NCHRP 10-96

GUIDE FOR CIVIL INTEGRATED MANAGEMENT (CIM) IN DEPARTMENTS OF TRANSPORTATION

Presentation
August 11, 2015

The Project Team
NCHRP 10-96

NCHRP Project Team

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Definition of CIM

"Civil integrated management (CIM) is a term that recently has come to be applied to **an assortment of practices and tools entailing collection, organization, and management of information in digital formats about a highway construction project**.."

- FHWA, AASHTO, ARTBA (2012)

- Tools for digital project delivery and asset management
  - such as, advanced surveying methods, model-based design (3-D), subsurface mapping of utilities, Automated Machine Guidance (AMG), electronic as-builts among others

Research Objectives

The objective of this research is to develop a guide to CIM that DOT managers can use to

a) Identify which CIM tools and processes to implement;

b) Identify the particular benefits, obstacles, and costs; and

c) Identify practical strategies to assist with implementation.

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

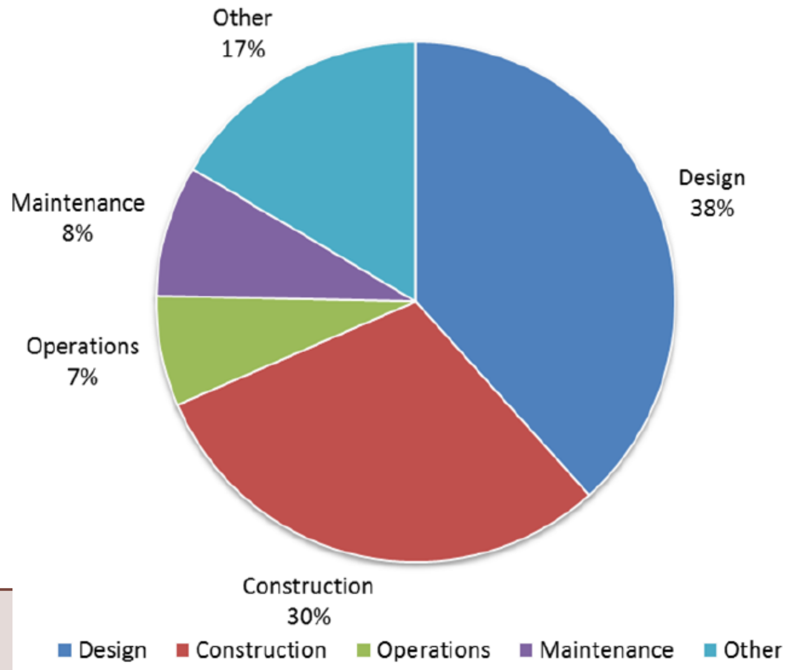
- identify practical strategies for increasing reliance on digital project delivery and asset management.

AGENCY SURVEY - DATA ANALYSIS

Survey participants

- Respondents from Design, Construction, Operations, or Maintenance.
- 40 States involved:

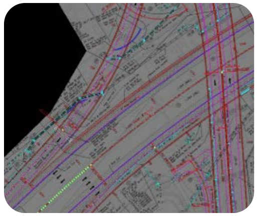
Alaska	Georgia	Maine	North Carolina	Rhode Island
Arizona	Hawaii	Maryland	Nevada	Tennessee
Arkansas	Idaho	Massachusetts	New Hampshire	Texas
California	Indiana	Michigan	New Jersey	Utah
Colorado	Iowa	Minnesota	New York	Virginia
Connecticut	Kansas	Mississippi	Ohio	Washington
Delaware	Kentucky	Missouri	Oregon	West Virginia
Florida	Louisiana	Montana	Pennsylvania	Wyoming



CIM Technology Clusters used for Surveys

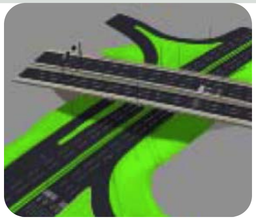
2D

- 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



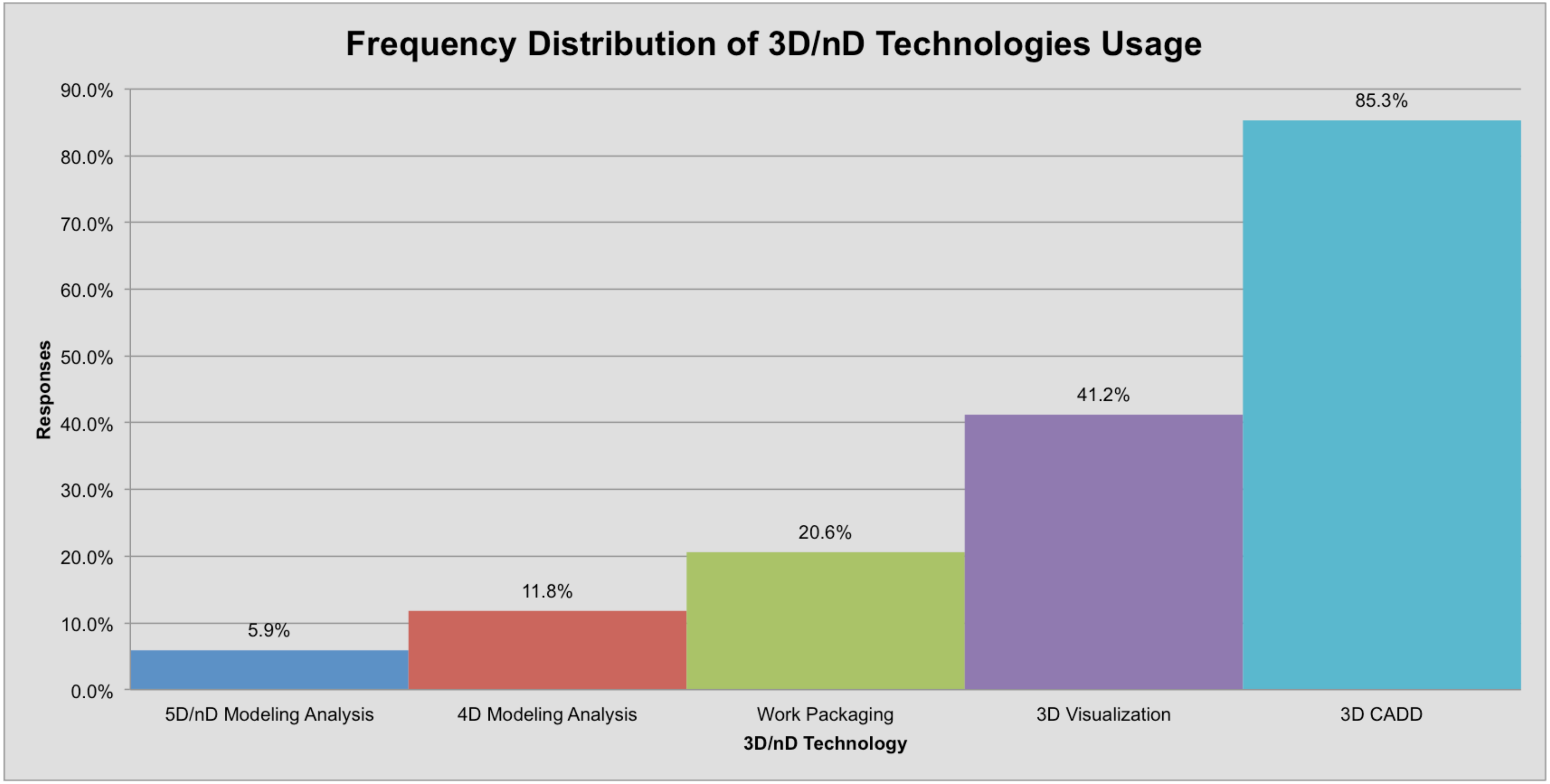
Sensing

- 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

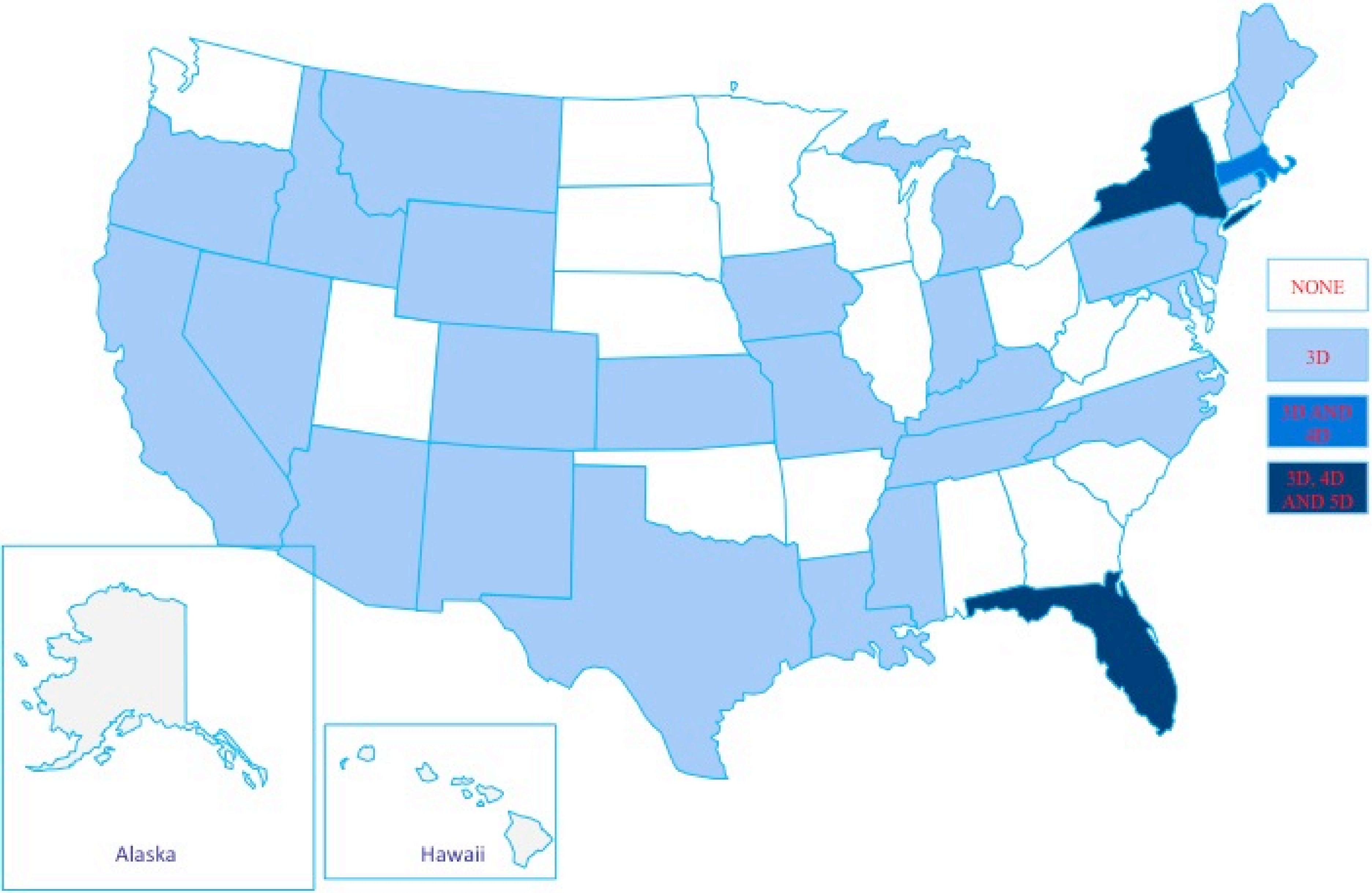
Survey results– 3D/nD usage level at DOTs



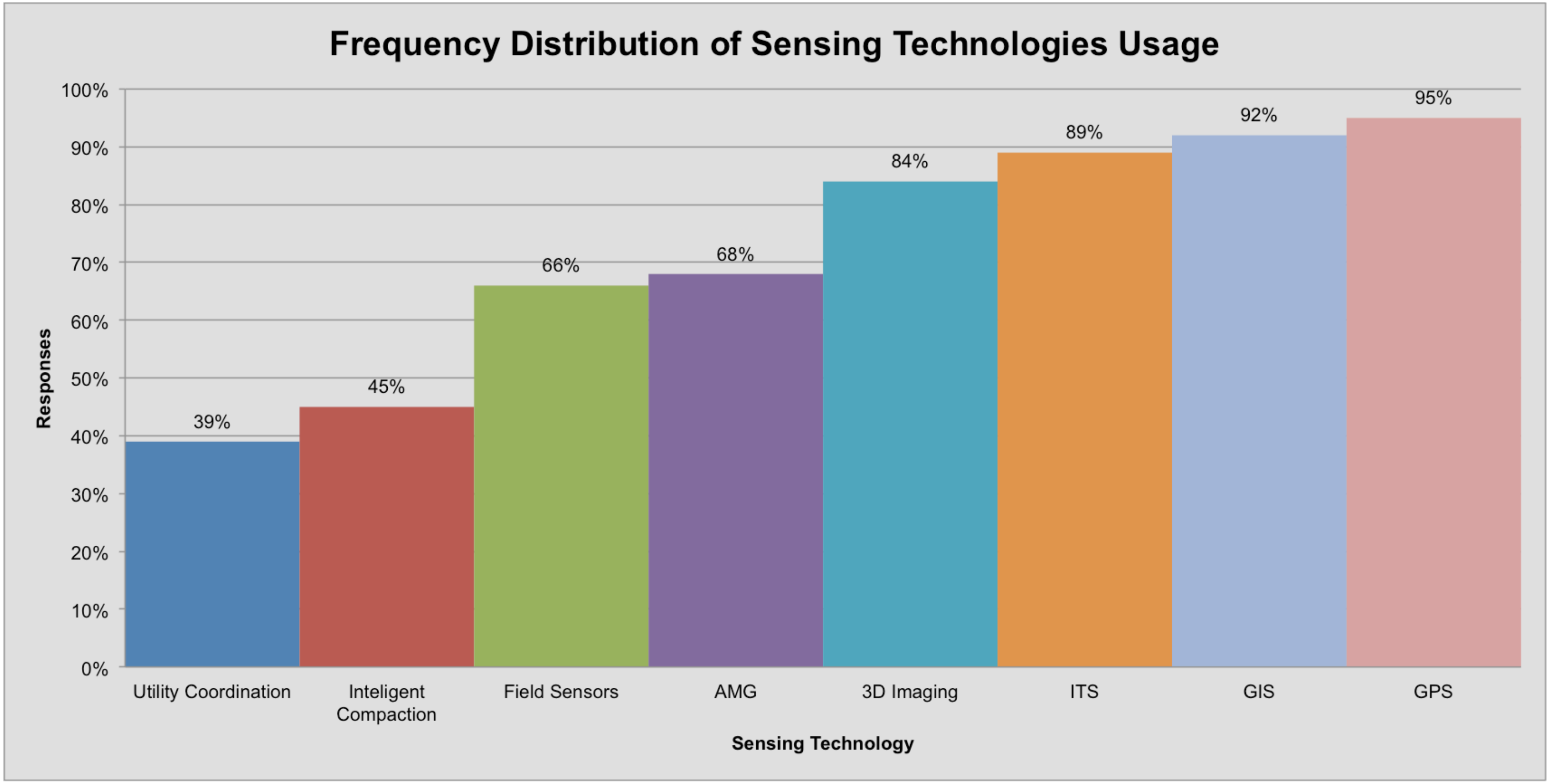
Inferences from responses:

- 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)

nD Usage Map



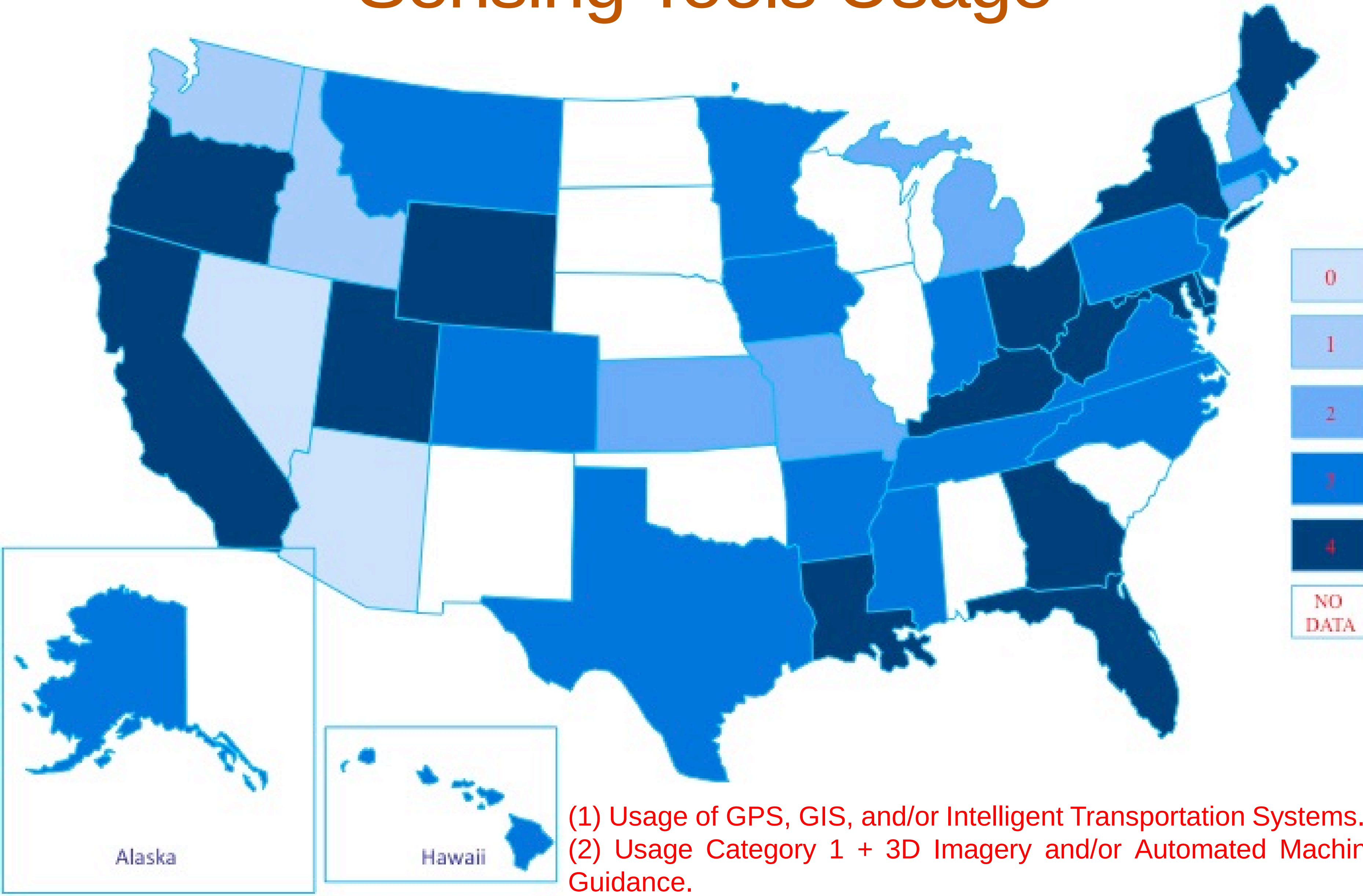
Survey results– Sensing usage level at DOTs



Inferences from responses:

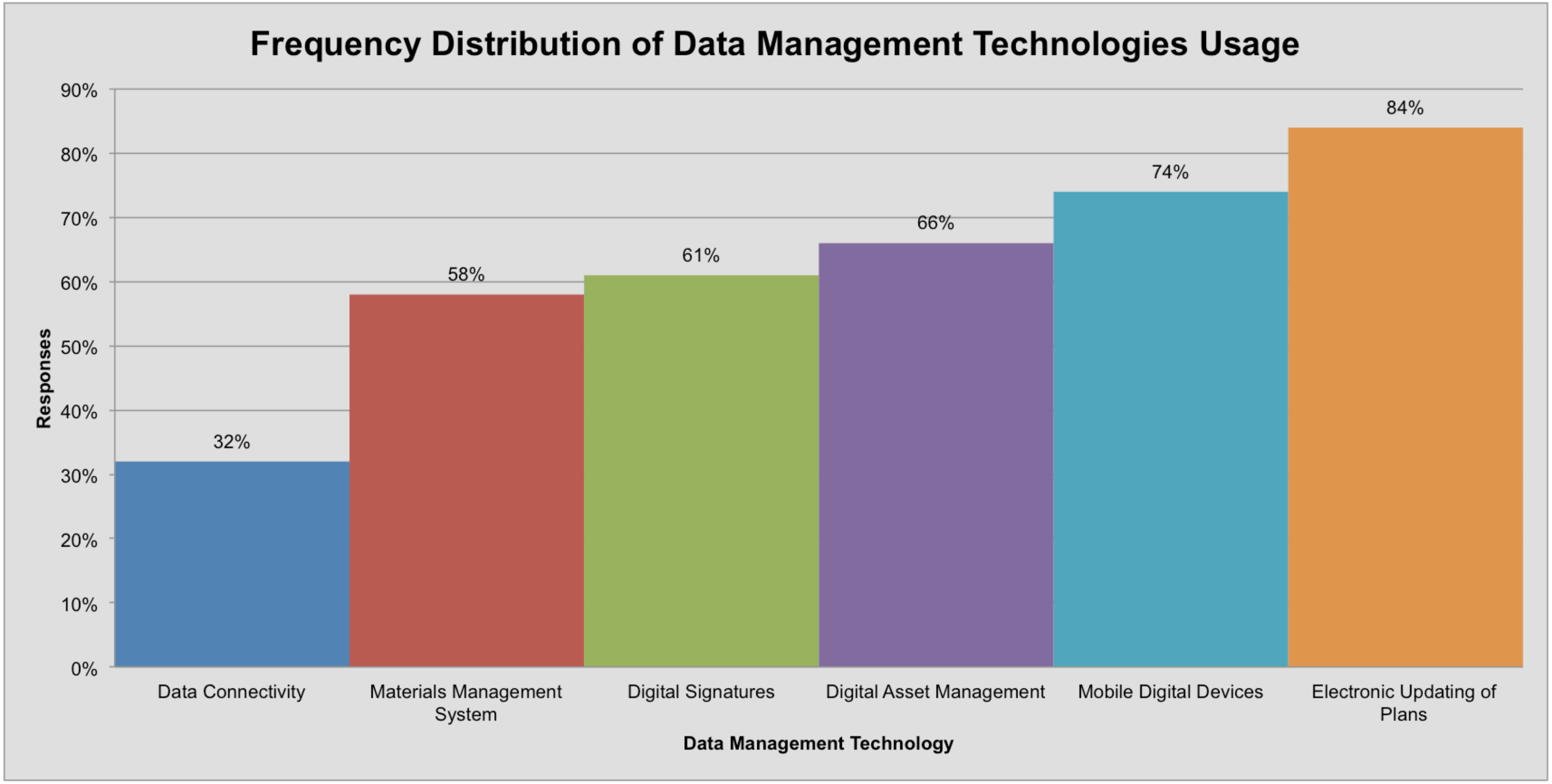
- CIM for utility coordination and Intelligent Compaction recorded low usage levels (likely to increase in future)
- GIS and GPS recorded highest usage levels (as per expectations since they have numerous applications)
- LiDAR recorded significant usage levels (need to investigate application areas)
- AMG shows encouraging trend (necessary to study AMG application for individual activities)

Sensing Tools Usage



(1) Usage of GPS, GIS, and/or Intelligent Transportation Systems.
(2) Usage Category 1 + 3D Imagery and/or Automated Machine Guidance.
(3) Usage Category 2 + Field Sensors and/or Intelligent Compaction.
(4) Usage Category 3 + Utility Coordination.

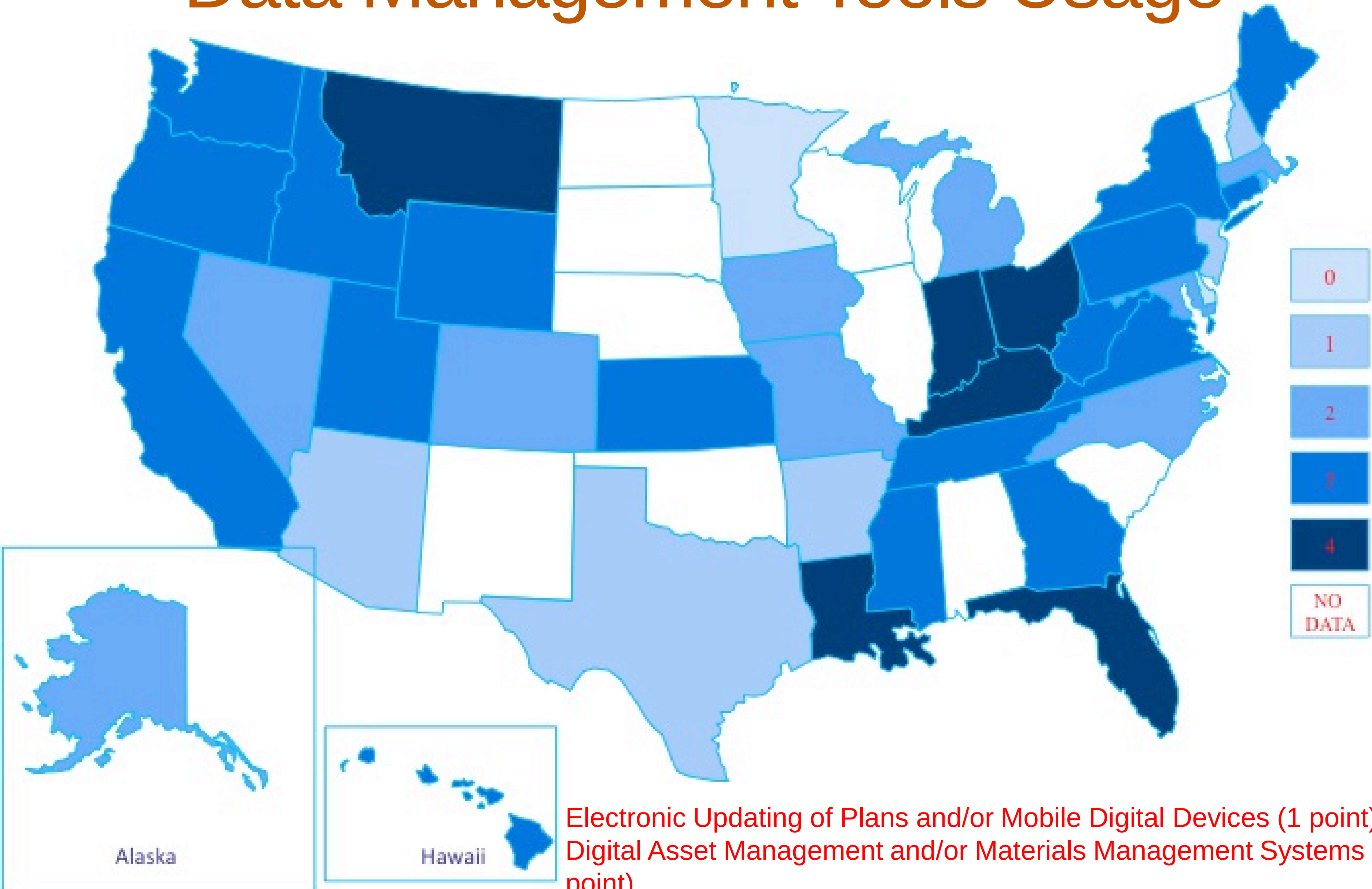
Survey results– Data Management usage level at DOTS



Inferences from responses:

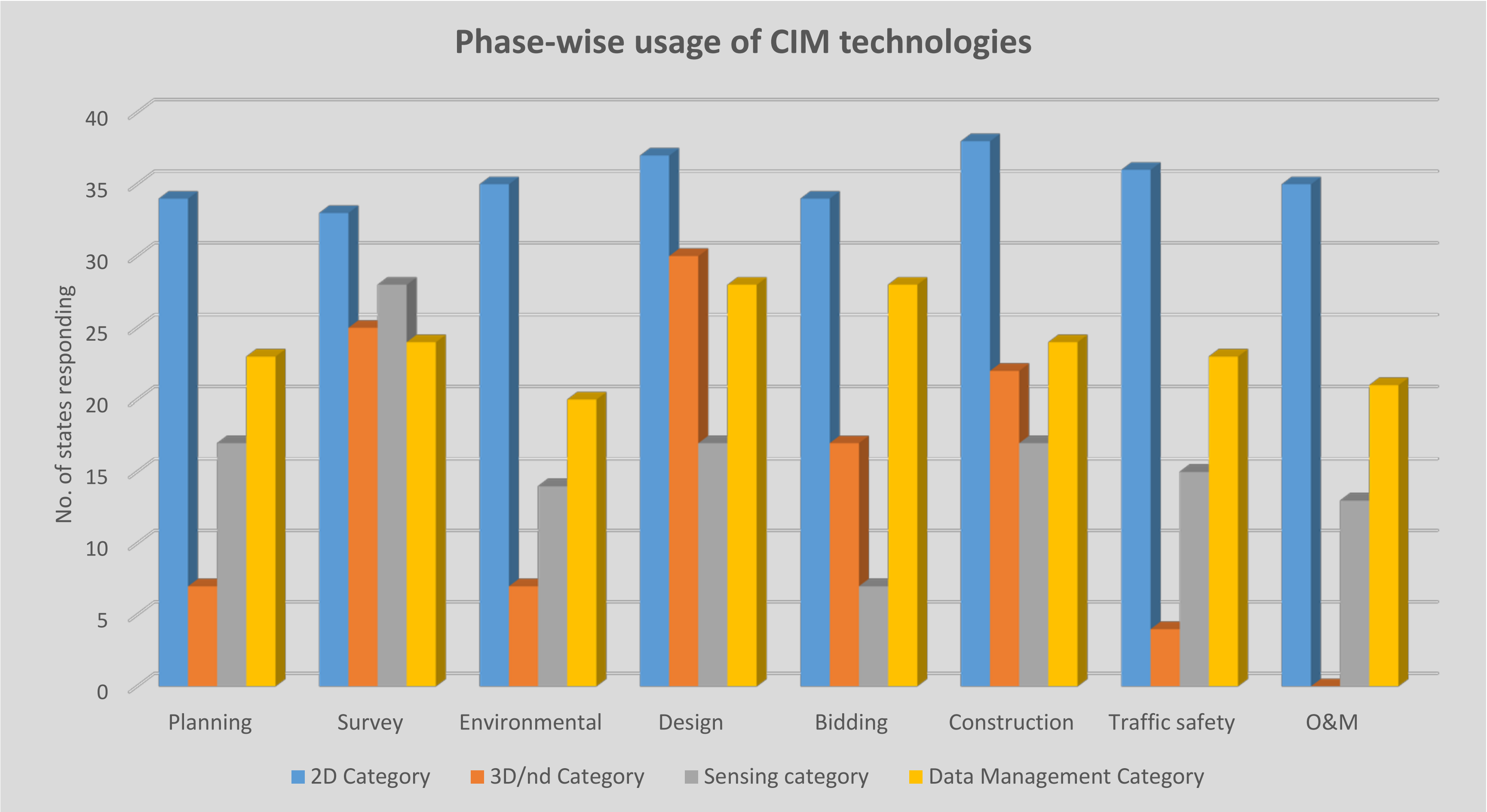
- Data connectivity (other than cellular towers) recorded the lowest usage (need to study further as RTN/CORS GPS networks are more common)
- Material management systems and digital signatures appears to be emerging applications
- Electronic updating and archiving of plans recorded highest usage (may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

Data Management Tools Usage



Electronic Updating of Plans and/or Mobile Digital Devices (1 point).
Digital Asset Management and/or Materials Management Systems (1 point).
Digital Signatures (1 point).
Data Connectivity (1 point).
TOTAL SCORE: Sum of points achieved

Survey results– Cumulative usage levels



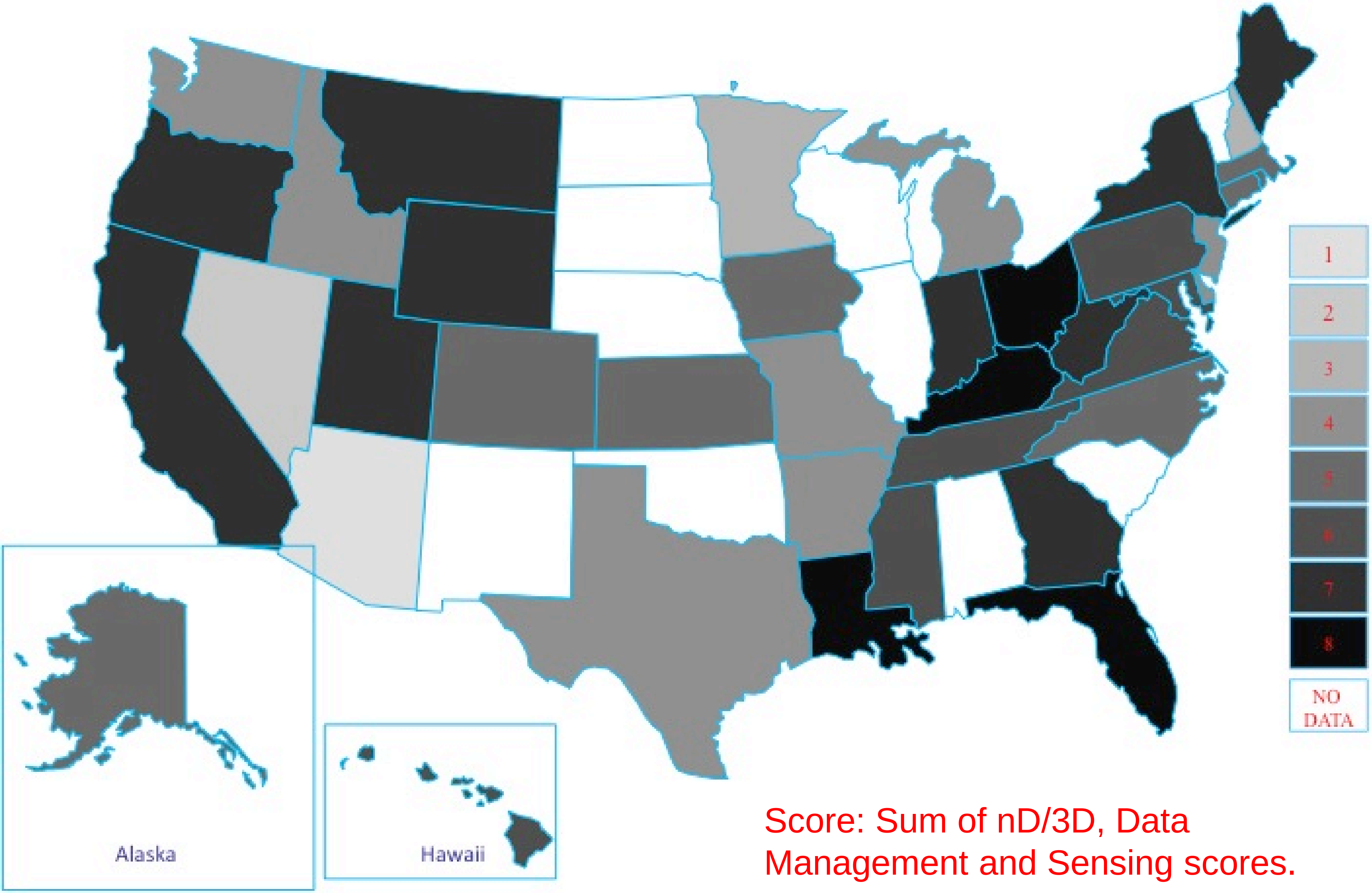
Inferences from responses:

Applications under 2D category dominant in all the phases (in-line with traditional practice, contractual issues)

Design and Construction phases recorded maximum usage of CIM (transition due to innovation/better tools for processes involved)

O&M phase reported lowest overall usage of CIM technologies (esp. 3D/nD) – area for future improvement

Cumulative CIM Technologies Usage



Score: Sum of nD/3D, Data Management and Sensing scores.

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

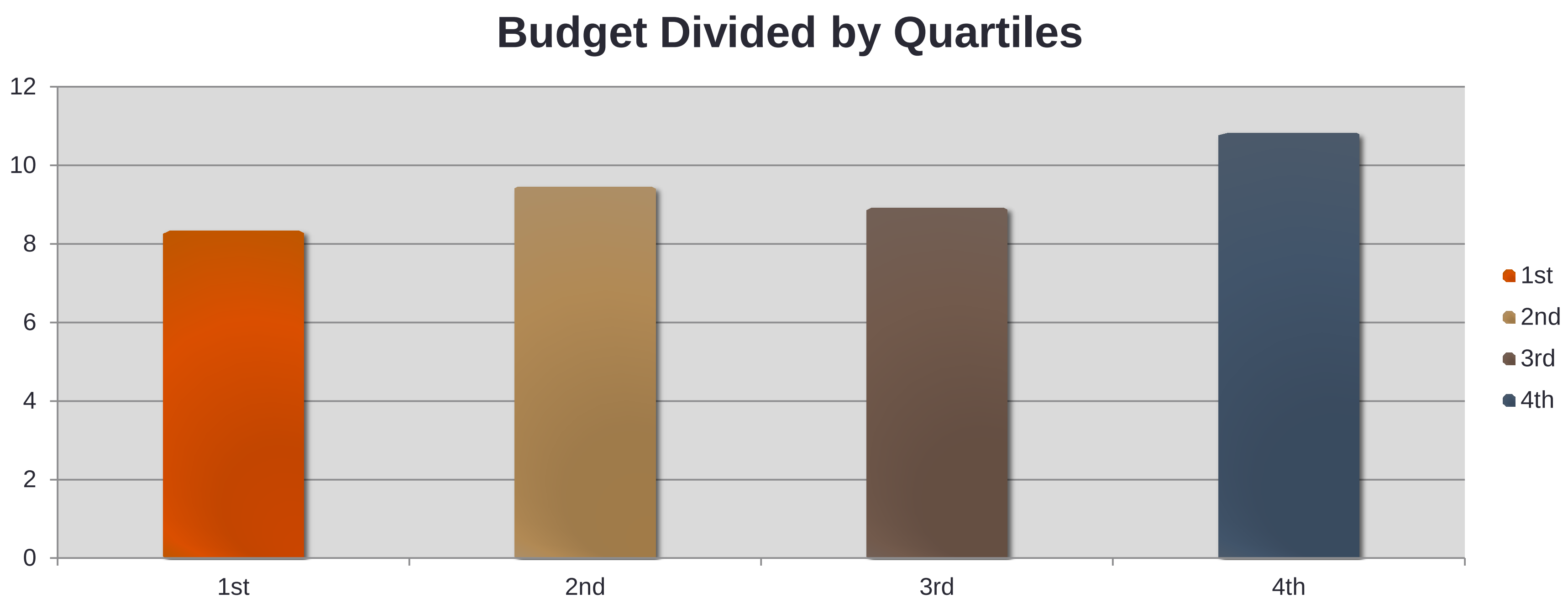
State DOT Budget

Level of Design In-House

Use of Alternative Contracts

ROI Research

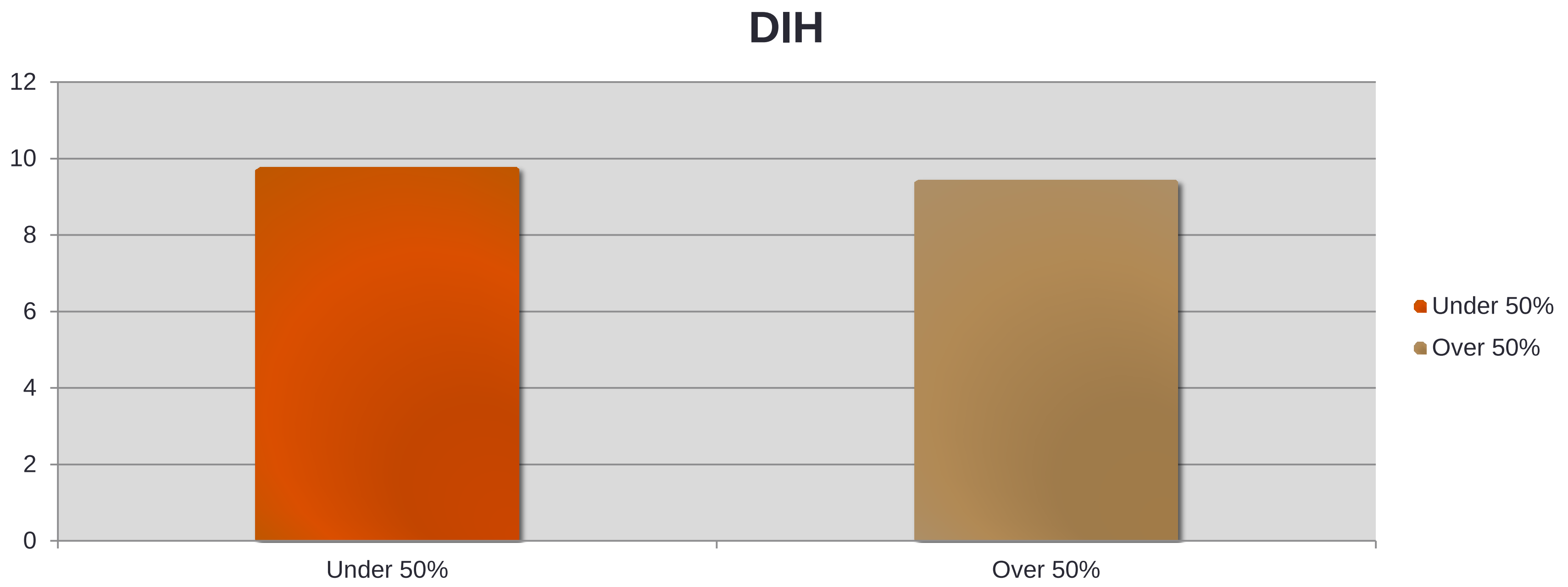
Budget vs. CIM Usage



Quartile	Maturity Mean
1st	8.33
2nd	8.149.45
3rd	8.92
4th	10.82

Significance	0.366
F	1.086

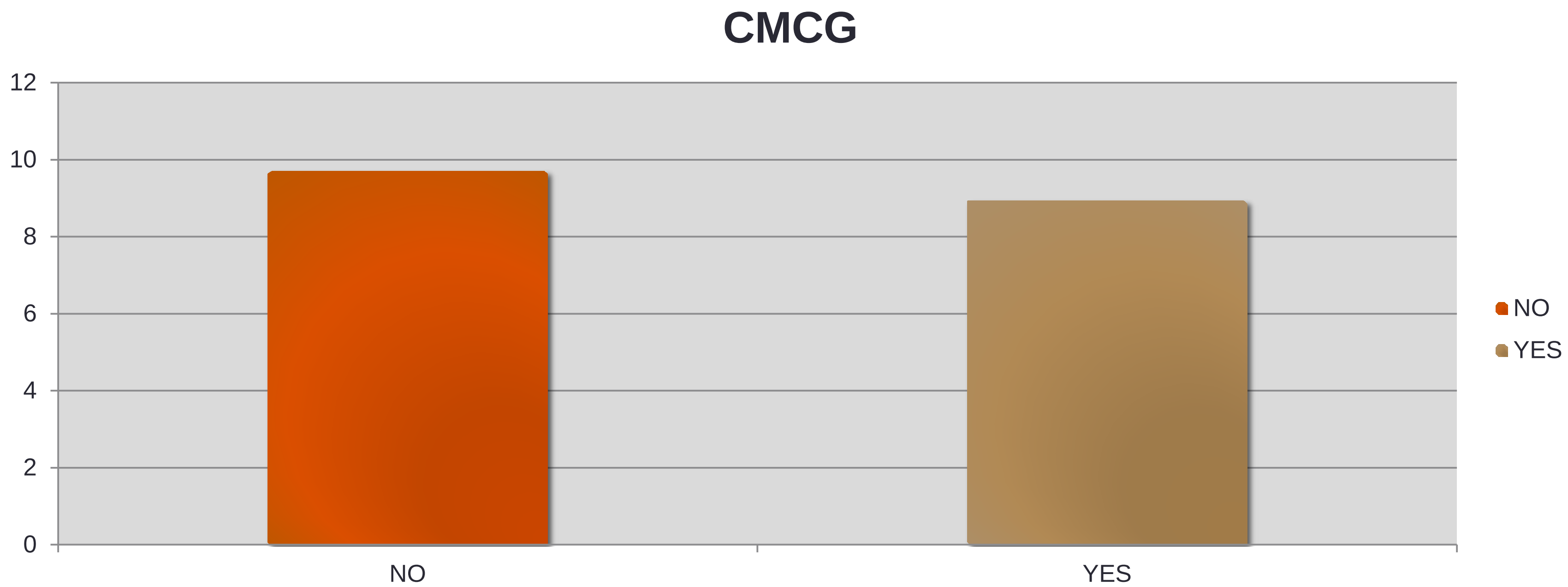
Percentage of Design Conducted in House vs. CIM Usage



Percentage	Maturity Mean
Under 50%	9.77
Over 50%	9.44

Significance	0.807
F	0.06

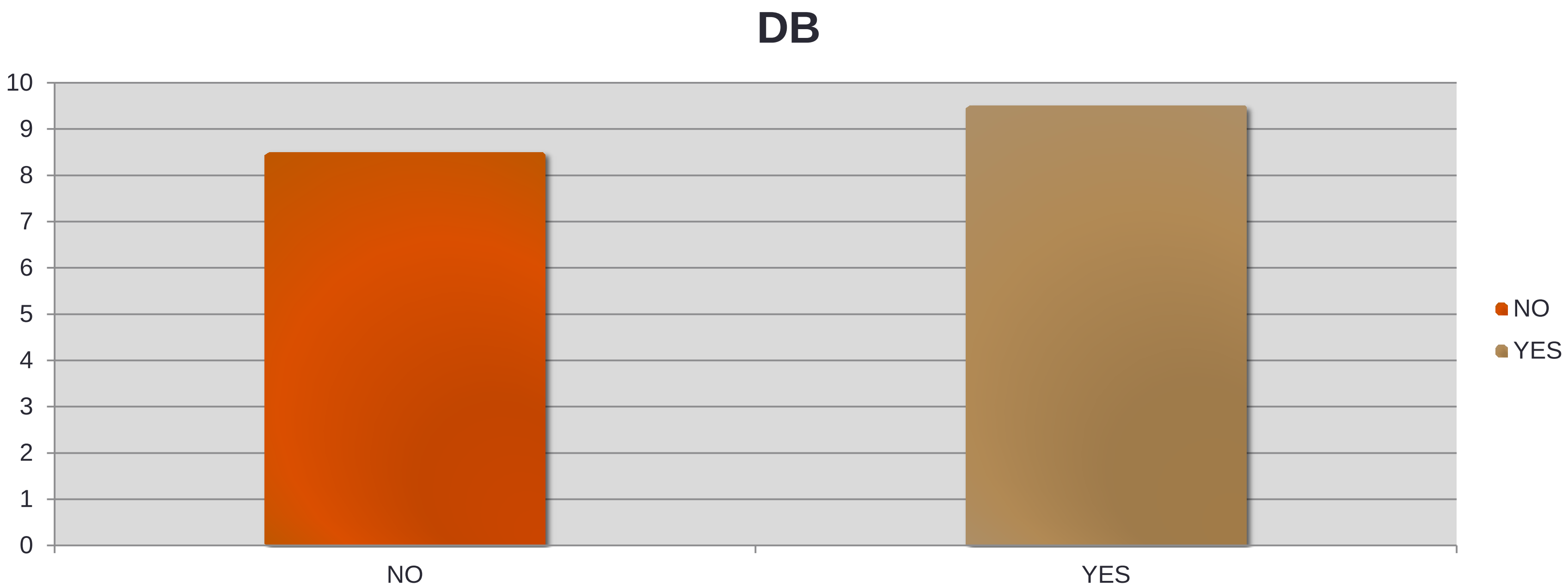
Usage of Construction Management/General Contracting as delivery method vs. Maturity



Answer	Maturity Mean
Yes	8.94
No	9.70

Significance	0.468
F	0.537

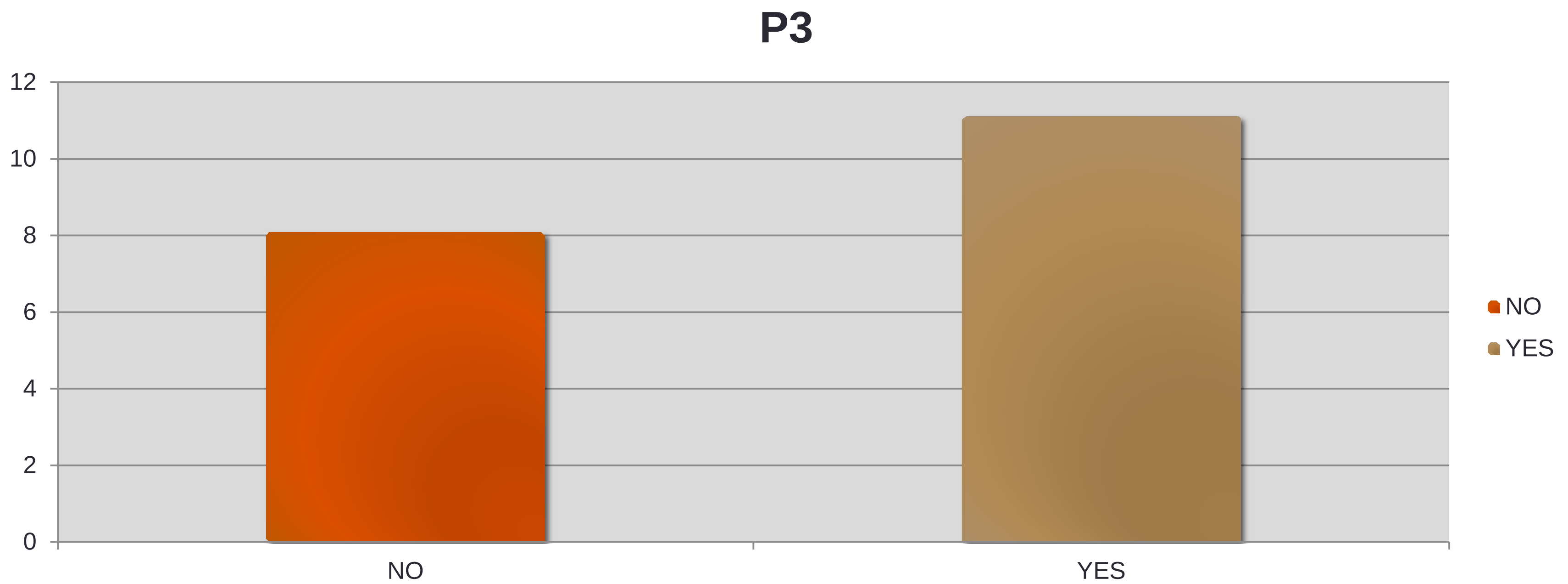
Usage of Design/Build as Delivery Method vs. CIM Usage



Answer	Maturity Mean
Yes	9.51
No	8.50

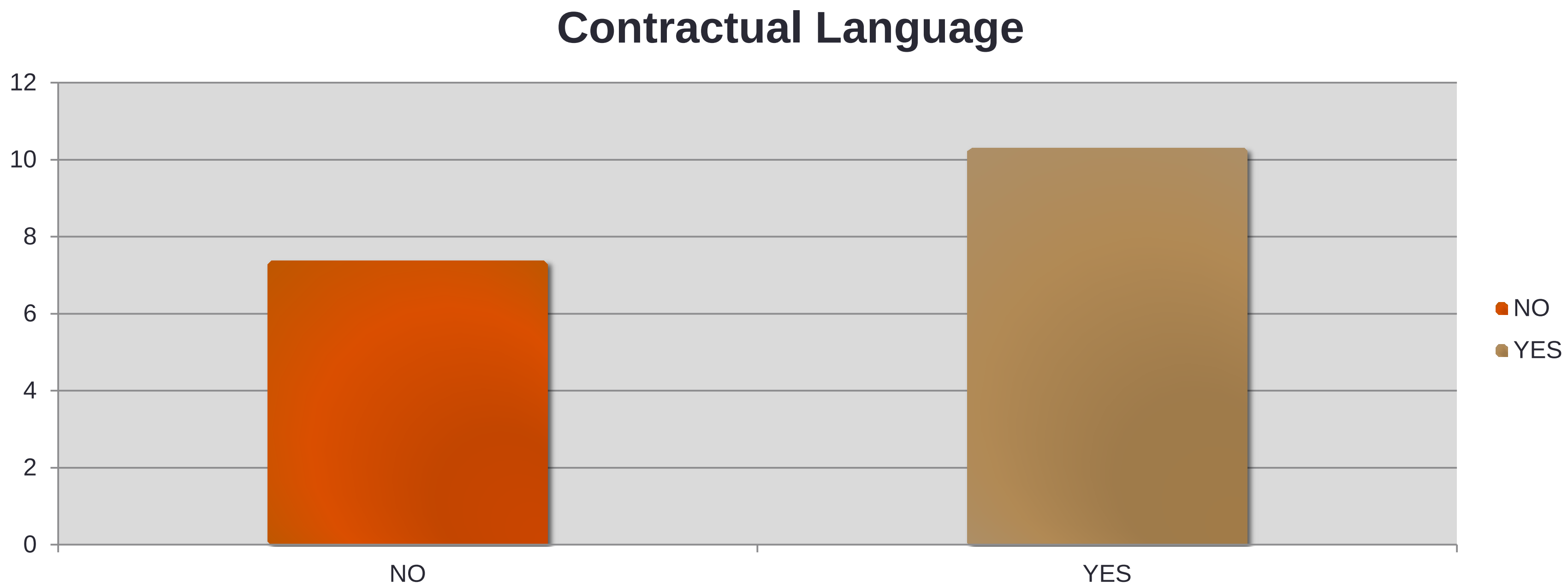
Significance	0.565
F	0.337

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



Answer	Maturity Mean	Significance	0.002
Yes	11.11	F	11.041
No	8.08	Increase (%)	37.5

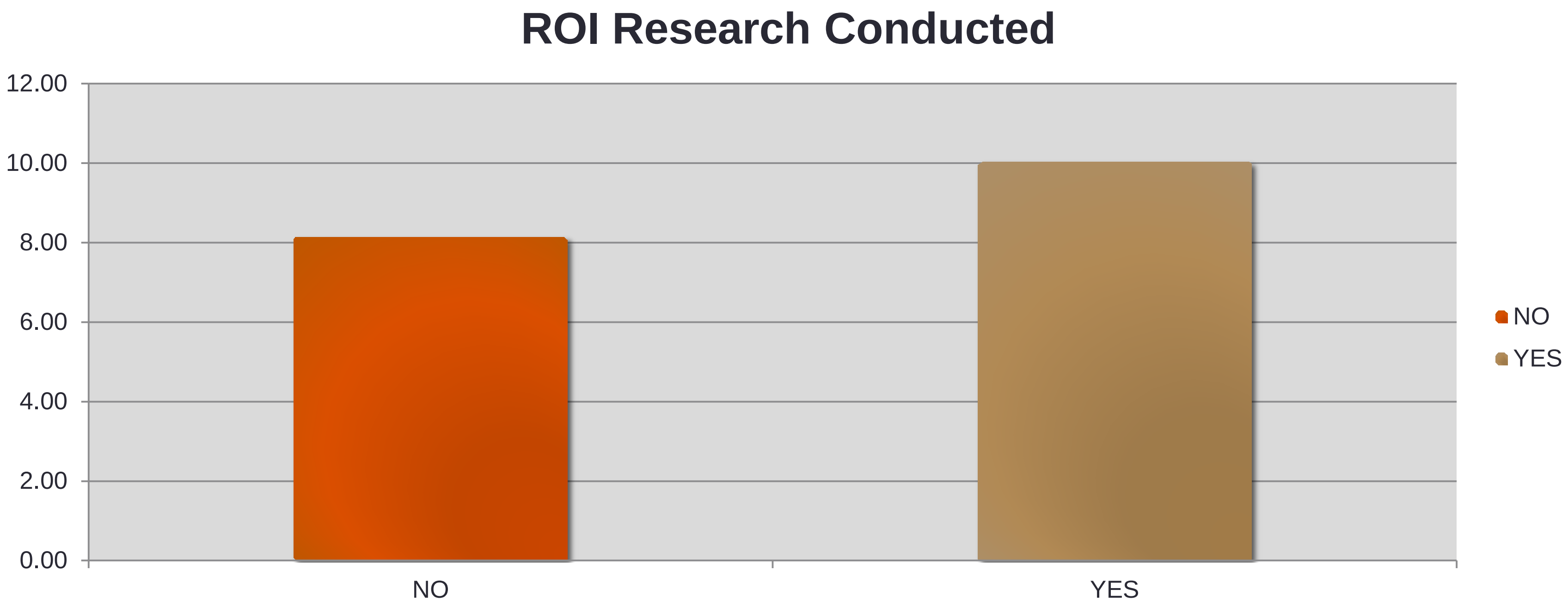
Usage of Contractual Language involving CIM vs. CIM Usage



Answer	Maturity Mean
Yes	10.30
No	7.38

Significance	0.006
F	8.331
Increase (%)	39.7

ROI Research vs. Maturity



Answer	Maturity Mean
Yes	10.03
No	8.14

Significance	0.078
F	3.277

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

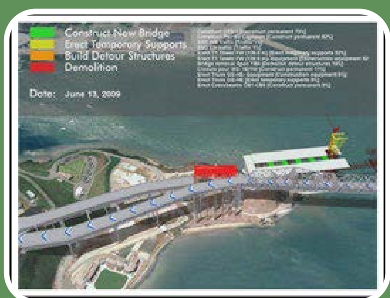
A few Examples

- 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

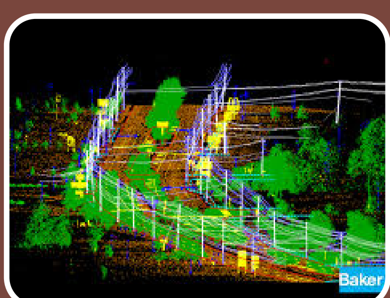
3D **design**

- **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*)



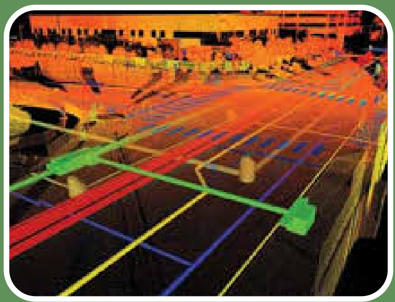
Advanced Surveying Methods(LiDAR/UAVs)

- **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)

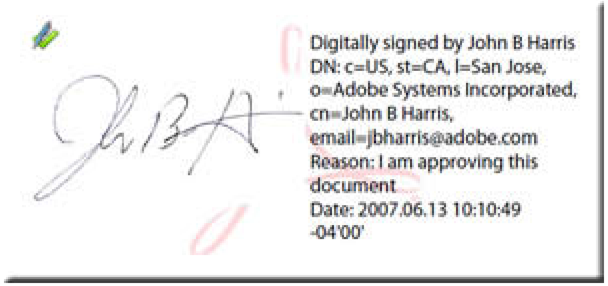
Lessons learned – ROI analysis

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).	clash detection processes on its SE Freeways Mitchell Interchange projects --Reported considerable reduction in RFIs, Change orders, and design issues ***(7% RFI REDUCTION IN $ 298 MILLION MITCHELL INTERCHANGE PROJECT)***
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)***

Lessons learned – Contracts and governance

- Contractual Issues
  - 2D plans governing documents (Plans, Specifications, Estimates)
  - “Information only” clauses on models- risk and liability issues (AMG)

- Legal
  - Statutory laws and agency rules yet to evolve to support model-based delivery (signatures and seals primarily on documents)
  - Lack of clarity in professional guidelines for Digital signatures (e.g. states’ Engineering Practice Acts)

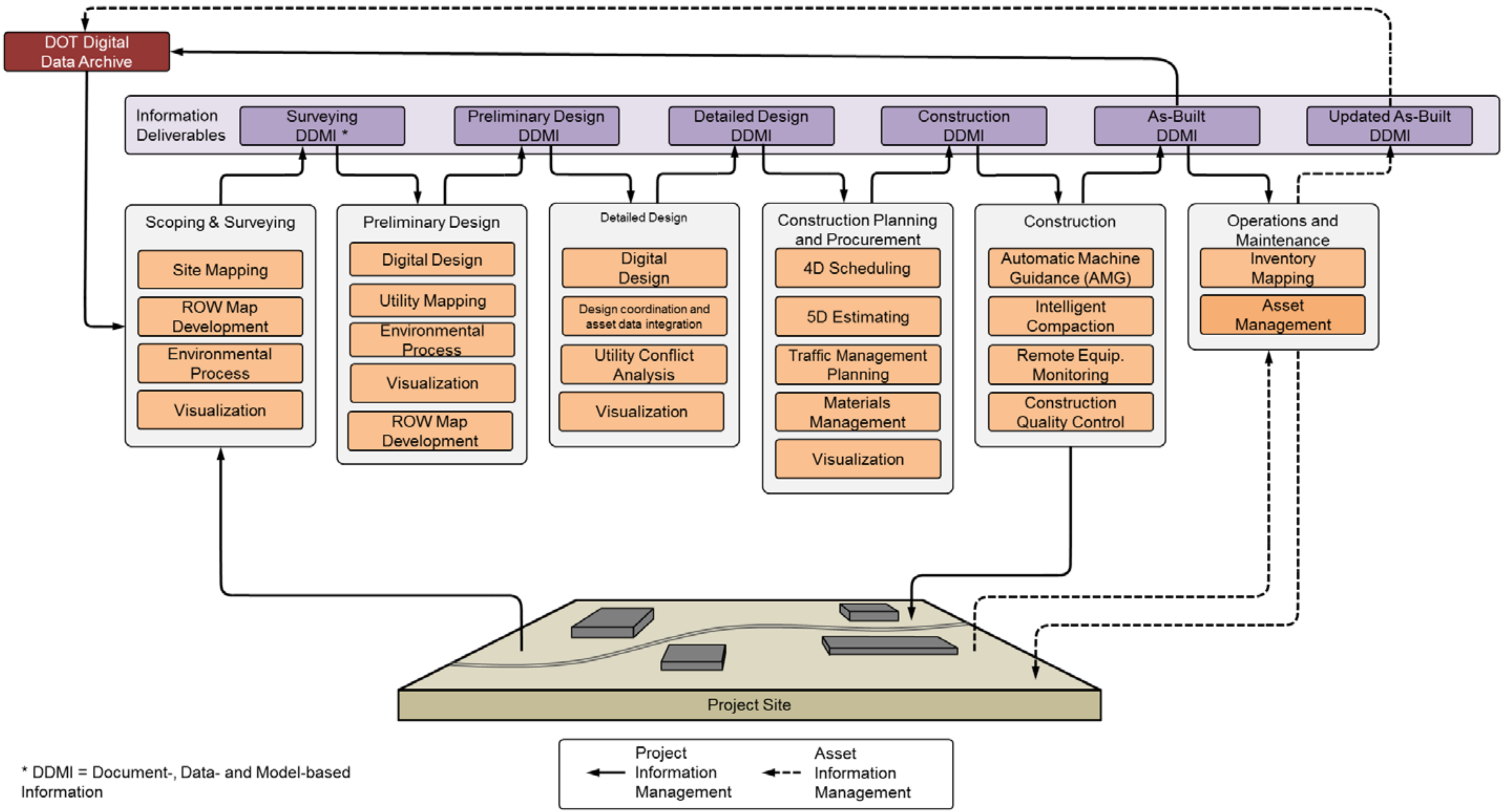


IMPLEMENTATION GUIDE

(Guide under validation process after first round of comments from the 10-96 Panel)

Impact of CIM on Project Workflow

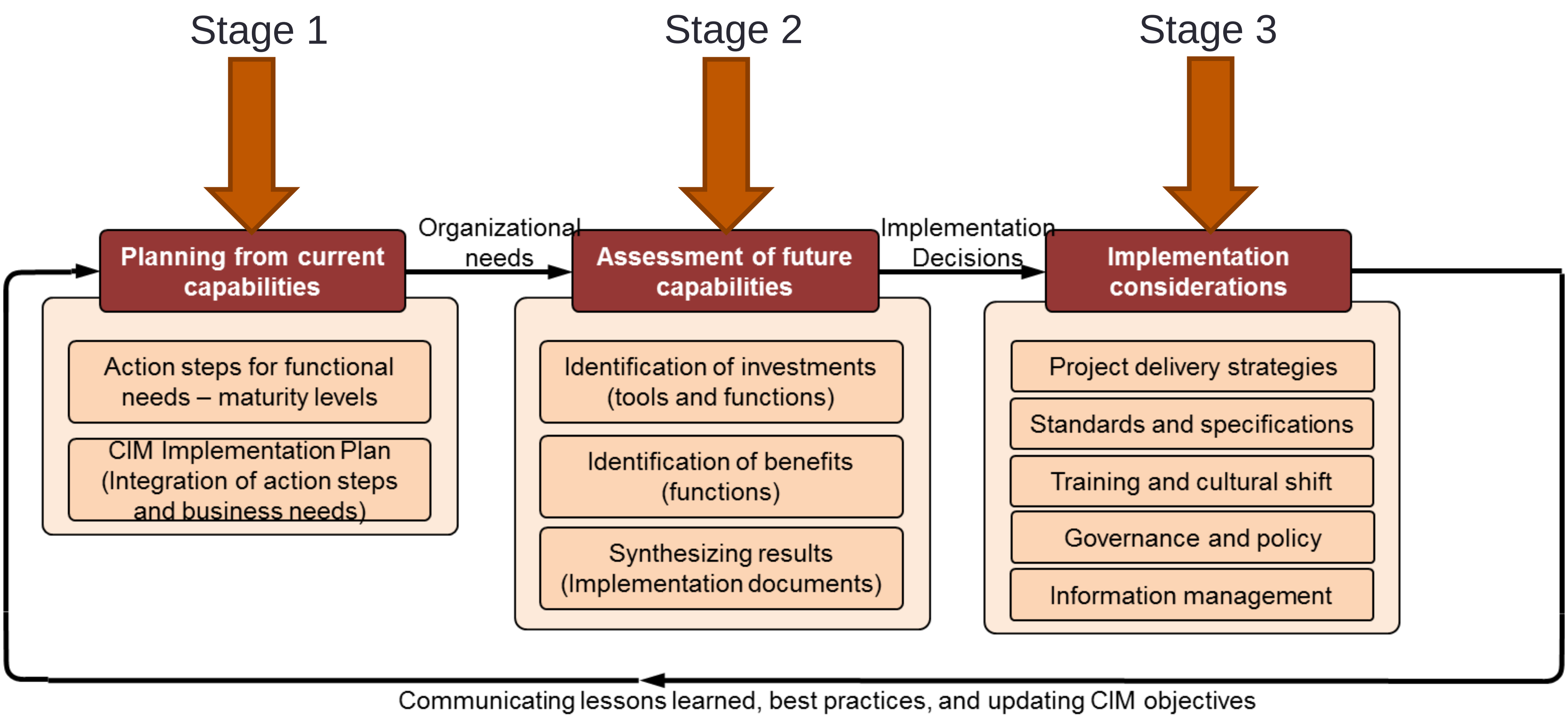
CIM Functions → Project Phases → Facility lifecycle



* DDMI = Document-, Data- and Model-based Information

Proposed Implementation Framework

- Three-stage process



Planning from current pract

- Gauging the divisions' current maturity levels
- Maturity model to understand functional needs for CIM related Divisions (*based on typical project*)
  - Scoping and surveying
  - Preliminary and detailed design
  - Construction planning procurement
  - Construction
  - Operations and Maintenance
  - Information Management

	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
Planning & 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; • 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 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); • 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 scheduling and estimating methods; traditional materials management; • Traffic Control Plans (TCPs) developed and visualized in 2D.	• 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 other subgrade 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	• 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 for QA/QC checks.	• 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 for QA/QC checks.
Operations & Maintenance Phase	• Document-based data and basic GIS support for various functions of O&M (Performance monitoring, infrastructure maintenance works, asset inventory, among others). • Data archives (databases) are electronic and updated periodically. • O&M operations are functionally separate from other phases.	• Electronic data with GIS platforms to support various functions of O&M. • Database systems are integrated, georeferenced and updated simultaneously with new information (less redundancy). • O&M operations are functionally separate from other phases.	• Model-based data and advanced GIS platforms to support various functions of O&M. • Data (database systems) and model elements are intelligently connected and georeferenced. • O&M operations are functionally integrated with other phases of project's lifecycle.
Information Management	• Most work processes and deliverables are Document-centric; although some are Data-centric, and a few are Model-centric. • Only Document-based information is digitally signed, and information is not geo-referenced. • Different disciplines develop their own DDMI, which is not shared in any collaboration platform. • Different disciplines follow different industry data standards. • Information handover occurs at completion.	• Most work processes and deliverables are Document- and Data-centric; although some are Model-centric. • Only Document-based information is digitally signed, but most of information (in all formats) is geo-referenced. • Different disciplines develop their own DDMI, which is shared in a collaboration platform. • All disciplines follow the same industry data standards. • (Most of) Information handover occurs simultaneously.	• Most deliverables are Data- and Model-centric; some deliverables are Document-centric. • All information (in all formats) is digitally signed and geo-referenced. • Different disciplines work on the same DDMI, which is stored and managed in one collaboration platform (integrated information management). • All disciplines follow the same industry data standards. • Information handover occurs simultaneously.

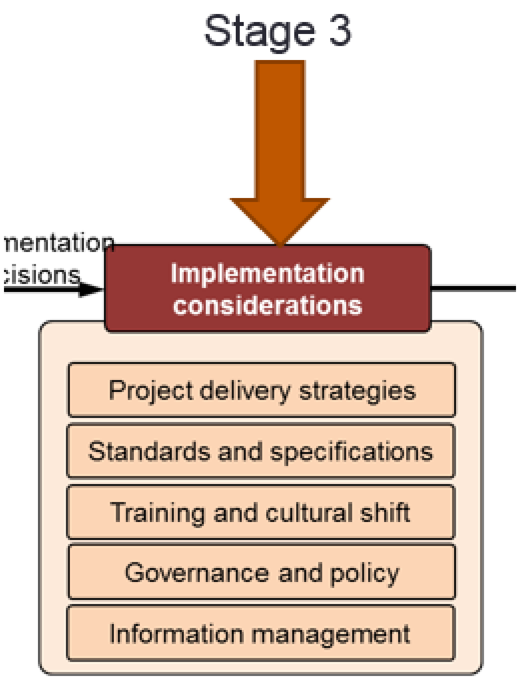
Assessment of future capabilities – Stage II

- Identification of investments – major category
  - Technology-related : hardware, software, equipment, technical training
  - Function-related : labor, standards and specifications, workflow disruptions
- 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 produc digital deliverables (for integrating geospatial information).
ND modeling tools	S	Discipline-specific needs for digital design (structures, utiliti roadway, drainage, and others) in 3D. Procuring software tools that enable geospatial integration design can be an added advantage.
Traffic simulation tools	S	Tools that enable microsimulation and macroscopic capabilities perform traffic analysis at required granularity.
Data Management Technologies		
Information management systems (project and asset)	S	Information management systems (documents, CAD fil databases, models, geospatial data). Efforts to integrate agency's Enterprise Resource Planning syst with project information systems.
GIS	S	GIS-enabled software platforms to serve across all CIM functio Capabilities of such applications include ability to perform spat querying and analyses, geospatial data integration, and provid geo-referenced base maps for several other functions.
Digital signatures	S	Digital identification (encryption technology) from Certif Authorities for the agency personnel requiring them. Investments for ensuring compatibility with informati management systems in place.
Surveying Technologies		
Airborne, mobile, and terrestrial LiDAR	S	Software platforms to process, analyze, visualize, and use t 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), iner measurement units, external wheel encoders, data loggers (mob and airborne).
GPS	E	GPS tool for installation on a variety of equipment as required surveying, design, construction automation, and as-bu verification using rovers. Augmentation with total stations to improve vertical accuracy.
GPR	S	Software tools to process the collected data (radargram) extract the utility information, construct 3D images, and integr them with other design entities.
	E	GPR equipment (optional integration with GPS a electromagnetic induction technology to improve efficiency).
RFID	E	RFID markers, with tags and readers, preloaded with necess geospatial and project-based information.
	S	Software platforms (GIS and Excel spreadsheets, among othe to load information.

Implementation considerations – Stage III

- The next stage provides a synthesis of implementation considerations for CIM that can act as ingredients for success.
- 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, formats of as-built data, O&M considerations during design, issues with reverse engineering models from plans



10-96 CIM Implementation Guide – Layout

1. **Overview of CIM tools and functions**
2. **Impact of CIM on project delivery**
    - Maturity model
3. **Implementation framework for CIM**
    - Planning from current practices – Stage I (Input from surveys)
    - Assessment of future capabilities – Stage II (Input from survey/case studies)
    - Implementation Considerations – Stage III (input from case studies)
4. **Supplemental resources**
    - Literature review – Summary
    - Current state of practice – Survey results
    - Case studies – Lessons learned
5. **References**
6. **Appendix**
    - Catalog of resources for CIM tools and functions

Thank you for listening!

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