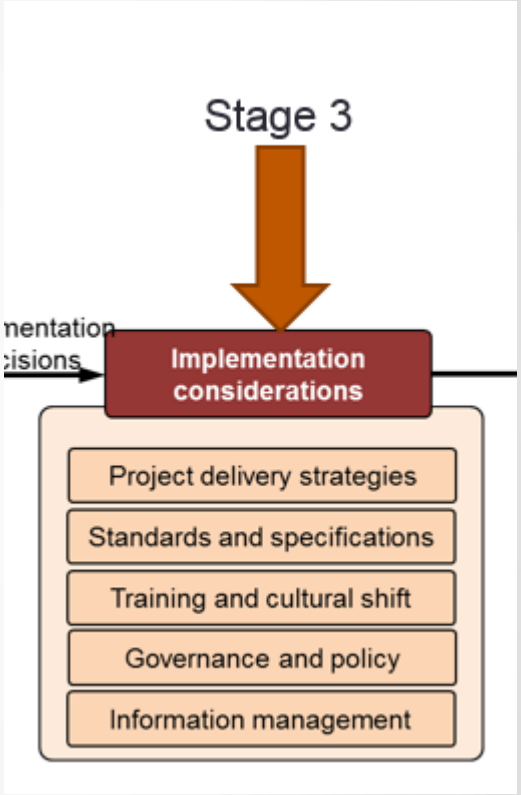
Stage II CIM Implementation Investment and Benefits

- Identification of investments – major category
- Identification of benefits
  - Direct : perceivable/measurable improvements for *CIM functions*
  - Indirect : coordination, long-term program improvements

CIM Tools	C*	Investment Specifications
Modeling Technologies		
2D digital design	S	Generally, none; additional investment can be towards producing digital deliverables (for integrating geospatial information).
ND modeling tools	S	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.
Traffic simulation tools	S	Tools that enable microsimulation and macroscopic capabilities to perform traffic analysis at required granularity.
Data Management Technologies		
Information management systems (project and asset)	S	Information management systems (documents, CAD files, databases, models, geospatial data). Efforts to integrate agency's Enterprise Resource Planning system with project information systems.
GIS	S	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.
Digital signatures	S	Digital identification (encryption technology) from Certified Authorities for the agency personnel requiring them. Investments for ensuring compatibility with information management systems in place.
Surveying Technologies		
Airborne, mobile, and terrestrial LiDAR	S	Software platforms to process, analyze, visualize, and use the resulting point clouds and the imagery. Innovative applications to extract 3D models.
	E	Laser scanner (total station)—terrestrial LiDAR. Sensors (need-based), GPS equipment (supporting data), inertial measurement units, external wheel encoders, data loggers (mobile and airborne).
GPS	E	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.
GPR	S	Software tools to process the collected data (radargram) and extract the utility information, construct 3D images, and integrate them with other design entities.
	E	GPR equipment (optional integration with GPS and electromagnetic induction technology to improve efficiency).
RFID	E	RFID markers, with tags and readers, preloaded with necessary geospatial and project-based information.
	S	Software platforms (GIS and Excel spreadsheets, among others) to load information.

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,



NCHRP 831 CIM Guide – Layout

- 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
  - Oregon DOT 2008: http://www.oregon.gov/ODOT/HWY/GEOMETRONICS/docs/engautokeyconcepts.pdf
  - Wisconsin DOT 2013:http://cmsc.engr.wisc.edu/WisDOT-3D-Technologies-Implementation-Plan-Final-Plan-2013-July-1.pdf
  - Utah DOT: 2014 http://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:4450,
- 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
  - http://www.dot.state.fl.us/structures/DesignExpo2012/CIM2012.shtm
  - http://web.ftba.com/convention/2015_presentations.aspx
- ODOT Design to Paver 2014 Workshop, http://designtopaver.org/
- FHWA 3D Engineered models webinar series, http://www.fhwa.dot.gov/construction/3d/webinars.cfm
- Digital project delivery presentations, IHEEP 2014 and 2015
  - http://www.iheep2014.com/webagenda.html
  - http://www.iheep2015.com/agenda.html

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

THE UNIVERSITY OF TEXAS AT AUSTIN
CENTER FOR TRANSPORTATION RESEARCH

University of Colorado
Boulder