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16. ABSTRACT
Virtual Design Construction (VDC) and Civil Integrated Management (CIM) are recent innovations that have been shown to improve project delivery and reduce cost through the entire lifecycle of a project. Integrating VDC/CIM within the organization’s delivery processes would lead to increased efficiencies for tax dollars, cost savings, reduce construction conflicts, decrease construction time, and enhanced workers’ and public safety. This research has evaluated the current state of VDC/CIM within Caltrans and collected the known VDC/CIM best practices through literature review of existing public information. In addition, this research has also created a strategic high-level roadmap that identifies the gaps and provides guidance on bridging the gap between the current and future state of VDC/CIM at Caltrans. In order to develop an organic structure within Caltrans for VDC/CIM implementation, formation of organizational level task forces is recommended. The task forces can then work with groups in charge of each Activity area and assist in guiding them through closing the gaps identified in this report and in pushing towards digital transformation.

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AHMCT

# Advanced Highway Maintenance and Construction Technology Research Center

Department of Mechanical and Aerospace Engineering
University of California at Davis

## Developing a Strategic Roadmap for Caltrans Implementation of Virtual Design Construction/Civil Integrated Management

Principal Investigator: Bahram Ravani
Authors: Sean Donohoe, Alireza Shams, Kin Yen

Report Number: CA20-3178
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# California Department of Transportation

Division of Research, Innovation and System Information

# Executive Summary

## Problem, Need, and Purpose of Research

Virtual Design Construction (VDC) and Civil Integrated Management (CIM) can be considered as the integration of digital technology into various aspects of transportation infrastructure projects. When combined, they can affect the entire lifecycle of a project. During project delivery VDC/CIM is about using digital technology to provide an environment for collaboration and increased data accessibility. In this manner, a common data source can be used over the whole project's lifecycle potentially eliminating paper plans and forms. In general VDC/CIM implementation can result in digital transformation of the project delivery and other processes. Caltrans has many aspects of VDC/CIM already implemented but there are gaps and a need for a comprehensive plan for broader integration within the entire organization. Integrating VDC/CIM within the organization's delivery processes would lead to increased efficiencies for tax dollars, cost savings, reduce construction conflicts, decrease construction time, and enhanced workers' and public safety. In order to identify the gaps in VDC/CIM implementations within Caltrans and integrate them into the organization, the current state of technologies used within Caltrans need to be assessed and compared to known best practices.

The purpose of this research is to produce a strategic high-level roadmap that identifies the gaps and provides guidance on bridging the gap between the current and future state of VDC/CIM at Caltrans. The strategic roadmap generated by the research provides an overview of Caltrans' current status and identifies where the deficiencies are with VDC and CIM implementation against best practices. With the strategic roadmap, key decision makers in Caltrans will be able to organize, prioritize, determine, finance, support, collaborate, coordinate, and develop a comprehensive multi-year and multi-discipline VDC and CIM implementation plan to enhance and integrate digital transformation of project delivery and other processes within Caltrans. The VDC and CIM implementation will help Caltrans to meet the implementation of efficiency measures to generate savings of 100 million each year requirement as mandated by California Transportation Commission for the Accountability and Reform Measures specified by Senate Bill 1 (SB1) The Road Repair and Accountability Act of 2017.

VDC and CIM technologies are evolving and the state of their implementation within Department of Transportations (DOTs) is periodically changing. Therefore identification of the state of these technologies and best practices provided in this report can be considered as a snapshot of the current state at the time that this research was conducted.

# Background

Recognizing the need for integration of VDC/CIM into Caltrans organization, an internal VDC team was formed in 2012. This team was tasked with generating a strategic roadmap, but the roadmap was not created. Today there are more external resources available that can be drawn upon to help alleviate past obstacles. One such external resource on the federal level is the EDC (Every Day Counts) initiative [1] which had only just started in 2012 when Caltrans last VDC team was formed. The EDC initiative has brought together many actors from industry and other states to present best practices and the state of the technology.

# Major Results and Recommendations

One key issue that VDC/CIM addresses are inefficiencies in the workflow caused by data flow issues. At every handoff where information is transferred via documents, some value is lost [2]. In the (Building Information Modeling (BIM) field (which is closely related to CIM), a curve known as the "BIM Curve" (a simplified version shown in Figure 1) illustrates this loss of value and compares it against a BIM approach [2]. The key aspect to note in Figure 1 is the transition to the maintenance & operations phase; the traditional method has a large drop in information value compared to the BIM or CIM approach. This curve also shows how each stage can add value to the previous stage when a BIM or CIM approach is used. An important aspect of the BIM or CIM approach is seamless sharing of information from the Preliminary stage, Design stage, Bidding & Construction stage and throughout Maintenance & Operations stage. This can be achieved by digital transformation.

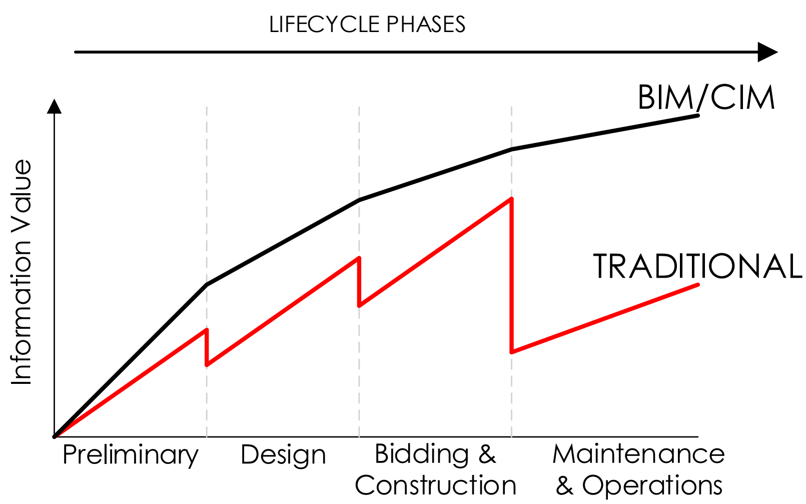


**Figure 1 BIM/CIM Curve adapted from [2]**

A NIST study [3] quantified the monetary value of interoperability issues similar to the red line of Figure 1. The NIST study [3] was conducted for capital facilities which specifically excluded transportation infrastructure [3]. The NIST study estimated the distribution of the monetary loss sustained as 16.8% in Planning/Engineering/Design, 25.7% in Construction, and 57.5% in Operations & Maintenance [3].

A benefit of implementing VDC/CIM (or BIM for infrastructure) is reducing the risk of errors and construction change orders later in a project. The result of reducing late changes can be illustrated by the well-known set of curves called the MacLeamy Curve [4]. A version of the MacLeamy Curve is shown in Figure 2. This curve illustrates a cost comparison between the traditional and the BIM/CIM approach in making changes. ***The takeaway is that making changes to a project earlier rather than later typically saves money and effort.***

Essentially, in the BIM/CIM approach it is substantially less expensive to make changes to a project as majority of the changes can be made in the Design Development phase. The Traditional approach has significantly less ability to make changes and the changes are more expensive to administer as they are in the Construction Documentation and Construction Administration phase. A comparison between the BIM/CIM approach and the Traditional approach is shown in Table 1.

**Table 1 BIM/CIM vs Traditional**

| | **BIM/CIM Approach** | **Traditional Approach** |
|---|---|---|
| Cost to change | Less expensive | More expensive |
| Ability to make change | Greater. Easier | Much less. More Difficult |
| Project Issue Resolution Phase | Mostly in the Design Development phase | Mostly in the Construction Doc phase |

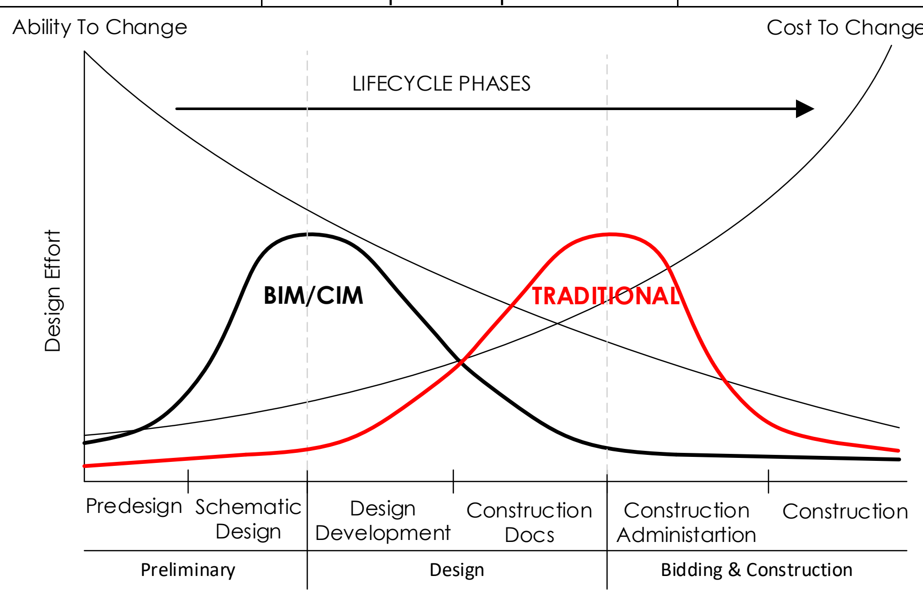


**Figure 2 The MacLeamy Curve adapted from [4]**

The summary of some of the results for selected CIM tools and tasks are provided below. These are organized in terms of CIM Activities and are derived from information collected internally from Caltrans, various DOTs, and industry consultants.

## *Surveying Activity*

In the Surveying activity, Caltrans has achieved various levels of maturity. Caltrans needs to identify or empower champions for Mobile LiDAR in certain areas that use this tool. In terms of other relevant VDC/CIM tools such as the use of GNSS (Global Navigation Satellite Systems), and tasks such as Data Sharing and Storage, however, there are gaps that require additional steps to reach maturity of the state of practice. In terms of use of UAS (Unmanned Aircraft System), Caltrans maturity is consistent with the emerging best practice and research. Caltrans therefore needs to continue training to expand its use cases, identify which data should be stored, and stay up-to-date on the emerging research. Furthermore, in the UAS area Caltrans has the opportunity to become a national leader if the organization continues and expands upon its current activities.

## *Design Activity*

Within the Design activity, the maturity levels are different for each of the six relevant VDC/CIM tools and tasks. Bridging the gaps for each of the tools and tasks requires a different number of steps to reach the maturity of the state of the practice. For example, in the VDC/CIM task of Roadway Design (as well as Structural Design) developing data exchange standards is an important step to bridge the gap. For other VDC/CIM tools and tasks, training, working with internal committees and investigating available platforms can fill in the gaps. For the 3D SUE task, a utility database now exists that will allow information to be available to any user in the state who needs it. The 3D utility database still needs champions and clear guidelines for populating it, but again, this can be an area where Caltrans can show national leadership.

## *Construction Activity*

In the Construction activity, the bidding and bid-estimating processes have the highest level of maturity within Caltrans, consistent with the state of the practice. The maturities of the remaining tools are varied. The As-built documentation task is an area where taking steps such as capturing data during construction can be integrated with asset management. Caltrans maturity level for the CM/GC (Construction Manager/General Contractor) task is consistent with the state of the practice. If Caltrans continues to expand its activities in this area, the organization can become a national leader. The AMG (Automated Machine Guidance) tool needs champions at the district level to push and expand the usage of the technology. EDMS (Electronic Document Management System) is an area tied to not only the Construction activity but also to Design and other areas. This is an area where working closely with others is needed to successfully implement an enterprise solution and obtain the most value. Mobile devices are an area where the infrastructure exists now. The main task is to integrate them with other systems such as the EDMS, digital signatures, and field data collection to capture more value.

## *Asset Management & Maintenance Activity*

The Asset Management & Maintenance activity steps are mostly data driven and will require integration of their valuable data with project delivery and planning. At the highest level, work can be done with the programs that supply data to asset management in order to improve data availability and reliability. For GIS (Geographic Information System) tools, there is a need to standardize naming conventions and move toward a federated statewide GIS system. In general, there appears to be a gap between Project Delivery and Maintenance. There is great potential for closer integration.

## *Environmental Activity*

The Environmental Activity typically deals with data on historic properties, natural resources, environmental factors, and obtaining permitting. Caltrans presently uses a paper-based system and 2D plans as well as databases that are not geospatial (not tied to GIS). Other state DOTs have developed and are using web-based systems that combine spatial and non-spatial data. Initial recommended steps are: collaborate with the EDMS (Electronic Document Management System) steering committee to assess the feasibility of using the EDMS System, develop a web-based application to access the existing database currently used by all districts, and finally, connect the existing database to the enterprise GIS.

## *Overall Recommendation*

In order to develop an organic structure within Caltrans for VDC/CIM implementation, formation of an organizational level task force is recommended. The task force can then work with groups in charge of each CIM Activity area and help guide them through closing the gaps identified in this report and pushing towards digital transformation. Since data and Geospatial integration play key roles in VDC/CIM implementation, it is recommended that the task force will include key personnel from Geospatial, asset Management, and Information Technology groups as well as others as champions. It is also recommended that within each CIM Activity, pilot implementation projects be identified that can help the relevant staff develop the needed workflow through first starting with pilot projects.

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# List of Acronyms and Abbreviations

| Acronym | Definition |
|---|---|
| 2D | Two Dimensional |
| 3D | Three Dimensional |
| 4D | Four Dimensional (typically means adding time) |
| 5D | Five Dimensional (typically means adding time and cost) |
| AASHTO | Association of State Highway Transportation Officials |
| ADA | Americans with Disabilities Act |
| ADOT | Arizona Department of Transportation |
| AEGIST | Applications of Enterprise GIS for Transportation |
| AHMCT | Advanced Highway Maintenance and Construction Technology |
| AIA | American Institute of Architects |
| AIM | Asset Information Model |
| AIR | Asset Information Requirements |
| ALDOT | Alabama Department of Transportation |
| AMG | Automated Machine Guidance |
| AMS | Advanced Management Solution |
| APCS | Automated Pavement Condition Survey |
| ArDOT | Arkansas Department of Transportation |
| AVD | Archived Vector Data |
| BCP | Budget Change Proposal |
| BEP | BIM-Execution Plan |

| **Acronym** | **Definition** |
|---|---|
| BIM | Building Information Modeling |
| BMP | Best Management Practices |
| CA PPM | California Project and Portfolio Management |
| CAATS | Contracts Agreements Auditing Tracking System |
| CAD | Computer Aided Design |
| CADD | Computer-Aided Design and Drafting |
| CART | Consultant Agreement Reporting and Tracking |
| CBD | Central Business District |
| CDE | Common Data Environment |
| CDOT | Colorado Department of Transportation |
| CIM | Civil Integrated Management |
| CITS | Consultant Invoice Transmittal System |
| CM/GC | Construction Manager/General Contractor |
| CMIS | Contract Management information System |
| CMM | Capability Maturity Models |
| COFRS | Colorado Financial Reporting System |
| COTS | Commercial-Off-The-Shelf |
| CPPS | Colorado Personnel and Payroll System |
| CTDOT | Connecticut Department of Transportation |
| D2 | Caltrans District 2 - Redding |
| DDM | Digital Design Model |
| DelDOT | Delaware Department of Transportation |

| Acronym | Definition |
|---|---|
| DES | Division of Engineering Service |
| DMI | Distance Measuring Instruments |
| DOT | Department of Transportation |
| DRISI | Division of Research, Innovation and System Information |
| DRS | Document Retrieval System |
| DTM | Digital Terrain Model |
| EDC | Every Day Count |
| EDM | Electronic Data Management |
| EDMS | Electronic Document Management System |
| EIR | Exchange Information Requirements |
| ESRI | Environmental Systems Research Institute |
| FAA | Federal Aviation Administration |
| FHWA | Federal highway administration |
| GDOT | Georgia Department of Transportation |
| GIS | Geographic Information System |
| GLONASS | Global Navigation Satellite |
| GNSS | Global Navigation Satellite System |
| GPR | Ground Penetration Radar |
| GPS | Global Positioning System |
| IC | Intelligent Compaction |
| IDP | Information Delivery Planning |
| IFC | Industry Foundation Classes |

| **Acronym** | **Definition** |
|---|---|
| IMMS | Integrated Maintenance Management System |
| IMU | Inertial Measurement Unit |
| IPD | Integrated Project Delivery |
| ISO | International Organization for Standardization |
| ITS | Intelligent Transportation Systems |
| KMZ | Keyhole Markup Language |
| LiDAR | Light Detection and Ranging |
| LIN | Level of Information Need |
| LOD | Level of Detail |
| LOI | Level of Information |
| LOV | Level of Visualization |
| LPA | Local Program Accounting |
| LRS | Linear Referencing System |
| MDSHA | Maryland State Highway Administration |
| MMRS | Massachusetts Management and Accounting System |
| MnDOT | Minnesota Department of Transportation |
| MTLS | Mobile Terrestrial Laser Scanning |
| NCDOT | North Carolina Department of Transportation |
| NCHRP | National Cooperative Highway Research Program |
| NEPA | National Environmental Policy Act |
| NIST | National Institute of Standards and Technology |
| NJDOT | New Jersey Department of Transportation |

| Acronym | Definition |
|---|---|
| NYSDOT | New York State Department of Transportation |
| OAKS | Ohio Administrative Knowledge System |
| ODOT | Oregon Department of Transportation |
| OE | Office Engineer |
| OIR | Organizational Information Requirements |
| P2S | Project Programming System |
| PA&ED | Project Approval and Environmental Document |
| PDF | Portable Document Format |
| PDT | Project Delivery Team |
| PennDOT | Pennsylvania Department of Transportation |
| PID | Project Initiation Document |
| PIM | Project Information Model |
| PIR | Project Information Requirements |
| PMRS | Project Management and Reporting System |
| PoD | Plans on Demand |
| PRSM | Project Resourcing and Schedule Management |
| QA/QC | Quality Assurance/Quality Control |
| RFID | Radio Frequency Identification |
| RIDOT | Rhode Island Department of Transportation |
| ROI | Return of Investment |
| ROW | Right of Way |
| RTK | Real Time Kinematic Network |

| Acronym | Definition |
|---|---|
| RTN | Real Time Network |
| SHOPP | State Highway Operation and Protection Program |
| SHRP2 | Strategic Highway Research Program 2 |
| STAs | State Transportation Agencies |
| STEVE | Statewide Tracking and Exchange Vehicle for Environmental Systems |
| SUE | Sub Surface Utility Engineering |
| TAMP | Transportation Asset Management Plan |
| TBC | Trimble Business Center |
| TSN | Transportation System Network |
| TxDOT | Texas Department of Transportation |
| UAS | Unmanned Aircraft Systems |
| UAV | Unmanned Aerial Vehicles |
| UDOT | Utah Department of Transportation |
| URISA | Urban and Regional Information Systems Association |
| VDC | Virtual Design and Construction |
| WBS | Work Breakdown Structure |
| WSDOT | Washington Department of Transportation |

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# CHAPTER 1: Introduction

## 1.1 Problem

Virtual Design and Construction (VDC) and Civil Integrated Management (CIM) are emerging paradigms. Together VDC and CIM can enhance project delivery while also enriching the data available to maintenance and operations. CIM promotes the reuse of data throughout the entire lifecycle of the project thus reducing the need for redundancy. Caltrans has some aspects of VDC/ CIM already implemented but for maximum impact these must be part of a comprehensive plan. It is anticipated that integrating VDC/CIM into Caltrans organization will lead to increased efficiencies and enhanced safety. In order to integrate VDC/CIM technologies into Caltrans an understanding of the current status within the organization as well as the state of technology will be needed. A high-level strategic roadmap is also required to guide the allocation of resources.

## 1.2 Objectives

The objective of this research is to create a high-level strategic roadmap that shows an overview of the current state of Caltrans, the gaps, and the known best practices. It is anticipated that this roadmap will assist with high-level decisions regarding how resources be most effectively allocated for the purpose of enhancing and integrating Caltrans VDC/CIM practices. Ultimately these decisions are expected to result in higher quality outcomes.

## 1.3 Scope

This work will not develop any new VDC/CIM technologies. The work will focus on four primary tasks:

- Task 1 evaluated Caltrans current state relative to VDC/CIM best practices (Chapter 2).
- Task 2 conducted a literature review and leveraged existing resources to evaluate the known best practices that others have publicly shared (Chapter 3).
- Task 3 considered the current status of Caltrans as well as the result of Task 2 to synthesize the gaps existing (Chapter 4).

- Task 4 developed the strategic roadmap for VDC/CIM integration at Caltrans. This document will be a high-level document and not include a detailed implementation plan (Chapter 5).

# 1.4 Background

The need for integration of VDC/CIM at Caltrans has been recognized for a number of years. Since 2010 the Advanced Highway Maintenance and Construction Technology (AHMCT) research center hosted a series of meetings on implementing VDC and lean operations with Caltrans. In addition to the work with AHMCT, Caltrans also formed an internal VDC team in 2012 that was going to generate a strategic roadmap, but to date this roadmap has not been completed. In 2016 Caltrans and FHWA hosted a peer exchange and workshop on 3D models with consultants and contractors. At the Caltrans/FHWA workshop "Challenge Cards" were generated that will be summarized in Chapter 2.

# 1.5 Literature

A number of valuable resources exist to aid in achieving the objective of this research. One such resource is the FHWA Every Day Counts (EDC) initiative which started in 2011 and is still continuing with EDC-5 for 2019-2020 [1]. The EDC initiative invites leaders in the field to discuss their experiences. The EDC initiative has discussed topics such as 3D modeling, intelligent compaction, e-construction, and more. Other states have also begun to look at VDC/CIM and generated some reports and information which may be used. Documents at the federal level such as the National Cooperative Highway Research Program (NCHRP) Report 831 also exist [5]. Documents from the BIM field, which is closely related to CIM, but for vertical construction, will also be considered. A much more detailed look at the literature will be considered in Task 2 (chapter 3).

## *1.5.1 Motivation*

At every stage of the project lifecycle, an information "hand-off" occurs. Traditional document based handoffs often lead to redundancies, information reinterpretation, and manual data entry; at each of these stages, potential translation errors exist and information value is lost [2]. In the BIM field (which is closely related to CIM) this concept of lost value can be represented graphically (a simplified version is shown in Figure 1.1) [2]. Of key importance here is the transition to Maintenance & Operations Phase, where the traditional method has a large loss in information value. By utilizing a BIM approach each stage of the project can build off the previous stage with minimal loss in value. Key to the BIM or CIM approach is the sharing of information. This concept will reemerge several times in this report.

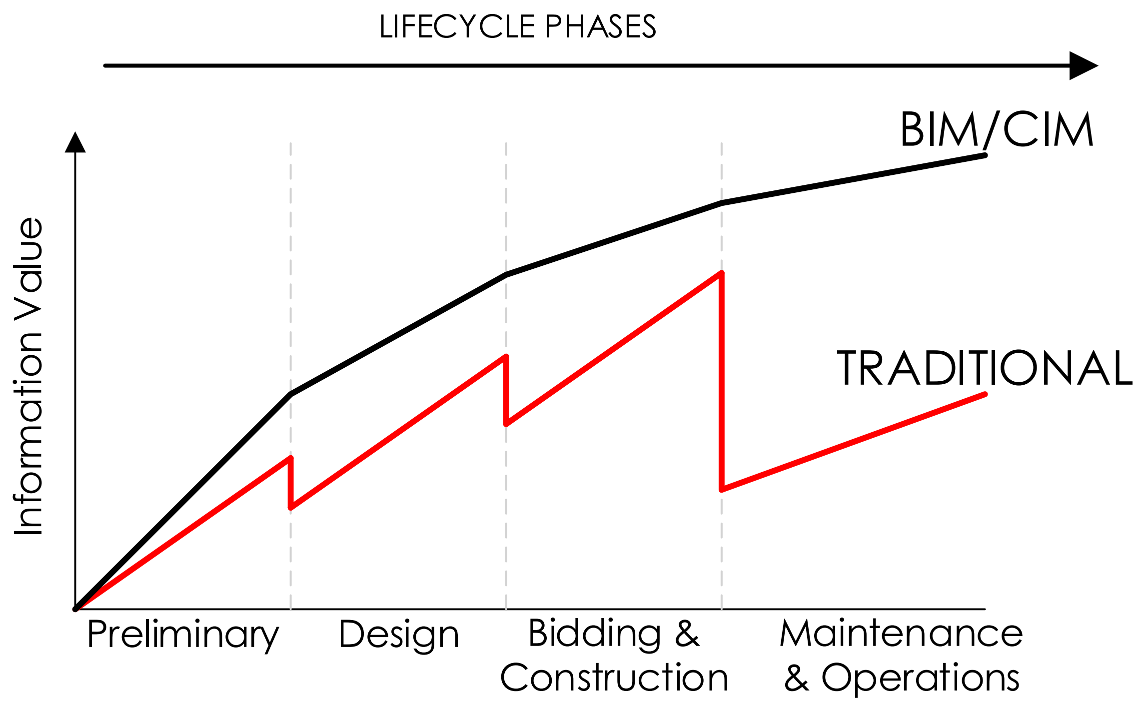


**Figure 1.1 BIM/CIM Curve adapted from [2]**

A NIST study [3] quantified the monetary value of interoperability issues similar to the red line of Figure 1.1. The NIST study [3] was conducted for capital facilities which specifically excluded transportation infrastructure [3]. The findings of [3] estimated the distribution of the costs as 16.8% in Planning/Engineering/Design, 25.7% in Construction, and 57.5% in Operations & Maintenance [3].

In addition to reducing the potential for loss of information value discussed above, it is logical to assume that another benefit of implementing VDC/CIM (or BIM for infrastructure) is to reduce the number of errors or change orders later in the project. Since BIM provides more transparent and accessible common data to all project stakeholders, errors may be more easily detected early, thus reducing change orders at the construction phase.

The MacLeamy Curve [4], shown in Figure 1.2, is a set of 4 curves sharing a horizontal axis that represents the lifecycle phases. The 4 curves illustrate cost to change, ability to change, and two distinct project delivery methods. This was originally developed to illustrate the Integrated Project Delivery (IPD) approach, but the concept can be applied to BIM. The takeaway is that shifting the project delivery curve left (i.e. spending more effort on earlier phases of project delivery) decreases cost while also making changes easier.

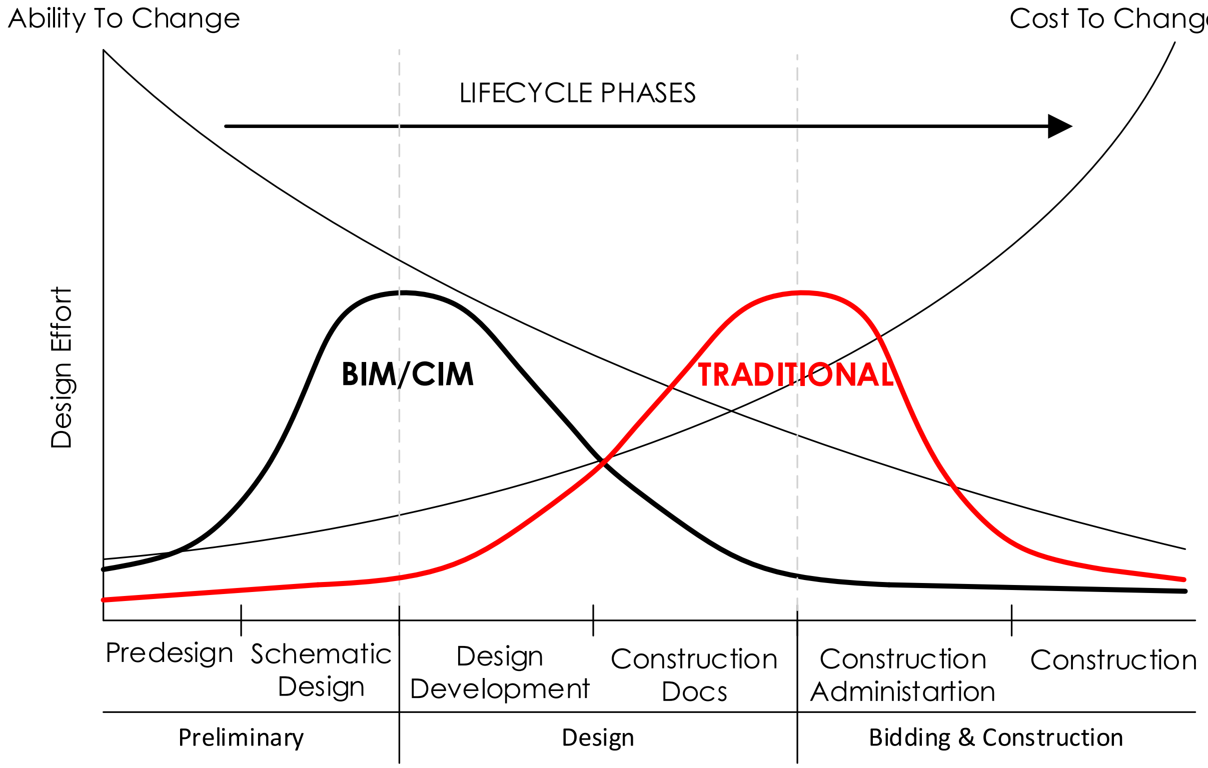


**Figure 1.2 MacLeamy Curve adapted from [4]**

In order to achieve CIM/BIM integration, an understanding of Caltrans current practices as well what are the known best practices will be required. A strategic roadmap that helps guide investment areas will also be required.

# 1.6 Research Methodology

The methodology of this research includes conducting high-level surveys, interviewing stakeholders, conducting literature reviews, and synthesizing the gaps uncovered. As a starting point, an online survey at Caltrans was used to measure the current status of VDC/CIM tools as identified in NCHRP 831. The survey results were used to identify potential strengths and weaknesses as well as to identify areas where more in-depth conversations are needed. More in-depth interviews with specific individuals and stakeholders were conducted as needed. Individuals also expressed their views on obstacles and difficulties that may pose a challenge to achieving VDC/CIM. In order to understand the best practices, a literature review was conducted that leveraged existing resources to collect information that had been publicly shared previously. Given the current state of Caltrans and the known best practices, gaps were identified. The results of the above work was then used to generate a high-level strategic roadmap for Caltrans to help guide integration of VDC/CIM within Caltrans.

## 1.7 Overview of Research Results and Benefits

The results of this work identified relative strengths within Caltrans as well as areas where there is opportunity for improvement. Summaries of gaps between Caltrans current practices and the known best practices have been tabulated. A high-level strategic roadmap diagram (Appendix A) illustrates potential paths. A map of data flows within Caltrans has also been generated and is included in Appendix B.

# CHAPTER 2: Assessing the State of Practice and Maturity of VDC/CIM within Caltrans (Task 1)

This chapter is intended to assess the current maturity of Virtual Design and Construction (VDC) and Civil Integrated Management (CIM) at Caltrans. In order to accomplish this task an internet-based survey internal to Caltrans was conducted. The results of the survey were used to identify potential strengths and weaknesses as well as areas where more in depth conversations were needed. Once the survey was completed, significant effort was spent on interviews with stakeholders in order synthesize specific gaps. Results from the 2016 Caltrans FHWA workshop were also used as a comparison and to identify challenges [6].

## 2.1 Caltrans Internal Survey

The survey was created to be generally consistent with NCHRP report 831 [5] by adopting their nomenclature, CIM organizational structure, and tool mapping with some modifications. In [5] there are four broad CIM activities including "Surveying, Design, Construction, and Project Management." In each activity there are CIM functions such as "Site Mapping", "Digital Design", and others. Each function contains various tools appropriate for their function (i.e. Site Mapping contains Mobile LiDAR). Some tools are applicable to more than one function. The 4 CIM activities in NCHRP 831 [5] were expanding by treating Asset Management and Maintenance and Operations as activities even though they are not activities by the definition of [5]. Both the Construction activity and the Design activity were also modified to better match Caltrans.

In addition to collecting data about CIM tools, the survey had the ability to correlate the data obtained to the project lifecycle. The correlation was accomplished by taking a slightly simplified project delivery flow chart from "How Caltrans Builds Projects" [7] and extending it to include Maintenance and Operations as well as Asset Management. The modified flow chart is grouped into four broad lifecycle stages named Preliminary Work, Detailed Work, Contracts & Construction Work, and Sustaining Work as shown in Figure 2.1. During the survey this chart was shown to each respondent in the introductory section and they were asked to indicate the corresponding lifecycle stage for their response. They were also asked to answer all questions relative to the project stage they indicated.

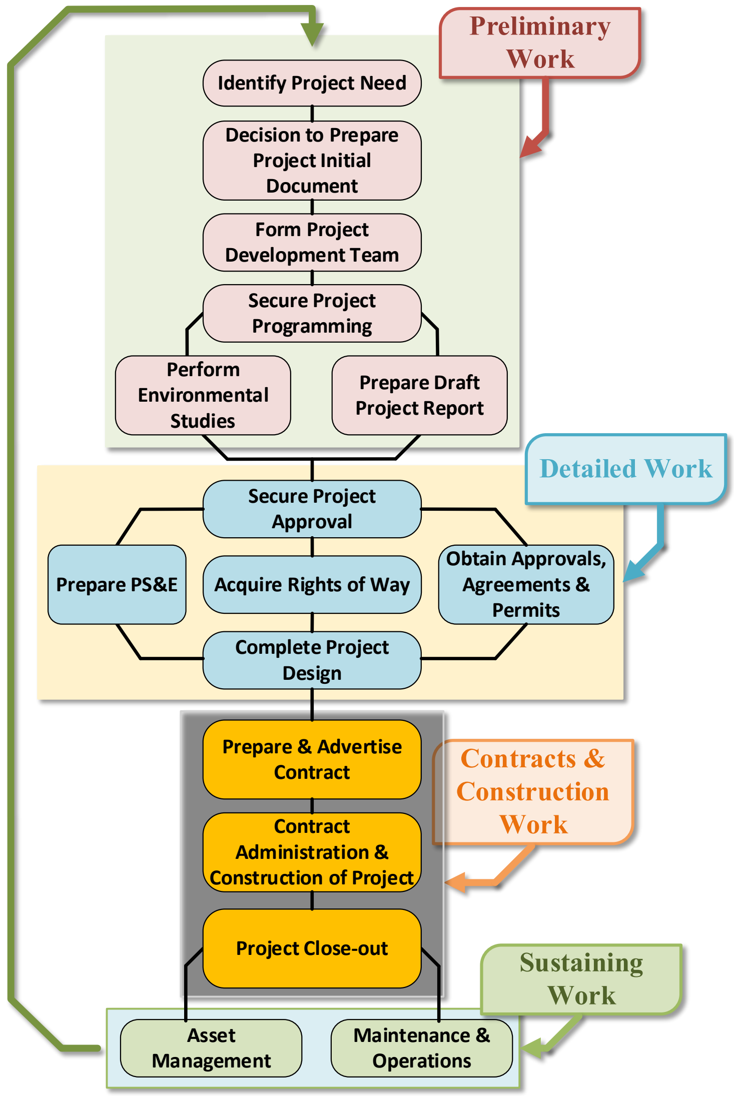


**Figure 2.1: Project Stages (Adapted and Modified from [7])**

The survey was presented to the project panel via Survey Monkey [8] which is an internet based platform. Everyone who received the survey was free to pass it on to those who may be subject-matter experts. In order to collect the most information, a decision was made to allow anyone who self-declared knowledge about an area to answer those questions. This increased the response potential, but may also have introduced some uncertainty in the maturity result.

Each project activity had an introduction page with a flow chart of the overall activity as in Figure 2.2 through Figure 2.6. On this page the respondent was asked if they were familiar with this activity and was given the opportunity to proceed with or to skip the activity entirely. Within a given project activity, each CIM function also had its own introduction page where a respondent could proceed to the questions or skip the function. The questions about each individual tool generally all had the same format and were presented as: "Please score each aspect of [the technology] maturity applied to [the function]," where the technology and function was filled in appropriately.

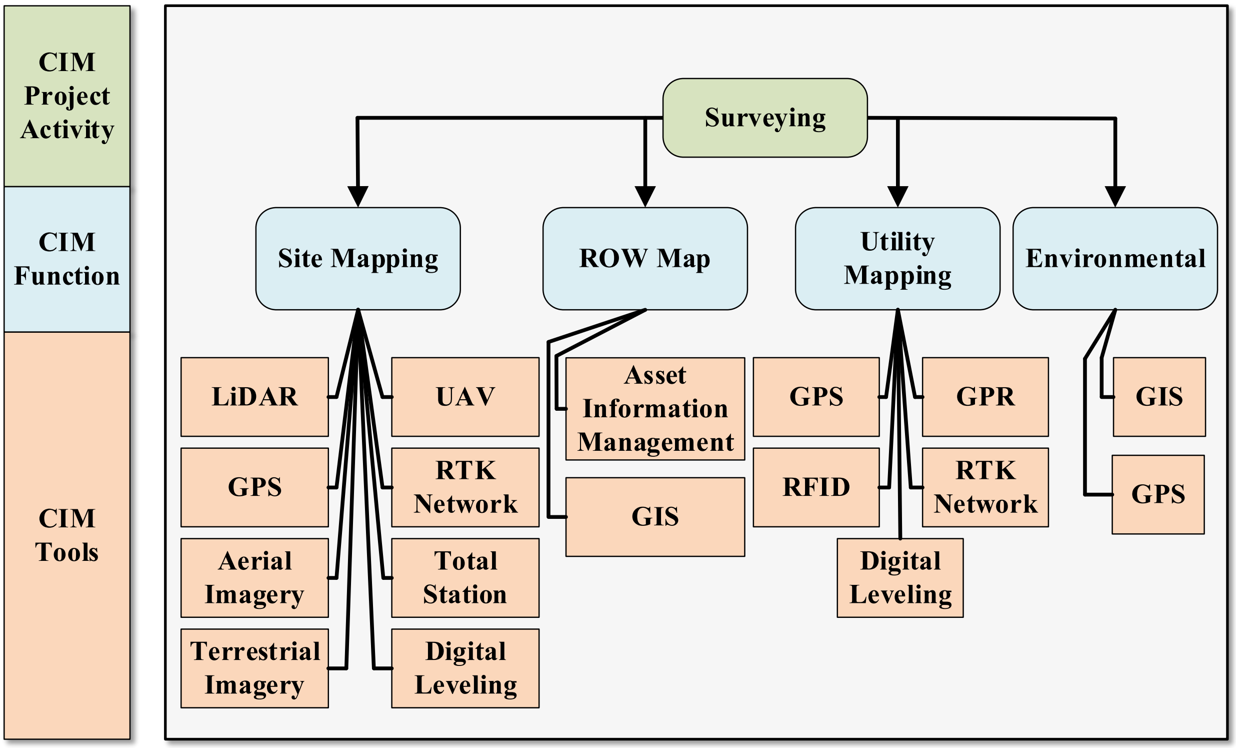


**Figure 2.2: General Organization of Surveying Questions**

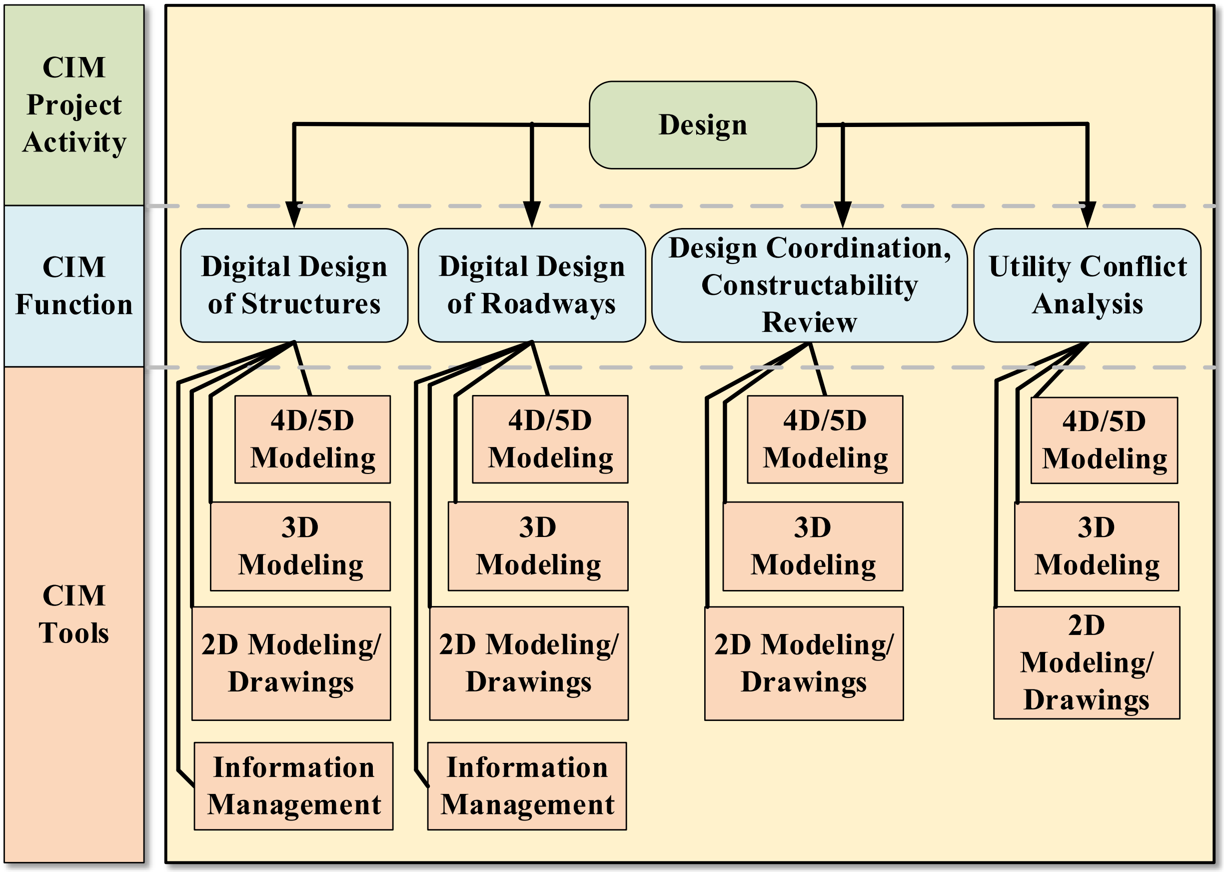


**Figure 2.3: General Organization of Design Questions**

It is noted that the project management CIM activity is different than Caltrans Division of Project Management (which focuses on resource management). Many functions in the project management section are part of construction project management, whereas "Traffic Management" is part of the Division of Traffic. Since people taking the survey could see the flow charts for each section, it is expected that the survey respondents could find the appropriate questions to answer. For purposes of this report the section related to construction project management has been highlighted.

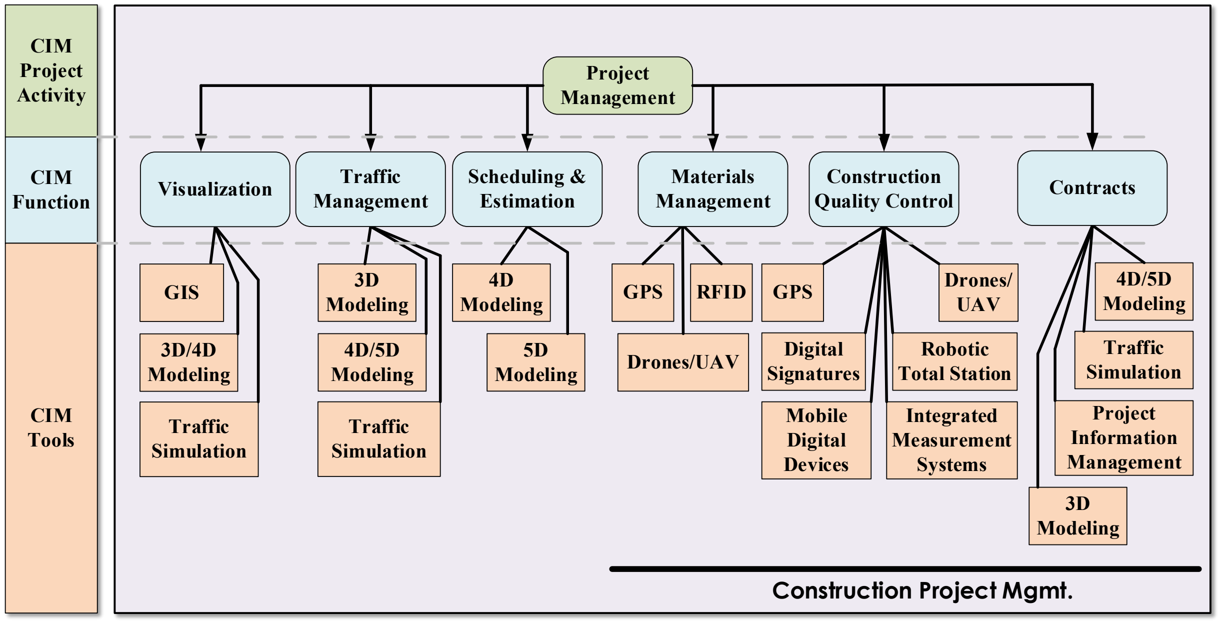


**Figure 2.4: General Organization of Project Management Questions**

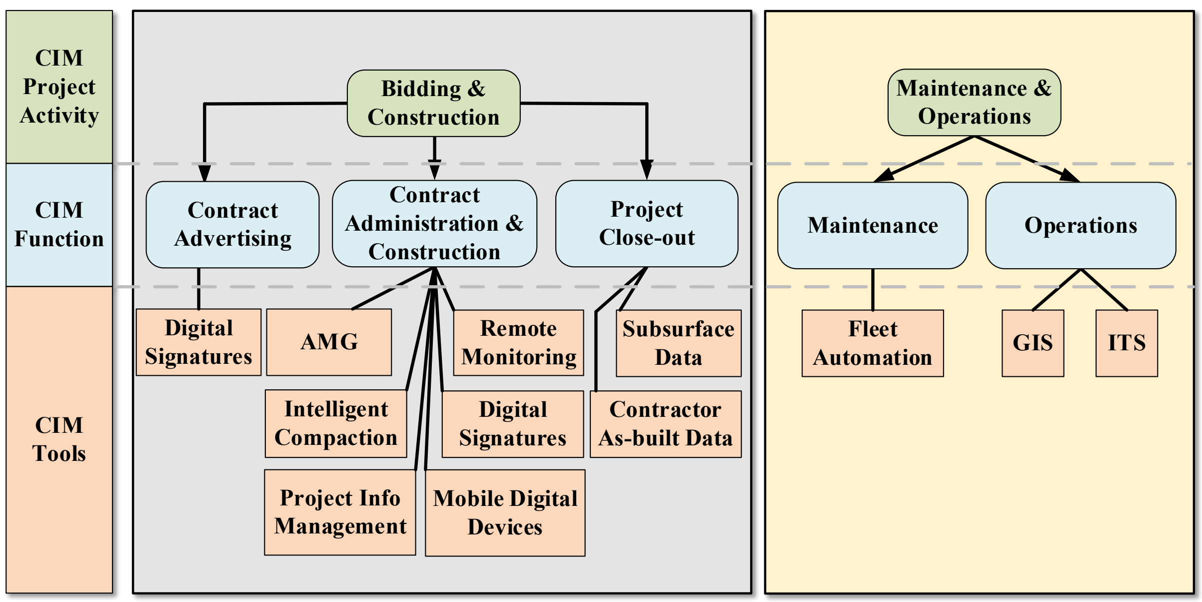


**Figure 2.5: General Organization of Bidding & Construction as well as Maintenance & Operations**

For the asset management questions, it is noted that each program (i.e. pavement, culverts, bridges, etc.) is responsible for collecting the data and choosing the appropriate tools to use. Not every tool shown in Figure 2.6 is necessarily the best tool to use for every task or is necessary to collect the required information. Part of the purpose of this section of the survey was to identify what tools are used.

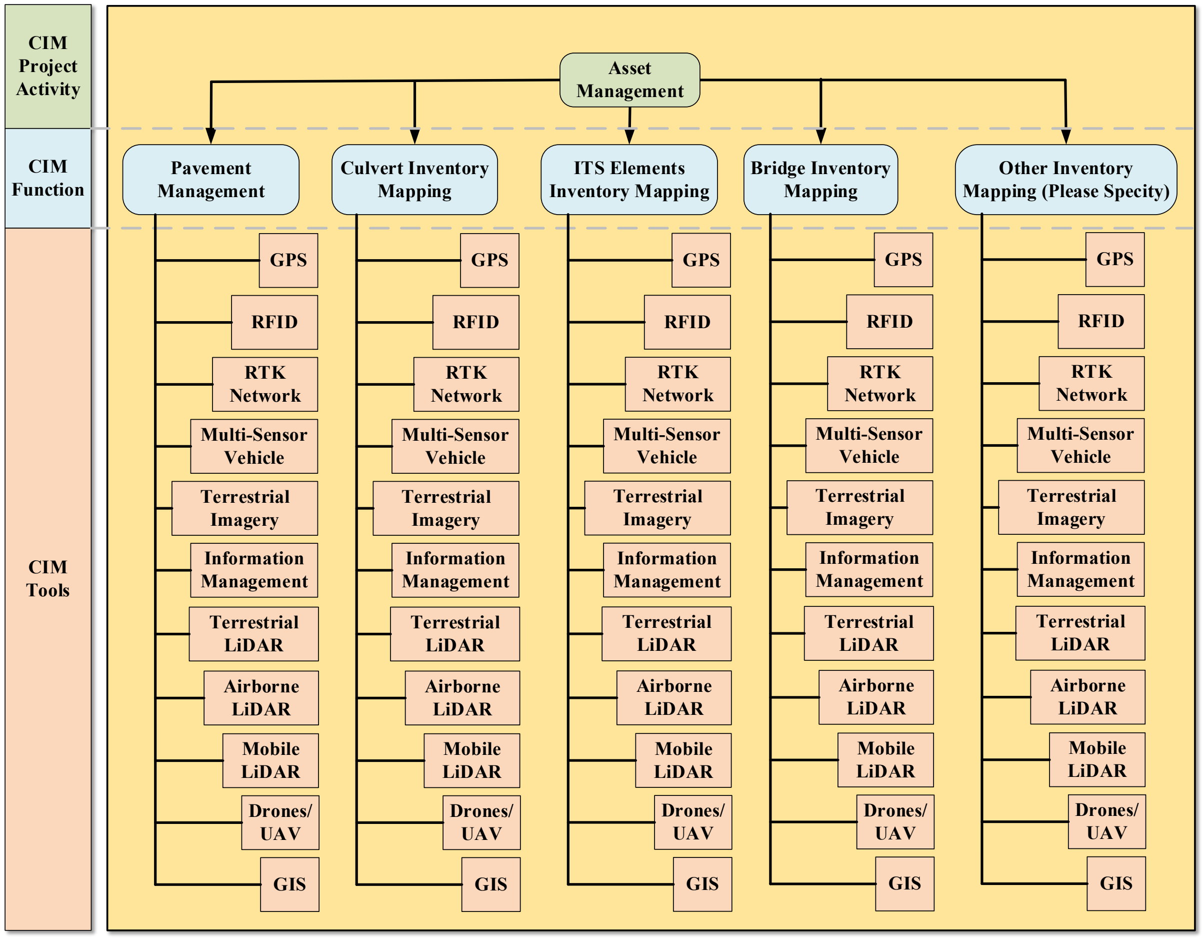


**Figure 2.6: General Organization of Asset Management Questions**

Rather than use the "CIM capabilities maturity model" from NCHRP 831 [5] more granular data was sought. In order to gather more data, a multifaceted approach was used by measuring five distinct facets of maturity separately. One rubric was created to measure the level of technology available (Infrastructure), one for the tool Training, and one for level of Implementation. The final two rubrics were inspired by Caltrans' previous VDC efforts, where they documented issues with Data Storage and Data Sharing as documented in a private communication. The five rubrics (Infrastructure, Project Level Implementation, Data Sharing, Training, and Data storage) each have six possible Levels of Maturity (0 to 5) and a written description of each score, as shown in Table 2.1. Survey respondents selected their answers for each tool from drop-down boxes that displayed the appropriate rubrics. There was also the ability to comment on "showstoppers and bottlenecks for CIM implementation," as well as general comments.

**Table 2.1: Survey Maturity Rubrics**

| Maturity | Infrastructure | Data Storage | Training | Data Sharing | Implementation |
|---|---|---|---|---|---|
| **0** | No technology available | No storage | No training | No sharing | No implementation or not yet considered |
| **1** | Limited technology owned but it is generally not available | Ad hoc storage of data (i.e. on external drives, desktops, etc., no central server) | Self-study using written material such as "owner's manual" | Limited data accessed through individuals who manage it | Started limited used of technology to supplement standard methods |
| **2** | Technology owned but availability is limited | Storage of some data on central server with no data retention policy in place | Number 1 above plus informal training by people who have some experience with the technology | All data through individuals who manage it | Initial testing on pilot projects to replace standard methods |
| **3** | Technology owned and available to most users, but no governing policies are in place | Storage of some data on central server with data retention policy in place | Web-based training courses available on demand | Partial sharing on local network | Used to replace standard methods for several projects |
| **4** | Technology owned and available to most users with governing policies in place | Full storage on central server with no data retention policy in place | Formal classroom training offered periodically | Everything available through web portal or on the cloud with no data governance policy in place | Implemented on many projects, full implementation lacks management support |
| **5** | Technology owned and fully available to all with governing policies in place | Full storage on central server and data retention policy in place | All of the above | Everything available through web portal or on the cloud and data governance policy is in place | State of the art with full implementation and management buy-in |

## 2.1.1 *The Survey Results*

The results of the survey can be viewed a number of ways. One way to view the survey data is to combine all stages of the project and look at each project activity (Surveying, Design, Bidding & Construction, Project Management, Asset Management, and Maintenance & Operations). The median value is used calculated over all responses and tools (with a zero or greater score) in each CIM Function. It should be noted that for some tools an AE contract is used, in the case of an AE contract the infrastructure facet may be of less value (such as for Airborne LiDAR). There may also be some variation between respondents. For example, in some cases the respondents reported a "5" for sharing and noted they have everything except a web portal, while others used a lower score. The survey data represents a moment in time, based on the subject matter experts who responded; these values may change with time. A more detailed look at the survey results showing values for individual tools along with the reported goals for some of the tools is given in Appendix E.

In Figure 2.7 through Figure 2.12, the tools that had a zero or larger maturity for the CIM function under consideration are shown on the right column. Tools that garnered no responses (or only "I don't know" responses) were not included.

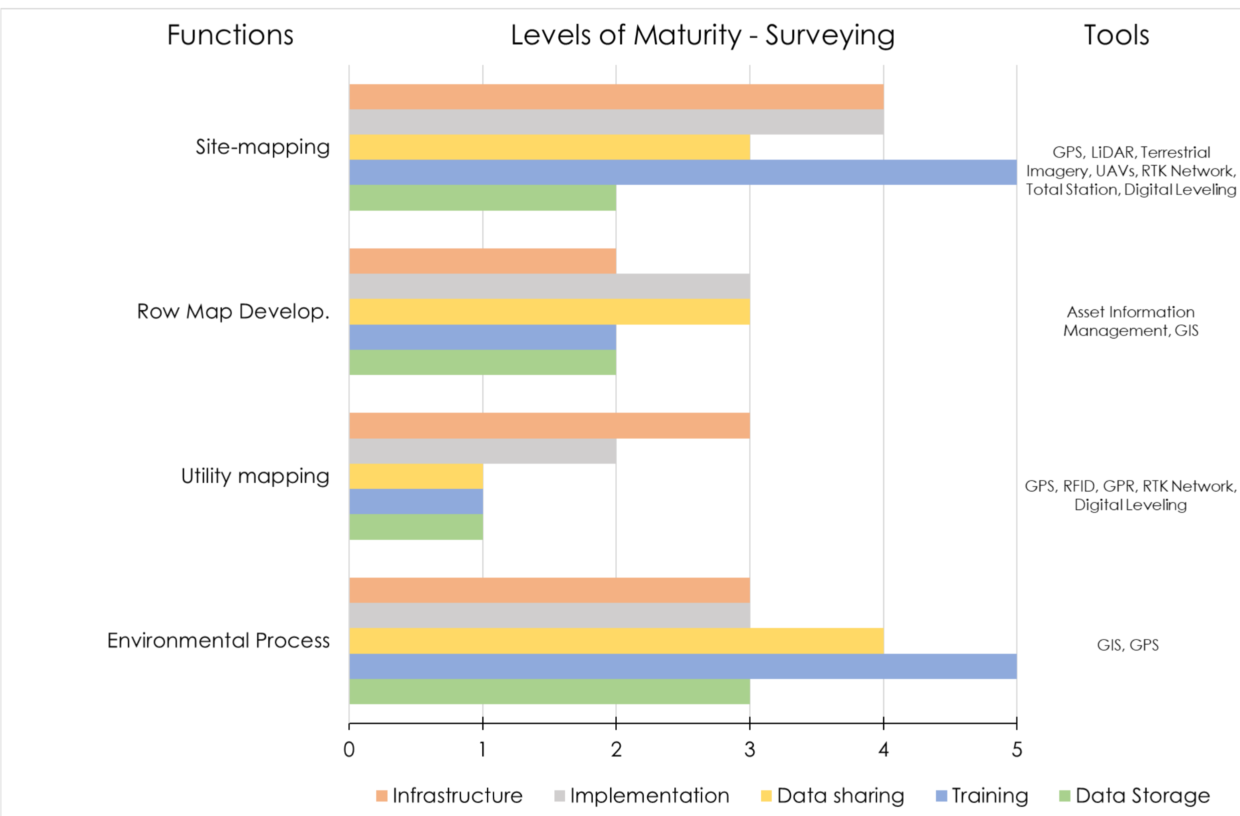


**Figure 2.7: Surveying Maturity**

From Figure 2.7 (the surveying questions), the area with the most potential for improvement seems to be utility mapping. More details about Caltrans subsurface utility engineering (SUE) practices applied to utility mapping will be discussed section 2.3.3.2.

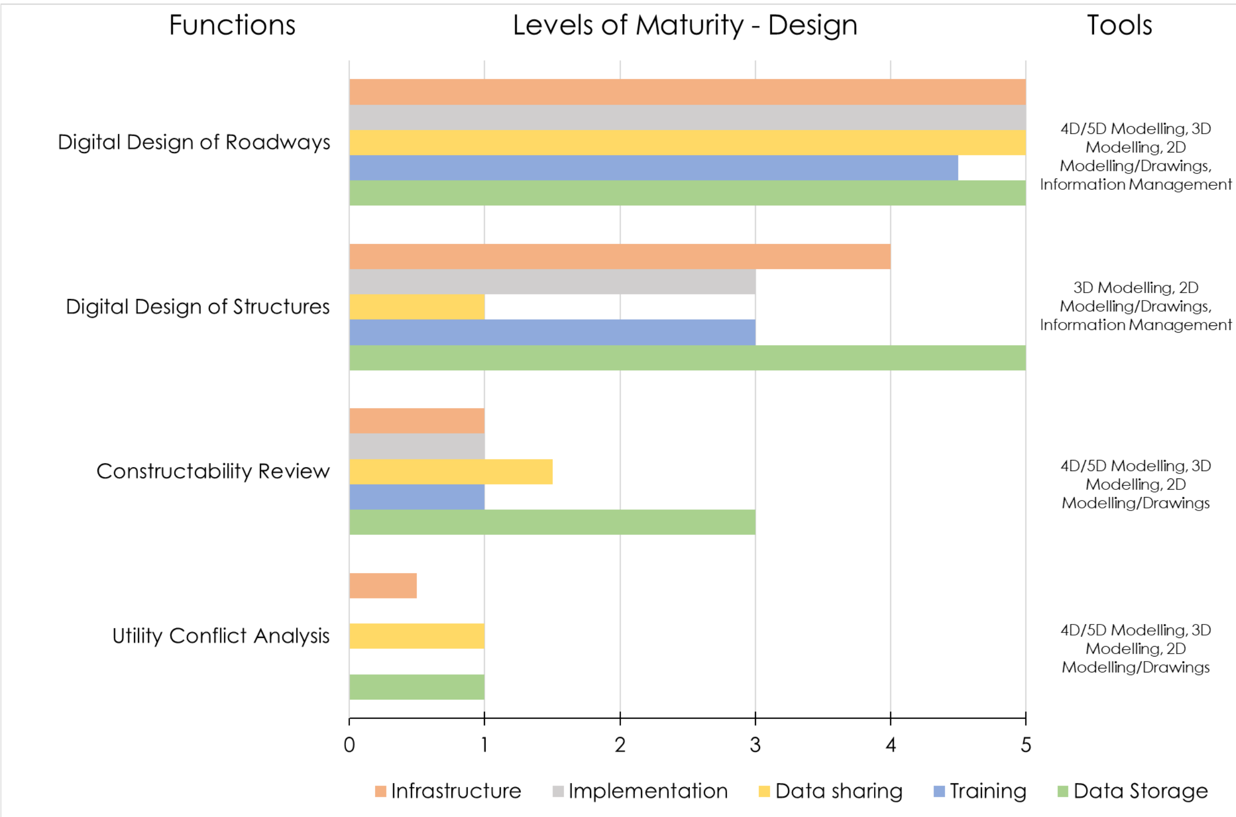


**Figure 2.8: Design Maturity**

From Figure 2.8 (the design questions) there seems to be a maturity discrepancy between roadway design and structure design. In the Design activity, it is clear from Figure 2.8 that Constructability review and Utility Conflict Analysis are areas that have large potential for gains.

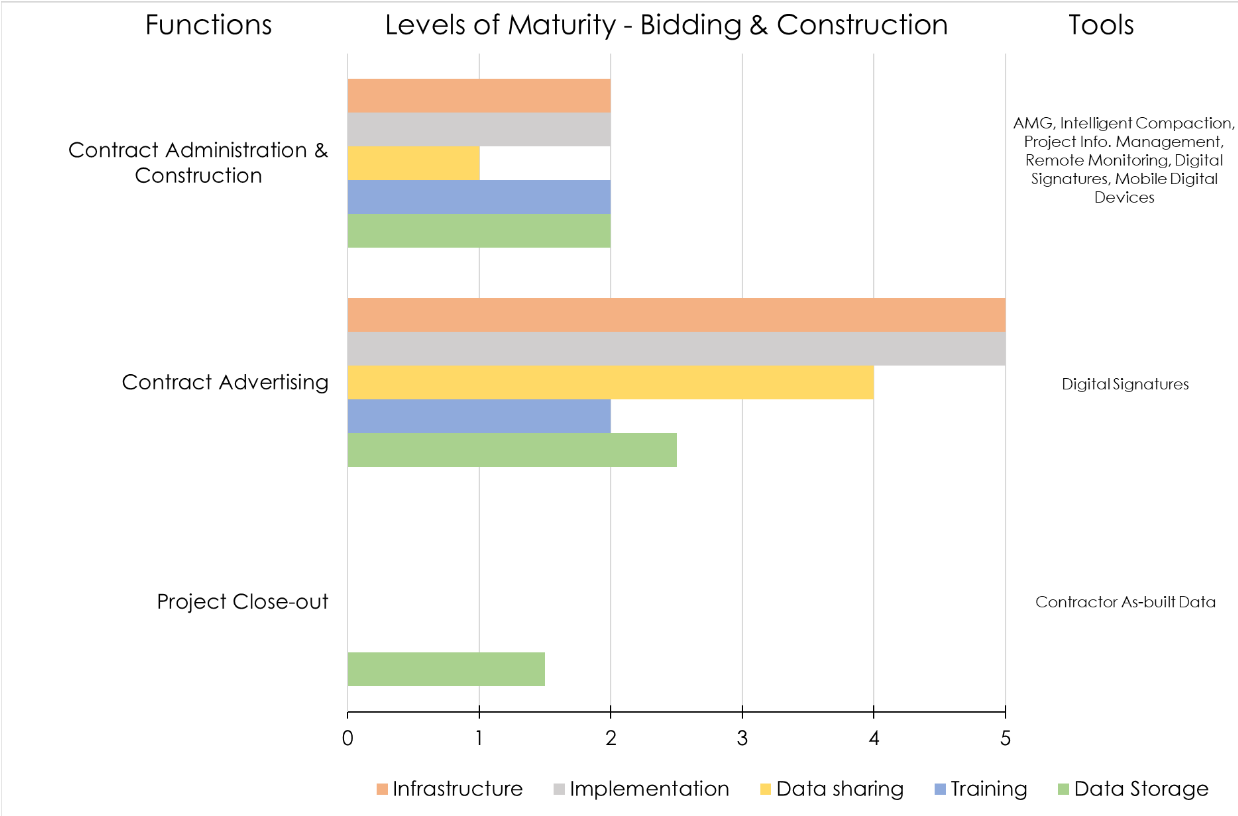


**Figure 2.9: Bidding and Construction Maturity**

From Figure 2.9, it seems that the area with the most potential for improvement is in “Project Close-out.” It is noted that the as-built survey questions were worded as contractor-provided data, and Caltrans does not collect as-built data from their contractors. More details about Caltrans practices are in section 2.3.4.4, with a comparison to other DOT’s in section 4.4.4.

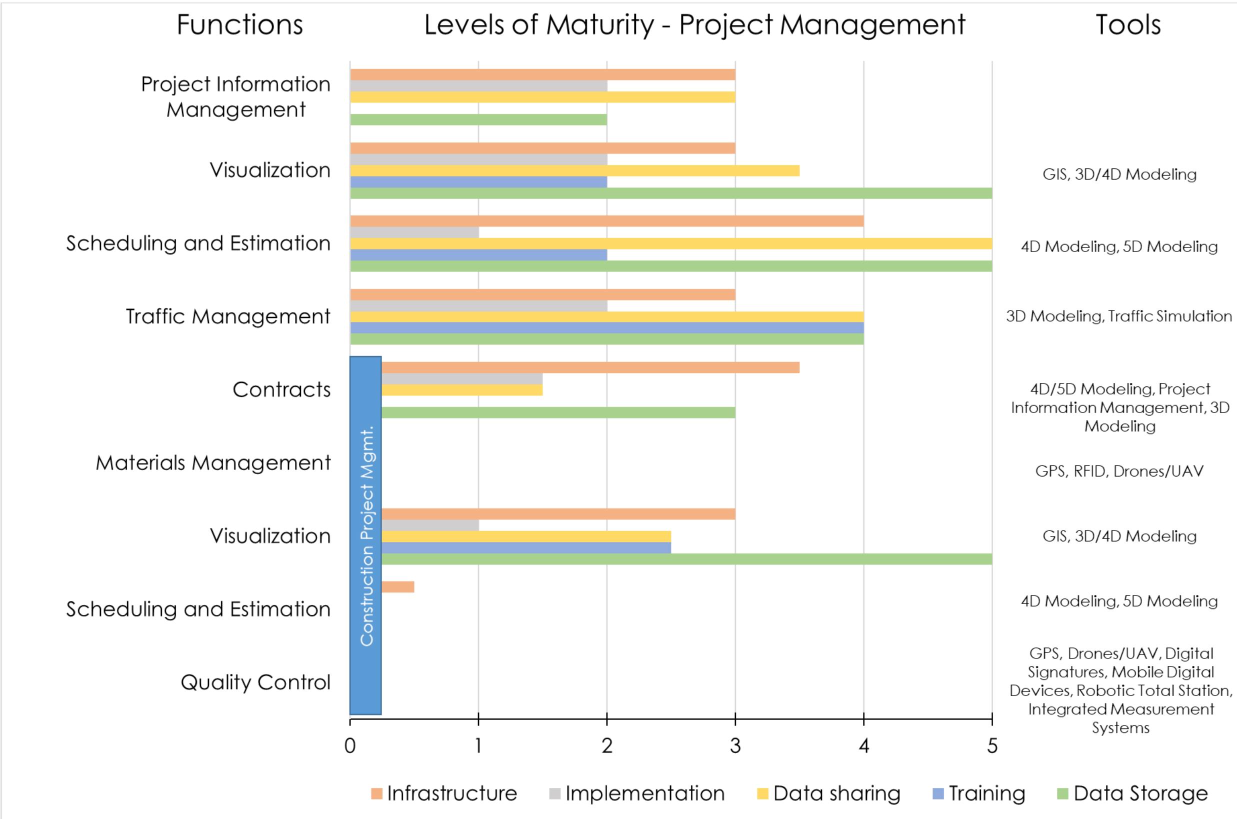


**Figure 2.10: Project Management Maturity**

For the project management activity shown in Figure 2.10, it is noted that "Contracts," "Materials Management," and "Construction Quality Control" are part of construction project management, while "Traffic Management" is part of traffic operations. For areas that show no bars, the median value of all tools shown was zero. From this plot, it seems that the construction project management area (where a lot of the e-Construction tools exist) is an area where there lies the most potential for improvement. Caltrans use of E-Construction tools will be discussed in section 2.3.4.2. Some project management function names/questions are common for both construction and project delivery, but their details are different in each group; these results are separated depending on the respondents' subject matter expertise.

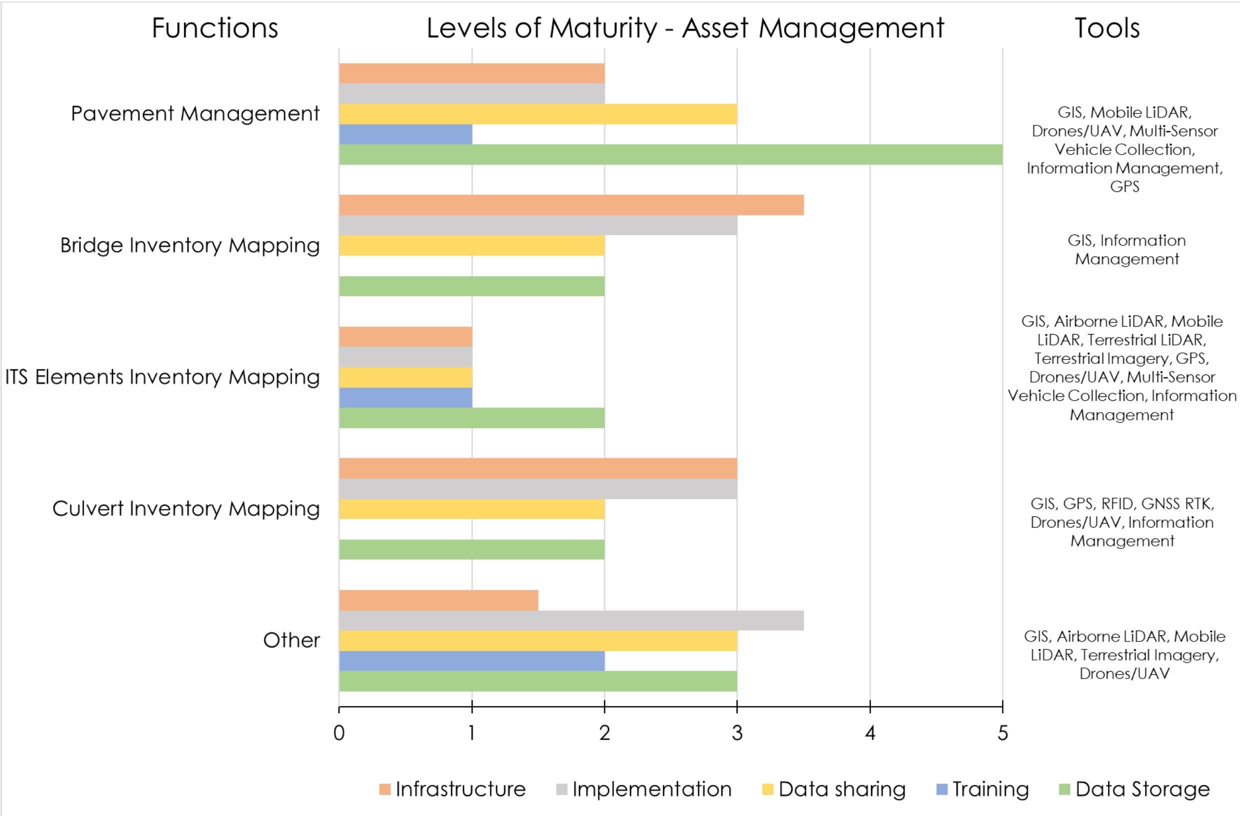


**Figure 2.11: Asset Management Maturity**

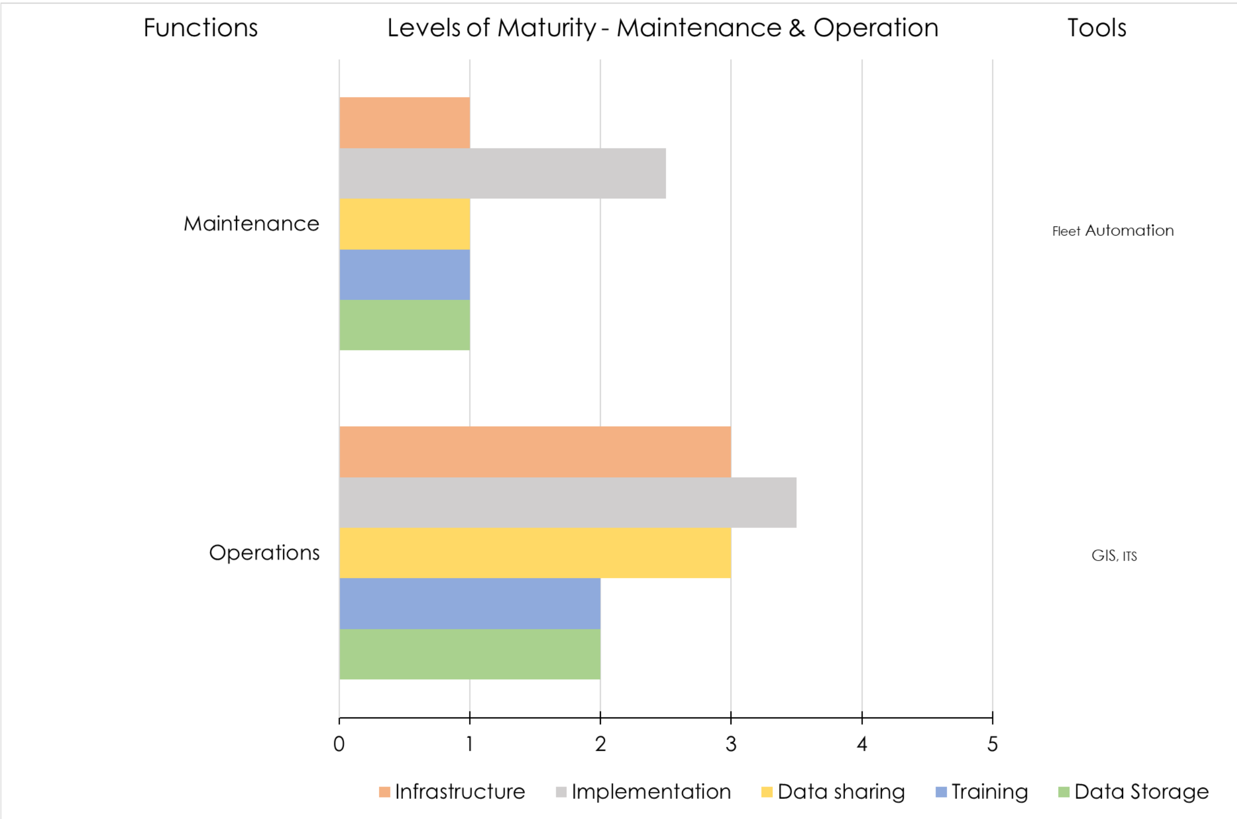


**Figure 2.12: Maintenance and Operation Maturity**

Within Caltrans, asset management is part of maintenance and operations, therefore Figure 2.11 and Figure 2.12 should be viewed in combination. For Figure 2.11, it is noted that the division of asset management does not prescribe what tools should be used; that decision is left up to the programs.

# 2.2 Caltrans 2016 Workshop

## *2.2.1 Comparison*

In 2016 Caltrans hosted a workshop with FHWA where they filled out a self-assessment covering a range of topics from Design to 4D to Asset Management [6]. This data was mapped to the results of the new 2018 maturity survey using a multi-step process. Step one was to decide which facet the 2016 question best fit from the 2018 survey (i.e. Infrastructure, Implementation, Training, Data Storage, and Data Sharing). The second step was to map the 2016 questions to their closest 2018 question. Some questions map in a one-to-one fashion such as "RTK Correction Source" from 2016 mapping to "GNSS Real Time Network" from 2018. However, some questions do not have a one-to-one mapping (i.e. one 2016 question maps to many 2018 questions).

An example of one-to-many can be seen in the 2018 survey question about AMG. Multiple questions from the 2016 data (i.e. "AMG", "Construction Specifications", "Road Design", and others) could all map to the 2018 AMG question. In a one-to-many case the median score from the 2016 questions was used. In either the one-to-one mapping, or the one-to-many mapping, some technologies also mapped from the 2016 survey data across multiple CIM activities in the 2018 maturity survey.

The result of performing the mapping as described for the Infrastructure facet is shown in Figure 2.13, Implementation is shown in Figure 2.14, and Sharing in Figure 2.15. This data was used only for comparison purposes and is not added to the results of the 2018 maturity survey data. It is noted that the data provided in these three figures should only be used for a rough comparison between maturity levels in 2016 and 2018. The comparison is rough because the survey methodology and questions in 2016 and 2018 were not conducted, framed or phrased in the same manner.

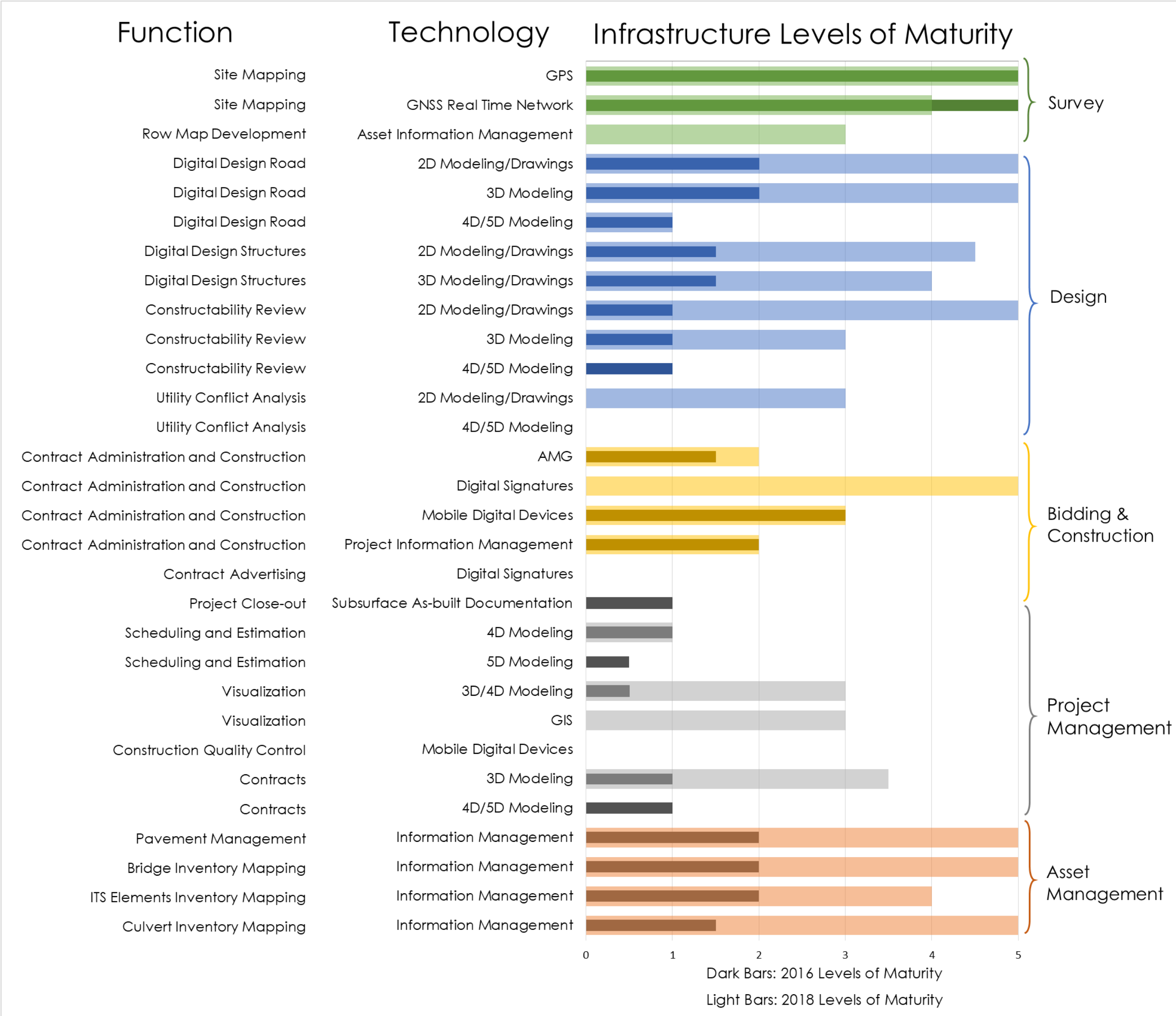


**Figure 2.13: Infrastructure Comparison between 2016 and 2018**

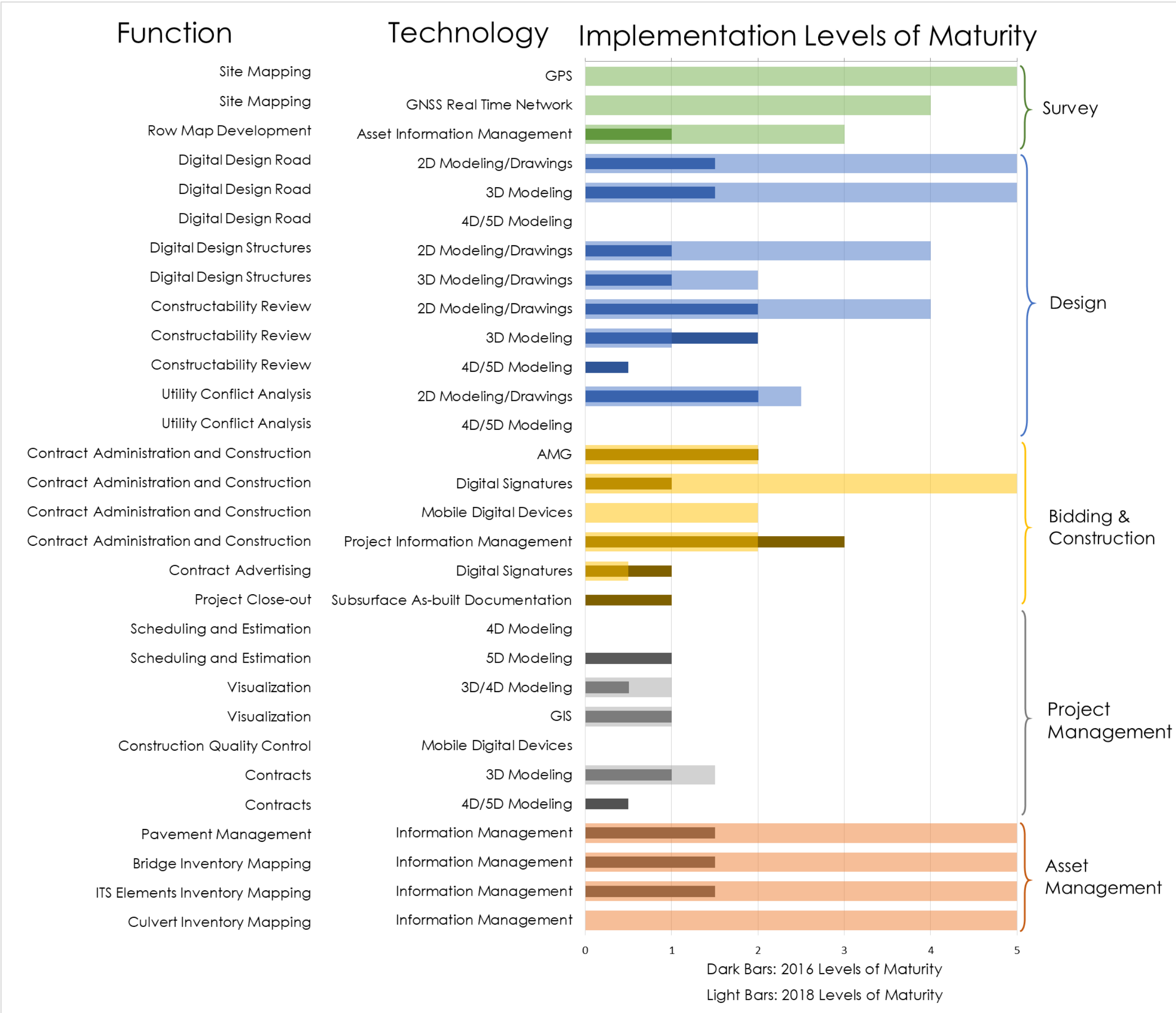


**Figure 2.14: Implementation Comparison between 2016 and 2018**

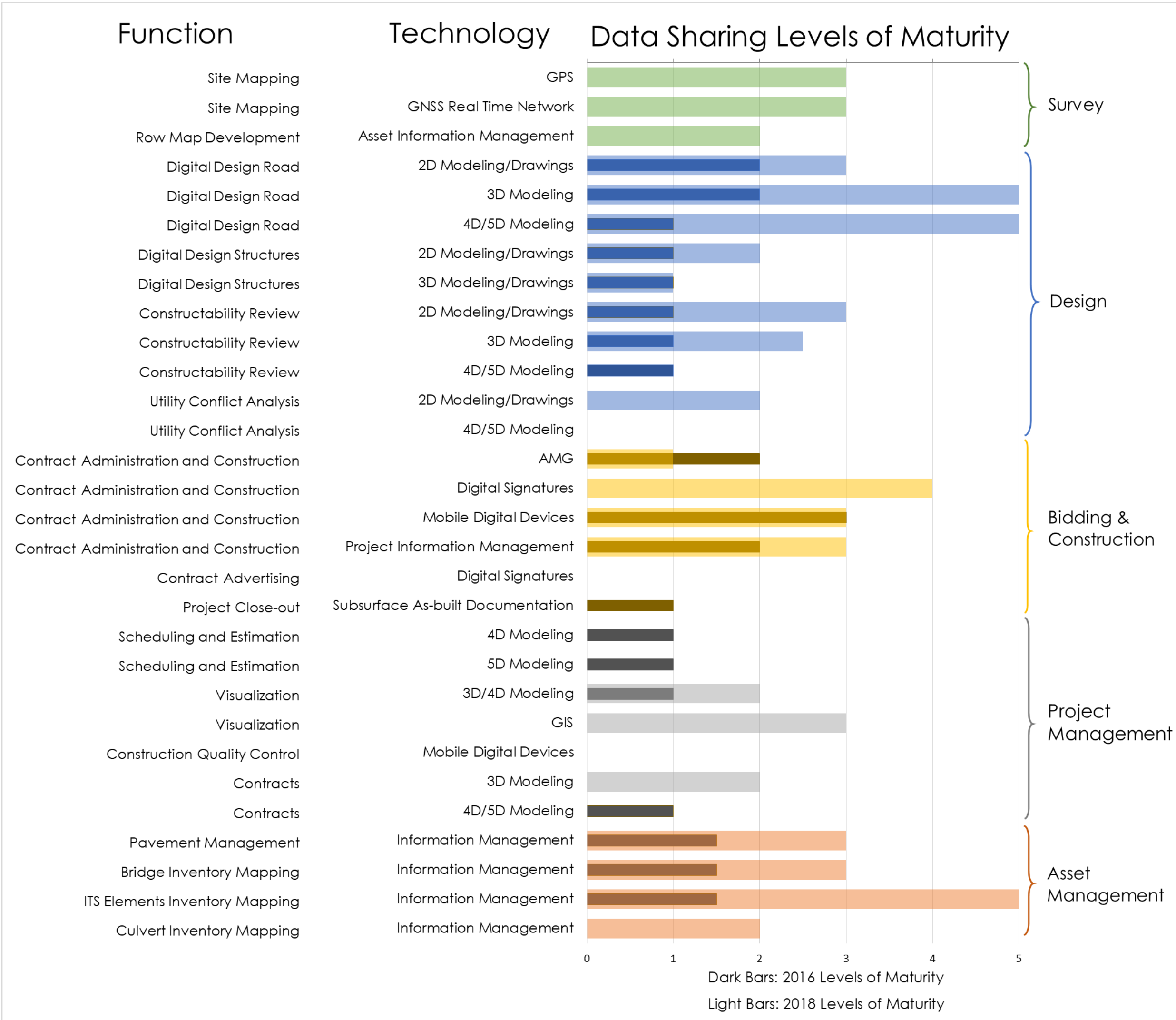


**Figure 2.15 Sharing Comparison between 2016 and 2018**

## *2.2.2 Challenges Identified*

Various challenges toward implementing CIM as discussed in the 2016 Caltrans/FHWA workshop [6] have been tabulated in Table 2.2 and Table 2.3. Possible ways to address challenges are tabulated in Table 2.4 from [6]. The most commonly reported challenges were standardizing practices, data interoperability & integration, and training. Although progress has been made, many of these challenges still exist, as will be shown in the gap analysis.

**Table 2.2: Challenge Card Identified Challenges tabulated from [6]**

| Challenges to Implement 3D Technologies (From Challenge Cards) | Number of Mentions | Job Titles | Employer (Number of Mentioned) |
|---|---|---|---|
| Standardizing practices | 22 | Project Engr (2), (Senior) Transportation Surveyor (5), Transportation Engr (3), Senior Bridge Engr (2), Industry Strategy Manager, Construction Area Engr, Bridge Design Office Chief, Chief GPS Surveyor, GPS Guy, | DOT(19), Contractor(2), Other(1) |
| Data interoperability & integration | 15 | Transportation Engr (2), Senior Bridge Engr (2), Construction (Automation) Engr (2), Engineer, Construction Automation Surveyor, Construction Area Engr, Project Manager, Resident Engr, Chief GPS Surveyor, | DOT(12), Contractor(3) |
| Training | 10 | (Senior) Transportation Surveyor (2), Project Engr (3), Survey Party Chief, Senior Bridge Engr, Bridge design Office Chief, Transportation Engr, Chief GPS Surveyor | DOT(10) |
| Hardware and software, especially to manage "Big Data" e.g. LiDAR point clouds | 7 | (Senior) Transportation Surveyor, Field Surveys Supervisor, Survey Party Chief, Engineer, Project Manager, CADD Specialist, Senior Transportation | DOT(6), Contractor(1) |

| Challenges to Implement 3D Technologies (From Challenge Cards) | Number of Mentions | Job Titles | Employer (Number of Mentioned) |
|---|---|---|---|
| | | Engr | |
| Management buy-in, e.g. to support the learning curve | 7 | (Senior) Transportation Surveyor, Senior Bridge Engr, Project Engr (2), Construction Automation Surveyor, Office Chief photogrammetry (& preliminary investigations) | DOT(7) |
| Finding a new way to commit to innovative practices to keep pace with change | 7 | Field Surveys Supervisor (2), Transportation Surveyor (2), Transportation Engr, Industry Strategy Manager, Construction Area Engr | DOT(5), Other(1) |
| Attracting new/young talent as the workforce ages towards retirement | 3 | Project Engr, Survey Party Chief, Transportation Surveyor | DOT(3) |

Table 2.3 provides a list of challenges that were also identified in 2016 Caltrans/FHWA workshop [6].

**Table 2.3: Implementation Challenges tabulated from [6]**

| Some of the challenges that were identified during the implementation breakout (from worksheet) | Number of Mentions |
|---|---|
| Staff need additional training and support to use 3D modeling software/hardware | 6 |
| Define discipline-specific roles for 3D modeling, e.g. create areas of specialization | 5 |
| Need an enterprise data warehouse to centrally store and share information | 3 |
| Need storage for enterprise data, especially LiDAR point clouds | 3 |
| Democratize information, make it accessible across the agency | 2 |
| Need to establish more integrated working practices, especially between design, survey, and construction | 2 |

| Some of the challenges that were identified during the implementation breakout (from worksheet) | Number of Mentions |
|---|---|
| Need to update or develop standards, specifications, and permits | 2 |
| Define a library of parametric parts for structure modeling | 1 |
| Need a WBS code for visualization and other 4D modeling to fund and track it | 1 |
| Define how to manage incompleteness and uncertainty in 3D models | 1 |
| Risk of over-engineering, especially small projects, spending too much time on 3D | 1 |
| Lack of confidence in 3D data | 1 |
| Lack of accountability for compliance with PD-06 | 1 |
| Proprietary data formats | 1 |
| Risk of data quality when non-surveyors begin using survey instruments | 1 |
| Job Responsibility/Duty statements and core competencies needed to keep up with modern tools and methods | 1 |
| Access to hardware and software to use 3D data | 1 |

Table 2.4 provides a list of possible solutions to the challenges that were also identified in 2016 Caltrans/FHWA workshop [6].

**Table 2.4: Possible Challenge Solutions tabulated from [6]**

| Some suggestions for overcoming these challenges (from worksheet) | Number of Mentions |
|---|---|
| Provide training opportunities to contractor partners | 3 |
| Explore PDF, Google Earth KMZ, and other options for viewing and marking up contractual 3D models | 3 |
| Communicate the how and why of upcoming changes | 3 |
| Map processes to guide data integration that meets all needs efficiently | 2 |
| Engage with industry to resolve roles and responsibilities for collecting 3D as-built data | 2 |
| Identify a range of competency requirements and differentiate training for different users | 1 |

| Some suggestions for overcoming these challenges (from worksheet) | Number of Mentions |
|---|---|
| Ensure that there is adequate support and training available to those who need it | 1 |
| Engage with industry to identify bridge data needs, potential uses, and opportunities | 1 |
| Focus on the user experience with software interfaces to minimize training needs | 1 |
| Manage technology deployment and update cycles | 1 |

## 2.3 Caltrans Interviews & Data

Significant effort was spent on interviewing Caltrans stakeholders in both group settings as well as individually. Information was collected from Aeronautics, Asset Management, Division of Engineering Services (DES), Division of Construction, Environmental, Land Surveys, Maintenance, Office of CADD and Engineering GIS Support, Project Management, and Traffic Operations. Information was also collected specific to data management, connected vehicles, and Intelligent Transportation Systems (ITS).

In addition to information collected through interview, data was also obtained from pre-existing public sources such as Caltrans documents.

The information collected was distilled down and used in various forms in the gap analysis and the roadmap. A summary of some of the information is contained in the following sections.

## 2.3.1 Environmental Analysis

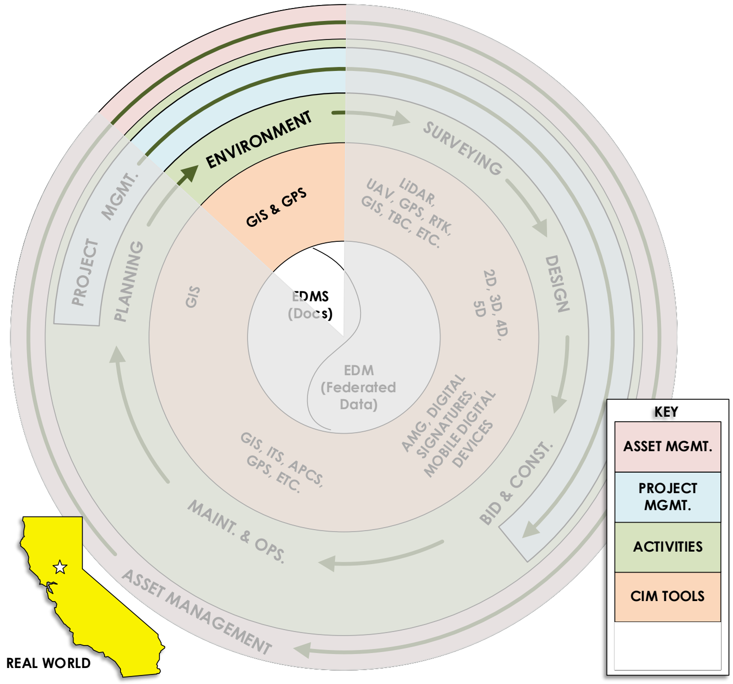


**Figure 2.16 Environmental Portion of VDC/CIM**

This section will discuss some specific VDC/CIM tools and their applications currently at Caltrans relating to Environmental analysis as shown in Figure 2.16. Information in this section comes from interviews with Caltrans and their subject matter experts.

The Division of Environmental Analysis at Caltrans is responsible for obtaining approvals, agreements, and permits as part of environmental studies. This is done as part of the Project Approval and Environmental Document (PA&ED) task. Project plans are required to obtain permits, and these plans are traditionally done in 2D. From discussions with Caltrans, a lot of environmental work is done with paperwork and 2D plans. It is unclear if a 3D model could be evaluated by external agencies that ultimately grant the permits.

The main database for environmental work is the Statewide Tracking and Exchange Vehicle for Environmental Systems (STEVE). The STEVE database is tied in to all the districts and to PRSM. STEVE includes a super container that allows projects to upload related documents. Environmental has a GIS system, but there is currently no way to get live data from STEVE into the GIS system. STEVE must be accessed through FilemakerPro and it is not a spatial database. Moving to a web-based system, so that all users won't need FilemakerPro to access the data, is currently under consideration.

## 2.3.2 *Surveying*

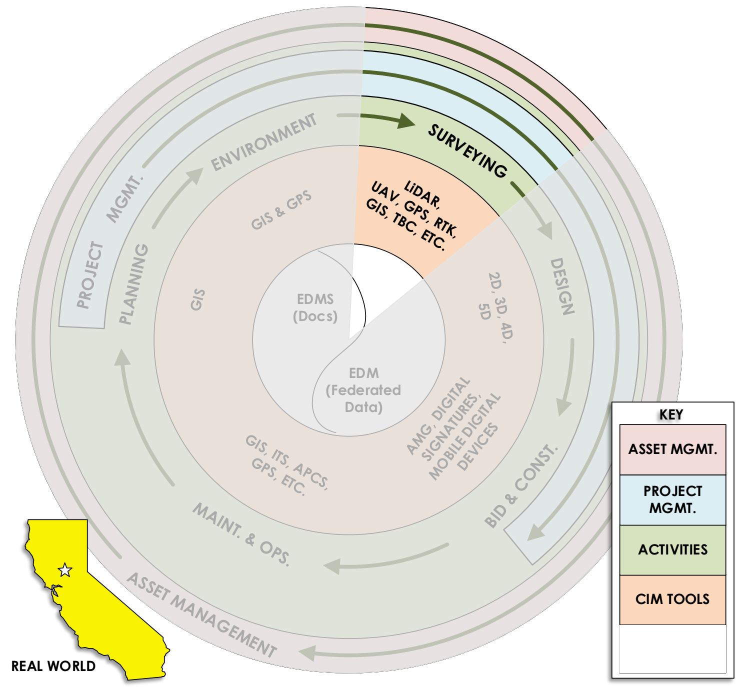


**Figure 2.17 Survey Portion of VDC/CIM**

This section will discuss some specific VDC/CIM tools and their applications currently at Caltrans relating to surveying as shown in Figure 2.17. Information in this section comes from interviews with Caltrans and their subject matter experts. Information from other sources is also included in this section where cited.

### 2.3.2.1 **LiDAR Mobile Mapping**

Caltrans operates two Mobile Terrestrial Laser Scanner (MTLS) vehicles statewide [9]. The Riegl VMX-1HA, as shown in Figure 2.18, and a Trimble MX8 MTLS are cost effective and one of the safest tools the Surveys program uses to achieve engineering grade design surveys, along with the collection of highway assets. Caltrans reported that MTLS generates very large files which are hard to move given the limited bandwidth Caltrans utilizes. The files are also hard to store and the raw point clouds are not typically shared with designers.

Over 340 MTLS projects have been completed statewide[1]. Typically, the data collected includes existing topography for pre-construction design purposes. Approximately 11% of network has been scanned representing approximately 150TB of data [10]. One survey respondent noted that post-processing (feature

[1] Based on current MTLS research with Caltrans by AHMCT.

extraction) of LiDAR data is labor intensive. When compounded with staff shortage, this may lead to a bottleneck.

**Figure 2.18 Caltrans Mobile Terrestrial Laser Scanning (MTLS) vehicle**

### 2.3.2.2 **GNSS & RTK**

Caltrans started its RTK network in the California central valley around 2005 [11]. It has been expanded to the current system of 145 stations with coverage over a significant portion of the state as shown in Figure 2.19.

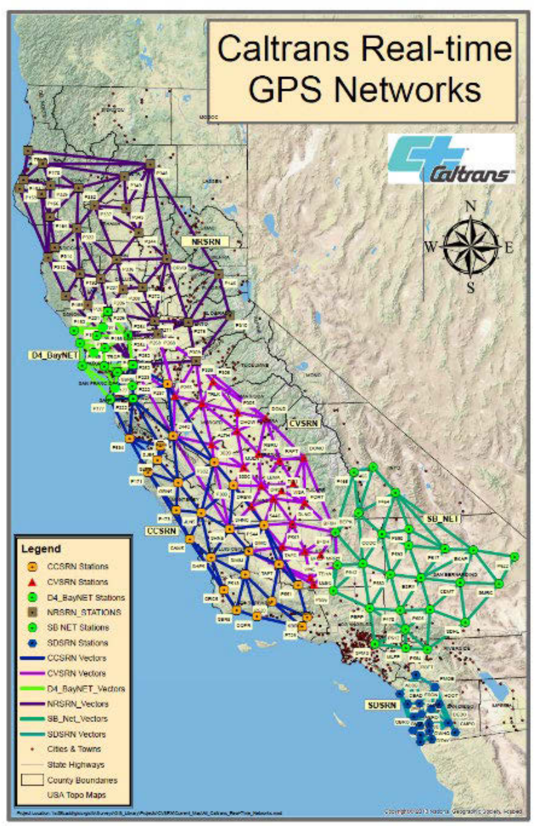


**Figure 2.19 Caltrans Real-Time Network [12]**

### 2.3.2.3 **Drones/UAV/UAS**

Drones (also known as UAV and UAS) are used for a range of activities by Caltrans. Caltrans Deputy Directive 118 establishes the policy for the use of UAS by Caltrans employees, consultants, and contractors. The Caltrans UAS Program, within the Division of Aeronautics, has established procedures, guidelines, and best practices that comply with federal regulations, state statutes, and Deputy Directive 118.The Division of Aeronautics reported that approximately292 drone missions have been conducted by Caltrans, and statewide there are 57 employees who are drone pilots certified by the Federal Aviation Administration and registered with the Division of Aeronautics. Caltrans has done some initial research on ESRI's Drone2Map. District 3 is using Bentley ContextCapture and Trimble software to process their drone imagery. Pix4D has also been used as a solution for processing drone imagery. Caltrans has reported that early testing of UAV's has shown the use of drones can provide a time savings of 50-70% in some field operations. A summary of drone data received from Caltrans is given in Table 2.5.

Based on conversations with Caltrans, it is not currently clear what data generated by drones should be stored. The images generated can form a large dataset which is hard to store.

**Table 2.5: Details for Caltrans Deployment of Drones**

| Area | Caltrans Status |
|---|---|
| **Application** | Rock slides, Surveying, Bridge insp., Construction monitoring, Earthwork calculation, Emergency response, Environmental, Hydrological, Geological, Quantities for payment purposes. |
| **Type of data** | Photogrammetry imagery, Videography, and LiDAR |
| **Number of Drones** | 25 (statewide) |
| **Policy** | Aeronautics has established a policy and procedures for the purchase and deployment of UAS. Available at https://uas.onramp.dot.ca.gov/ |
| **Some Sample project** | Four land and rock slide projects, D4 Route 35, Alameda 84, Berryessa rock slide, Keeler/Zurich Pit Mining and Reclamation as well as Mud Creek and the Paul's slide. |
| **Software** | Pix4D, Agisoft, PhotoScan, ContextCapture and Trimble |
| **Accuracy Goal** | Vertical : +/- 5 cm to +/- 1cm |
| **Achievements** | Safety, Efficiency, Sustainability |
| **Objectives** | Safe application of use in Caltrans business practices<br>Compliant use activities with regulations<br>Establish guidelines for operation<br>Facilitate administrative activities |

# 2.3.3 *Design*

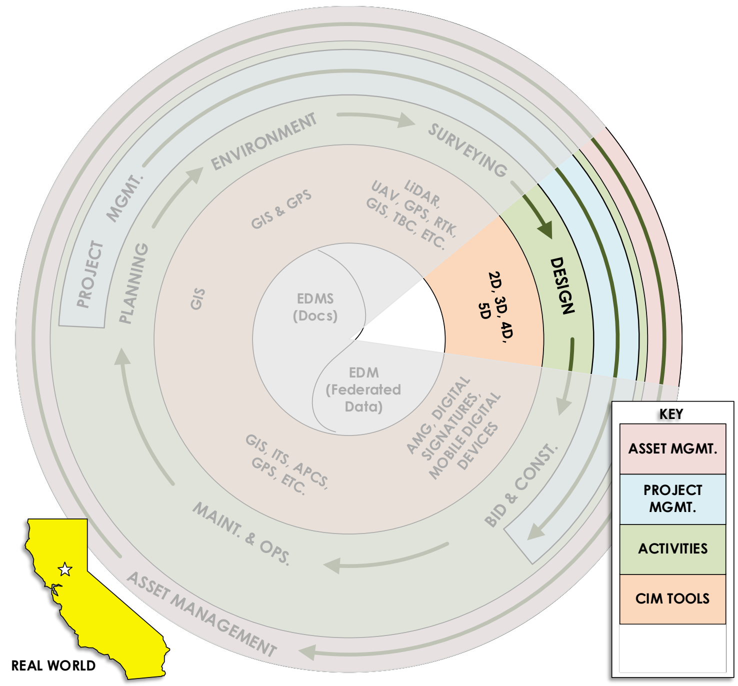


**Figure 2.20 Design Portion of VDC/CIM**

This section will discuss some specific VDC/CIM tools and their applications currently at Caltrans as relates to design as shown in Figure 2.20. Training procedures specific to design will also be discussed. Information in this section comes from interviews with Caltrans and their subject matter experts. Information from other sources is also included in this section where cited.

## 2.3.3.1 **2D/3D Modeling and Analysis**

From stakeholder interviews, it was found that Caltrans defined different levels of included features for 3D models in February 2013 as shown in Table 2.6. A cross-section from a 3D model provided by Caltrans is shown in Figure 2.21, illustrating the kind of details included.

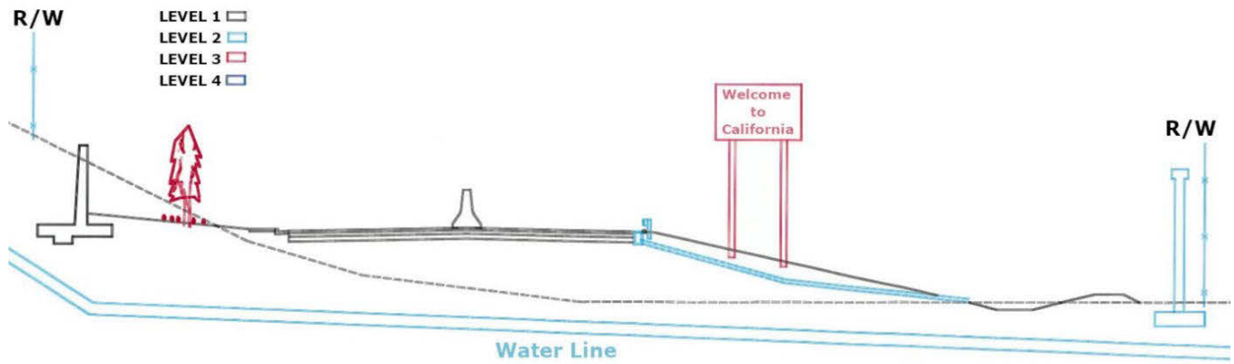


**Figure 2.21: Example 3D Model Cross Section Showing Included Features from Caltrans Personal Communications**

**Table 2.6: Caltrans 3D Model Included Features**

| | |
|---|---|
| Level 1<br>Features that make up the Finish Grade of a project whereby Basic Drive-through and safety issue identification can be accomplished | • Original Ground DTM<br>• Finish Roadway Surface<br>• Retaining Walls<br>• Median Barriers<br>• Curbs, Dikes, and Sidewalks |
| Level 2<br>Added features for improved Drive-through and conflict resolution | • Drainage<br>• Bridge Cones and Structures<br>• Curb Ramps<br>• Utilities<br>• Metal Beam Guard Rails<br>• Soundwalls |
| Level 3<br>Asset Management – Advanced Drive-throughs | • Signs, Striping & Pavement Markers<br>• Wall Texture, landscaping<br>• Higher level asset inventory<br>• Graphical Point Cloud integration |
| Level 4<br>Animation | • Full Animation<br>• Multi-Dimensional integration (4D, 5D) |

Caltrans current workflow requirements correspond to Level 1 in Table 2.6. However, some engineers are already producing some Level 2 details, such as Bridge Cones and Curb Ramps. Some individuals also commented that the current computer hardware and network bandwidth can make working with Civil3D files difficult. Moving to a higher level of 3D maturity may require some upgrades.

From personal communications with Caltrans, there are variations in the workflow for different projects and districts. Generally, the current workflow is such that roadway design staff from the districts generate Civil3D data, but this data is not used consistently by Structures. Some Structures designers do use Civil 3D Data-Shortcuts, but this is not typical practice. Some data is converted to MicroStation for Structures to use. Caltrans project directories can be used to share data, but this is not done consistently. Roadway Design and Structures largely operate in parallel; such that, if roadway geometry changes, Structures may not know about it until later in the process if they do not use the shared directories.

The legal plan is generated in 2D for contractors with 3D models available in some cases for informational purposes (as per Caltrans policy directive Policy Directive 06). Personnel communications with Caltrans indicated that some designers are still reluctant to share 3D models for fear it may open them up to liability while also adding more work.

Table 2.7 provides a summary of design tools, and Table 2.8 provides a summary of analysis tools used by Caltrans. For Table 2.7 it is noted that Structures uses a combination of 2D and 3D, depending on the designer's skill set.

**Table 2.7 Caltrans Design and Analysis Tools**

| Roadway | Structure | Comment |
|---|---|---|
| MicroStation | MicroStation | 2D plan generation for bid advertisement |
| - | AASHTOWare Bridge Design[1] | Bridge design |
| Civil 3D | - | roadway design (2D/3D) |
| - | Tekla | Contractors used for visualization and fabricators |
| Civil 3D | Civil 3D | Bridge layout |
| InfraWorks[2] | InfraWorks[2] | - |

[1]*Under consideration*

[2]*Being evaluated for visualization and planning for PAED.*

**Table 2.8: Caltrans Structures Analysis Software Tools**

| Commercial Tools | In House Developed Tools |
|---|---|
| AASHTOWare Project Suite, Adina, Align, ANSYS, Apile, Apile Plus, BAMS/DSS, Bentley Pro Structures, Bentley Rebar, BIRIS, BRASS, CANDE, CSIBridge, Crystal Ball, Eriksson Pipe, ET Culvert, Falsework Check, GeoHECRAS, Group, LARSA 4D, Lpile Plus, Lpile, Leap, LRFD Simon/NSBA Splice, MDX, Midas Civil, Midas FEA, Midas GTS NX, MS Bridge, OpenBridge Modeler, OpenSEES, PG Super, PIPECAR, Proconcrete Pro, Plaxis 2D | CT Abut, CTBridge, CTBC, CTBDS, CT Bent, CTFlex, CTRigid, CT Pier, Deck Contours, RetWall, Snail |

### 2.3.3.2 **SUE Tools**

Caltrans reports that design has created a 3D utility database as part of Transportation Research Board's Strategic Highway Research Programs 2 (SHRP2) R01A program. This utility database can be viewed by users statewide and utility engineers will be able to add data to the database. Geotechnical services from DES also have SUE investigation abilities. Caltrans has a Ground Penetrating Radar system, but only a limited number of subject matter experts exist for the GPR and it is not part of the standard process.

As part of SHRP2 R01A, a 3D Utility database was created. Caltrans SHRP2 R01B validated the SUE system. SHRP2 R01B (R7) also allowed for acquisition of TDEMI hardware, GeoSoft for data analysis, and additional training. Three sites have been tested and compared against the old SUE data. [13], [14]. An image of the equipment acquired as part of SHRP2 is shown in Figure 2.22 with the antenna in front.

**Figure 2.22 Caltrans SUE Van**

## 2.3.3.3 **Training**

Relative to roadway design software, Caltrans Office of CADD and Engineering GIS holds annual training for districts and on an as-needed basis. DES structures had a specialized training for its users on Civil 3D but it was not widely adopted.

## 2.3.3.4 **Constructability Review**

Constructability review can be considered part of the collaboration process as it involves a number of disciplines working together. Collaboration is discussed in more detail in section 2.3.8.3. Based on comments received from the Caltrans user survey, the process is implemented in 2D, and a survey respondent stated that only one district uses electronic files. Currently, designers use 3D to identify errors, but the model is not shared with constructability review. 3D models have been used as part of coordination in rare cases.

# *2.3.4 Bidding & Construction*

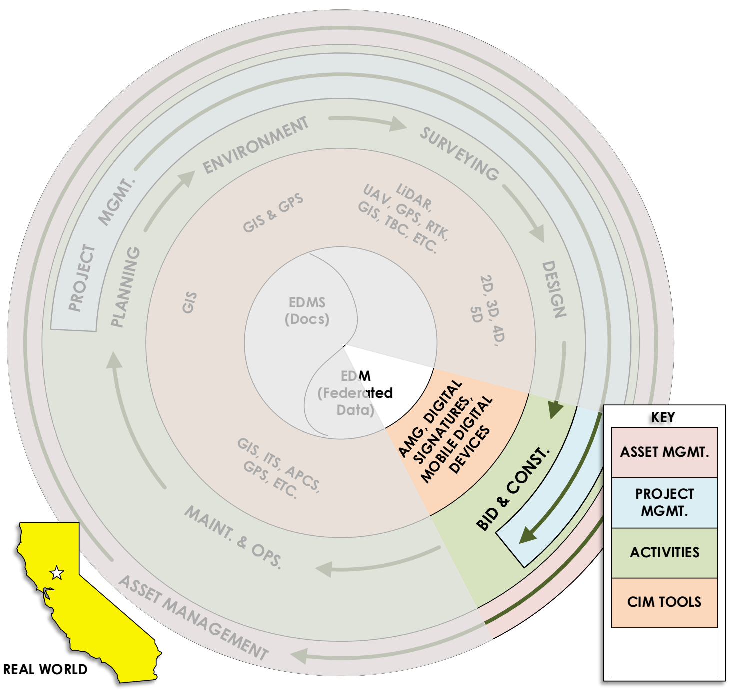


**Figure 2.23 Bidding and Construction portion of VDC/CIM**

This section will discuss some specific VDC/CIM tools and their applications currently at Caltrans as it relates to bidding and construction as shown in Figure 2.23. Training procedures and as-built documentation will also be discussed. Information in this section comes from interviews with Caltrans and their subject matter experts. Information from other sources is also included in this section where cited.

### 2.3.4.1 **Automated Machine Guidance (AMG)**

Caltrans current AMG specification is for projects with greater than 5000 cubic yards of earthworks. For AMG to work, the digital 3D models must be available (which can be provided as per PD-06). In addition, good coverage of the work area by GNSS is required for AMG without additional staking or survey control.

In November 2016, Caltrans used AMG for the Clark road (State Road 191) curve correction project. The project was conducted according to 5-1.24 "Construction Surveys", 5-1.25 "Automated Machine Guidance", and 5-1.26 "Grade Quality Control" specifications. The project was finished February 2018 and resulted in $140K and $108K savings in survey support and earthwork cost, respectively [15].

### 2.3.4.2 **e-Construction**

#### *2.3.4.2.1 Digital Signatures*

After a contract is executed, any additional signed documents are completed with wet signatures. For some documents used in Caltrans, Adobe digital signatures may be available.

#### *2.3.4.2.2 Mobile Digital Devices*

From discussions with Caltrans it was found that half of construction field staff, resident engineers, inspectors, and senior engineers are using iPads. The material technicians and surveyors do not use iPads. Caltrans currently has 1,000 iPads for construction staff and the goal for next year is 100% deployment of iPads.

Caltrans primarily uses iPads for 2D PDFs of plans and cross sections, daily reports, inspection reports, communication, and taking photos and/or videos. Office 365 is on the iPads, and, although iPads have the capability to handle 3D models, Caltrans is not currenlty using this 3D capability.

Caltrans has recently conducted an internal survey about the use of their iPads. The resulting data showed that using the iPads resulted in an estimated $2,100 per year savings per inspector, due to reducing the need to drive to the field office. Additional savings of $280, per inspector per year, are also estimated, from the reduction in the amount of printing needed [16].

#### *2.3.4.2.3 Electronic Document Management System (EDMS)*

Caltrans uses, or has tested, a number of options for EDMS. Structures design uses Falcon/DMS for document management [17], and construction has tested ProjectWise, which is the Bentley software for document retention and management. Interviews and surveys with Caltrans personnel revealed that a

Windows file system is also used; construction is considering the use of Falcon; and construction uses FileMaker Go and Office 365 on their iPads. Caltrans also currently has an EDMS steering committee that is trying to support the selection of an enterprise EDMS software for Caltrans. A summary of the document management tools are shown in Table 2.9.

**Table 2.9 Summary of Caltrans Document Management Tools**

| Software/Tools | Application |
|---|---|
| Falcon DMS [17] | Piloting for Document Management |
| ProjectWise [18] | Tested for document management, and not currently in use |
| e-Builder | Used by one project in D4 (San Mateo 101) for project management |

### *2.3.4.2.4 Bidding & Contract Administration*

From personal communications, Bid Express is used to sign and seal initial bid contracts while AASHTOWare preconstruction is used for bid estimates. The bidding system for Caltrans is being upgraded to AASHTOWare Bids [19]. A summary of Caltrans e-Construction tools is given in Table 2.10.

**Table 2.10: Caltrans Bidding & Contracts Software**

| Area | Software/Tools | Application |
|---|---|---|
| Bidding and Contracts | AASHTOWare Preconstruction [based on personal communications] | Bid estimate and pre-construction |
| | AASHTOWare Bids [19] | Bidding |
| | Bid Express (run by Infotech) | Signing and sealing contracts |

For electronic submittal and administration of contractor claims, Caltrans has developed an application and conducted 20 pilot projects [20]. Caltrans also has a billing system to pay contractors [21]. Local program accounting (LPA) process invoices and local agencies were able to view their invoices at Vendor Payment History website, but it is currently undergoing digital accessibility upgrades.

### *2.3.4.2.5 Intelligent Compaction*

Caltrans recently added Intelligent Compaction (IC) to the specifications using an integrated management system based on GPS to make sure roller/inspectors cover the whole surface [21]. Caltrans also uses an inertial profiler, to get the profile of the road, based on the suspension of the car [21].

#### 2.3.4.3 **Training**

For GNSS inspection of projects, there is a new just-in-time training program and there are on-demand videos being developed for the future.

#### 2.3.4.4 **As-Built Documents/Data**

Caltrans has acknowledged the importance of as-built plans and reaffirmed such in a 2006 memo. The memo states: "It is imperative that the California Department of Transportation (Department) maintains complete and accurate contract records, including as-Built plans, to assist in the development of future projects… [22]."

Based on interviews with the Caltrans panel members, the typical workflow at Caltrans is to redline paper plans and have the districts or the Division of Engineering Service (DES) update the plans based on the redlines. The as-builts are created based on point checks by field personnel and are not typically based on surveys of completed projects. As-built data is stored in a number of locations, including the Caltrans Document Retrieval System (DRS) [23]. The Caltrans maintenance crews do not use the as-built data for regular activities. The contractors do not generally provide as-built data to Caltrans.

## 2.3.5 Maintenance, Operations, & Asset Mgmt.

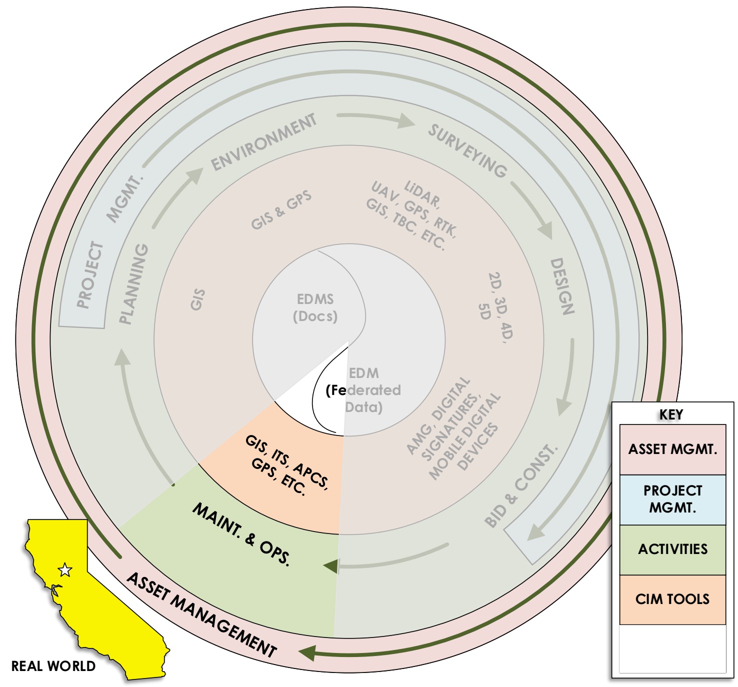


**Figure 2.24 Maintenance, Operations, and Asset Management Portion of VDC/CIM**

This section will discuss some specific VDC/CIM tools and their applications currently at Caltrans as it relates to maintenance, operations, and asset management as shown in Figure 2.24. Information in this section comes from interviews with Caltrans and their subject matter experts. Information from other sources is also included in this section where cited.

### 2.3.5.1 **Asset Management**

Asset management utilizes information generated by many different sources (or programs) within Caltrans (Pavements, APCS, Surveying, Bridges, etc.) for the purpose of analyzing what work will be needed on the assets. The data is not owned by asset management, and the various programs are responsible for ensuring the data quality and deciding how best to collect the data. The Transportation Asset Management Plan (TAMP) produced by Caltrans includes information on the National Highway System (NHS) for pavement and bridges as well as the State Highway System (SHS) pavement, bridges, drainage, TMS, and supplementary assets [24]. California has 10-year performance targets for key assets [24].

A new platform called TAMS is currently being developed as a performance management system designed to optimize decision making. TAMS is not just a work management system. TAMS will not replace existing asset systems, but will integrate information from them as well as from geospatial relations, corporate data sets (i.e. traffic volumes, etc.), financial data, and more. A high-level depiction of TAMS is shown in Figure 2.25. The TAMS system will allow for a more complete look at the whole Caltrans network in order to guarantee future performance. Some of this data will be available to Caltrans internally.

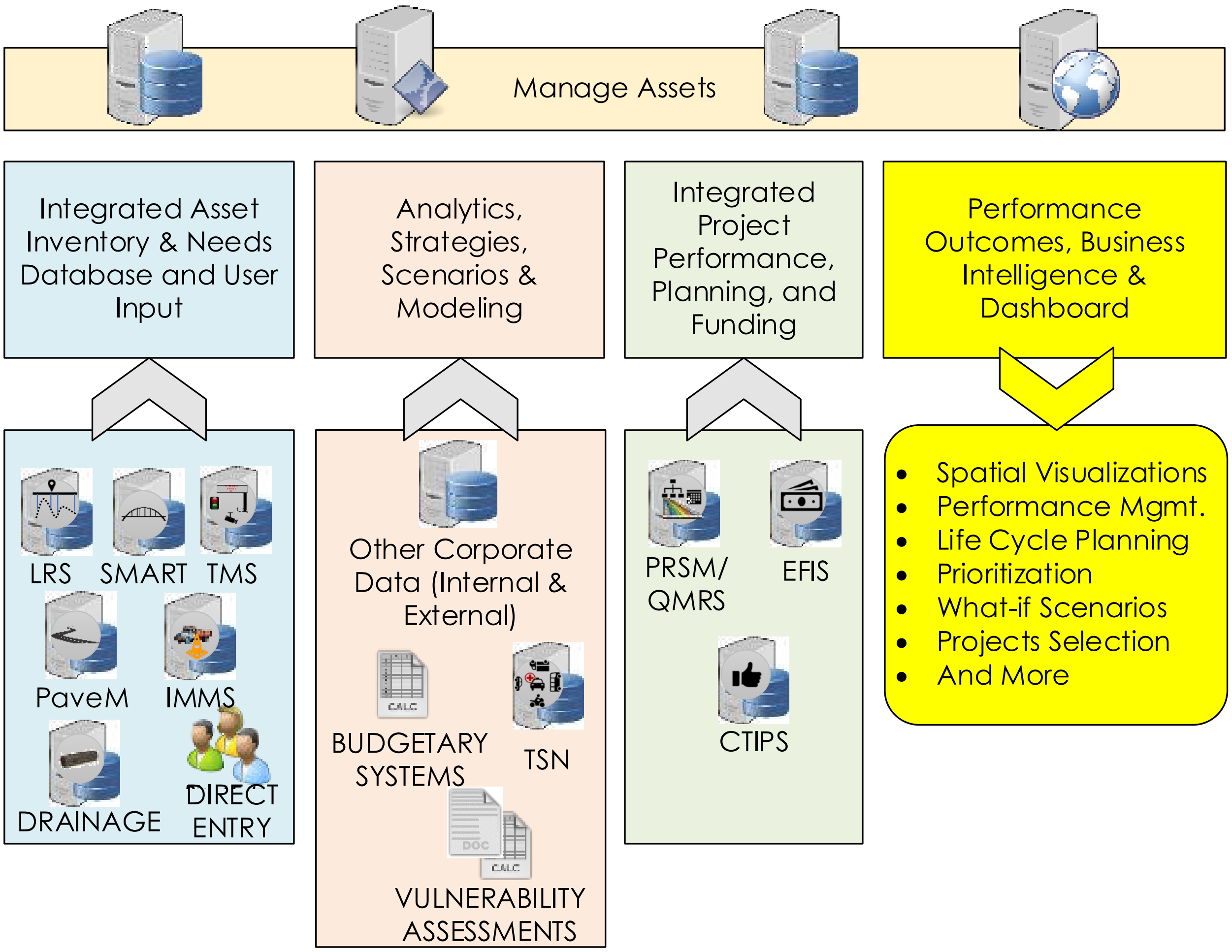


**Figure 2.25 TAMS System Adapted from [25]**

### 2.3.5.2 Asset Data Collection

Caltrans programs collect asset data about pavement, bridges, drainage, TMS, and other supplementary assets. In addition to this information, the Caltrans Division of Maintenance is actively pursuing an asset collection survey contract to "develop a statewide inventory, and an associated geodatabase of Signs, Barriers, Guardrails, Crash Cushions, End Treatment, Pedestrian Facilities and Bicycle Facilities [26]." This will cover approximately 15,311 centerline miles and the data will include [26]:

Street Imagery

Point Clouds

Roadway assets inventory

Web interface for viewing and editing the data

When this data collection is completed there will be a need for a data repository and data management processes. Capturing 3D digital as-built records is vital to achieving automation in highway construction. Caltrans is currently conducting a preliminary investigation about data collection, extraction and management. The principal idea is to collect data once, and use many times.

PaveM, which is the hallmark system for pavement management, is one source of data for asset management. Communications with Caltrans have indicated that PaveM requires significant amounts of manual labor to extract pavement related data from as-built records.

#### 2.3.5.3 Maintenance

As discussed in 2.3.5.1, a number of data repositories exist and each is owned by the various programs (i.e. Pavements, APCS, Surveying, Bridges, etc.). Caltrans is not currently conducting Photolog to capture images, but there exists a large inventory of data over approximately the past 50 years. The Integrated Maintenance Management System (IMMS) is used to record and report maintenance activities. Information from IMMS can be shared with others if they ask for specific items.

The main method used for maintenance to provide information to project delivery is through the design for maintenance/safety review. At the 60% and 95% review, maintenance can add their perspective to projects being developed.

## 2.3.6 *Project Management*

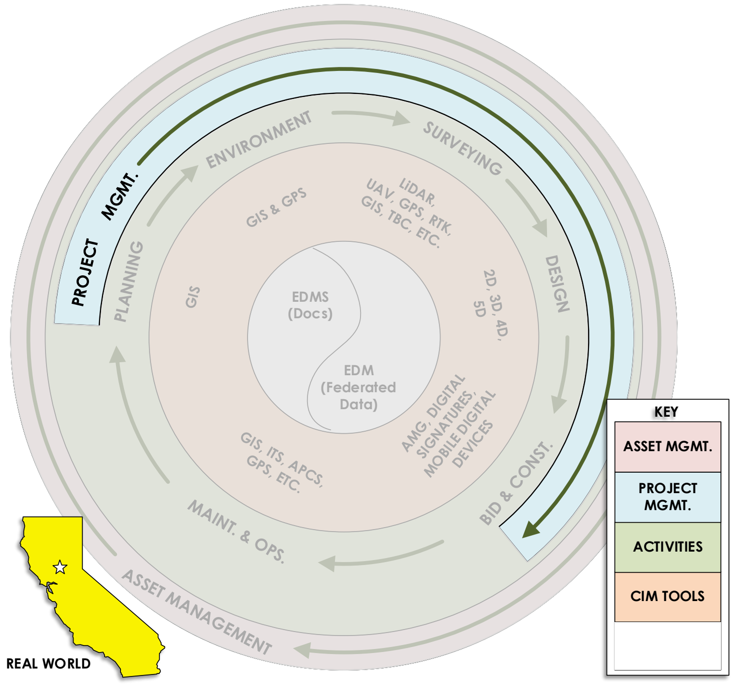


**Figure 2.26 Project Management portion of VDC/CIM**

This section will discuss some specific VDC/CIM tools and their applications currently at Caltrans as it relates to project management as shown in Figure 2.26. Information in this section comes from interviews with Caltrans and their subject-matter experts. Information from other sources is also included in this section where cited.

Caltrans Division of Project Management is focused on resource management and not on the details of how a project is completed. The official tool used is Project Resourcing and Schedule Management (PRSM), which has been in use since 2014 [27]. PRSM is Commercial-Off-The-Shelf (COTS) software and a well-established project management system for approximately 3,000 Caltrans users [27], [28]. Although Caltrans was originally not using PRSM for scheduling [27], they report that PRSM is now the official scheduling tool. Primavera is not considered a standard software, but may be used by some districts. The CA PPM (previously named CA Clarity) is the core of PRSM, however, Caltrans is using an outdated version of CA PPM [27]. The agency is working on upgrading to the current version [27] and is working on different elements of automation for the consultant contracts and invoicing [29]. A second software, developed in-house by Caltrans, known as VISION, exists that can be used by task managers to generate input for PRSM. Caltrans use of PRSM is summarized in Table 2.11.

**Table 2.11: Caltrans Project management tools from [27] and personal communications**

| Tools | Application | Comment |
|---|---|---|
| **Oracle Primavera** | Project Scheduling | Used by some districts |
| **PRSM / CA PPM** | Project resourcing | Since 2014 |
| | Annual budgeting | 3000 users |
| | Scheduling | |

## 2.3.7 Electronic Data Management (EDM)

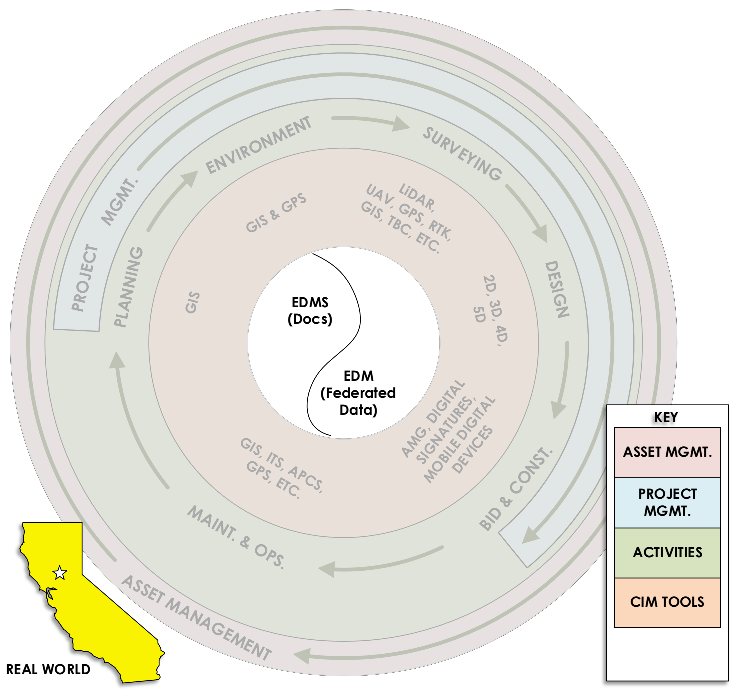


**Figure 2.27 Data Management portion of VDC/CIM**

This section will discuss some specific VDC/CIM tools and their applications currently at Caltrans as it relates to electronic data management as shown in Figure 2.27. Information in this section comes from interviews with Caltrans and their subject matter experts. Information from other sources is also included in this section where cited.

Since Civil Integrated Management (CIM) is a data centric topic, an understanding of data flows within the organization is helpful. A significant number of databases were identified and a map was generated to show how these fit together as shown in Appendix B.

Related to data and document management, Caltrans has a number of efforts under way. Some of Caltrans efforts are highlighted here. There is an enterprise data governance effort currently in progress, which has drafted a data quality management plan. The Electronic Document Management System (EDMS) steering committee is facilitating the implementation of an enterprise EDMS. Asset management is pursuing building a new system, known as TAMS, which will integrate many high-level data sets and be an authoritative source of information. The Division of Project Management also has its own data governance effort underway.

At a very high level, data flows in Caltrans can be summarized as follows:

- Asset Management shares with Planning & Programming;
- Survey generates terrain models that are shared with Design;
- Design uses survey models to make roadway surfaces that are also used by hydraulics. Design also shares data with Division of Engineering Services, Environmental and Right of Way. Plan Specifications and Estimate (PS&E) are given to the Office of Engineering;
- Construction typically transfers official records via paper copy;
- Districts have server space they use for GIS, and data can be published to share with ArcGIS Online and the portal;
- QMRS is available online to share project assignment data, budgets schedules, and project scope.

### *2.3.8 Other Caltrans Areas*

This section contains other items that do not directly fit into one of the above discussed categories or tools that are in broader usage within Caltrans. Information in this section comes from interviews with Caltrans and their subject matter experts. Information from other sources is also included in this section where cited.

#### 2.3.8.1 **Construction Manager/General contractor (CM/GC)**

In 2012, Caltrans was authorized to use CM/GC on six pilot programs [30]. Based on personal communication, Caltrans was given general authority to use GM/GC on projects over $10 million in 2018, and currently 13 CM/GC projects are ongoing. Caltrans prefers to get a CM/CG contractor involved during the environmental phase, but 30% design has also been done. The contractor acts in an advisory role and the goal is to create cost savings for Caltrans. The CM/GC Contractor provides a bid to Caltrans, and if the price is acceptable, then the CM/GC contractor will be the general contractor to construct the project [30], [31]. Caltrans reported that they anticipate 12 projects per year can be successfully procured; so far the 10% savings goal has been exceeded.

#### 2.3.8.2 **Connected Vehicles**

Caltrans reports that connected vehicle technologies are an area of ongoing research which includes vehicle-to-infrastructure technology. District 11 and 12 plan to install over 100 roadside units to transmit information to vehicles. EDGE computing is being considered in order to keep lag times low and to not overwhelm the backhaul of the network.

#### 2.3.8.3 **Collaboration**

Caltrans has a Project Delivery Team (PDT) that meets during project development, though some interview participants noted that it may not always be fully effective. With a goal of improving the PDT, Caltrans hosted a summit on the PDT effectiveness in 2016 [32]. At the summit, districts 1-12, DES (north & south) and HQ worked on posters to enhance the PDT [32].

Between project delivery and maintenance and operations there exists an opportunity for more integration. Maintenance can provide input at the 60% design and the 95% design stage. From discussions with Caltrans, it seems that one limiting factor in more collaboration between maintenance and project delivery is time and resources. This lack of collaboration leads to some groups on the maintenance side having to input a lot of information manually (such as for the PaveM database).

#### 2.3.8.4 **GIS**

Caltrans has an ESRI GIS system. Data generally does not transition from one stage of the lifecycle to the next, which may result in data being created and recreated. It was also noted that naming conventions and attributes are not standardized, and that can create difficulties in trying to locate information. Voyager search is being implemented now to help with data searches. A tool called 1Integrate from 1Spatial is being used to find errors in data.

A GIS tool called Plans on Demand (PoD[2]) provides geo-referenced right-of-way maps to Caltrans and eventually the public. The PoD project is similar to the system Arizona DOT and others use. Caltrans received funding for this project through an FHWA innovation grant.

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[2] Plans On Demand (http://aii.transportation.org/Pages/Plans-on-Demand.aspx)

#### 2.3.8.5 **ITS Elements**

Interviews about ITS elements found that these systems are referenced using the LRS system and there is an internal GIS dataset. Work is currently ongoing to define the lifecycle of the ITS elements.

# CHAPTER 3: Assessing the State of the Art and the Literature Review of VDC/CIM in Transportation (Task 2)

The primary purpose of task 2 is to evaluate the known best practices in VDC and CIM. The definition of "Virtual Design and Construction (VDC) is the use of integrated multi-disciplinary performance models of design-construction projects to support explicit and public business objectives [33]." The definition of Civil Integrated Management (CIM) "is the collection, organization, and managed accessibility to accurate data and information related to a highway facility [34]." The significance of VDC/CIM is reinforced by its inclusion in the strategic Every Day Counts (EDC) initiative coordinated by the Federal Highway Administration (FHWA) and the American Association of State Highway Transportation Officials (AASHTO) [1]. VDC/CIM is a very broad topic; therefore, to complete this task, many existing resources were leveraged, and relevant literature was reviewed.

Federal resources about this topic are very broad and include a wealth of information. NCHRP report 831 includes a description of VDC/CIM, discusses many CIM tools, shows how VDC/CIM can impact a DOT, and includes a maturity assessment matrix [5]. The EDC initiative (started in 2011) encompasses numerous webinars and reports covering topics, including 3D models, intelligent compaction, 4D/5D modeling, e-construction, and more [1]. It is noted here that e-construction itself is a broad field, covering tools such as digital signatures, mobile digital devices, Radio Frequency Identification (RFID), and others.

Other resources considered include reports from individual states, academic articles, research efforts, and webinars. In addition to the publicly available sources, a representative sample of consultants and contractors were interviewed to provide further details about the state of the art from an industry perspective.

In addition to VDC/CIM specific resources, resources from another closely related field known as BIM (from the vertical construction industry) have been considered. The concept of BIM and VDC/CIM are so closely related that there is even some debate about changing the name of CIM to BIM for infrastructure.

Related to VDC/CIM or BIM implementation, there is an FHWA effort regarding BIM for infrastructure called "Advancing the Development and Deployment of BIM Infrastructure [35]." Caltrans and FHWA have also recently hosted a Digital Construction Inspection workshop [36].

# 3.1 ISO Framework

Before considering the many technological tools that can be applied as part of VDC/CIM, organization of projects will be considered. In order to ensure that VDC/CIM tools are applied in an integrated way, an overall plan should be generated for the project. One resource to guide planning for a VDC/CIM project comes from the BIM field and is part of the ISO standards.

The International Organization for Standardization (ISO) has a set of standards that they say are applicable to civil infrastructure. The main ISO standard for BIM is 19650-1:2018 [37]. In this standard several important documents are defined that can serve to guide information and data management throughout a projects lifecycle. These documents include [37]:

- *Organizational Information Requirements (**OIR**): "Information needed to answer or inform high-level strategic objectives."*
- *Asset Information Requirements (**AIR**): "managerial, commercial and technical aspects of producing asset information."*
- *Project Information Requirements (**PIR**): "information needed to answer or inform high-level strategic objectives… in relation to a particular built asset."*
- *Exchange Information Requirements (**EIR**): "managerial, commercial and technical aspects of producing project information… include the information standard… and procedures."*
- *Asset Information Model (**AIM**): "supports the strategic and day-to-day asset management processes"*
- *Project Information Model (**PIM**): "supports the delivery of the project and contributes to the AIM to support asset management activities."*

The above documents serve to clearly identify types of information needed, who is designated to provide it, how will it be shared, and what details will be included.

## *3.1.1 Information Handling*

A federated strategy for handling information can be designed to "explain how the information model is intended to be divided" as well as "explain the methodology to manage interfaces associated with the asset during its delivery phase or operation phase [37]." A Common Data Environment (CDE) also needs to be defined as a standard to ensure everyone who needs data can access it [37]. A CDE may make use of LandXML, Industry Foundation Classes (IFC), or some proprietary software. The IFC standard is vendor-neutral and is an open international standard being used in the vertical industry to describe built assets [38]. An example of a CDE concept is shown in Figure 3.1.

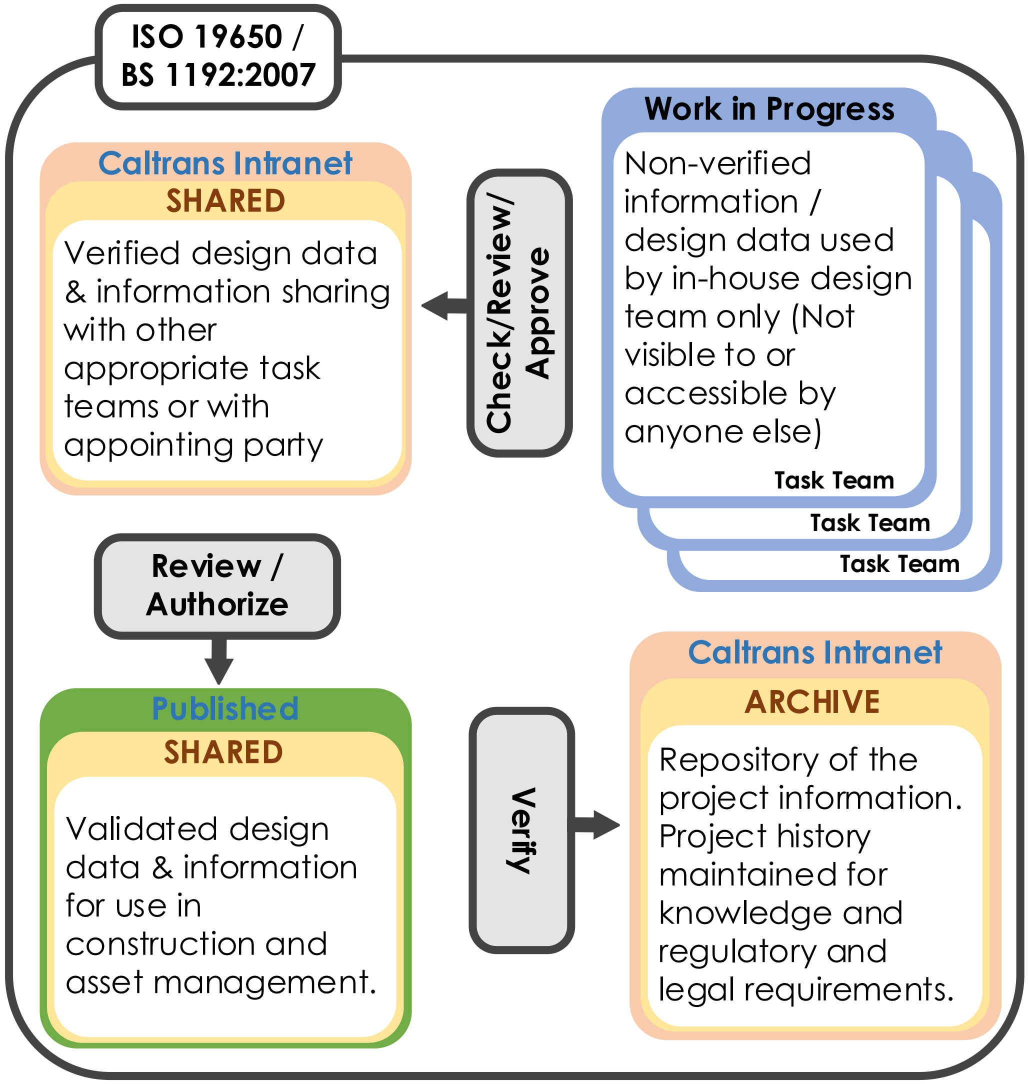


**Figure 3.1 Common Data Exchange Concept adapted from [37], [39]**

Early in the planning stage of the project, the ISO defined Level of Information Need (LIN) is also important. The LIN dictates how much information is required and is similar to the Level of Development and Level of Detail [40]. This may be part of the AIR, EIR, PIR, or OIR.

Following this ISO process may help avoid loss of information value when making the transition between stages in the project lifecycle.

### *3.1.2 Roles and Responsibilities*

As part of the ISO 19650 standards, a need is also identified for Information Delivery Planning (IDP) to decide who is responsible for delivering what, and when. The IDP should answer how to meet the AIR and EIR requirements. As part of the IDP, a responsibility matrix may be created [37]. The stakeholders who will be part of the project need to be considered. The team typically consists of an "appointed party" who provides the information, an "appointing party" who receives the information (such as the project owner), and a "delivery team" which may be a complex organization like Caltrans. The roles and responsibilities need to be assigned appropriately given the organization and the projects.

## 3.2 BIM Execution Plans

The above ISO standards are the framework that standardize the language and methods used for a BIM execution plan. When the ISO standards are applied to a real world project, a BIM execution plan can be developed. Penn State University has a BIM Project Execution Planning Guide that can serve as a template for BIM execution plans [41]. Some of the items in the BIM execution plan include process maps, information exchange, and project execution plan [41]. It is noted that the Penn State guide is focused on the vertical building industry and as such may need some modification for the horizontal industry and customization for Caltrans. The exact modifications required, and the extent of the modifications require an experienced subject matter expert and may change between projects depending on the specific needs of Caltrans.

## 3.3 High Level Summary

After considering the project level planning, the individual VDC/CIM tools can now be considered. To determine what CIM technologies State Transportation Agencies (STAs) are using, Sankaran et al. conducted a survey. If the STA had used CIM technologies, according to NCHRP 831 [42], on two or more projects, a value of "1" was assigned to the technology for the STA. If the STA had either experimented with the relevant tool once (piloting) or had not used it, a value of "0" was assigned [43]. Based on the list of CIM technologies [42], a CIM usage score for each STA could vary from 1 (only use 2D mapping) to 19 (full CIM use) [43]. Delaware used many advanced sensing tools (IC, AMG, and GPS, among others) but few data management tools [43]. Nevada used many data management tools (such as mobile digital devices, digital signatures, and electronic as-built management) but few sensing ones [43]. Iowa, Georgia, and California reported that they had adopted all the sensing technologies and some data management one (e.g., electronic updating of plans, mobile digital devices, and digital signatures) [43]. Virginia and Washington reported deploying data management tools while having experimented with the prominent sensing tools (GPS, GIS, ITS, and AMG) [43]. Wisconsin, New York, and Florida reported expertise in using 3D, 4D, and 5D processes for project delivery [43].

## 3.4 VDC/CIM Component Technologies

This section will now look at what others are doing with VDC/CIM tools as they apply to specific areas.

## 3.4.1 Environmental Analysis

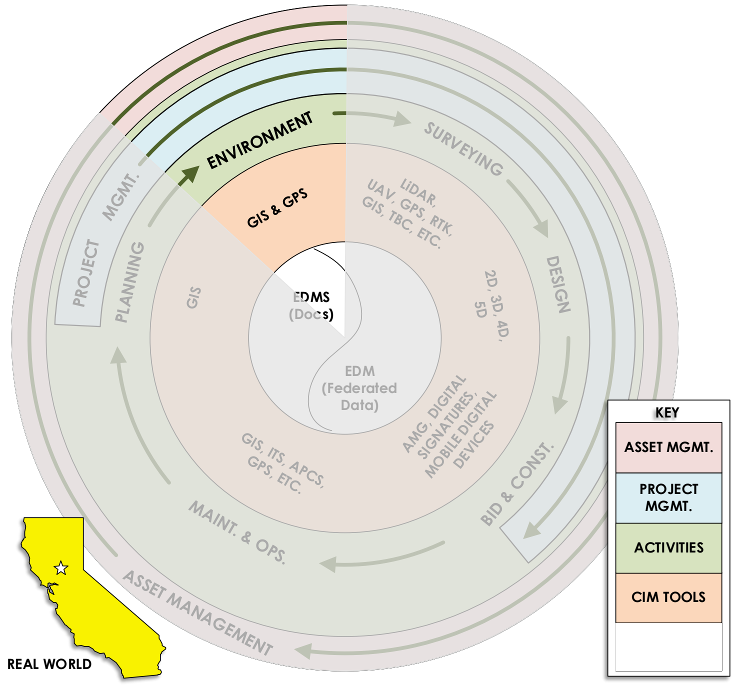


**Figure 3.2 Environmental Portion of VDC/CIM**

This section will discuss some specific VDC/CIM tools and their applications found during a search of the literature as they relate to environmental analysis as shown in Figure 3.2.

Virginia uses the CEDAR system which combines spatial and non-spatial data. It is an internal web-based tool and it synchronizes nightly with the project pool [44]. PennDOT has a screening tool implemented in 2011 that checks over 30 GIS layers. Data can be added at any phase of the planning stage [45]. South Carolina has a Project Screening Tool that is used in early stage planning [45]. Tennessee DOT has the Statewide Environmental Management System which is web-based and uses GIS [46].

# 3.4.2 Surveying

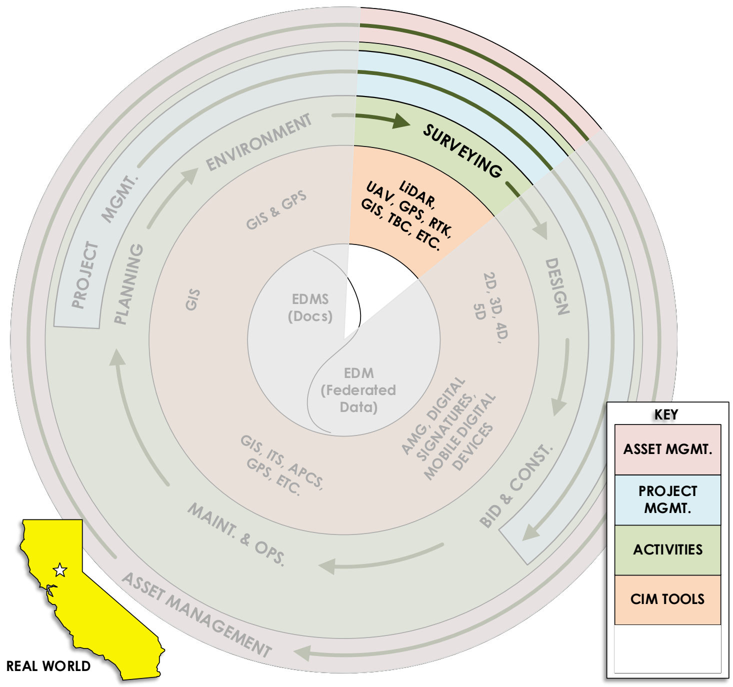


**Figure 3.3 Survey Portion of VDC/CIM**

This section will discuss some specific VDC/CIM tools and their applications found during a search of the literature as they relate to surveying as shown in Figure 3.3.

## 3.4.2.1 **Automation & Robotics**

Robotics may not be commonly used in construction projects, however, there are projects where robotics (especially the robotic total station) could be helpful [47]. Bock (2007) gave a brief overview of using robotics efficiently [48], for example, a surveying robot can provide real-time position of a tunnel boring machine [47]. Robotic total station can also be used to guide AMG for high precision [49].

## 3.4.2.2 **LiDAR Mobile Mapping**

The integration of Mobile Terrestrial LiDAR Scanning (MTLS) technology is valuable for transportation agencies looking to increase efficiency. LiDAR technology uses laser scanners to collect geospatial data that results in high accuracy point clouds used in virtual design and construction (VDC) [50]. It revolutionizes the traditional survey, design and engineering practices [51].

ODOT started using LiDAR in 2011; however, it was used mainly for resource mapping, not for engineering design, due to low accuracy [47]. In 2015 ODOT upgraded their LiDAR with Leica Pegasus, which integrates vehicle mounted laser scanners with GPS, DMI, and IMU [47]. Sillars, et al. (2017) conducted a study using information from pilot projects at Oregon Department of Transportation (ODOT) and other DOTs regarding return of investment (ROI) for the advanced technology initiative [47]. The results of the study show mobile mapping caused an ROI of almost 300% for ODOT [47].

Mobil Terrestrial LiDAR (MTLS) could help DOTs to save time on data collection with acceptable accuracy. Minnesota Department of Transportation (MnDOT) with the help of Continental Mapping Consultants used MTLS on the Minnesota Highway reconstruction project [52]. The Minnesota Highway reconstruction project data was collected within six weeks and achieved a 1 cm vertical accuracy (at 1 Sigma) [52]. More details about what other states use compared to Caltrans will be discussed in Chapter 4.

#### 3.4.2.3 **Drones/UAV/UAS**

Drones, Unmanned Aerial Vehicles (UAVs), and Unmanned Aerial Systems (UAS) are terms that are generally used interchangeably. Due to lower initial cost and ability to access hard-to-reach locations, there is high demand for using Unmanned Aerial Vehicles (UAVs). This is evidenced by a recent survey conducted by Association of State Highway Transportation Officials (AASHTO) [53]. Drones can access hard-to-reach locations, which can supplement conventional activities, such as bridge safety inspection [54].

Drones have started to be used by many organizations for many purposes. The March 2018 survey conducted by AASHTO found that 20 state DOTs - Alaska, Arizona, Colorado, Delaware, Georgia, Iowa, Maine, Mississippi, Montana, Nebraska, Nevada, New Jersey, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, Tennessee, Utah, and West Virginia - have incorporated drones into their daily operations and 15 state DOTs - Alabama, Connecticut, Idaho, Illinois, Indiana, Kansas, Kentucky, Louisiana, Massachusetts, Michigan, Minnesota, New Hampshire, South Carolina, Texas, and Virginia - are in the research phase - testing drones to determine how they can be utilized [55]. Drones can also be used for aerial imagery data [56], although the Federal Aviation Administration (FAA) must approve all drone testing [53].

The following are examples of different state transportation agencies' drone deployments. Minnesota uses UAVs for bridge inspection [54] while Washington has evaluated UAV applications in aerial roadway surveillance [54]. North Carolina, New Jersey, and Ohio are using UAVs in construction inspection and real-time monitoring, traffic incident management, aerial 3D corridor mapping, emergency response assessments, and traffic congestion assessments [54]. Utah has used UAVs for rapid, high-quality data acquisition from surveys to routine inspections [54]. Colorado is using UAVs to monitor geo-hazards in more than 40 mountainous corridors with highly accurate data collection [54]. MDOT has used drones instead of humans to inspect dangerous locations, bridges, and other construction projects [56], [57]. Oregon DOT has a drone-usage policy and has 20 ODOT employees certified to fly their drone systems [58]. A summary of some drone uses are shown in Table 3.1.

**Table 3.1: Drones application in other DOTs**

| DOT | Drone Application |
|---|---|
| **MnDOT** | Bridge inspection [59] |
| **WSDOT** | Aerial roadway surveillance [59] |
| **NCDOT** | Construction inspections; Accident-scene reconstructions [59] |
| **NJDOT** | Structure inspection; Real-time project monitoring [59] |
| **ODOT** | Bridge inspection [60], Traffic Monitoring; Emergency response operation [59] |
| **UDOT** | High-speed data acquisition [59] Sign inspection and LiDAR [61] |
| **CDOT** | Monitor Geo Hazards [59] |

A case study, based on ODOT using UAVs for bridge inspections, showed an average cost of $73,800 without UAV systems and a potential savings of approximately $10,000 if a UAV is used [60]. Dorsey claimed a normal bridge deck inspection which takes hours with heavy equipment, can be done in 2 hours which results to over $4000 cost saving [53].

## *3.4.3 Design*

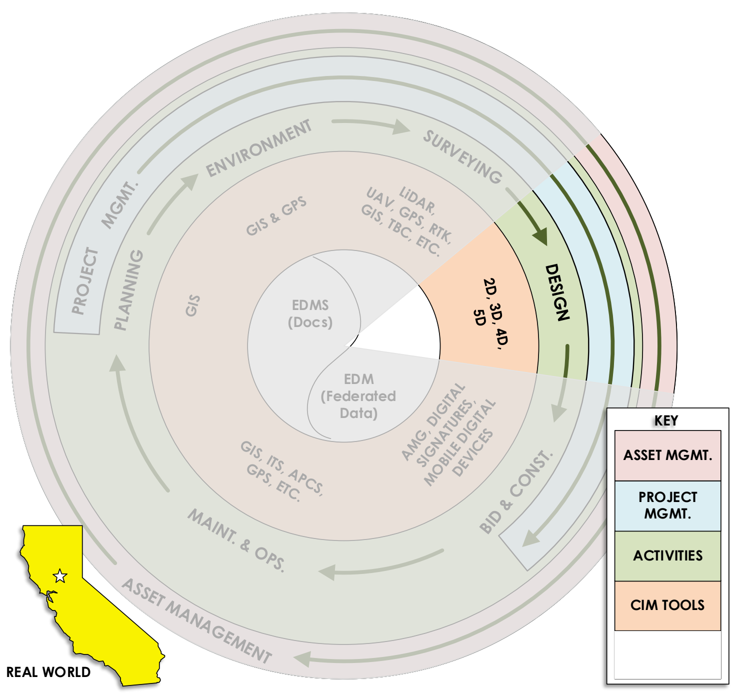


**Figure 3.4 Design Portion of VDC/CIM**

This section will discuss some specific VDC/CIM tools and their applications found during a search of the literature as they relate to design as shown in Figure 3.4.

### 3.4.3.1 **2D/3D/4D/5D Modeling**

A number of DOT's and other entities in the transportation sector have used the 3D model as the legal document in at least a pilot project including: Utah DOT, Iowa DOT, and Illinois Tollway [62]. The 3D implementation initiative from Utah is publicly available [63]. Kentucky has also modified its specifications to give the 3D model precedent over the 2D plans [64].

Related to releasing 3D models, a QA/QC process is needed. Michigan has in house QC process for its models [65] which it applies before releasing them[3].

In addition to 3D modeling, several DOT's have also used 4D modeling for design-bid-build projects. CTDOT used a consultant generated 4D model for risk management and included it during contract advertising for information only [66]. RIDOT has also used consultant generated 4D models [67].

In general, a study of DOT's, commissioned by Caltrans about 3D/4D/5D, found a number of positive outcomes, including time and cost savings [68]. More details about what other states use, compared to Caltrans, will be discussed in Chapter 4.

### 3.4.3.2 **SUE Tools**

On the Birmingham CBD interstate project a 3D model was created that included all of the subsurface utilities [69]. Alabama DOT used a consultant with GPR, Conductive Coupling, Test Holes, and Conventional Survey to create a full 3D model of the utilities for the CBD Interstate Project [70]. Virginia uses GPS/RFID to tag new and existing utilities, while Michigan documented the utilities by conducting high accurate surveying during installation [71]. ASCE has a guideline for utility data that defines accuracy requirements, data exchange, and more [72]. The FHWA has documented federal laws and guidelines related to utilities and noted that utilities pose a unique challenge, since they are not owned by the highway agencies [73]

### 3.4.3.3 **Constructability Review**

Constructability review is a form of collaboration. MDOT is using Bluebeam PDF software along with ProjectWise Milestone to collaborate on reviews. This workflow was developed as part of the AASHTO Project PS&E C-Rev [74]. Bluebeam allows a project to be worked on in real-time by multiple users simultaneously while viewing each other's comments [74]. The Idaho

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[3] As per conversation with Fair Cape Consulting

Transportation Department has started using a PDF viewer as a platform for plan reviews, comments, and revisions, rather than using email to view and approve the documents [20].

## *3.4.4 Bidding & Construction*

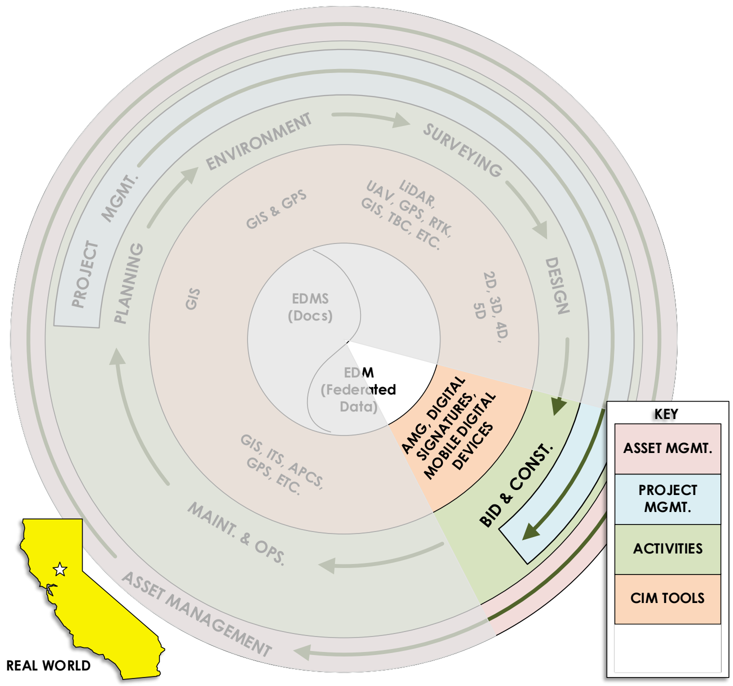


**Figure 3.5 Bidding and Construction portion of VDC/CIM**

This section will discuss some specific VDC/CIM tools and their applications found during a search of the literature as they relate to bidding and construction as shown in Figure 3.5.

### 3.4.4.1 **Automated Machine Guidance (AMG)**

AMG integrates construction machinery with GPS and uses 3D engineering models[75]. AMG can increase productivity, improve accuracy, and has been shown to save time by 50% and 75% respectively [76], [77]. Florida Department of Transportation (FDOT) saved over $350,000 by using AMG on a 4.1-mile addition of four lanes to a highway [76]. Arizona DOT (ADOT) has produced computer-aided design documents for users of various design software products and has discovered the file formats that work best for contractors for machine guidance and survey layout [20]. One study showed that ODOT benefited by millions of dollars through their deployment of AMG and 3D engineering models [47]. More details about what other states use, compared to Caltrans, will be discussed in Chapter 4.

## 3.4.4.2 e-Construction

The concept of e-Construction is defined as the creation, review, approval, distribution, and storage of highway construction documents in a paperless environment [20]. In the case of MDOT, e-construction techniques have saved roughly $12 million "in paper (7 million pieces), postage, envelopes, and storage [78]". One study also showed that ODOT gained large quantifiable benefits from using e-Construction and Electronic Document Management [47].

Summary data about the implementation of e-Construction and partnering across many different states can be seen in Figure 3.6 from [20].

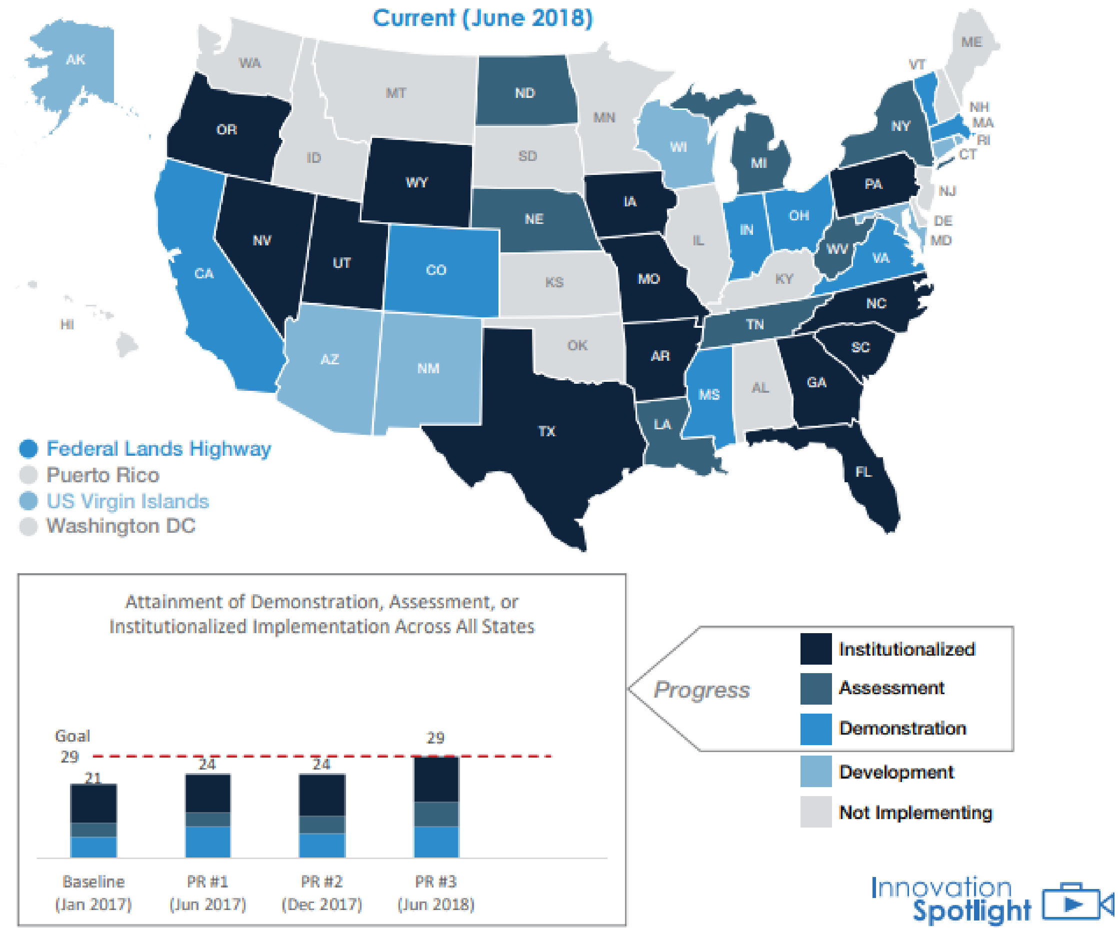


**Figure 3.6: e-Construction & partnering Implementation across the U.S [20]**

### *3.4.4.2.1 Digital Signatures*

Digital Signatures are a component of e-Construction that allow different stakeholders to verify their identity, sign, and seal the digital documents [47]. ODOT uses DocuSign CoSign (formerly ARX CoSign [79]) for its digital signatures. MDOT has integrated digital signatures with its document management system and mobile devices as can be seen in a demonstration video[4]. More details about what other states use, compared to Caltrans, will be discussed in Chapter 4.

### 3.4.4.2.2 Mobile Digital Devices

Mobile devices have been discussed in the EDC-3 initiative [21]. Arkansas DOT (ArDOT) and Delaware DOT (DelDOT) construction inspectors use mobile devices in their daily reports [20]. Similarly, RIDOT is using tablets in the field to collect information and create daily activity reports on seven pilot construction projects including new bridge construction, bridge replacements, roadway drainage and paving, and guardrail installation [20]. Iowa uses their mobile devices with Esri products to capture as-built data for some items during construction [80]. PennDOT uses a GeoSnap application which allows field personnel to take photos combined with geospatial coordinates that can be linked in to their GIS system [81].

Florida, Iowa, and Michigan DOTs use Apple iPads, while Texas and Utah DOT use the Microsoft Surface Pro for their remote device to capture information [82]. Iowa DOT is using tablets (iPad Gen4/Air2) for culvert inspection with an ArcGIS collector app, and an external Bluetooth receiver [83].

Washington DOT (WSDOT), TxDOT, and MnDOT were part of the Headlight Project to pilot mobile devices and wireless connections for project inspection. The result of the pilot project showed that on average each inspector could collect 2.75 times more data while saving 1.78 hours per day [84]. More details about what other states use, compared to Caltrans, will be discussed in Chapter 4.

### 3.4.4.2.3 Electronic Document Management (EDMS)

EDMS is a platform for organizing documents in a paperless process. In Arkansas, all contracting system workflow is paperless and project staff and contractors are able to see the status of all submittals and approvals [20]. In a push to discourage paper, "FDOT updated specifications to remove language related to printing, paper, etc." [47]. The Idaho Transportation Department (ITD) uses project collaboration software that it shares with Local Highway Technical Assistance Council and local agencies for electronic document management on Federal-aid projects [20]. ODOT and MDOT use ProjectWise [85], for managing documents electronically in engineering, architectural, and construction projects [47]. ODOT utilizes SharePoint 2010 for document storage [21] and the GOFORMZ company to make digital tables and documents that users add data to [21]. TxDOT has used FileNet [86] and ProjectWise for

[4] Digital Signature Demonstration Video (https://www.youtube.com/watch?v=HAbYgqgnyB8)

document management [47]. More details about what other states use, compared to Caltrans, will be discussed in Chapter 4.

Related to paperless change orders and submittals, a number of electronic approaches have been used. Pennsylvania DOT (PennDOT) uses customized collaboration and document management software systems for contractors to submit documents to PennDOT electronically for review and approval [20]. The Kentucky Transportation Cabinet launched an all-electronic change order process and is implementing fully electronic funding authorizations [20]. Ohio DOT (ODOT) utilizes AASHTOware site manager for change orders and status updates of the documents [21].

The Oregon OTIA III State Bridge Program completed a cost benefit analysis on multiple tools [87]. They spent approximately $180K setting up ProjectWise for their electronic drawing system, and spent approximately $10,750 per year on license fees and staff hours [87]. They determined the electronic drawing system had a negative cost benefit ratio and discontinued its use, however, it was noted that this tool may be useful in the future [87].

#### *3.4.4.2.4 Bidding & Contract Administration*

Many states are using AASHTOWare products such as (BAMS/DDS, Expedite Bids, Preconstruction and Estimator) in the bidding system [17]. This suite of software can be licensed for $475,000 per year, with unlimited use under the AASHTOWare project site license, but some of the software also requires AASHTO membership [88].

For contract management, Table 3.2 includes brief case studies for various state DOTs.

**Table 3.2: Contract Management Systems**

| **Tools** | **State** | **COTS or In-House or Modified** | **Application/Comments** |
|---|---|---|---|
| **SharePoint Professional Services Contract** | KY [29] | Modified | Web-based customized Professional Services Contract application in SharePoint<br><br>Manage contract workflow<br><br>Allow users to centrally manage a database that includes advertisements, projects, contracts, production hour estimates and an associated project schedule timeline |

| Tools | State | COTS or In-House or Modified | Application/Comments |
|---|---|---|---|
| **SciQuest TCM** | UT [29], [89], [90] | COTS | In February 2017, "SciQuest" name changed to "Jagger"<br><br>TCM in Utah DAS is used for: Contract development, Review Rounds Process, eSignature Process, and Amendment Process |
| **P2S** | SC [29], [91] | In-House | Project Programming System (P2S)<br><br>Quick and reliable source to gather, maintain, and report project information from beginning to end for all agency users<br><br>Holds all funded projects and is a hub for multiple associated systems such as Site Manager, Primavera, Web Transport, etc. |

Table 3.3 includes brief case studies for invoice processing systems.

**Table 3.3: Invoice Processing Systems**

| Tools | State | COTS or In-House or Modified | Application/Comments |
|---|---|---|---|
| **CITS** | FL [29], [92] | In-House | Consultant Invoice Transmittal System (CITS) is a web-based application<br><br>CITS includes details about consultant contracts, invoices to review, invoices in progress and rejected invoices.<br><br>CITS interfaces with all in-house customized systems |
| **CMIS** | GA [29], [93], [94] | COTS | Contract Management information System (CMIS)<br>Web interface |

| Tools | State | COTS or In-House or Modified | Application/Comments |
|---|---|---|---|
| | | | Allows vendor to submit and track a submitted invoice for GDOT processing and comment on GDOT Vendor Evaluations<br><br>Perform a historical invoice search for your associated vendor profiles<br><br>Allows GDOT to review and approve invoices electronically Provides less administrative efforts & time savings |
| **OAKS** | OH [29] | In-House | Ohio Administrative Knowledge System (OAKS) includes finance, human capital management, enterprise performance management, enterprise learning management and customer relationship management modules<br><br>Ohio DOT uses several systems including Consultant service system/consultant evaluation system, Scope and SFE System, Ellis, and Excel. |
| **Other** | NV [29] | In-house | Upgrading its in-house system so as to:<br>Process internal electronic invoice approvals, generate payment vouchers, accept approvals of payment vouchers, and communicate within the financial system to make payments to consultants |

#### 3.4.4.3 **Training**

NYSDOT has yearly training for construction surveying, and a specification known as 625, that requires contractors to provide three days of training for GPS equipment that is supplied by contractors [95].

### 3.4.4.4 **As-built Documents/Data**

MnDOT and Iowa DOT capture as-built data for some items during construction [80]. MnDOT has a special provision for contractors to provide information to fill its GIS database, while Iowa uses mobile devices with Esri products to capture data in the filed [80]. Both Utah and New York require contractors to provide a 3D model as-built in terms of a LiDAR scan [96]. MDOT is looking at ways to replace the process of scanning 2D as-built files with electronic mark-ups [97]. In Michigan, the contractors are responsible for providing as-built for projects. Currently, contractors print the plan files, mark them up, then sends scans back to ProjectWise; however, some contractors may use other software. MDOT reviews files for general quality assurance (QA)/quality control (QC), mark as complete, and store in ProjectWise [97]. In Washington, the WSDOT staff manage as-built drawing by printing plans, marking them up, and scanning to the project file [97].

## *3.4.5 Maintenance, Operations, & Asset Mgmt.*

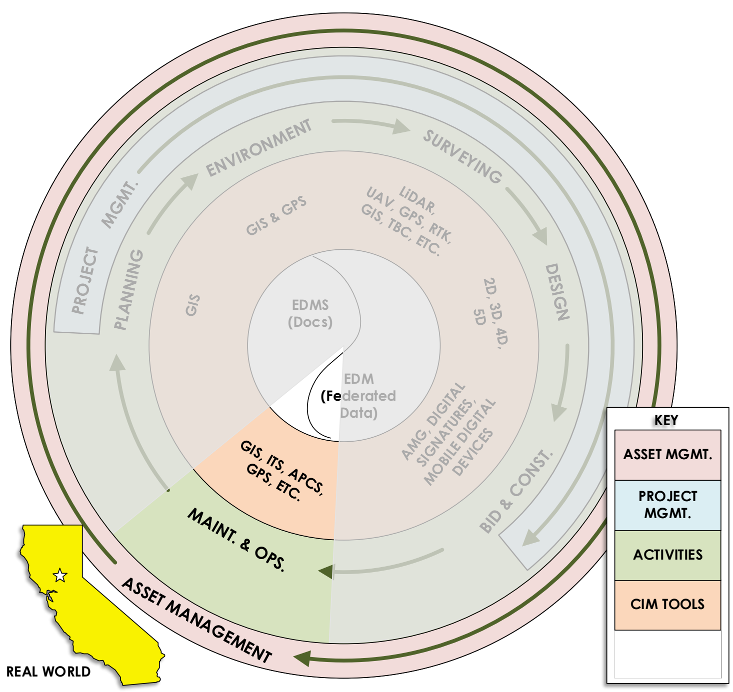


**Figure 3.7 Maintenance, Operations, and Asset Management Portion of VDC/CIM**

This section will discuss some specific VDC/CIM tools and their applications found during a search of the literature as they relate to maintenance, operations, and asset management, as shown in Figure 3.7.

## 3.4.5.1 **Asset Management and Data Collection**

Each state must have an asset management plan for the national highways [98]. The transportation asset management plan (TAMP) for Utah [99] categorizes assets in three tiers with tier one being the highest-value assets.

Practices related to data collection and organization vary between states. Each year, UDOT collects condition data of roadway assets [100]. Utah's asset data is organized, stored, and available via UDOT data Portal [101]. Oregon DOT recently created a new system called TransInfo that integrates many separate data sets [102] and FACS-STIP which is web-based and creates GIS maps with asset data [103].

# *3.4.6 Electronic Data Management (EDM)*

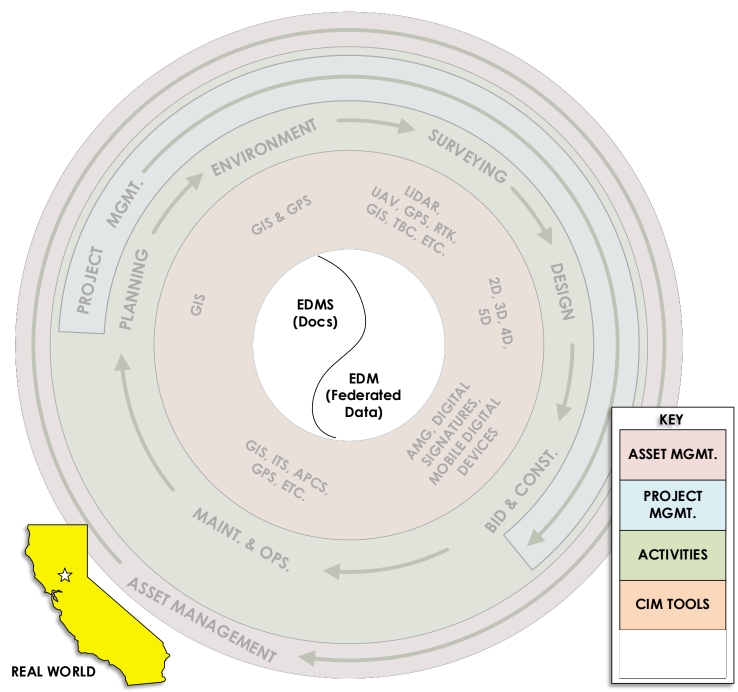


**Figure 3.8 Data Management portion of VDC/CIM**

This section will discuss some specific VDC/CIM tools and their applications found during a search of the literature as they relate to electronic data management as shown in Figure 3.8.

EDM refers to technologies used to store and manage engineering data within a digital database. Data and data storage, along with data management, have been pointed out as "foundational concepts" of CIM [104]. As discussed, ISO 19650-1:2018 [37], a federated system of data management, can be used. Connecticut DOT uses a federated system for their data management with legacy systems feeding data into a spatial GIS and a data warehouse [105]. As part of a data management system the concept of a common data exchange environment can be used, as defined in ISO 19650-1:2018 [37]. Florida DOT's data governance efforts, called the "Roads Initiative," is looking at data reliability and sharing ability at an enterprise level [106] [107]. Case studies for data management also exist from the FHWA, where several states reported they are either developing standards or have unofficial standards [108].

## *3.4.7 Others*

This section contains other items that do not directly fit into one of the above discussed categories or tools that are broader in their usage.

### 3.4.7.1 **Construction Manager/General Contractor (CM/GC)**

FHWA issued the final rule for CM/GC effective 1/3/2017 [30]. The contractor can act as a consultant in the design process, which may lead to several advantages, such as: fostering innovation, mitigating risk, improving cost control, and optimizing construction schedules [109]. Early procurement of CM/GC is important, and it may be beneficial if it is done before completing the NEPA approval process [30]. Arizona, Utah, Oregon, Washington State and others have rules allowing at least limited use of CM/GC [109].

### 3.4.7.2 **Connected Vehicles**

Utah DOT and transit authority have worked together to install connected vehicle technology in several corridors [61]. Some transit busses work with the connected infrastructure to coordinate green lights [61]. Plans exist to extend the system to snow plows [61].

### 3.4.7.3 **GIS**

One technology component of CIM includes Geographic Information Systems (GIS). Transportation Agencies have integrated GIS into their decision-making and analysis process [110]. The Utah Department of Transportation (UDOT) developed a GIS-based system called "Uplan" in 2009. Uplan is a web-based tool that uses the ESRI ArcGIS Online cloud platform [111]. Uplan is an interactive planning and analysis tool for data analysis, mapping, managing large data, decision making, and project development which serve different stakeholders [111]. UPlan helps with gathering different types of information (e.g., spreadsheets, word documents, PDF, etc.) which previously were managed separately by individual groups; gathered data is shared in a geospatial environment with a live dynamic map [112]. UPlan works with UGate and Linear Bench. UDOT spent roughly $500,000K developing UGate and Linear Bench, and now commercial software based on UDOT's system can be licensed by others for less than $20k per year [113].

Pennsylvania DOT has a GIS based system known as "Maintenance-IQ" that replaced roughly 50 old systems with a well-defined QA/QC processes [81]. Maintenance-IQ includes data for business intelligence, asset management, and project management [81].

To assess the deployment of GIS, the Federal Highway Administration (FHWA) has promoted the Capability Maturity Models (CMM) by Urban and Regional Information Systems Association (URISA) [110], [114]. The CMM is "a tool to assess an organization's ability to accomplish a defined task or set of tasks" [115]. The following state DOTs completed the CMM assessment: Arizona, Iowa, North Carolina, Ohio and it is an ongoing process in the following DOTs: Michigan, Oregon, and Tennessee [110], [114]. As part of a case study including IDOT, Ohio DOT, TDOT, and Oregon DOT, it was noted that completing a CMM requires a significant time investment, and that the specific implementation lacked some items relevant to state DOT's [110]. CMM ratings for GIS fall into four different levels of maturity (see Figure 3.9) [114]. Completing this assessment in-depth was outside the scope of this project, but it may be considered in the future.

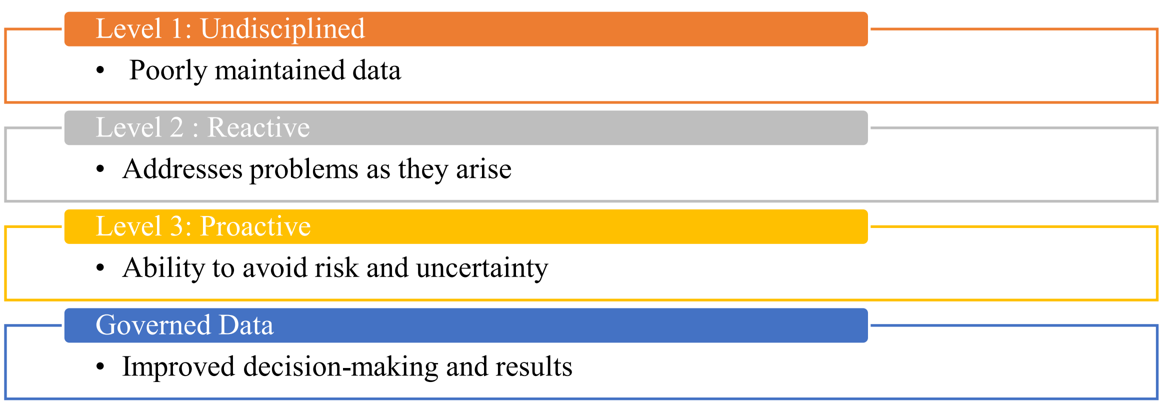


**Figure 3.9: GIS Ratings Level [114]**

### 3.4.7.4 **Project Bundling**

Project Bundling is the practice of combining smaller projects (preservation, rehabilitation, or replacement projects) into one larger infrastructure project [116]. DelDOT is bundling contracts to address preservation issues on bridges and culverts [116]. PennDOT conducted a three-county pilot project that rebuilt, replaced, or removed 41 county-owned structures and saw a 25–50 percent savings on design and a 5–15 percent savings on construction cost [116]. PennDOT followed up on this success by pursuing a statewide, 558-bridge bundling contract [116]. Ohio DOT's Bridge Partnership Program is replacing or rehabilitating 220 county bridges over a period of three years [116]. Georgia

DOT's Design-Build Bridge Replacement Program, for 25 local bridges [116]. Oregon DOT' repaired 271 bridges using 87 project bundles. Missouri DOT's $685 million Safe & Sound Bridge Improvement Program replaced or rehabilitated 802 State bridges over a period of 3.5 years [116].

#### 3.4.7.5 **Training**

Adopting CIM requires the use of many new technologies; as such, training and specifications may be helpful. New York State DOT (NYSDOT) provides yearly CADD training as well as self-help resources for many tasks including CAD, Mapping, ProjectWise, and others [95].

# CHAPTER 4: Synthesis of Results of Tasks 1 & 2 and Gap Analysis (Task 3)

This task takes what other state DOTs, consultants, and contractors have done and are doing (from Task 2) and compares those results with the information collected about Caltrans (from Task 1). Additional information is also added as appropriate in order to identify gaps.

## 4.1 Environmental Analysis

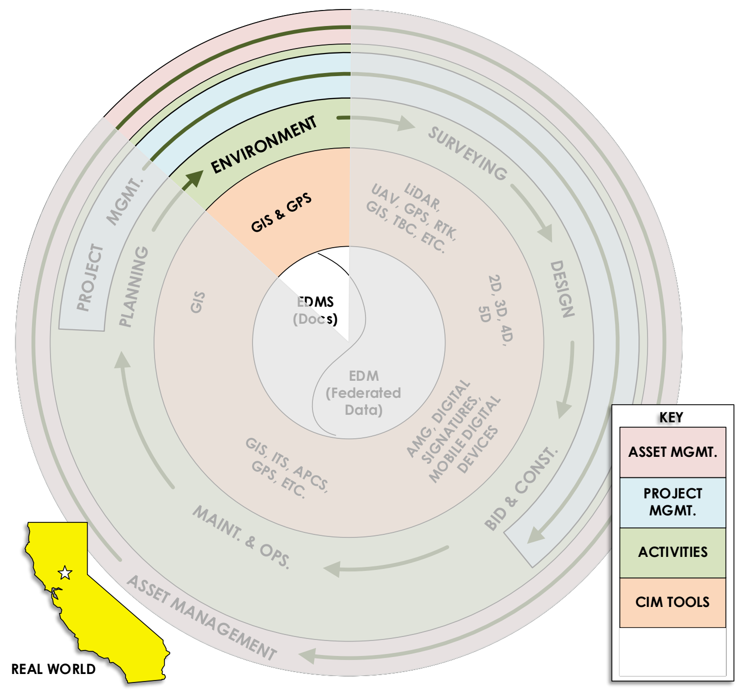


**Figure 4.1 Environmental Portion of VDC/CIM**

This section will compare Caltrans current state of practice to select others for specific VDC/CIM tools relative to environmental analysis, as shown in Figure 4.1. Environmental management, impact calculations, and reporting are a common part of infrastructure projects. A comparison of Caltrans main environmental data system with other states is shown in Table 4.1.

**Table 4.1 Main Environmental System Comparison**

| State | Tool |
|---|---|
| **California** | Non-spatial STEVE system tied-in to all districts. Districts can upload documents to super container. |
| **Virginia** | Web based CEDAR system that combines spatial and non-spatial data [44]. |
| **Pennsylvania** | Screening Tool that checks GIS layers [45]. |
| **South Carolina** | Project Screening Tool used in early-stage planning [45]. |
| **Tennessee** | SEMS system that is web-based and uses GIS [46]. |

# 4.2 Surveying

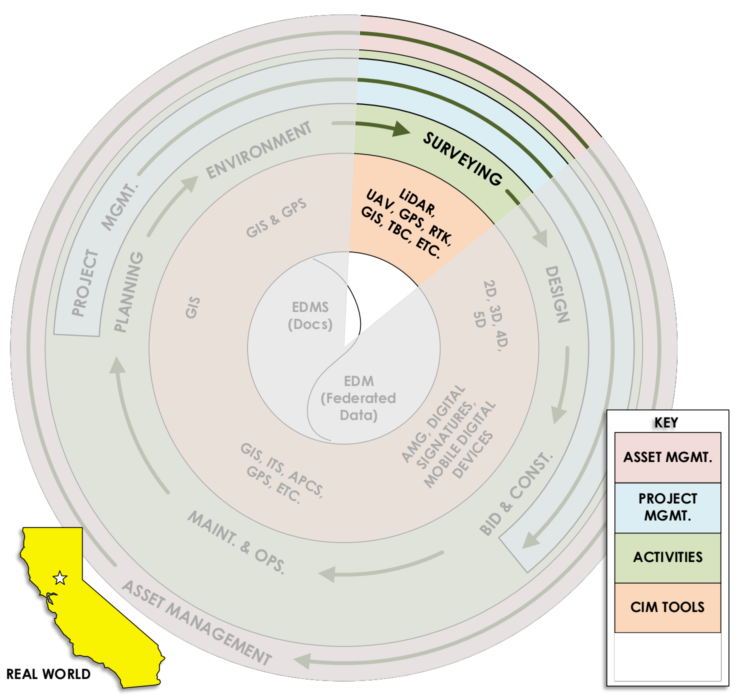


**Figure 4.2 Survey Portion of VDC/CIM**

This section will compare Caltrans current state of practice to select others for specific VDC/CIM tools relative to surveying as shown in Figure 4.2.

### 4.2.1 *LiDAR Mobile Mapping*

Table 4.2 represents the use of Mobile LiDAR within Caltrans compared to other DOTs. One issue raised with LiDAR data at Caltrans is that they are very large file sets that are hard to store and hard to move. Some designers would also like access to pre-construction LiDAR data; they also noted that the data has a very short lifespan before construction work invalidates it. Working with IT to consider a cloud hosting service for these large datasets may help to alleviate this problem, and with the proper data governance, could allow designers to access the data they need.

**Table 4.2: Deployment of Mobile LiDAR in Caltrans vs. other DOTs**

| Transportation Agency | Tools | Example Application |
|---|---|---|
| **California** | MTLS Vehicles: Trimble MX8 & Riegl VMX-1HA | Over 340 projects completed statewide[5]. Typically used for collecting existing topography data for design purposes (pre-construction). Caltrans is not currently collecting as-built information (post-construction). Approximately 1,700 centerline miles out of Caltrans total network have been scanned, representing approximately 150TB of data [10]. |
| **Oregon** | Topcon IP-S2HD Leica Pegasus | Surveying, Vertical clearance, Asset management, Pavement evaluation, Slide monitoring, Accident reconstruction, etc.[47] |
| **Florida** | Consultant and contractors | LiDAR-based 3D plans and as-builts[117] |
| **Minnesota** | Continental Mapping Consultant, Inc.[52] using Riegl VMX-250 | Highway 23 reconstruction project.[52] |
| **Utah** | Mandli Communication (Velodyne LiDAR)[118] | Asset management [118] |
| **Iowa** | Riegl VMX-250[119] | Used to create 3D models for planning and design phases ( completed statewide) [120] |

[5] Based on current MTLS research with Caltrans by AHMCT.

### *4.2.2 Drones/UAV/UAS*

Since the use of drones is still developing, this is an emergent area of research; as such, information may change quickly. Caltrans current usage as well as some other states are shown in Table 4.3.

Table 4.3: Drone/UAS/UAV Ussage for Various DOT's

| **State** | **Usage** |
|---|---|
| **Caltrans** | Rock slides, Surveying, Bridge insp., Construction monitoring, Earthwork calculation, Emergency response, Environmental, hydrological, geological |
| **Minnesota** | Bridge Inspection [54] |
| **Washington** | Evaluated for Roadway Surveillance [54] |
| **North Carolina, New Jersey, Ohio** | Construction Inspection, Traffic Incident Management, 3D Corridor Mapping, Emergency Response Assessment [54] |
| **Oregon** | Has drone usage policy and 20 ODOT employees certified to fly [58] |
| **Utah** | High speed data acquisition [59] Sign inspection and LiDAR [61] |

# 4.3 Design

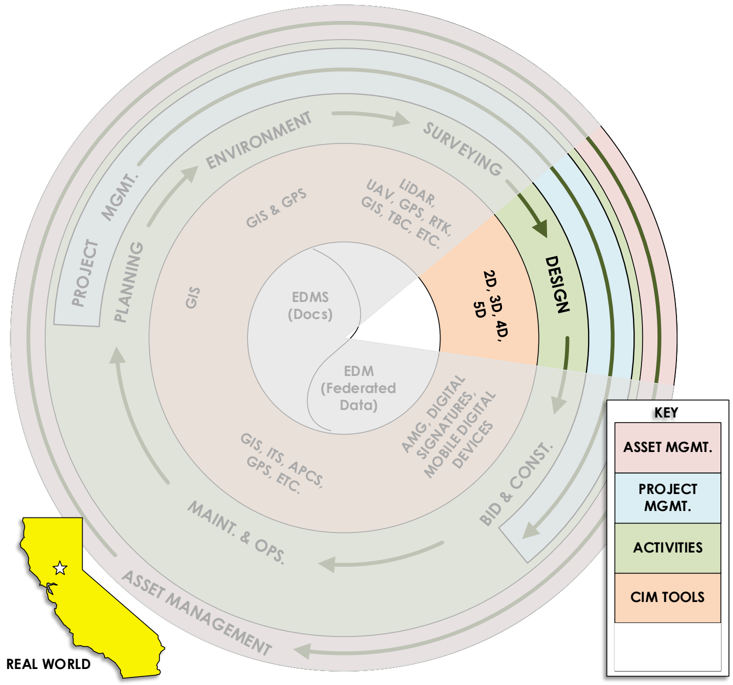


**Figure 4.3 Design Portion of VDC/CIM**

This section will compare Caltrans current state of practice to select others for specific VDC/CIM tools relative to design, as shown in Figure 4.3.

## *4.3.1 2D/3D/4D/5D Modeling and Analysis*

3D design is a modern tool that is gaining momentum. Some contractors report that they often take 2D plans and convert them to 3D [121]; as such, if 3D models were available, it would save some redundant work.

Caltrans uses both Civil 3D and MicroStation software, Table 4.4 compares the design software used by Caltrans to that of other states. It is also noted that other CAD software (i.e. SolidWorks) is used by Caltrans equipment shop.

**Table 4.4: 2D/3D/4D/5D Software Summary**

| State | Software Used or Required by Contract |
|---|---|
| **California** | Civil 3D, MicroStation [122] |
| **Florida** | Civil 3D, Geopak, MicroStation [68], and OpenRoads [123] |
| **Georgia** | InRoads and MicroStation [124] |
| **IDAHO** | InRoads and MicroStation [125] |
| **Iowa** | Geopak [68], looking at using Bentley Navigator (Open Roads) [83] |
| **Kentucky** | InRoads and MicroStation [126] |

| State | Software Used or Required by Contract |
|---|---|
| **Missouri** | Geopak and Microstation [68] |
| **Minnesota** | MicroStation and Power Geopak [127] |
| **Nebraska** | MicroStation and Geopak [128] |
| **Nevada** | InRoads, Microstation [129] |
| **New York** | Has required in contract: Bentley Microstation for 3D, Oracle Primavera P6 for cost-loaded scheduling, and Synchro Professional or Autodesk Navisworks for 4D/5D development [130], as well as InRoads [68] |
| **North Carolina** | Geopak [68], and OpenRoads [131] |
| **Oregon** | InRoads [132], and MicroStation [133] |
| **Pennsylvania** | Microstation is the standard software of the department, and the other software used by department is InRoad (April 2016) [134] - [135] |
| **Texas** | Bentley (MicroStation, Geopak, Descartes) [136]<br>TxDOT Bridge Geometry System (BGS) [137] |
| **Utah** | AutoTurn, InRoads, Microstation, OpenRoads, ProjectWise, SignCAD [138] |
| **Virginia** | Geopak/OpenRoads and MicroStation [139] |
| **Washington** | Microstation and PowerInRoads [140] |
| **Wisconsin** | Civil 3D [68] Bentley LEAP Enterprise Suite [141] |

A summary of Caltrans 3D usage compared to other state DOT's is shown in Table 4.5. Individual Caltrans districts and projects may have a higher level of 3D modeling maturity than the baseline requirement. It is noted that more communication on the availability of 3D models can benefit Caltrans, since some contractors may not be aware that Caltrans can provide 3D models.

**Table 4.5: Summary 3D Usage for Roadways and Structures**

| State | Roadways | Structures |
|---|---|---|
| **California** | Policy Directive 06 (category 2) states that 3D models should be provided for earthwork projects. CY (February 2016) [142]. Items defined as "Level 1" in Table 2.6 are currently created in 3D, but the final plans are typically in 2D. | Horizontal and vertical alignments are created in Civil3D while the final model is a mixture of 3D and 2D depending on the designers. The final plans are typically in 2D. |

| State | Roadways | Structures |
|---|---|---|
| **Iowa*** | | 3D used for Visualization & Constructability in some structure projects (April 2015) [143] |
| **Kentucky** | Piloted 3D model as final plan for bidding (March 2013) [64] | |
| **Michigan** | | 3D bridge modeling software tested on real projects (May 2018) [144] |
| **Minnesota** | EPG237.14 requires a 3D workflow using GEOPAK for highways and bridges (July 2018) [145] | |
| **North Carolina** | Piloting OpenRoads Designer on eight projects (January 2019) [131] | |
| **Oregon** | 3D Digital Design elements provided Using MicroStation and InRoads (2012) [146] | |
| **Utah** | Has bid a 3D Model as legal document (April 2016) [147] Has completed 11 projects with model as legal document [61]. | |
| **Washington** | | Used in conjunction with MicroStation's other 3D modeling applications, LumenRT is used for visualization (2016) [148] |
| **Wisconsin** | Implement Civil 3D as roadway design software (2017) [149] | Collaborative 3D models used for structures (January 2015) [141] |

*Piloted 3D model as the legal document [62].

Caltrans could modify their current workflow by extending the use of Civil 3D into structure design. If Roadway Design and Structures Design used integrated or compatible software for 3D modeling it would allow greater interactions. For example, by using the districts' data shortcuts, the user will be immediately notified if the source material is modified.

### *4.3.2 SUE Tools*

A comparison between California and other states is shown in Table 4.6 Table 4.6 for Sub Surface Utility Engineering tools.

**Table 4.6: SUE Comparison Table**

| State | SUE Tools/Usage |
|---|---|
| **California** | Caltrans has a statewide 3D utility database but work still has to be done to develop champions for its use. Geotechnical services from DES also has limited resources for SUE investigation. The use of Ground Penetrating Radar is not part of the standard process. |
| **Alabama** | Used consultant with GPR, Conductive Coupling, and Test Holes to generate 3D model of utilities on the CBD Interstate Project [70] |
| **Virginia** | Used GPS/RFID to tag new and existing utilities [71]. |
| **Michigan** | Piloted documenting utilities by surveying during installation, found that coordinating surveying and construction was challenging [71]. |

### *4.3.3 Constructability Review*

Constructability review is a collaborative process. A comparison between Caltrans and other states is shown in Table 4.7.

**Table 4.7 Constructability Review Comparison**

| State | Status |
|---|---|
| **California** | Typically implemented in 2D, with one district known to have used electronic files. |
| **MDOT** | Bluebeam PDF software along with ProjectWise Milestone, this workflow was developed as part of the AASHTO Project PS&E C-Rev [74] |
| **Idaho Transportation Dept.** | PDF viewer for plan reviews, comments, and revisions [20]. |

# 4.4Bidding & Construction

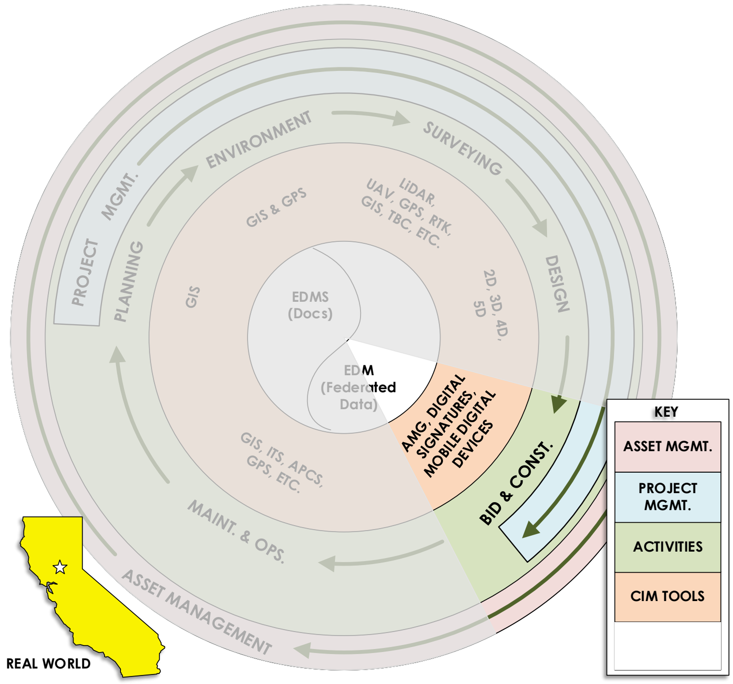


**Figure 4.4 Bidding and Construction portion of VDC/CIM**

This section will compare Caltrans current state of practice to select others for specific VDC/CIM tools relative to bidding and construction, as shown in Figure 4.4.

## *4.4.1 Automated Machine Guidance (AMG)*

AMG integrates construction machinery with GPS and incorporates 3D engineering models. Table 4.8 represents a summary of AMG findings for various DOT's including Caltrans.

**Table 4.8: AMG related findings [15], [76], [150]–[154]**

| State | Project | Excavation | Fine Grading | Asphalt paving | Concrete | Depth Milling | Impact | Impact Details |
|---|---|---|---|---|---|---|---|---|
| **California** | Clark Rd Curve Correction | X | - | X | - | - | Time/Material saving, Improving safety and productivity | Shortens construction time & cost, Fewer grade setters, Night work safety, Less stakes/surveys. |
| | Tudor Bypass | X | - | X | - | - | | |
| | Pigeon Pass | X | - | X | - | - | | |
| | Brawley Bypass | X | - | X | - | - | | |
| **New York** | US219 | - | - | X | - | - | Cost Saving, | 75% saving in earthwork |

| State | Project | Excavation | Fine Grading | Asphalt paving | Concrete | Depth Milling | Impact | Impact Details |
|---|---|---|---|---|---|---|---|---|
| | Southern Expwy S5 | X | X | X | - | - | Improve Safety | labor costs, 80% reduction in staking costs, 50% reduction in earthwork material overruns, 4-6% savings in material overruns, Less people exposed to accident risk |
| | Parkville Bypass | X | X | X | - | - | | |
| | Prospect Mountain | X | X | X | - | - | | |
| | Luther Forest infrastructure | X | X | X | - | - | | |
| **Florida** | 12.5 mile hwy widening | - | - | - | - | - | Time Saving, Material Saving | Compressed project by 8 months, 70% reduction in overbuilding material, $350,000 savings, Smoother road, Less lane closures & shorter project duration, Decreased inspection costs |
| | Adding 4 lanes to 4.1 miles semi-urban highway | - | - | - | - | - | | |
| **Utah** | I-80 paving project | X | X | - | X | X | Cost/time Saving, Quality Improvement | - |
| **Nevada** | I-15 interchange | X | X | X | - | X | - | - |
| | I-15 3R | - | - | X | - | X | - | - |
| **Wisconsin** | Zoo interchange | - | - | - | X | - | - | - |
| | Zoo interchange WTP | - | - | X | X | - | - | - |
| | Zoo interchange Core 1/2 | X | X | - | X | - | - | - |
| | I-94 Mitchel interchange | X | X | X | X | - | - | - |

| State | Project | Excavation | Fine Grading | Asphalt paving | Concrete | Depth Milling | Impact | Impact Details |
|---|---|---|---|---|---|---|---|---|
| **Michigan** | I-96 Reconstruction | X | X | - | X | - | - | - |
| **Missouri** | Loose Creek Bypass | X | X | - | X | - | - | - |
| | Route 264 Phase 3 | X | X | - | X | - | - | - |
| | Concrete Overlay | - | - | - | X | - | - | - |
| **Oregon** | US-97 | X | - | - | - | - | - | - |
| | OR-140 | X | X | - | - | - | - | - |

## *4.4.2 e-Construction*

e-Construction comprises several technologies with its goal being the collection, review, approval, and distribution of highway construction contract documents in a paperless environment [20].

### 4.4.2.1 **Digital Signatures**

Table 4.9, presents the number of states known to use various digital signature solutions, with Caltrans highlighted. It is noted that some states use multiple solutions, but the most popular digital signature solution is DocExpress, with DocuSign with Adobe Digital Signatures tied for second place.

**Table 4.9: Known Users of Digital Signature Solutions Based on Data From [17] and personal communications**

| Software Tool for Digital Signatures | Number of DOT Users | Users |
|---|---|---|
| **Adobe Acrobat Digital Signature, BidExpress, and Digitized** | **1** | **California** |

| Software Tool for Digital Signatures | Number of DOT Users | Users |
|---|---|---|
| **Signatures.** | | |
| **ePersona** | 1 | Louisiana |
| **CoSign** | 1 | Michigan, Oregon [155](formerly ARX CoSign [79]) |
| **Topaz Tablets** | 1 | Minnesota |
| **Bluebeam** | 1 | Virginia |
| **Adobe Digital Signatures** | 6 | Virginia, New York, Missouri, Connecticut, Colorado, Alabama |
| **DocuSign** | 6 | Wisconsin, Texas, Ohio, Nebraska, Georgia, Alabama, Utah |
| **IdenTrust** | 3 | Virginia, Louisiana, Florida |
| **DocExpress** | 7 | Arkansas, Iowa, Maine, Montana, New Hampshire, Oregon, Vermont |

One type of digital signature is the cryptographic signature. Cryptographic signatures may be considered for general documents since they can be integrated into the EDMS system and the workflow. Cryptographic signatures are also allowed under CA digital signature rules (i.e. CA code of regulations Title 2, Division 7, Chapter 10, §22000, also known as 2 CCR § 22000 and 2 CA ADC § 22000) [156]. A short example showing EDMS and digital signature integration was done by MDOT as discussed previously[6].

#### 4.4.2.2 Mobile Digital Devices

In general, mobile devices can be used for many different applications. A comparison of mobile digital devices used by Caltrans and other states are shown in Table 4.10.

**Table 4.10: Mobile electronic devices deployment [82], [84] and personal communications**

| Mobile Device | State | Users | Application |
|---|---|---|---|
| **Apple iPad** | California | Half of construction field staff, resident engineers, inspectors, senior engineers | Plans and specifications, Daily report, Inspection report, Communication, Taking photo and videos |

[6] https://www.youtube.com/watch?v=HAbYgqgnyB8

| Mobile Device | State | Users | Application |
|---|---|---|---|
| **Apple iPad** | Michigan, Florida, Iowa, Washington Minnesota | Project inspectors, Project engineers, Project managers | All inspection observation (photo, video, temperature, weather, and etc.), Inspection report, daily report, email communication, submit start and end of their shift, search through project plan, specification, and documents |
| **Microsoft Surface pro** | Texas, Utah | | |

* Washington, Texas, and Minnesota used HeadLight Inspection Unit

A further comparison of Caltrans mobile device usage compared to other states is given in Table 4.11.

**Table 4.11 Mobile Device Usage**

| State | Usage |
|---|---|
| **Caltrans** | Plans and specifications, daily report, Inspection report, Communication, Taking photo and videos |
| **Aransas and Delaware** | Construction inspectors use mobile devices in their daily reports [20] |
| **Rhode Island** | Collect information and create daily activity reports on seven pilot construction projects [20] |
| **Iowa** | Using with Esri products to capture as-built data for some items during construction [80] |
| **Pennsylvania** | GeoSnap application to take photos and combine with geospatial coordinates [81] |

### 4.4.2.3 **Electronic Document Management (EDMS)**

Table 4.12 below shows the number of states known to use each Electronic Document Management (EDMS), with Caltrans highlighted at the top. From Table 4.12, it seems that ProjectWise is the most popular commercial software tool for electronic document management, followed by SharePoint, and then Falcon/DMS. As discussed previously, Caltrans has a steering committee looking into an enterprise EDMS tool.

**Table 4.12: Other States known EDMS tools [17], [155]**

| Software Tool for EDMS | # of State DOT Using | Users |
|---|---|---|
| Falcon/DMS<br>e-Builder[1]<br>SharePoint | 1 | California[2] |
| Interchange | 1 | Utah |
| CADAC | 1 | Virginia |
| Custom | 7 | Arizona, Georgia, Illinois, Maine, Massachusetts, Minnesota, Pennsylvania |
| DocExpress | 6 | Arkansas, Maine, Montana, New Hampshire, Oregon, Vermont |
| e-Builder | 1 | Arkansas |
| e-Box | 1 | Vermont |
| Falcon/DMS | 8 | Wyoming, Virginia, South Carolina, Rhode Island, Ohio, New Jersey, Alabama, Caltrans |
| HummingBird | 1 | Florida |
| OnBase | 2 | Wisconsin, Nebraska |
| ProjectWise | 30 | Colorado, Connecticut, Delaware, Georgia, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Nebraska, Nevada, New Jersey, New York, Ohio, Oregon, Rhode Island, South Carolina, Texas, Utah, Virginia, Washington, West Virginia |
| PlanGrid | 1 | Colorado |
| ProjectSolve | 1 | Florida |
| SharePoint | 10 | Wisconsin, Washington, Ohio, North Carolina, Missouri, Minnesota, Louisiana, Kentucky, Indiana, Alabama |
| File Net | 1 | Texas |

[1]*Used by one project in D4 (San Mateo 101) for project management.*

[2] *Structures use only; Construction is piloting Falcon/DMS and other software.*

### 4.4.2.4 **Bidding & Contract Administration**

Comparing the results of Task 1 and Task 2 for the bidding section, many states are using systems similar to Caltrans (i.e. components of AASHTOWare). No significant gaps were identified at this time.

Based on personal communications, Caltrans is considering using the AASHTOWare Project Construction & Materials module for contact administration. For electronic submittal and administration of contractor claims, Caltrans also has developed an application and conducted 20 pilot projects. In addition, there is also an ongoing pilot with LCP tracker for electronic submittal of payroll.

### *4.4.3 Software Costs*

The known costs for some document management, digital signature, and collaboration solutions are presented in Table 4.13, based on [87], [155], [157], [88] and [158].

**Table 4.13: Known Costs for Various e-Construction Tools Based on Data From [87], [155], [157], [88], [158]**

| Software Tools for EDM, Digital Signatures, and Bid Management | Initial Cost Range | Annual Cost Range |
|---|---|---|
| **DocuSign** | Utah: $15K [155] | Utah: $20K [155] |
| **DocExpress** | | Iowa: $100K [157] |
| **e-Docs** | Unknown | Florida: $224K [155] |
| **FileNet** | Pennsylvania: $1M [155]<br>Oregon OTIA III: $273K [87] | Pennsylvania: $500K [155]<br>Oregon OTIA III: $421K [87] |
| **ProjectWise** | Texas: $12-$15M [155]<br>WDOT: $65K [155] | Texas: $11M-$12.5M [155]<br>Connecticut: $150K [155] |
| **ProjectSolve** | Unknown | Florida: $125 per month per contract (~800K per year) [158] |
| **SharePoint** | Utah: $600K [155] | Utah: $255K [155] |

Table 4.14 provides a summary of costs associated with various project scheduling software, as well as contract management and invoice processing software.

**Table 4.14: Project scheduling, contract management, and invoice processing systems cost**

| Software | Cost |
|---|---|
| **Microsoft project** | Project Online Essentials: $7.00 (user/month)<br>Project Online Professional: $30.00 (user/month)<br>Project Online Professional: $620.00 (one time |

| Software | Cost |
|---|---|
| | purchase) |
| **Oracle Primavera** | There are different license prices ($75 - $70,000) [159] |
| **Consultant Invoice Transmittal System (CITS)** | Cost of implement: $2 million,<br>Annual cost to maintain: $80,000 |
| **SharePoint Online** | $400,000 implementation cost, plus $5.00 user/month [160] |
| **SciQuest TCM** | Licensing is $265,119 (5-year contract), plus additional costs |

## 4.4.4 As-built Documents/Data

As-built data can take many forms ranging from redline paper plans to GIS databases to 3D LiDAR scans. A comparison of Caltrans practices to other state DOTS is shown in Table 4.15.

**Table 4.15 As-Built Data Comparison**

| DOT | Summary Technique |
|---|---|
| **Caltrans** | Redline paper plans, update plans based on redlines, store in the Caltrans Document Retrieval System (DRS), no post-construction survey. |
| **MnDOT** | MnDOT has a special provision for contractors to provide information to fill its GIS database [80] |
| **Iowa** | Mobile devices with Esri products to capture some data in the field [80] |
| **Utah** | Requires contractors to provide a 3D LiDAR scan [96] |
| **New York** | Requires contractors to provide a 3D LiDAR scan [96] |
| **MDOT** | Scanning back plans into ProjectWise, with MDOT doing QC/QA [78]. |

Table 4.16 shows different levels of as-built data maturity as defined by [161]. From Table 4.16: Caltrans is at maturity level 5, however, it is noted that this maturity rating does not differentiate old methods from modern systems like GIS and 3D Point clouds.

**Table 4.16: As-built data maturity level [161]**

| Maturity Level | Description |
|---|---|
| **1 - Initial** | Paper plans are redlined and archived |
| **2 - Evolving** | PDF plans are redlined and archived electronically |
| **3 - Defined** | CADD files are updated based on paper/PDF redlines |
| **4 - Managed** | As-built data are captured and delivered digitally if requested |
| **5 - Enhanced** | The format for capturing as-built data is standardized and required on projects |

# 4.5 Maintenance, Operations, & Asset Mgmt.

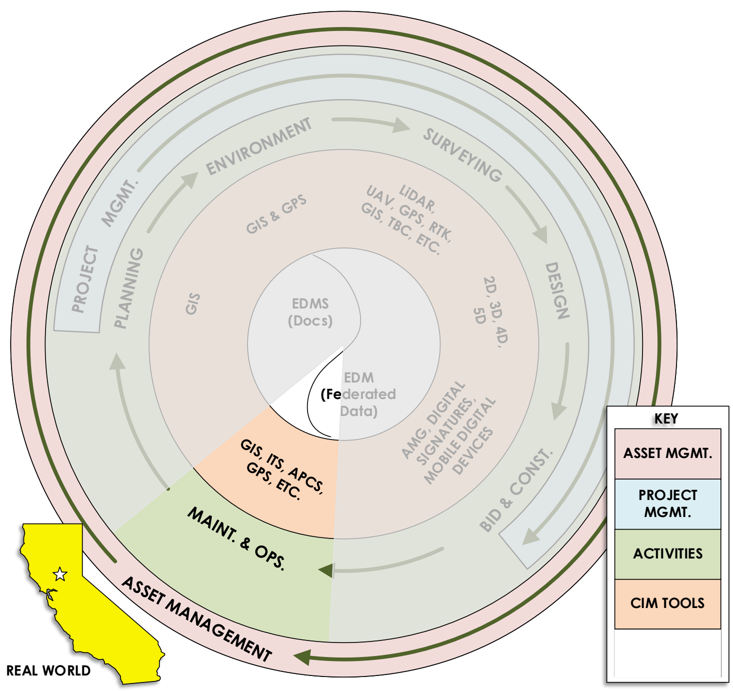


**Figure 4.5 Maintenance, Operations, and Asset Management Portion of VDC/CIM**

This section will compare Caltrans current state of practice to select others for specific VDC/CIM tools relative to maintenance, operations, and asset management as shown in Figure 4.5.

## 4.5.1 Asset Management

A summary of Caltrans asset management system compared to other DOT's is shown in Table 4.17.

**Table 4.17 Caltrans vs Other DOT's**

| DOT | Summary Technique |
|---|---|
| **Caltrans** | Asset management utilizes information generated by many different sources. A new performance management system known as TAMS is under active development. The Caltrans TAMP has 10-year performance metrics and a gap analysis. |
| **UDOT** | Assets are categorized in 3 tiers [100]. Asset data is organized, and available via UDOT data Portal [101]. |
| **All States** | As of 2019 each state has a TAMP with varying levels of detail included beyond the beyond the federally mandated information [98]. |

## 4.5.2 Asset Data Collection

Caltrans programs collect asset data about pavement, bridges, drainage, TMS, and other supplementary assets. In addition, Caltrans is actively pursuing an asset collection survey contract. Which will include "Signs, Barriers, Guardrails, Crash Cushions, End Treatment, Pedestrian Facilities and Bicycle Facilities [26]." A comparison of Caltrans with others is shown in Table 4.18.

**Table 4.18 Data Collection Caltrans vs Other DOT's**

| DOT | Summary Technique |
|---|---|
| **Caltrans** | Asset information collected about key assets. Maintenance is actively pursuing an asset collection survey contract to expand asset information. |
| **UDOT** | Each year, UDOT collects condition data of roadway assets [100] |
| **Oregon** | One particular type of asset (signs) are collected using electronic mobile devices with GPS [103]. |

# 4.6 Electronic Data Management (EDM)

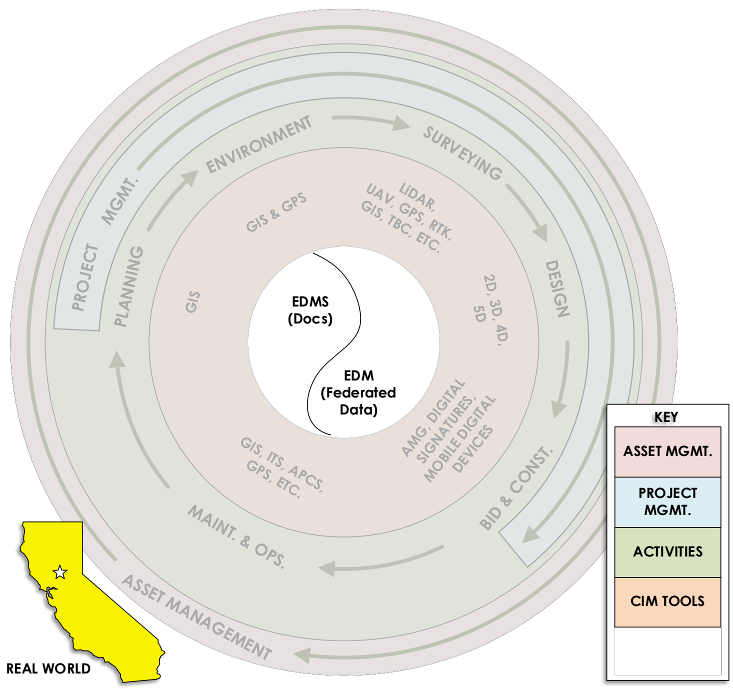


**Figure 4.6 Data Management portion of VDC/CIM**

This section will compare Caltrans current state of practice to select others for specific VDC/CIM tools relative to electronic data management as shown in Figure 4.6. Electronic data management is related to sharing data and making sure everyone who needs it has access. For the gap analysis, this topic is split up and addressed as part of the individual tools as well as data sharing, data storage, and integration topics in the later summary of gaps tables.

# 4.7 Others

This section contains other items that do not directly fit into one of the above discussed categories or tools that are broader in their usage.

## *4.7.1 Construction Manager/General contractor (CM/GC)*

CM/GC is a relatively new area and represents an alternate project delivery methodology unlike the standard design-bid-build method. Caltrans has guidance on this, and other states also have laws relative to this process. No significant gaps were noted; however, some panel members and contractors noted that CM/CG might be an avenue for exploring implementation of BIM tools.

## *4.7.2 GIS*

GIS technologies can be a component of electronic data management and are often seen being used for maintenance and asset management. Table 4.19 compares several states GIS usage compared to Caltrans.

**Table 4.19: GIS system usage**

| State | GIS Status |
|---|---|
| **Caltrans** | Esri GIS system is available. Data generally does not transition from one stage of the lifecycle to the next. For maintenance there are over 100 datasets. |
| **Utah** | UPlan web-based ESRI ArcGIS online cloud platform [111]. Used to share data in a geospatial environment and create live dynamic maps [111]. |
| **PennDOT** | Maintenance-IQ system with a well-defined QA/QC process including business intelligence, asset management, and project management [81]. |

FHWA will soon release a guidebook titled, "Applications of Enterprise GIS for Transportation (AEGIST) Guidebook" that may provide guidance in this area.

## *4.7.3 Partnering*

In 2008, partnering became mandatory for Caltrans contracts [21]. In Colorado, CDOT is developing tools such as an escalation matrix and an issue tracking form to improve partnering efforts [20].

### *4.7.4 Training*

Training is shown in the summary gaps as a component for several areas. For more details, please see Table 4.20 through Table 4.24.

# 4.8 Summary of Gaps

Caltrans currently has a number of ongoing efforts to address some aspect of VDC/CIM integration within the organization. There is an ongoing data quality management plan and data governance effort. The QMRS system is being rolled out. There is an EDMS steering committee looking at enterprise document management. Asset management is working on TAMS as an authoritative source of information.

Caltrans' current status, known best practices, gaps, and recommendations are summarized at a high level in Table 4.20 through Table 4.24. The known best practices are examples of the most advanced cases that were found during the literature review process, however, they may not be fully applicable to Caltrans. In addition to the differences between the known best practices and the current processes, the gaps also contain synthesized issues. In each table the recommendations column has a note that looks like **{E,I}**. The letter **E** indicates this is an enterprise effort, **I** indicates this would likely also involve IT. The **{E,I}** indicator serves to highlight which items may be harder to accomplish. Items lacking the **{E,I}** indicator are likely to be accomplished easier. For Table 4.23, there is an additional column for industry practices. All tables also have a blank column for short-term goals that can be filled out in the future as a first step toward a future implementation plan. Specific software's related to some of the technologies in these tables are included in Appendix F. It is important to bear in mind that technology is quickly changing, and that the best practices, the resulting gaps, and the recommendations may change with time.

## *4.8.1 Summary Environmental Gaps*

Table 4.20 contains the summary data for the Environmental activity. Note that although EDMS is included in environmental, it is actually an enterprise system and therefore also shows up in many other areas. An enterprise EDMS system will require cooperation among many divisions.

**Table 4.20 Environmental**

| Technology | Caltrans (Image Now) | DOT Known Best Practices | Gaps | Recommendations | Short Term Goals |
|---|---|---|---|---|---|
| EDMS | Environmental currently uses a lot of paperwork and 2D plans | No Data | No access to digital plans & 3D; Interface for workflow to resource agencies | Work with EDMS steering committee to consider EDMS options. **{E,I}** | |
| Database | STEVE database in non-geospatial and requires FilemakerPro to access. | Web-based system to access data [44] [46]. | Lacking web-based access to database, database not geospatial. | Create web-based application to access STEVE. **{I}** | |
| GIS | GIS data is not tied to live data in STEVE. | GIS tied to current environmental data [44] [46]. | Live environmental data not tied to GIS data. | Tie GIS data to STEVE live data making information easier to share.<br><br>Connect to enterprise GIS system. **{E,I}**<br><br>Enhance GIS development environment to be equal to the production environment in order to aide development of STEVE GIS capabilities. **{I}** | |

## 4.8.2 *Summary Surveying Gaps*

Table 4.21 contains the summary information for the Surveying activity.

**Table 4.21 Surveying**

| **Technology** | **Caltrans (Image Now)** | **DOT Known Best Practices** | **Gaps** | **Recommendations** | **Short Term Goals** |
|---|---|---|---|---|---|
| Mobile LiDAR | Over 340 projects completed statewide[7]. Typically used for collecting existing topography for design purposes (pre-construction). Caltrans does not typically collect as-built information (post-construction). Approximately 11% of network has been scanned representing approximately 150TB of data [10].<br><br>Tools: Trimble MX8 & Riegl VMX-1HA | Iowa DOT using for 3D planning and design [120].<br><br>Oregon using for surveying [47].<br><br>Florida LiDAR-based 3D plans and as-builts [117].<br><br>Utah for statewide asset-management [118]. | Post construction as-built survey not typically done.<br><br>Data collection not state wide.<br><br>LiDAR data not used in planning.<br><br>LiDAR data not Integrated to a central Digital Highway Repository | Obtain champions for post construction data collection (i.e. As-built).<br><br>Expand data collection beyond project level.<br><br>More trained personnel to process the data. | |
| Airborne LiDAR | Surveys Manual Chapter 13 lacks Airborne LiDAR[9] Standards.<br><br>Airborne LiDAR operated via A&E contract with specifications on a project basis. | SCDOT's I-85, I-26, I-85, low-attitude Aerial Mapping for Hydrological features, Paved surface, Vegetation, and utilities using TerraSolid, INPHO Match-AT software[162]. | Survey manual lacks guidance/standards on Airborne LiDAR. | Develop Airborne LiDAR Standard. | |

[7] Based on current MTLS research with Caltrans by AHMCT.

| Technology | Caltrans (Image Now) | DOT Known Best Practices | Gaps | Recommendations | Short Term Goals |
|---|---|---|---|---|---|
| GNSS | Caltrans is currently running a 145 station RTN.<br><br>Surveys Manual Chapter 6 lacks guidance on Real Time Networks or GLONASS[9]. | GNSS Standards on RTN and GLONASS [163]. | Survey Manual lacking GNSS and GLONASS standards/operational guides. | Develop GNSS Standard. | |
| Data sharing & Storage | Topo data shared in Civil 3D DWG and MicroStation DGN via district project delivery servers[8]. If other groups want data, need method to let them know about it[9].<br><br>Functional groups outside of Design may not use the district servers.<br><br>In limited cases, 3D point cloud data is shared with designers[10].<br><br>Large data sets have to be put on external drives and shipped[9]. | FDOT uses Amazon cloud via TopoDOT. | Limited storage for large data sets (and for backup of large data).<br><br>Point cloud data not readily transferred and accessed.<br><br>Point cloud data not generally shared with designers.<br><br>Cloud based tech. is not utilized for data sharing. | Work with IT to consider a (possibly cloud based) hosted solution for data storage of large files (i.e. point clouds). **{I}**<br><br>See report [164] for literature review and possible solutions related to MTLS data storage, discovery, and sharing. **{I}**<br><br>Tie in to common data exchange with project delivery.<br><br>Increase network bandwidth. **{I}** | |

8 As per conversation with Survey, an option to transfer data form the field directly into Civil3D via the cloud does not exist.
9 As per conversation with Survey
10 As per conversation with District 04

| Technology | Caltrans (Image Now) | DOT Known Best Practices | Gaps | Recommendations | Short Term Goals |
|---|---|---|---|---|---|
| UAS | Statewide, there are 50 employees who are drone pilots.<br><br>Caltrans Deputy Directive 118 establishes the policy for UAS use by Caltrans[11].<br><br>UAS usage varies widely between districts. Some have used UAS for tracking quantities, site documentation, surveying, inspection, environmental, and more. | An emerging area of research and best practice development. | Lacking ability to store drone data.<br><br>Lacks training facilities.<br><br>Not widely utilized. | Continue developing standards, identify training site, expand training and use cases.<br><br>Identify which data should be stored.<br><br>Increase broader utilization. | |

## *4.8.3 Summary Design Gaps*

Table 4.22 contains the summary data for the Design activity. It is noted that although EDMS is included in design, it affects many areas and should be seen as an enterprise system.

[11] As per conversation with Aeronautics

**Table 4.22 Design**

| Technology | Caltrans (Image Now) | DOT Known Best Practices | Gaps | Recommendations | Short Term Goals |
|---|---|---|---|---|---|
| EDMS | Falcon/DMS used by structures[12].<br><br>Roadways uses a windows-based filing system with standard directories and folder structure. | 43 States have implemented EDMS systems in various capacities, many DOTs using ProjectWise with Bentley Data. | Lack of enterprise EDMS system (not only a Design issue).<br><br>Lack of standard document version control. | Work with EDMS steering committee and other divisions to pilot test and implement some enterprise software. **{E, I}** | |
| Roadway Design | Civil 3D current models require Level 1 items from Table 2.6, some may use Level 2 or higher[13]. | Unified software (i.e. MnDOT model) OR Common Data Exchange with Structure Design. | 3D model not fully vetted (see legal document).<br><br>Lacking coordination with Structure Design.<br><br>3D Model Level of Detail and Development standards not clear. | Develop workflow and guidelines for 3D model level of detail, features, and visualization.<br><br>Work on common data exchange standards. | |
| Structure Design | MicroStation (2D-Drawings) along with a large set of independent programs for analysis. Designs completed in a mixture of 2D and 3D depending on designer skills[14]. | Unified software (i.e. MnDOT model)<br><br>Common Data Exchange (i.e. ISO model). | Design often not done in 3D.<br><br>Lacking coordination & Data Exchange with Roadway Design. | Increase level of 3D utilization.<br><br>Work on common data exchange standards with Roadway Design | |

[12] As per conversation with Division of Engineering Services
[13] As per conversation with Division of CADD and GIS
[14] As per conversation with Project Delivery District 04

| Technology | Caltrans (Image Now) | DOT Known Best Practices | Gaps | Recommendations | Short Term Goals |
|---|---|---|---|---|---|
| | | MDOT and WDOT using 3D for structures [141] [144]. | | | |
| Legal Document | Currently, legal document in 2D with 3D for information only through PD-06. | Utah DOT, Iowa DOT, and Illinois Tollway 3D model as legal document [62].<br><br>Michigan has in-house QC on models before releasing them [15] and [65]. | 3D model not for full legal documents.<br><br>3D Models that will match 2D plans.<br><br>Proper communication of existence of 3D Models or Generation of such models for Contractors. | Develop workflow for 3D models as legal documents. Add additional QA/QC to 3D model.<br><br>Standardize and Monitor Contractor Communications.<br><br>Contractors suggested a steering subcommittee for 3D and 4D would be helpful (similar to the falsework committee and the structures committee)[16]. | |
| Training | When Civil3D was implemented for Roadways, Structures extended a specialized training to its users, but it was not widely adopted[17]. | Yearly CADD training [95] and online training [165]. | Structures lacking training on 3D.<br><br>No training for QA/QC of 3D models as legal document. | Identify champions for structures 3D training.<br><br>Expand training for 3D modeling. | |

[15] As per conversation with Fair Cape Consulting
[16] As per conversation with Granit Rock and Ghilotti Brothers
[17] As per conversation with Division of Engineering Services

| Technology | Caltrans (Image Now) | DOT Known Best Practices | Gaps | Recommendations | Short Term Goals |
|---|---|---|---|---|---|
| | Office of CADD and Engineering GIS has annual training for districts in addition to training on an as-needed basis[18]. | | | Add training for 3D as legal document QA/QC. | |
| Collaboration | Structures and Roadway meet at start/60%/90% and when files uploaded into Expedite. With PDT they may meet regularly[19]. If road geometry changes, structures may not know about it until later in the process[20]. | Multiple competitors in emerging market such as Autodesk BIM 360 Glue [166], Tekla BIMsight [167].<br><br>For constructability, review MDOT using Bluebeam [74] and [21].<br><br>Maryland provides comments on the 3D model at each design milestone [169]. | Lack of collaboration platforms within the organization.<br><br>Lack of collaboration between structures and roadways.<br><br>Constructability reviews not done in 3D or with a collaborative platform. | Investigate collaborative platforms/workflows for use with project delivery team. **{I}**<br><br>Increase use of Civil3D data shortcuts by DES.<br><br>At the organizational level, start a pilot project for a commercial collaborative platform. **{E,I}** | |

[18] As per conversation with Division of CADD and GIS

[19] As per conversation with Division of Engineering Services

[20] As per conversation with Office of Photogrammetry

[21] Note: Industry has used 3D for constructability review, Skanska Level 400 model [168].

| Technology | Caltrans (Image Now) | DOT Known Best Practices | Gaps | Recommendations | Short Term Goals |
|---|---|---|---|---|---|
| 3D SUE | Caltrans has a federated group that collects SUE data (DES- Geotechnical Services) and a Zero Phase memo authorizing SUE. As part of SHRP2 R01A, a 3D Utility database was created. Caltrans SHRP2 R01B validated the SUE system. R15B allowed for acquisition of TDEMI hardware, GeoSoft for data analysis, and additional training. Three sites have been tested and compared against the old SUE data.<br><br>Subsurface utilities as-built has no champion, limited GPR system subject matter experts, and it is not part of the standard process[22]. | Virginia uses GPS/RFID to tag new and existing utilities. Michigan documented the utilities by conducting high accuracy surveying during installation [71]. | Subsurface utilities not generally mapped.<br><br>SUE database is lacking clear workflow (responsibility for populating is not clear).<br><br>SUE Database is not integrated. | Develop Standards/Procedures for SUE.<br><br>Develop training for utility engineers.<br>Identify Champions. | |

## 4.8.4 *Summary Construction Gaps*

Table 4.23 contains the summary data for the Construction activity. It is noted that although CM/CG is included in construction, it is actually an alternative delivery method that affects design and other areas as well. Furthermore, EDMS shown here should be seen as an enterprise system. For the industry column, some experiences on jobs other than horizontal construction are included.

[22] As per conversation with Office of Photogrammetry

**Table 4.23 Construction**

| Technology | Caltrans (Image Now) | DOT Known Best Practices | Industry | Gaps | Recommendations | Short Term Goals |
|---|---|---|---|---|---|---|
| Digital signature | BidExpress to sign initial contract as part of advertising process[23].<br><br>Once under contract, change orders and other materials all use wet signatures[23]. | Florida: Approval for financial docs, board of engineers approval for signing plans [170]<br>EDC-3 FDOT claims it saves them $22 million per year. | Crypto-graphic signatures such as DocuSign are common[24]. | Digital signatures only applied to limited document.<br><br>No digital signatures once under contract. | Explore signature systems compatible with EDMS and mobile devices. **{E,I}**<br><br>Expand use of digital signatures to other documents. | |
| Mobile Devices | Plans and specification (2D), daily & Inspection report, email, photos and videos[23].<br><br>Also uses FileMaker Go and Office 365<br><br>Tools: iPad | Inspection observation (photo, video, temperature, weather, etc.), inspection reports, daily reports, email, video call, start/end of shift, searchable project plan, specifications, digital signature, and integrate with EDMS software(e.g. ProjectWise)[82], [84], [171]. | No Data | iPads not integrated with EDMS.<br><br>Daily Engineering Reports not Fully Electronic.<br><br>Have not added digital signature ability on iPad. | Integrate with EDMS. **{I}**<br><br>Continue to work toward electronic daily engineering reports.<br><br>Test GPS accessory with GIS collector for data collection (see as-built documents).<br><br>Add digital signature software on iPads. **{I}** | |

[23] As per conversation with Division of Construction
[24] As per conversation with Ghilotti Bros

| Technology | Caltrans (Image Now) | DOT Known Best Practices | Industry | Gaps | Recommendations | Short Term Goals |
|---|---|---|---|---|---|---|
| EDMS | Have evaluated ProjectWise and identified shortcomings, now considering Falcon[23]. | 43 States have implemented EDMS systems in various capacities, many DOTs using ProjectWise with Bentley Data. | Spreadsheets, email, PlanGrid, Procore. Some jobs require proprietary systems [172].<br><br>Consultants may use ProjectWise or match the DOT [96]. | Lack of enterprise EDMS systems such as ProjectWise or Falcon (not only a Construction issue). | Work with EDMS steering committee and other divisions to pilot test enterprise software. **{E,I}**<br><br>Contractors recommended that the Resident Engineer use the EDMS system [172]. | |
| Bidding and Bid Estimates | Currently AASHTOWare Bids is used [23] [25]. | Most states with information available are using AASHTO BAMS/DDS and Bids or Expedite [17]. | Some use Agtek for estimating and Trimble products for grade checking [172]. | No significant gaps identified. | No significant steps to take. | |
| AMG | Optional Specs are used widely but mandatory specs were only recently implemented and used on limited projects so far. | I-80 (Utah)<br>I-15 Mesquite interchange (Nevada) | Many contractors may use AMG for grading, and some use AMG for paving [96]. | | Develop district AMG champions.<br><br>Expand AMG use beyond earthworks. | |

[25] Information obtained from quarterly meeting

| Technology | Caltrans (Image Now) | DOT Known Best Practices | Industry | Gaps | Recommendations | Short Term Goals |
|---|---|---|---|---|---|---|
| | Construction and Surveying working together on inspection tools, but currently there is a lack of surveying tools for inspection[23].<br><br>AMG is considered for projects over 5,000 cubic yards of earthwork and new alignments [173]. | Use AMG for Excavation, Fine Grading, Variable Depth Milling, concrete paving (I-80), and asphalt paving (I-15). | | Caltrans mandatory AMG spec only used for earthworks but not for paving, and variable depth milling.<br><br>Shortage of advanced tools for inspection.<br><br>Design model not used for verification. | Work toward using design models for verification. | |
| As-built documents | Document Retrieval System (DRS) stores Archived Vector Data (AVD), (that is an updated dgn file), pdf, and TIFF Format [23] which are 2D files. | MnDOT and Iowa DOT capture as-built data for some items during construction [80].<br><br>MDOT has initiative to replace scanning 2D as-built file with electronic mark-ups [97]. | Many private contracts require contractors to provide as-built data.<br><br>Contract specific formats, Revit, Gehry BIM software, etc. [172]. | No 3D as-builts.<br><br>Data collected during inspection not readily usable for asset mgmt. purposes. | Update all relevant manuals so Microfilm requirements are removed.<br><br>Consider post construction survey, or digital data collection during construction inspection. | |

| Technology | Caltrans (Image Now) | DOT Known Best Practices | Industry | Gaps | Recommendations | Short Term Goals |
|---|---|---|---|---|---|---|
| | Microfilm is no longer required[26] while the existing manuals state Microfilm as a requirement.<br><br>No post-construction surveys are performed. | Utah & New York require contractor to provide LiDAR scan as-built [96]. | | | Consider using Mobile LiDAR in post-construction survey to create 3D as-builts. | |
| CM/GC (Although a delivery process, it is included here under technology to be covered in Construction) | Started in 2013, 13 projects completed.<br><br>Authority to use for projects over $10 million. | No known best practice. | Indicated that it may be a good venue to test BIM tools. | No significant gaps. | No significant steps to address gaps, but consider using to test VDC/CIM tools. | |
| Contract Administration System | Currently using old system that requires a lot of manual reporting to meet current requirements. | One potential option is AASHTOWare Project Construction & Materials module. | Truebeck Construction has used scans to track against the schedule [174]. | Current system is partially digital and out of date. Does not allow for seamless meeting of all the require-ments. | Get management support to implement new all digital system such as ASHTOWARE Project Construction or other similar systems. **{E,I}** | |

[26] As per conversation with Division of CADD and GIS

| Technology | Caltrans (Image Now) | DOT Known Best Practices | Industry | Gaps | Recommendations | Short Term Goals |
|---|---|---|---|---|---|---|
| 4D Model | Generally, no 4D Model Used.<br><br>Only use 2D and 3D; for scheduling, use a calendar system not integrated with modeling. | CTDOT had consultant generate 4D model for risk management. Model used during advertising phase for information only [66]. RIDOT also uses consultant 4D Model [67]. | Large contractors using 4D for sequencing (risk mgmt.) [96]. Skanska 5D L400 model for Chelsea Viaduct [168].<br><br>Some use Preimivera P6 with schedules compared against 3D model [172]. | Lack of 4D modeling capability.<br><br>Lack of a 4D based risk manageme nt process for projects aside from construct-ability review, which is 2D. | Investigate software and procedures for 4D model.<br><br>Develop guidelines for when and how to use 4D model.<br><br>Consider updating constructability review process based on 4D modeling implementation. | |

### 4.8.5 *Summary Maintenance*

Table 4.24 contains the summary data for the Maintenance activity.

**Table 4.24 Maintenance**

| Technology | Caltrans (Image Now) | DOT Known Best Practices | Gaps | Recommendations | Short Term Goals |
|---|---|---|---|---|---|
| Data Collection | Caltrans is pursuing an asset collection survey contract to "develop a statewide inventory and an associated geodatabase"[27] but this is not at implementation stage.<br><br>Survey manuals include specs for data accuracy for terrestrial and mobile LiDAR as well as use of DRONES.<br><br>Roadway images not currently collected, but Photolog has 50 years of data. Roadways images now part of APCS[28]. | Each year, UDOT collects condition data of roadway assets [100].<br><br>Oregon collects sign data using electronic mobile devices with GPS [103]. | No statewide asset data collection process.<br><br>No present gaps on data accuracy specs.<br><br>There are gaps on data reliability aside from pavements.<br><br>Data discovery can be difficult. | Continue the asset collection survey contract process through implementation.<br><br>Work with programs (Culverts, Bridges, Pavements, etc.) to improve data availability, reliability, accuracy, and discovery. | |
| Maintenance Data Sharing & Integration | Design for maintenance/safety allows maintenance perspective input at the 60% and 95% review. Data in IMMS can be shared with others if they ask for specific information[29]. | Maintenance-IQ System (Penn DOT): Data is accessible for all users throughout the design process, and maintenance IQ facilitate exchange reporting data[81]. Similar to Go!NC (NCDOT) [81]. | Maintenance data not integrated and readily accessible by project delivery. | Integrate data with systems accessible by project delivery. **{E,I}** | |

27 As per conversation with Asset Management
28 As per conversation with Division of Traffic
29 As per conversation with Division of Maintenance

| Technology | Caltrans (Image Now) | DOT Known Best Practices | Gaps | Recommendations | Short Term Goals |
|---|---|---|---|---|---|
| | Can place items on intranet, division chief can share items at board meetings[29]. | | | | |
| GIS | Used to display IMMS data, rest areas, there are over 100 datasets. But it is hard to say how they are owned or maintained[29] [30].<br><br>Voyager search tool being implemented. | Maintenance-IQ System (PennDOT) Go!NC(NCDOT) [81].<br><br>ArcGIS online Portal (ALDOT) iMap(MDSHA) [81].<br><br>UPlan web-based cloud platform for sharing data in a geospatial environment and creating live dynamic maps [111]. | Lack of clear naming convention and attributes.<br><br>Data generally does not flow through a project's lifecycle. | Pilot statewide federated GIS system. **{E,I}**<br><br>Apply standard naming convention, and gather data dictionary from data sources.<br><br>Consider the completion and expansion of the use of TAMS as the baseline for integration and standardization of geo-spatial and non-geospatial data. **{E,I}**<br><br>To aid data discovery an enterprise search system should be considered. **{E,I}** | |

## 4.8.6 *Summary Asset Management Gaps*

Table 4.25 contains the summary data for the Asset Management activity.

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[30] As per conversation with Division of Research, Innovation and System Information

**Table 4.25 Asset Management**

| Technology | Caltrans (Image Now) | DOT Known Best Practices | Gaps | Recommendations | Short Term Goals |
|---|---|---|---|---|---|
| Asset Mgmt. Data Sharing & Storage | Each program has its own mechanism to share data. PaveM for pavement, TMS for traffic operation, ArcGIS online and spreadsheets[31].<br><br>There also exists SHOPP, Culvert Database, and Bridge Database. Specifications exist for storing data in an online repository, but there is no platform for it[29] [32].<br><br>The TAMS system is under development to integrate many datasets and make date driven decisions[31]. | All asset data are organized, stored, and available via UDOT data Portal [101].<br><br>MDSHA integrated all data into ArcGIS [81].<br><br>ALDOT's open data is offered through an ArcGIS online portal. Similar to iMAP (MDSHA) [81].<br><br>GO!NC and Maintenance-IQ System (PennDOT) [81]. | Data input reliability highly variable.<br><br>Need authoritative platform to interface with programs.<br><br>Lack of complete & integrated digital models of all assets. | Work with programs to standardized files, Create Data Dictionary, and complete the TAMS system to integrate data from individual programs. **{E,I}** | |

[31] As per conversation with Asset Management
[32] As per conversation with Program of Geospatial Data

# CHAPTER 5:
# Developing a Roadmap for VDC/CIM Integration within Caltrans (Task 4)

This task looks at the gaps and the best practices and formulates high-level strategic steps that can be taken to decrease the gap.

## 5.1 High-Level VDC/CIM

As a way to view VDC/CIM, two versions of the CIM diagram [175] were created. The version in Figure 5.1 is more in line with the NCHRP 831 [5] organization as also used in the Caltrans internal survey described in section 2.1. Figure Figure 5.1 is more in line with Caltrans operations. In both versions, data and documents are in the center and form a virtual world. The "real world" (i.e. the physical world that is operated upon) is on the outer ring. Between the real world and the virtual world there are multiple layers or rings.

In Figure 5.1, tools that generate data are placed on the layer closest to the center, followed by CIM functions that use the tools, CIM activities that incorporate the CIM functions, and business activities are on the fourth ring. Figure 5.2 has an additional ring embedded in the CIM activities ring for project management. In either image, the arrows show how different areas can access data from the others through the virtual world, and data is recycled throughout the project lifecycle.

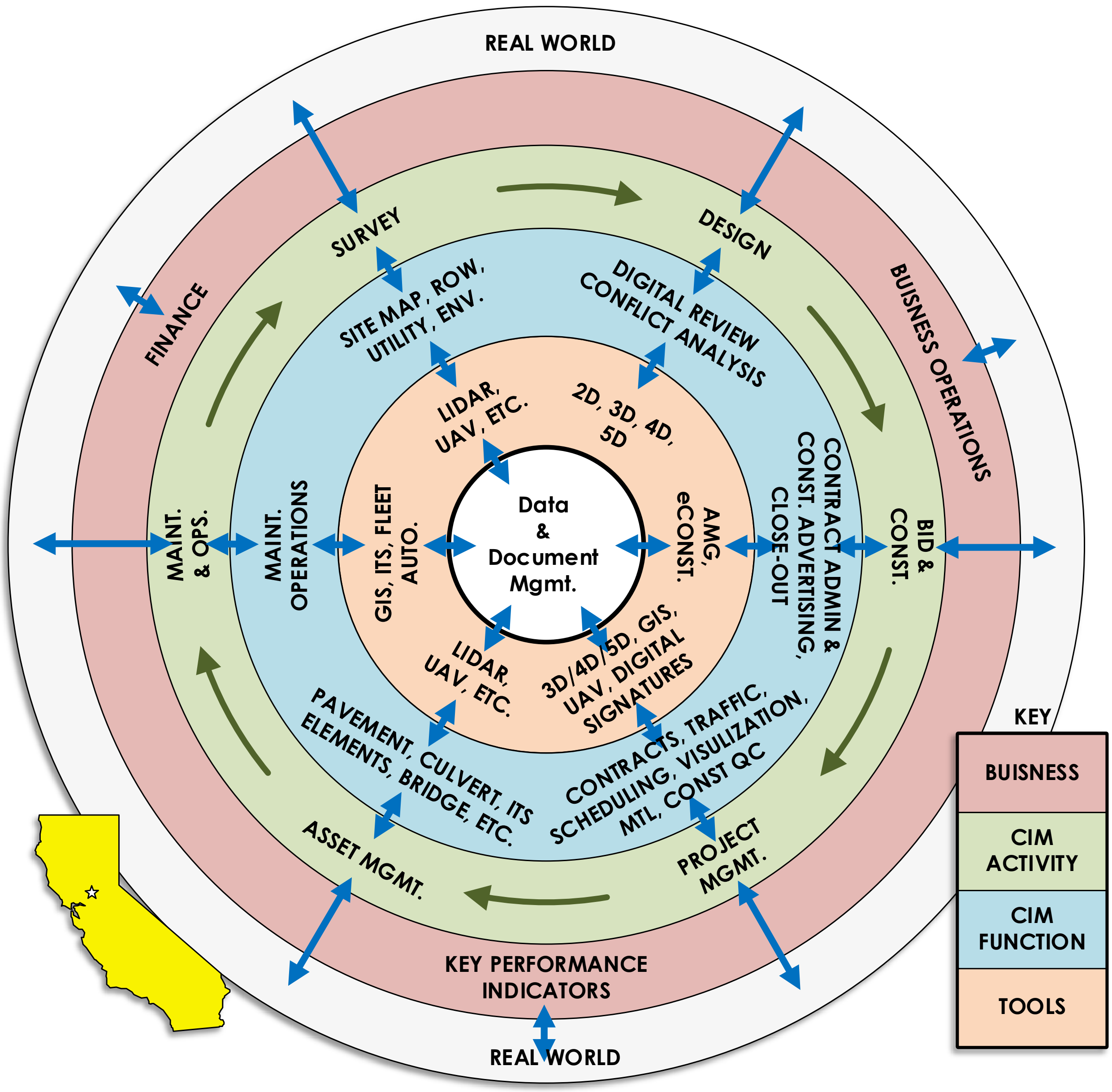


**Figure 5.1 Modified CIM Diagram adapted from [175] Showing Organization Structure Similar to NCHRP 831 [5]**

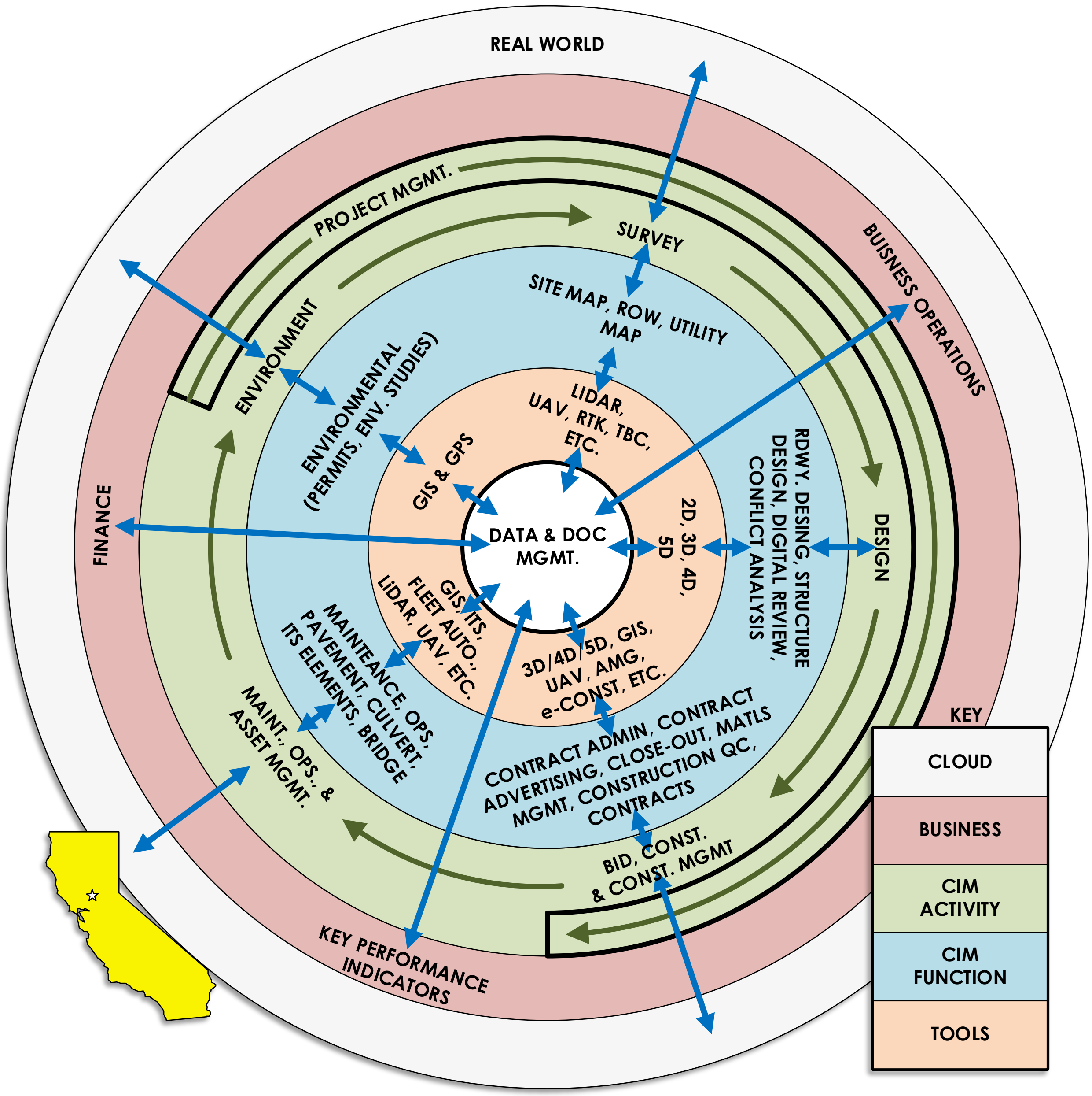


**Figure 5.2 Modified CIM Diagram adapted from [175] Designed for Caltrans Operations**

# 5.2 High-Level Workflow and LOD

A high-level workflow showing suggested relevant Level of Detail (LOD) values on the outer ring is shown in Figure 5.3. The LOD starts at 100 and increases to 500, the exact transition points between the intermediate LOD (i.e. 200, 300, 350, 400) can be decided when crafting the execution plan for the project. A more detailed discussion and proposal for LOD is shown below. Figure

5.3 is intended to show what the fully integrated VDC/CIM workflow looks like at a very high level.

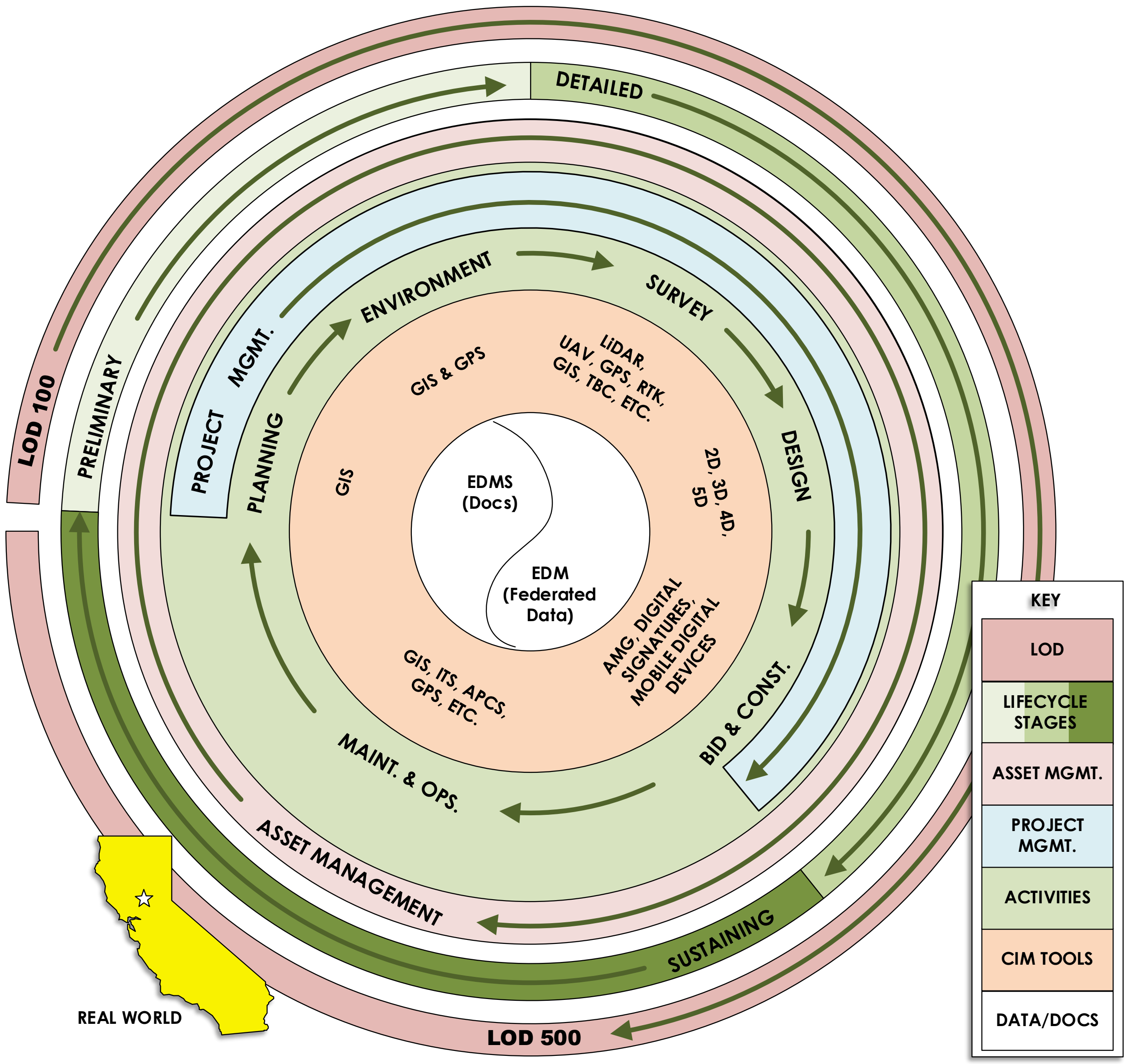


**Figure 5.3 Strategic Workflow Showing Level of Development**

The concept of the LOD is a standard that defines how much detail is included in the model. The vertical construction industry has LOD specifications [176] but there is some debate about their application to the horizontal industry. Caltrans, since 2013, has had levels of included features (Table 2.6) and has proposed two levels of 3D model detail (Table 5.1).

**Table 5.1 Caltrans 3D Model Details**

| Level | Caltrans 3D Model Details |
|---|---|
| **1** | The model includes all permanent features in 3-D x-y-z coordinates and shows 3-D dimensions.<br><br>For roadway design, roadway sections, embankments, and other features are shown in 3-D coordinates with 3-D dimensions.<br><br>For structures, bridge structures are shown in 3-D coordinates with 3-D dimensions. |
| **2** | Incorporate Level 1 details, and add 3-D reinforcing steel details in roadway cross-sections and bridge structure elements (Level 1 is a higher level 3-D model and Level 2 is an elaborate, detailed 3-D model of the design features). |

During discussions with WSP it was noted that a single LOD may not be enough and that Level of Development, Level of Detail, and Level of Visualization are needed. Other sources such as ISO also have the concept of Level of Information Need [40]. The UK uses Level of Information and Level of Detail[177]. Applying the above concept, Caltrans existing definitions for included features (Table 2.6) and levels of 3D model detail (Table 5.1) can be combined with a Level of Visualization. The result fitted to a traditional 100 to 500 scale (as used by AIA in the vertical industry [176]) is shown in Table 5.2. During the execution plan stage, Table 5.2 could be used to define what the expected result is; different departments may require different levels. Note that Table 5.2 is a proposed framework and may require further evolution.

**Table 5.2 Proposed Level of Detail, Information, and Visualization (LODIV) for Caltrans**

| Level | Level of Detail[33] (LOD - defines details of included features) – Contractor Level | Level of Information[34] (LOI - defines included features) – Customer Level Roadways / Structures | Level of Visualization[35] (LOV - defines visualization of included features) – Public Level |
|---|---|---|---|
| **100** | Conceptual model defined, may be mostly or all 2D<br><br>*"Diagrammatic or schematic model elements; conceptual and/or schematic layout"* [176] | Original Ground DTM, Finish Roadway Surface, Retaining Walls, Median Barriers, Curbs, Dikes, and Sidewalks | 2D Sheets |
| **200** | Permanent features using a mixture of 2D and 3-D x-y-z coordinates with 3-D dimensions where applicable. | Drainage, Bridge Cones and Structures, | Engineering Model Basic renderings without realistic materials or textures |

[33] Level 300, 400 from Caltrans 3D modeling levels, BIMForum materials also incorporated as cited.
[34] Based on Caltrans existing levels of 3D features from 2013
[35] Level 300, 400, and 500 based on (http://www.civilfx.com/3-levels-3d-visualization)/

| Level | Level of Detail[33] (LOD - defines details of included features) – Contractor Level | Level of Information[34] (LOI - defines included features) – Customer Level Roadways / Structures | Level of Visualization[35] (LOV - defines visualization of included features) – Public Level |
|---|---|---|---|
| | *"Schematic layout with approximate size, shape, and location of equipment; approximate access/code clearance requirements modeled"* [176] | Curb Ramps, Utilities, Metal Beam Guard Rails, Sound walls | |
| **300** | All permanent features in 3-D x-y-z coordinates and shows 3-D dimensions.<br><br>For roadway design: roadway sections, embankments, and other features (see LOI column for examples) are shown in 3-D coordinates with 3-D dimensions.<br><br>For structures: bridge structures are shown in 3-D coordinates with 3-D dimensions.<br><br>*"Modeled as design-specified size, shape, spacing, and location of equipment; approximate allowances for spacing and clearances required for all specified anchors, supports, vibration and seismic control that are utilized in the layout of equipment; access/code clearance requirements modeled"* [176] | Signs, Striping & Pavement Markers Wall Texture, Landscaping | Composite photo renderings[35] including artistic touches not necessarily part of the engineering models |
| **350** | *"Modeled as actual construction elements size, shape, spacing, and location/connections of equipment, actual size, shape, spacing, and clearances required for all specified anchors, supports, vibration and seismic control that are utilized in the layout of equipment; actual access/code clearance requirements modeled"* [176] | N/A | N/A |
| **400** | Incorporate Level 300 details, and add 3-D reinforcing steel details in roadway cross-sections and bridge structure elements.<br><br>*"Supplementary components added to the model required for fabrication and field installation"* [176] | Higher level asset inventory, Graphical Point Cloud integration | 3D Animated renderings[35] including features from LOI column and artistic fill |

| Level | Level of Detail[33] (LOD - defines details of included features) – Contractor Level | Level of Information[34] (LOI - defines included features) – Customer Level Roadways / Structures | Level of Visualization[35] (LOV - defines visualization of included features) – Public Level |
|---|---|---|---|
| **500** | Included details have been field verified | Multi-Dimensional integration (4D, 5D) | Interactive visualizations[35] including features from LOI column with artistic fill |

# 5.3 Building Information Modeling Concepts

It is not enough to implement technologies: to achieve a high level of VDC/CIM integration, system level workflows must be developed. System level workflows can be developed with concepts from the field of Building Information Modeling (BIM).

- Common Data Exchange environment as seen in ISO 19650-1:2018 [37]
- Federated Data as seen in ISO s19650-1:2018 [37]

As part of the ISO 19650 standards there exists numerous roles and responsibilities. These roles and responsibilities need be assigned based on the Caltrans organization structure and existing Caltrans personnel roles and responsibilities. Private industry typically has a BIM Manager appointed as part of the project delivery/procurement framework. There is also a CAD Manager that works with the BIM manager to support the translation of the 3D information to the 2D deliverables required by the client. Often some additional 2D detailing may be required for items that can be complex to model in 3D.

The BIM manager can also follow the project through its lifecycle to monitor, manage, and facilitate the common data exchange environment (see Figure 5.4). As previously discussed, the common data exchange may make use of the IFC format which is vendor-neutral and is part of an international standard (ISO 16739-1:2018) [38]. BuildingSMART, a worldwide industry body, is leading the effort to extend the existing IFC standard data schema to horizontal infrastructure such as IFC Bridge and IFC Road. IFC Bridge has reached Candidate Standard, and it is currently available for review and comment [178]. IFC Road is in development. AASHTO Board of Directors administrated resolution AR-1-19 recommends the adoption of IFC Schema as the national standard for AASHTO States on October 9, 2019 [179].

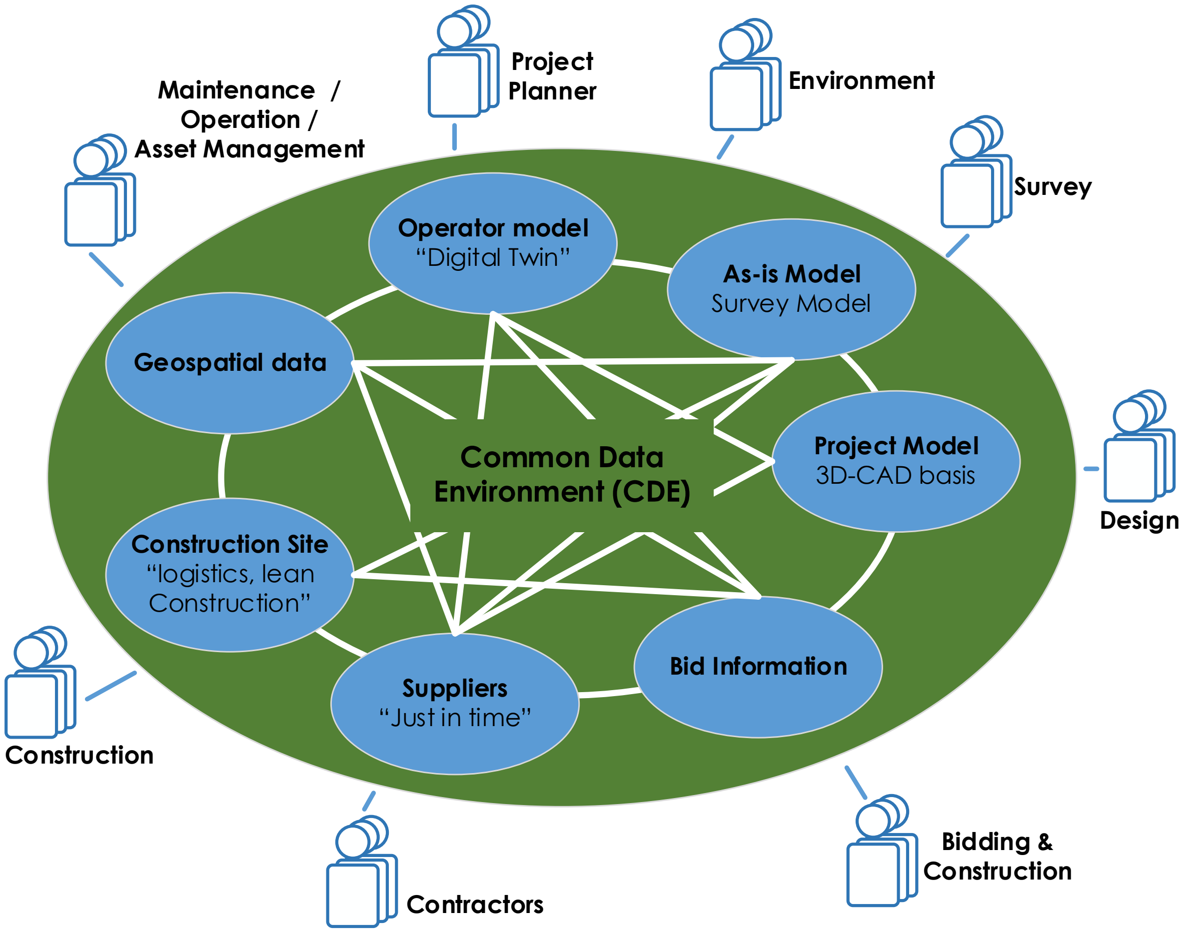


**Figure 5.4 Enterprise Federated CDE Concept for Caltrans adapted from [180]**

# 5.4 Roadmap

A strategic roadmap is provided in Appendix A that shows milestones as well as technological dependencies. The roadmap is a complex graphic that is best viewed in sections. Items on the far left represent Caltrans' current status, items on the far right are the ultimate goal of VDC/CIM implementation. The section in the middle highlights milestones that can be achieved in small steps on the way to the ultimate goal. From top-to-bottom the roadmap is broken into different activities such as environmental, surveying, design, construction, project management, and maintenance. These different activities are interconnected in various ways and at times achieving a milestone requires the cooperation of several. A red box is drawn to highlight the paperless project delivery and how that will require the cooperation of construction, design and others. Even when there are not direct connections shown it is still understood that advancing to a new milestone in one area has a general effect on the other areas by increasing Caltrans overall VDC/CIM integration in some way.

## 5.5 Issues Expected to Affect Full Implementation

Integrating VDC/CIM into Caltrans organization is a complex issue that encompasses many parts of the organization. This work provides a high-level strategic roadmap to help make decisions about where limited resources can be allocated; however, a detailed implementation plan for any one component is outside the scope of this work.

# CHAPTER 6: Conclusions and Future Research

Caltrans has implemented some VDC/CIM tools and technologies at various levels of maturity within divisions and offices. "The bottom-up approach alone from the BIM applications is insufficient to accomplish the cultural change… for a successful introduction of BIM" [180]. To get the maximum benefit from VDC/CIM, an enterprise approach needs to be considered that contains the whole lifecycle of a project. The goal of this work was to develop a strategic roadmap for VDC/CIM implementation and integration in Caltrans. In order to do this, the project was broken into 4 main tasks:

- Task 1 was to evaluate Caltrans' current status relative to VDC/CIM practices. This was done primarily through a survey and a significant number of interviews and meetings.
- Task 2 was to conduct a literature review and, by leveraging existing resources, evaluate the known best practices that others have publicly shared. As part of this task several consultants and contractors were also contacted.
- Task 3 was to compare the results of Task 1 and Task 2 to synthesize the gaps. As part of this process a one page summary for the main CIM project activities was generated.
- Task 4 was to develop a high-level strategic roadmap for VDC/CIM integration at Caltrans.

The results of this work generated a complex roadmap for VDC/CIM integration (Appendix A) as well as tables summarizing gaps and next steps. The scope of this work was to be high level and as such a detailed implementation plan was out of scope. The roadmap provided action items and intermediate milestones/objectives. A large body of work remains in determining the how and when. VDC/CIM integration action items and milestones may be viewed and classified in terms of elements of VDC/CIM as shown in Figure 6.1. Managers must look beyond the application of VDC/CIM technologies and implement other elements of VDC/CIM to complete cultural and institutional change for VDC/CIM integration.

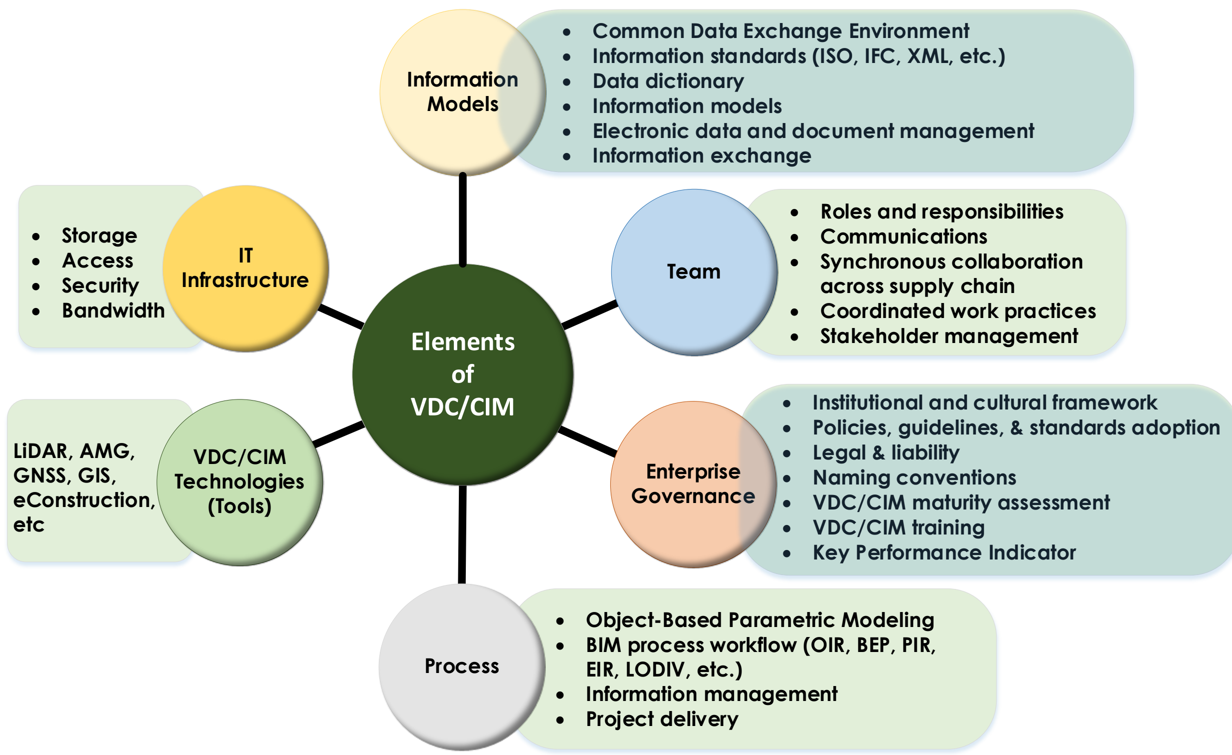


**Figure 6.1 Elements of VDC/CIM adapted from [2], [180], [181]**

Some key contributions of this work include generating an enterprise level understanding of Caltrans current methodologies as well as generating a roadmap to help move forward in the VDC/CIM integration effort.

# 6.1 Summary of Selected Issues and Recommendations

In 2016 Caltrans and FHWA hosted a workshop where cards were filled out to identify challenges toward implementing 3D technologies. The top three mentioned items from the 2016 workshop are in Table 6.1. The top two items mentioned, “Standardizing practices” and “Data Interoperability & Integration” still exist today in various ways. A number of gaps related to these topics were presented in the summary tables of Chapter 4, some of which include:

- Roadway and Structure design are not well integrated.
- Naming conventions are not standardized in GIS, making data discovery difficult.
- Maintenance databases are largely stand alone and not integrated.
- Asset management is working on a new system (TAMS), but it needs standardized, reliable, information as inputs.

- Lack of an enterprise EDMS system for managing documents (some areas do have systems in place such as Falcon used by Structures Design).

**Table 6.1: Challenge Card Identified Challenges tabulated from [6]**

| Challenges to Implement 3D Technologies (From Challenge Cards) | Number of Mentions |
|---|---|
| Standardizing practices | 22 |
| Data interoperability & integration | 15 |
| Training | 10 |

The third most common challenge identified was training. Implementing new technologies always requires robust training. Some of the issues identified related to training, or that training could help, include:

- Training needed to QA/QC a 3D model if it is going to be a legal document.
- Training and workflow needed for Subsurface Database.
- Training on use of 3D for structures.

Related to training, it was noted that some designers are hesitant to release 3D models for fear that it adds more work or opens them up to liability. This may be an issue that can be partially addressed with training.

### *6.1.1 Major Results and Recommendations*

The summary tables of Chapter 4 provide a detailed look at the gaps and recommendations. This information is summarized here at a high-level. This summary is organized in terms of CIM Activities and is derived from information collected internally from Caltrans, various DOTs, and industry consultants. **The three columns in Figure 6.2 are: the current state of practice (left), the known best practices (right), and steps to fill in the gaps (center)**. The data in each quadrant of Figure 6.2 corresponds to a different CIM Activity within the Caltrans organization. **The four CIM Activities shown are Surveying, Design, Construction, and Asset Management & Maintenance**. Environmental is not shown in Figure 6.2 but is also included in the analysis of this report.

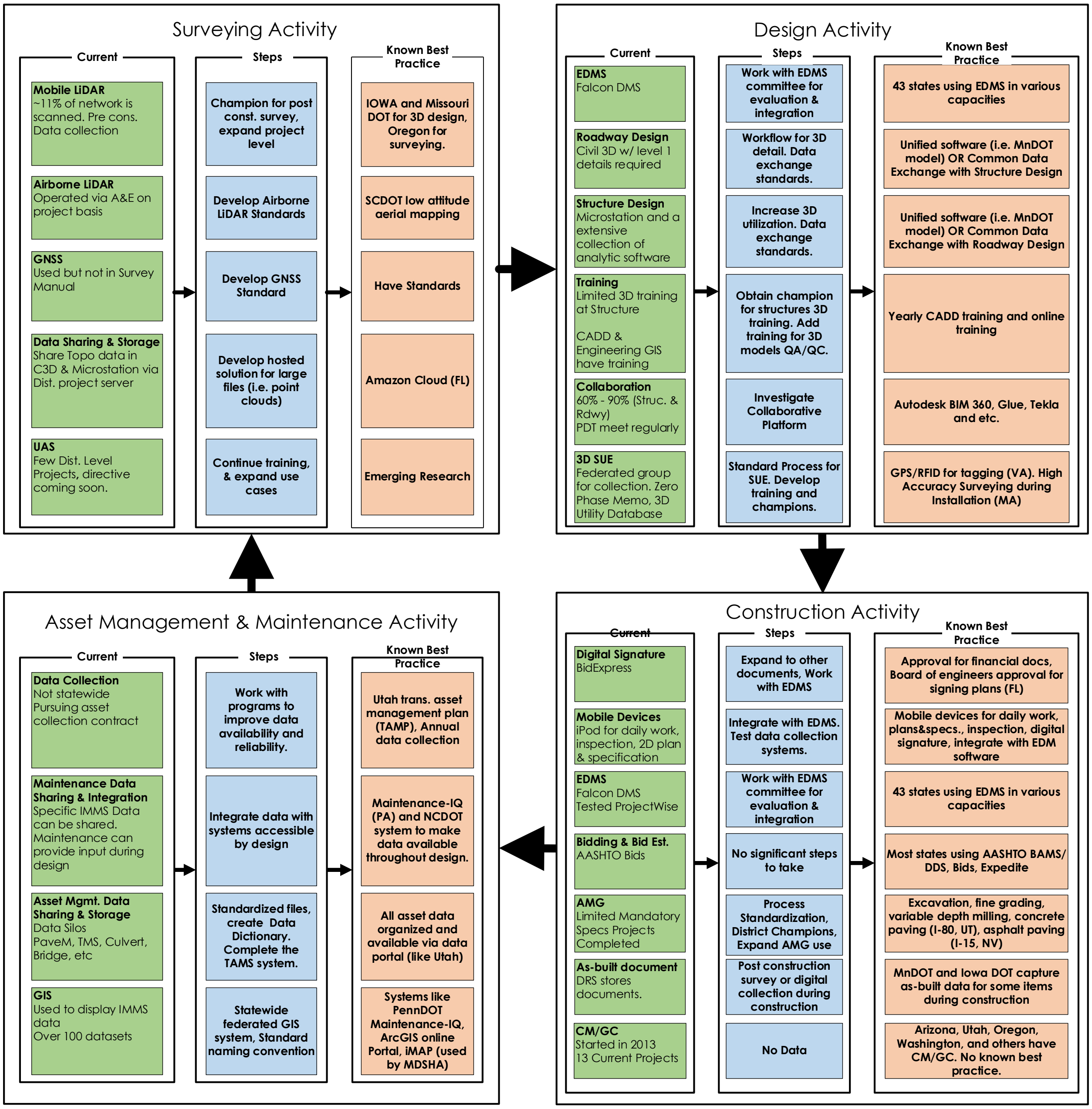


**Figure 6.2 VDC/CIM Tool and Task Maturity by Activity and Steps to Achieve Goals**

## 6.1.1.1 Surveying Activity

In the Surveying activity, various levels of maturity are seen. From Figure 6.2 it is clear that Caltrans needs to identify or empower champions for Mobile LiDAR in certain areas that use this tool. In terms of other relevant VDC/CIM tools such as the use of GNSS (Global Navigation Satellite Systems), and tasks such as Data Sharing and Storage, however, there are gaps that require additional steps to reach maturity of the state of practice. In terms of use of UAS (Unmanned Aircraft System), Caltrans maturity is consistent with the emerging best practice and research. Caltrans therefore only needs to continue training to expand its use cases, set policies for what should be stored, and stay up-to-date on the emerging research. Furthermore, in the UAS area Caltrans has the opportunity to become a national leader if the organization continues and expands upon its current activities.

#### 6.1.1.2 **Design Activity**

Within the Design activity, the maturity levels are different for each of the six relevant VDC/CIM tools and tasks, defined in Figure 6.2. Bridging the gaps for each of the tools and tasks requires a different number of steps to reach the maturity of the state of the practice. For example, in the VDC/CIM task of Roadway Design (as well as Structural Design) developing data exchange standards is an important step to bridge the gap. For other VDC/CIM tools and tasks, training, working with internal committees and investigating available platforms can fill in the gaps. For the 3D SUE task, a utility database now exists that will allow information to be available to any user in the state who needs it. The 3D utility database still needs champions and clear guidelines for populating it, but again, this can be an area where Caltrans can show national leadership.

#### 6.1.1.3 **Construction Activity**

In the Construction activity, the bidding and bid-estimating processes have the highest level of maturity within Caltrans, consistent with the state of the practice. The maturities of the remaining tools are varied. The As-built documentation task is an area where taking steps such as capturing data during construction can be integrated with asset management. Caltrans maturity level for the CM/GC (Construction Manager/General Contractor) task is consistent with the state of the practice. If Caltrans continues to expand its activities in this area, the organization can become a national leader. The AMG (Automated Machine Guidance) tool needs champions at the district level to push and expand the usage of the technology. EDMS (Electronic Document Management System) is an area tied to not only the Construction activity but also to Design and other areas. This is an area where working closely with others is needed to successfully implement an enterprise solution and obtain the most value. Mobile devices are an area where the infrastructure exists now. The main task is to integrate them with other systems such as the EDMS, digital signatures, and field data collection to capture more value.

#### 6.1.1.4 **Asset Management & Maintenance Activity**

The Asset Management & Maintenance activity steps are mostly data driven and will require integration of their valuable data with project delivery and planning. At the highest level, work can be done with the programs that supply data to asset management in order to improve data availability and reliability. For GIS (Geographic Information System) tools, there is a need to standardize naming conventions and move toward a federated statewide GIS system. In general, there appears to be a gap between Project Delivery and Maintenance. There is great potential for closer integration.

#### 6.1.1.5 **Environmental Activity**

The Environmental Activity (not show in Figure 6.2) typically deals with data on historic properties, natural resources, environmental factors, and obtaining permitting. Caltrans presently uses a paper-based system and 2D plans as well as databases that are not geospatial (not tied to GIS). Other state DOTs have developed and are using web-based systems that combine spatial and non-spatial data. Initial recommended steps are: collaborate with the EDMS (Electronic Document Management System) steering committee to assess the feasibility of using the EDMS System, develop a web-based application to access the existing database currently used by all districts, and finally, connect the existing database to the enterprise GIS.

#### 6.1.1.6 **Overall Recommendation**

For Caltrans VDC/CIM implementation, formation of an organizational level task force is proposed. The task force can work with groups in charge of each CIM Activity and help them through closing the gaps in pushing towards digital transformation. Since data and Geospatial integration play key roles in VDC/CIM implementation, the task force should include key personnel from Geospatial, asset Management, and Information Technology groups as well as other VDC/CIM champions. It is also recommended that within each CIM Activity, pilot implementation projects be identified that can help the relevant staff develop the needed workflow through first starting with pilot projects.

## 6.2 Future work includes

The scope of this project was high level and as such no detailed implementation plans were developed. In order to successfully integrate VDC/CIM into Caltrans a detailed implementation plan will be required. More detailed studies of individual components as represented in this work may be required for some areas (i.e., moving to 3D as the legal document, going completely paperless, etc.). Some issues will require solutions of a larger scope than others. Issues such as training for specific tasks may require a local solution or change in just one area; while implementing an EDMS system that interacts with CIM functions or departments in Caltrans will require an enterprise level solution. Enhancing data exchange may be addressed by using a common data exchange methodology along with a federated data approach such as is suggested in the ISO standard.

This work incorporates knowledge obtained from industry and experts, from EDC presentations, interviews, and Caltrans subject-matter expert knowledge. Ultimately the roadmap is an open architectural framework that allows incorporation of various specific tools/software. In order to move forward, Caltrans and their partners will have to decide on specific products. Selection of specific products may be aided by conducting pilot projects and collaboration with stakeholders. Subject matter experts for both VDC and CIM should be consulted when developing detailed implementation plans. Industry consultants and contractors potentially have more experience delivering projects by applying BIM principles, especially with experience in the vertical construction industry. It was suggested by industry that CM/GC may be a good venue to test BIM tools with Caltrans. Through the CM/GC process an exchange of operational knowledge may benefit Caltrans. As part of this process Caltrans CIM activities can more closely interact with external entities such as contractors and consultants.

Regarding data management, the roadmap recommends a federated system. A federated system will allow incorporation of different data silos while also allowing individual areas to maintain ownership and stewardship of their data. Issues of data security, although outside the scope of this document, will have to be considered in the detailed implementation plans.

There are many technological tools that can be applied as part of VDC/CIM. In order to ensure that VDC/CIM tools are applied in an integrated way, an overall plan should be generated. At the project level this may be part of a BIM execution plan.

In general, true integration of VDC/CIM requires cooperation: continued management support and policy mandates will be required and closer collaboration between relevant departments and stakeholders will be needed.

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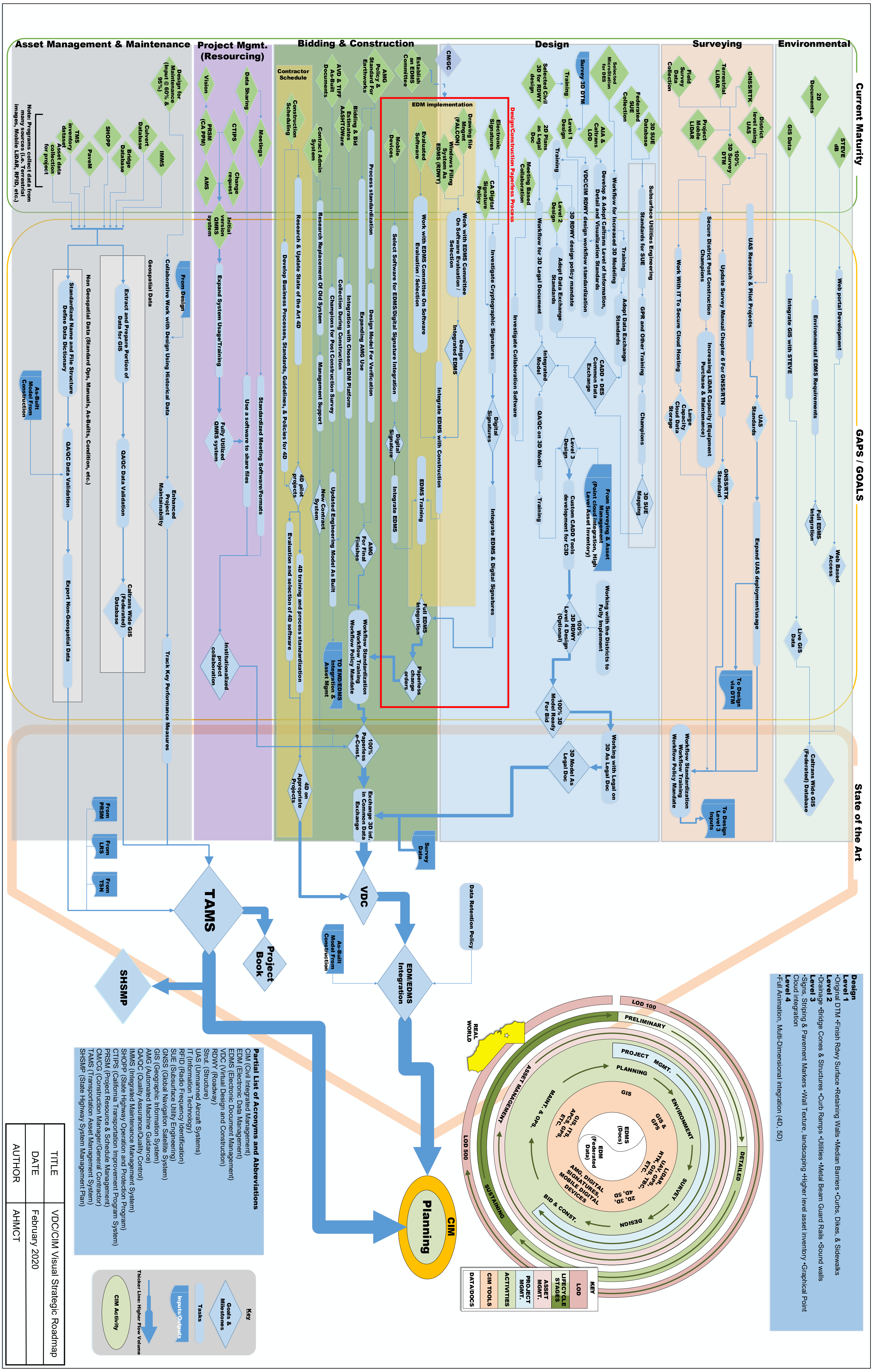
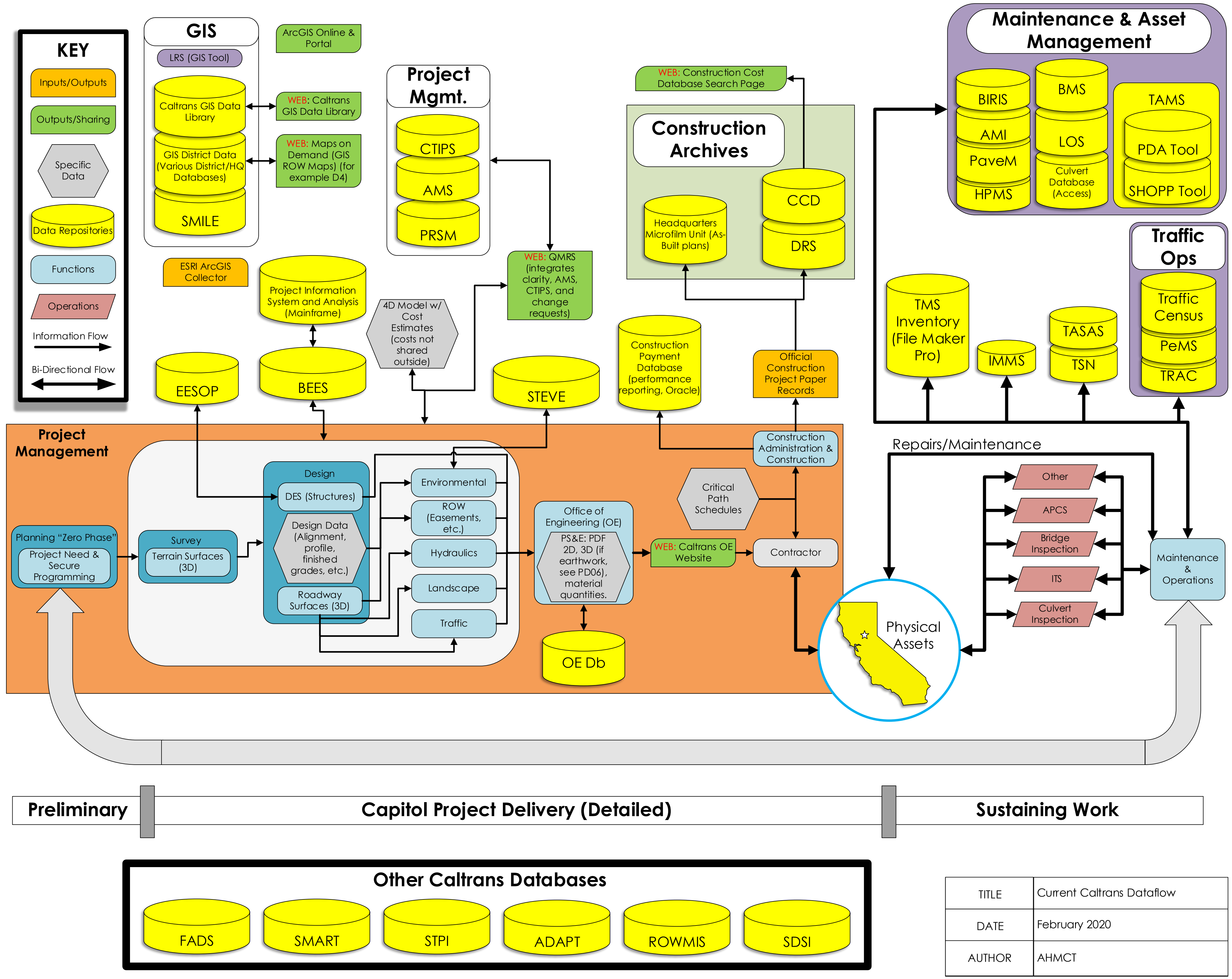
# Appendix A: Roadmap



# Appendix B:
## Caltrans Data Flow Chart

| Acronym | Name (Information) |
|---|---|
| ADAPT | Resolve ADA grievances statewide |
| AMI | Asset Management Inventory |
| AMS | Accounting Information (funding, expenditure, hours budget) |
| BEES | Basic Engineering Estimating System (Preparation of Estimates, Mainframe) |
| BIRIS | Rehab projects & Bridge Maintenance Activities |
| BMS | Bridge Management System |
| CCD | Construction Cost Database (Historical cost info, MySQL) |
| CTIPS | CA Transportation Improvement Project (Project programming, Allocated funding) |
| DRS | Document Retrieval System (As-Built, TIFF, AVD, Oracle) |
| EESOP | Electronic Structures Status of Projects (FileMaker Pro) |
| FADS | Federal Aid Data System |
| HPMS | Highway Performance Monitoring System (National Highway Route Inventory/Traffic/Geometries) |
| IMMS | Integrated Maintenance Management System |
| LOS | Level of Service |
| OE Db | Office of Engineer Database |
| PaveM | Pavement Management System |
| PDA Tool | Maintains project delivery asset data (SHOPP & non-SHOPP projects, minimal data quality assurance) |
| PeMS | Traffic Data for Planning |
| PRSM | Project Resourcing and Schedule Management (Milestones, Oracle, uses CA Clarity PPM). |
| ROWMIS | Right of Way Management Information System |
| SDSI | Storm Drain System Inventories |
| SHOPP Tool | State Highways Operations & Protection Program Tool |
| SMART | Inventory of Structure, Inspection Tracking, Project Ranking & Status |
| SMILE | Survey Monument Information Locator and Exporter |
| STEVE | Standard Tracking and Exchange Vehicle for Environmental |
| STIPI | Consolidated planned & programed transportation project data for transition tracking |
| TASAS | Traffic Accident Surveillance and Analysis System |
| TMS | Transportation Management Inventory |
| TRAC | Software Development |
| TSN | Inventory/Traffic/Collisions/Investigations/Analytics |




| | |
|---|---|
| TITLE | Current Caltrans Dataflow |
| DATE | February 2020 |
| AUTHOR | AHMCT |

# Appendix C:
# 2016 Caltrans Goals

The 2016 Caltrans/FHWA workshop [6] identified a number of goals and difficulties with implementing certain aspects of CIM. Table C.1 contains a list of the short-term goals. Due to changes in technology and passing time these goals may need to be revisited. An individual from Caltrans D4 suggested an alternative approach to these goals: “Identify a project for VDC/CIM, integrate VDC/CIM technologies to test, conduct the project with a concurrent design process, and document the findings.”

**Table C.1 Short-Term Goals (2 years or less) from [6]**

| **Short-term goals that participants thought could be achieved within 2 years included (from worksheet)** |
|---|
| Pilot 30% design reviews involving const., structures, roadway, utility, and survey dept. where the review specifically looks at a consolidated, multidisciplinary 3D model |
| Design 30% of new bridge structures in 3D including concrete finishes and rebar in the model, and model structural elements including pier caps and hinges |
| Provide training to district staff on how to create 3D PDFs |
| Differentiate Civil 3D training to develop “super users” in the Regions who can assist their peers on challenging modeling concepts and provide over-the-shoulder support |
| Pilot 3D inspection methods to identify optimum distribution of responsibility between surveyors and inspectors |
| Use the refined non-Standard Special Provision for AMG on pilot projects and collect measurable data to quantify the outcomes |
| Partner with the FHWA Division Office to demonstrate the cost overruns incurred from utility issues and elevate to senior Caltrans executives |

Table C.2 provides a list of the longer term goals identified by the 2016 Caltrans/FHWA workshop [6]. The project panel has been asked about progress towards the short term goals as well as challenges encountered toward achieving them. Some of these responses are included in the Appendix.

**Table C.2 Long Term Goals from [6]**

| Longer-term goals suggested by participants included (from worksheet) |
| --- |
| Implement a formal 3D model review checklist that is used at routine 30/60/90/final design reviews |
| Maintain regular industry feedback on the detail and frequency of structural 3D models provided as part of PD-06 |
| Designers are trained to, and are able to invest in visualization where they find it beneficial |
| Add a work breakdown structure code to provide for the 4D model review process before releasing models with bid documents; i.e. make 4D reviews a formal process |
| Maintain a fully-developed specification, but keep it as a special provision that is constantly reviewed to adapt to evolving technology |
| Implement SHRP2 R01A and R15B to develop a utility data repository and conflict matrices, and provide training to designers on how to use the matrices tools to assess utility-related risks and Bentley Map |

# Appendix D:
# Project Management

Many different software exist that are usable for project scheduling. Table D.1 provides a summary of the software used by various state DOTs for their project scheduling.

### Table D.1 Other DOTs Project Scheduling

| Tools | State | COTS or In-House Or modified | Application/ comments |
|---|---|---|---|
| **Microsoft Project** | CO[29], [182] | COTS | Established in 2013<br>Project scheduling<br>Coordinate production milestones for completion of assigned tasks. |
| **Microsoft Project** | MA[69][183] | COTS | Project scheduling |
| **Microsoft Project & Oracle Primavera** | NH [29], [184] | COTS/COTS | Adopted in 2009<br>Project Scheduling<br>Manage critical path schedule<br>All electronic files shall be compatible with MS Project<br>Implementing internal controls for PMs to manage project schedules<br>MS Project is official tool |
| **Oracle Primavera** | FL[29], [185] | COTS | Project scheduling, planning, managing, and updating projects within five-year work program |
| **Oracle Primavera** | ND[186] | COTS | Critical path method schedule |
| **Oracle Primavera** | WI [29], [187] | COTS | Only large or major projects use Primavera<br>Project scheduling<br>Managing the baseline budgets |

| Tools | State | COTS or In-House Or modified | Application/ comments |
| --- | --- | --- | --- |
| **Oracle Primavera** | MN[29], [188], [189] | COTS | 2009 began converting construction projects from PPMS to Primavera<br>Training needed for project managers<br>Improved project delivery could be attributed to design schedules or increased attention to on-time delivery |
| **TPro & Oracle Primavera** | GA [29], [190] | COTS/COTS | TPro and Primavera are designed to provide GDOT project schedulers, Project Managers and preconstruction personnel<br>TPro is a preconstruction Project management System<br>Oracle Primavera is commonly used |
| **Other** | OH [29], [191] | In-House | ODOT was awarded $6.8 million in federal funds for T2O project. As part of that project, ODOT is considering the use of a more elaborate scheduling tool |

# Appendix E:
# More Survey Results

More details on the results of the survey are shown below in Figures E.1 through Figure E-25. For each figure, a plot is shown representing a type of technology applied to various functions within some activity. The circular dots are reported goals for the tool usage.

## Surveying

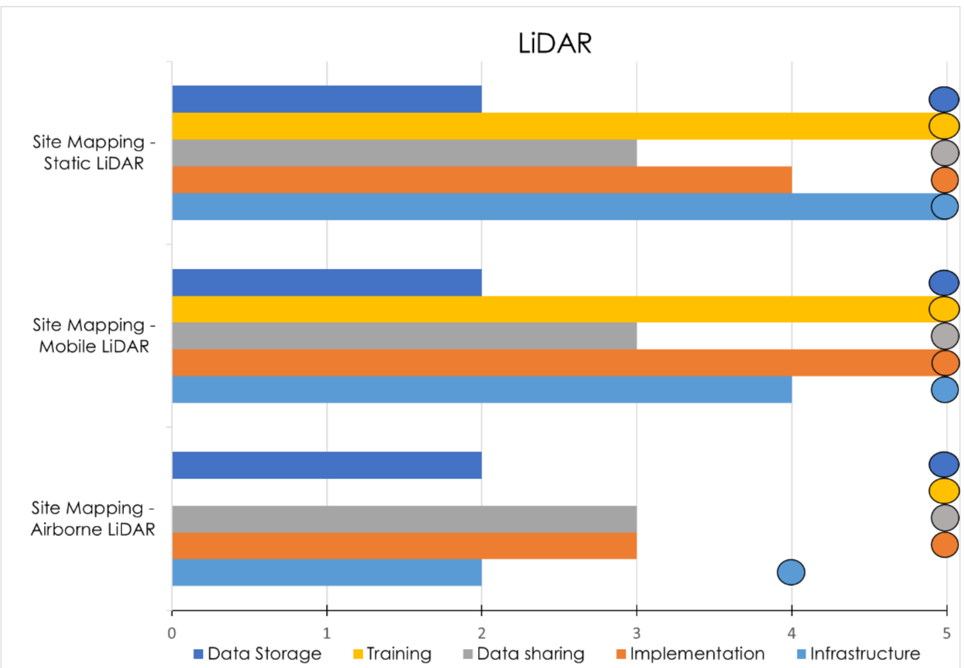



**Figure E.1 Surveying LiDAR Usage for Various Functions**

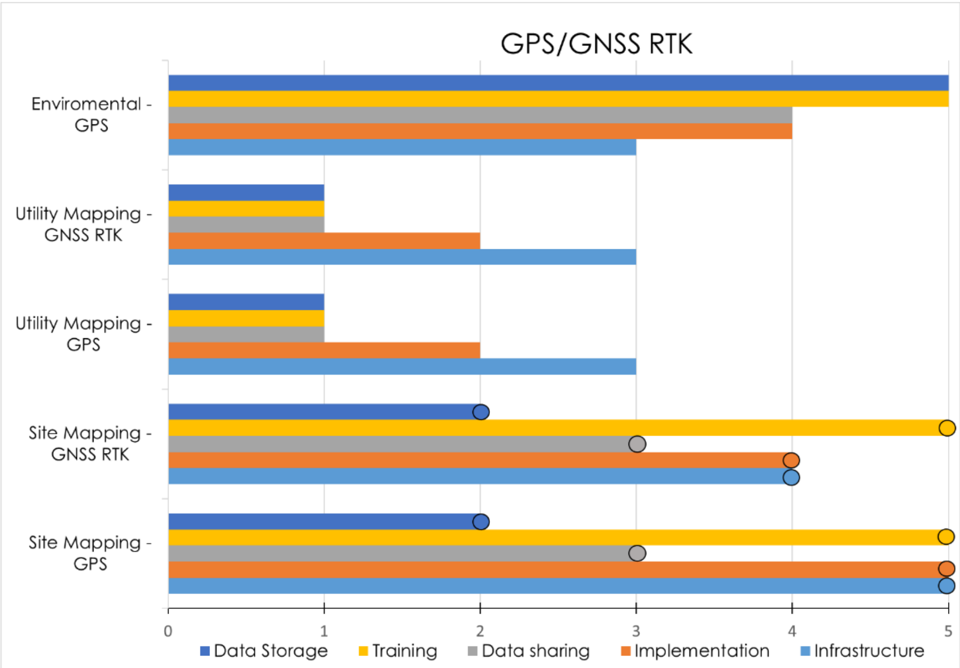



**Figure E.2 Surveying GPS/GNSS Usage for Various Functions**

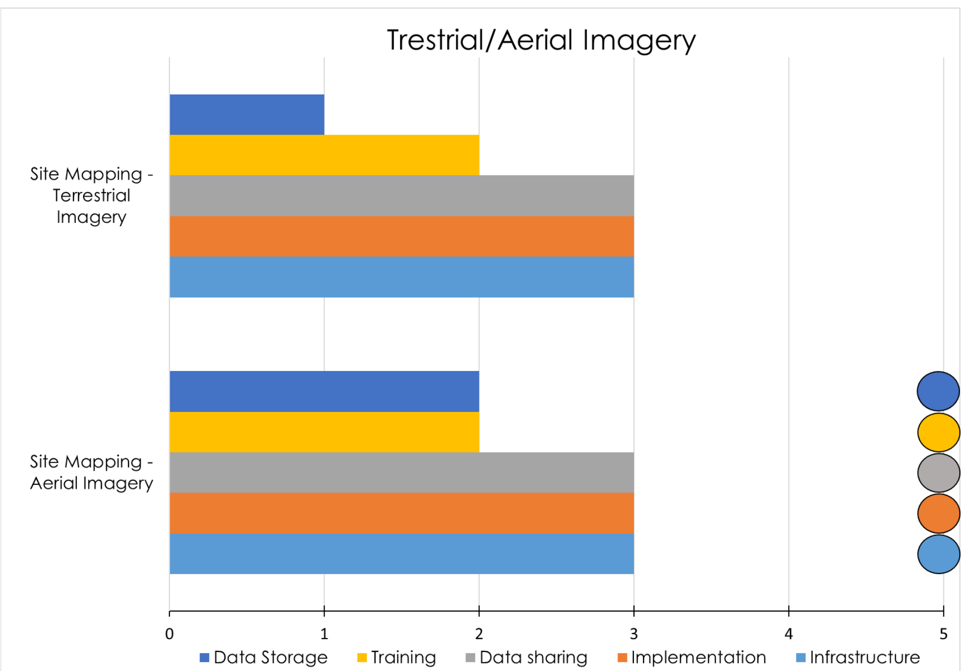



**Figure E.3 Surveying Imagery Usage for Various Functions**

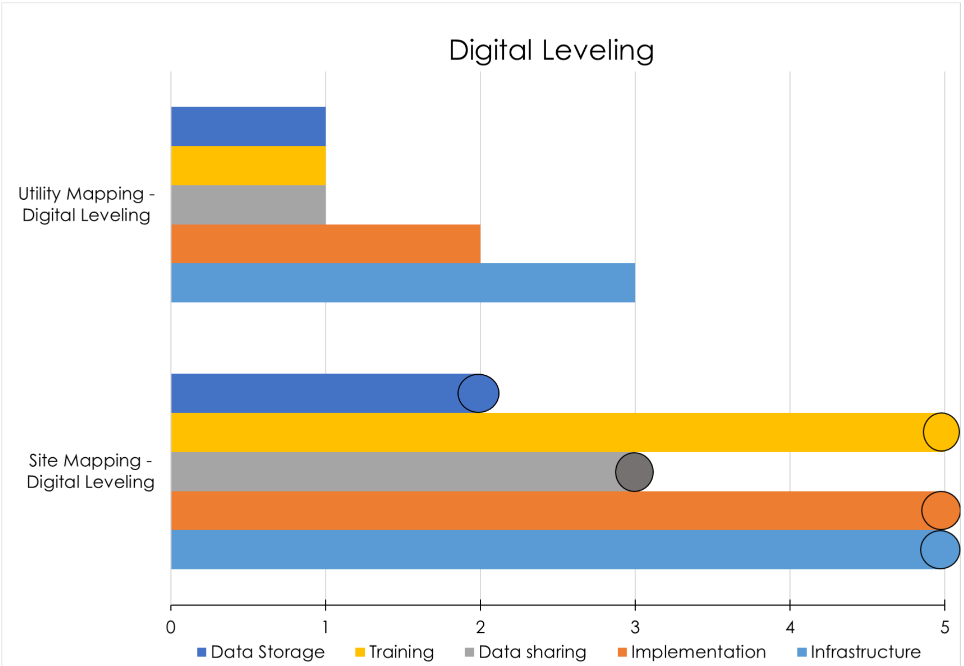



**Figure E.4 Surveying Digital Leveling Usage for Various Functions**

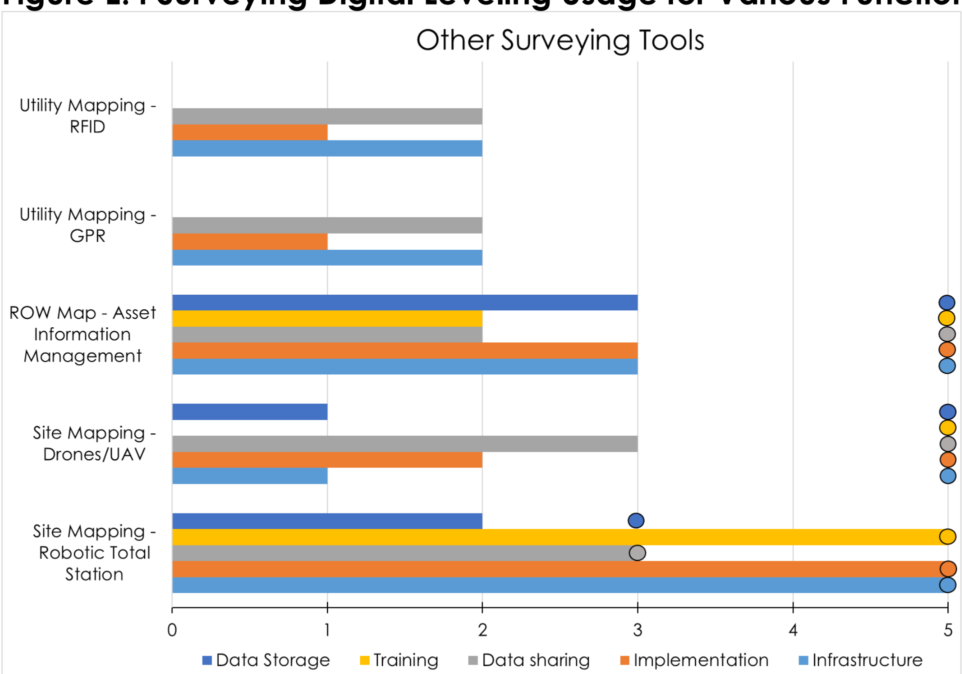



**Figure E.5 Surveying Other Tools Usage for Various Functions**

# Design

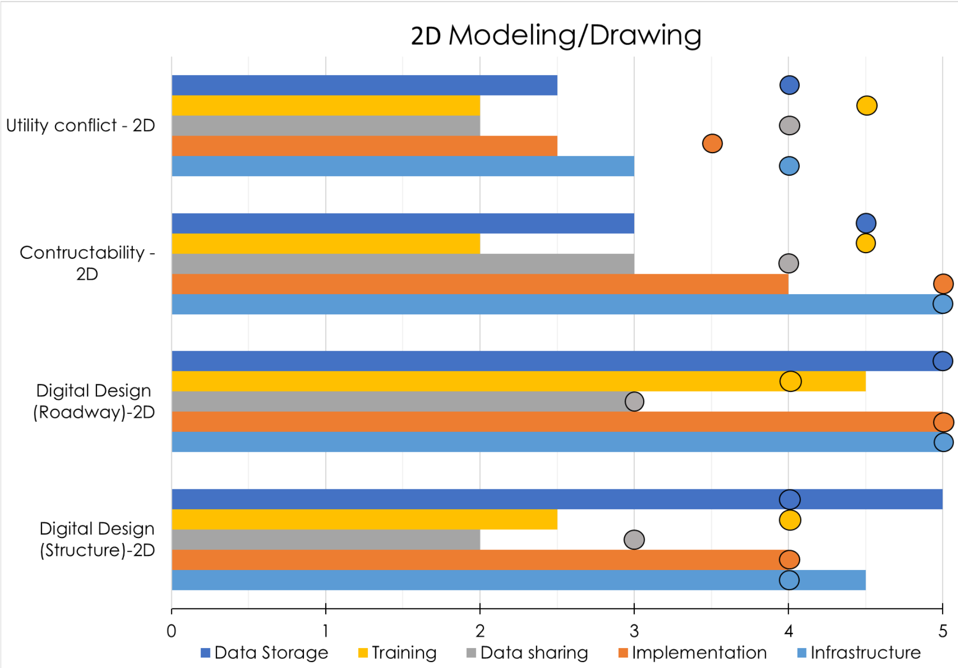



**Figure E.6 Design 2D Modeling Usage for Various Functions**

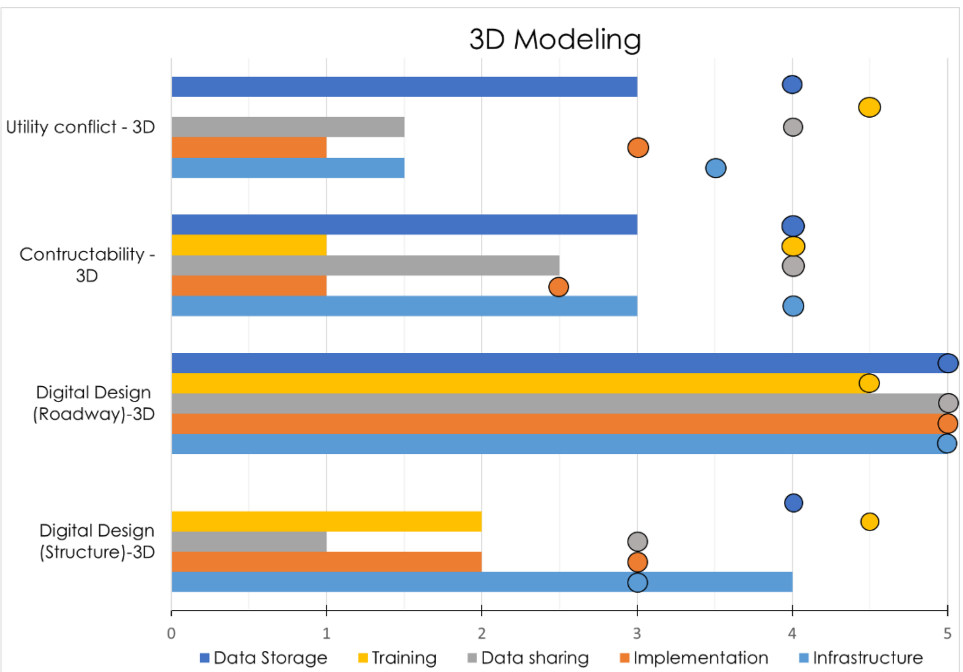



**Figure E.7 Design 3D Modeling Usage for Various Functions**

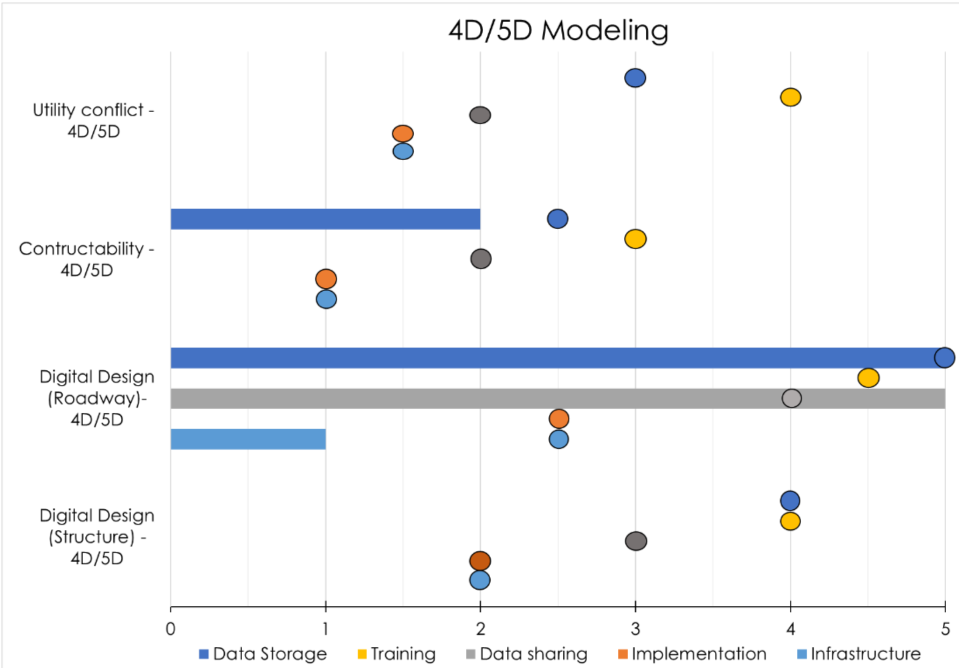



**Figure E.8 Design 4D/5D Modeling Usage for Various Functions**

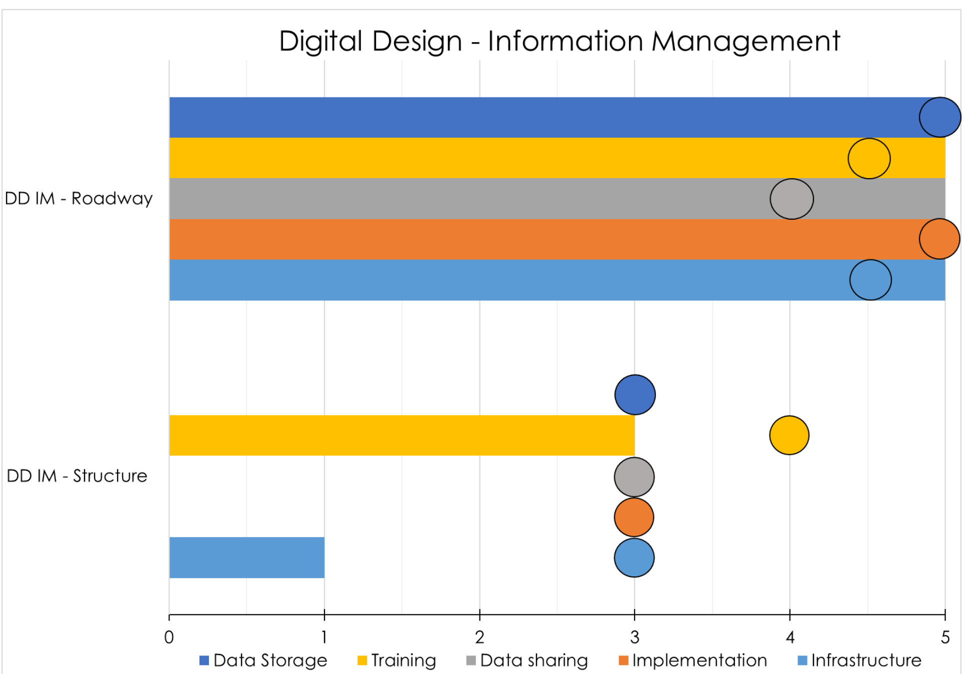



**Figure E.9 Design Information Management Usage for Various Functions**

# Construction

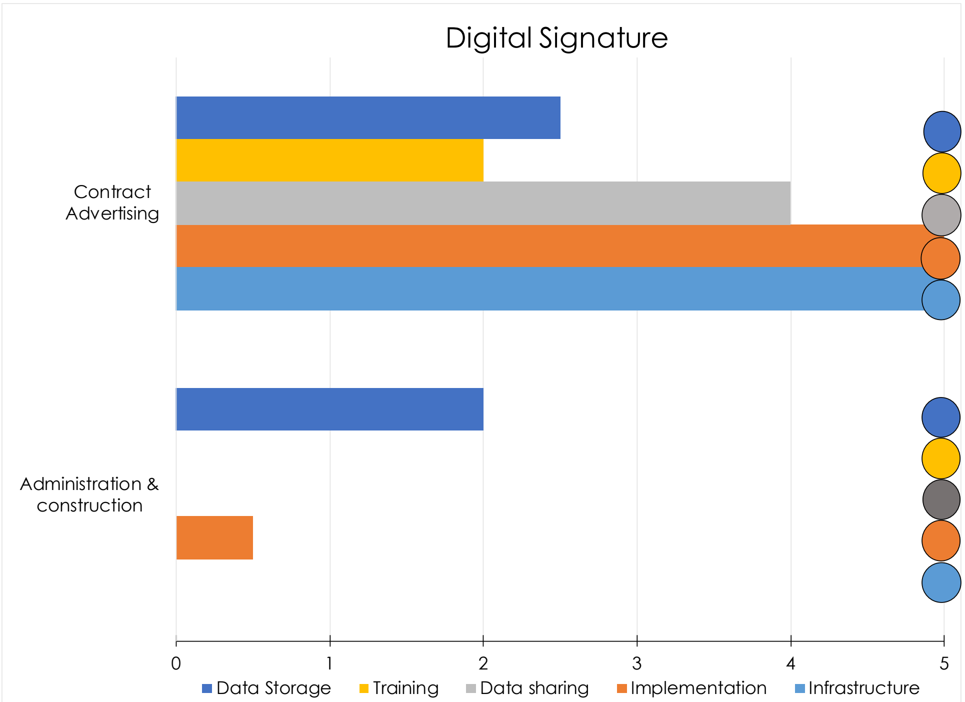



**Figure E.10 Construction Digital Signature Usage for Various Functions**

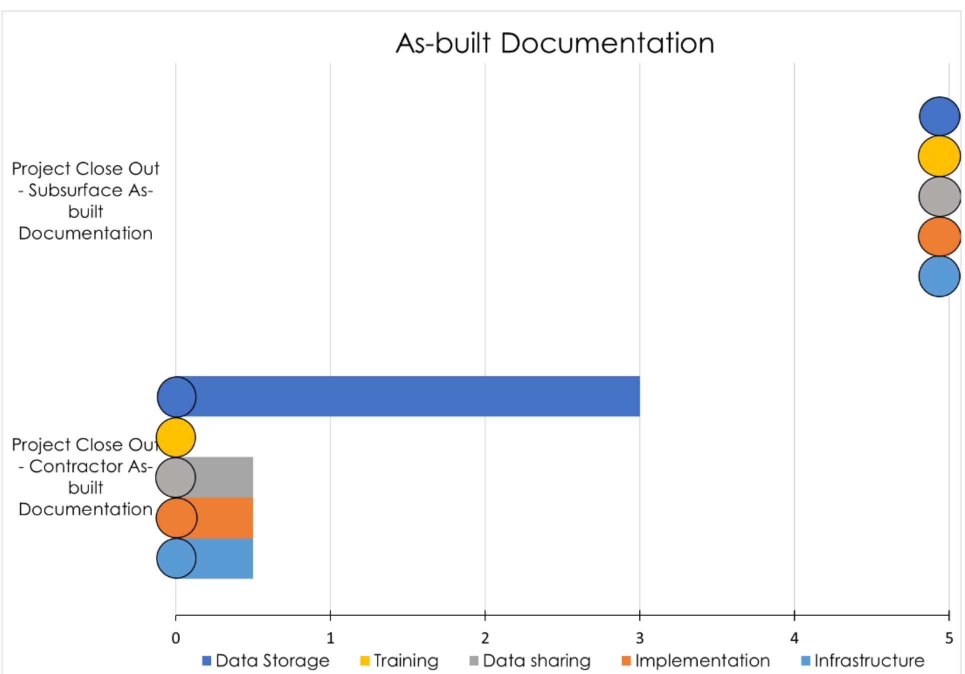



**Figure E.11 Construction As-Built Documentation**

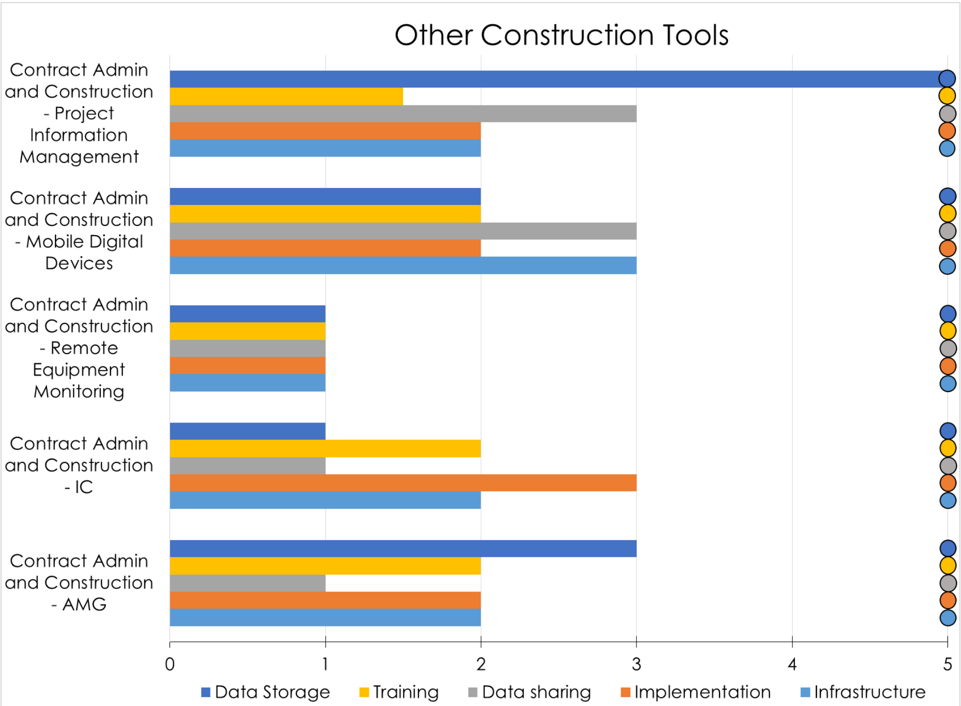



**Figure E.12 Construction Other Tool Usage for Various Functions**

# Construction Project Management

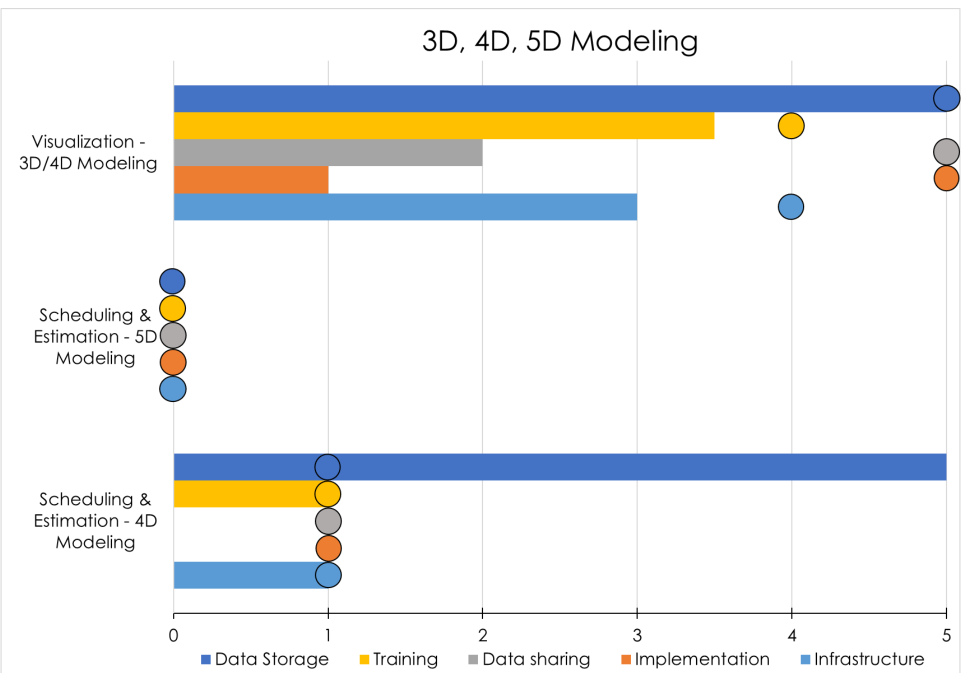



**Figure E.13 Construction Project Mgmt. 3D/4D/5D Usage for Various Functions**

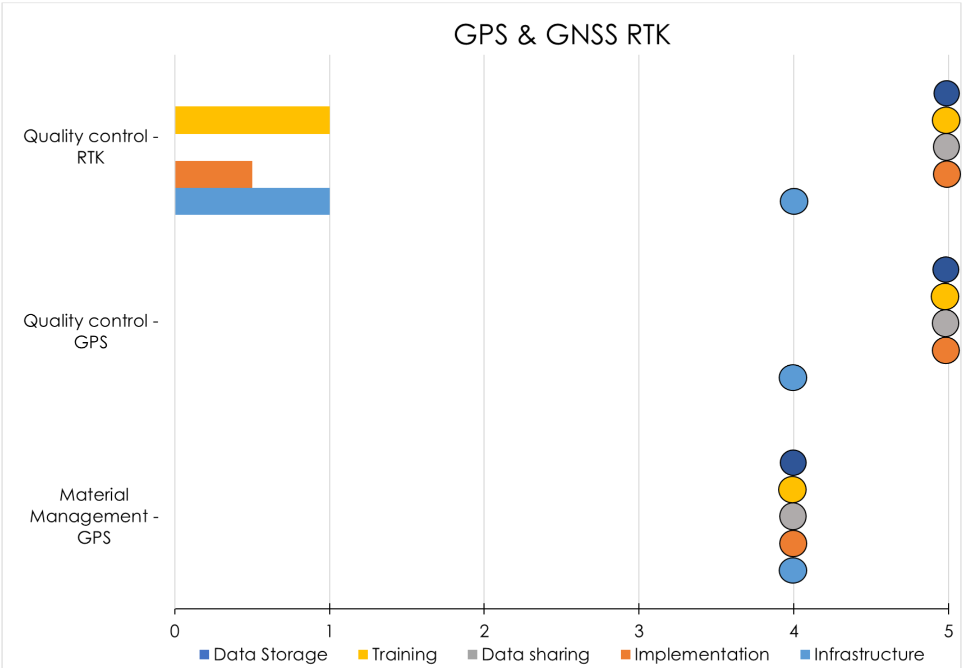



**Figure E.14 Construction Project Mgmt. GPS & RTK Usage for Various Functions**

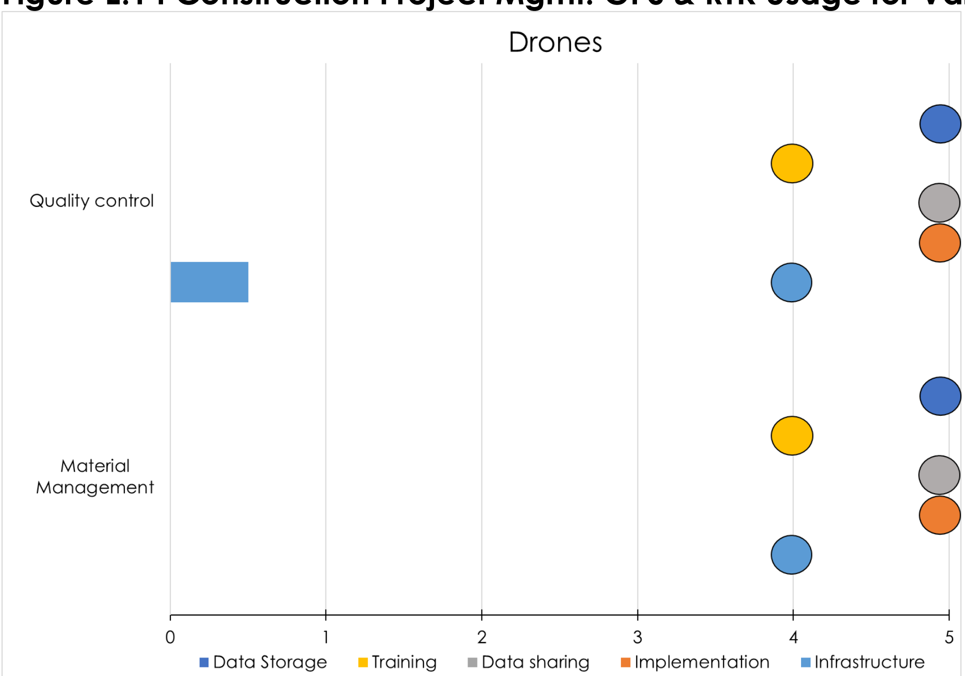



**Figure E.15 Construction Project Mgmt. Drones Usage for Various Functions**

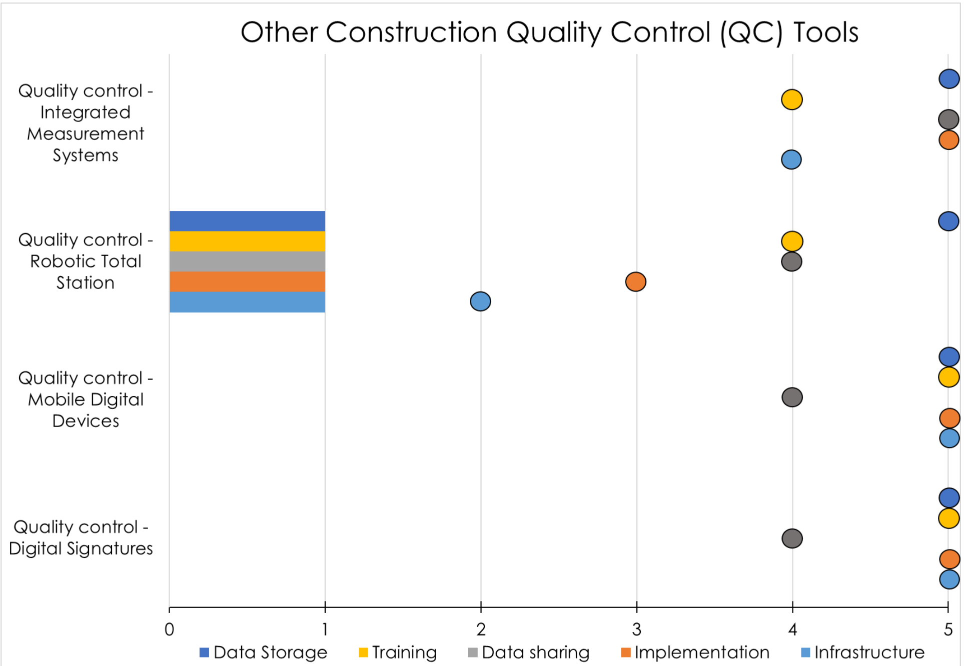



**Figure E.16 Construction Project Mgmt. QC Usage for Various Functions**

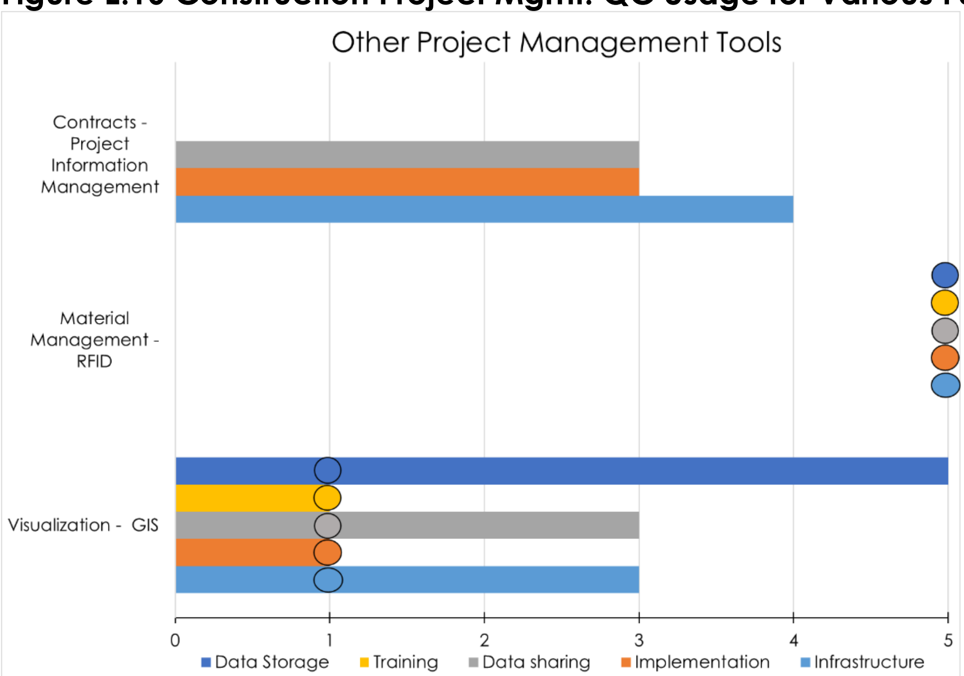



**Figure E.17 Construction Project Mgmt. Other Tools Usage for Various Functions**

# Project Delivery Project Management

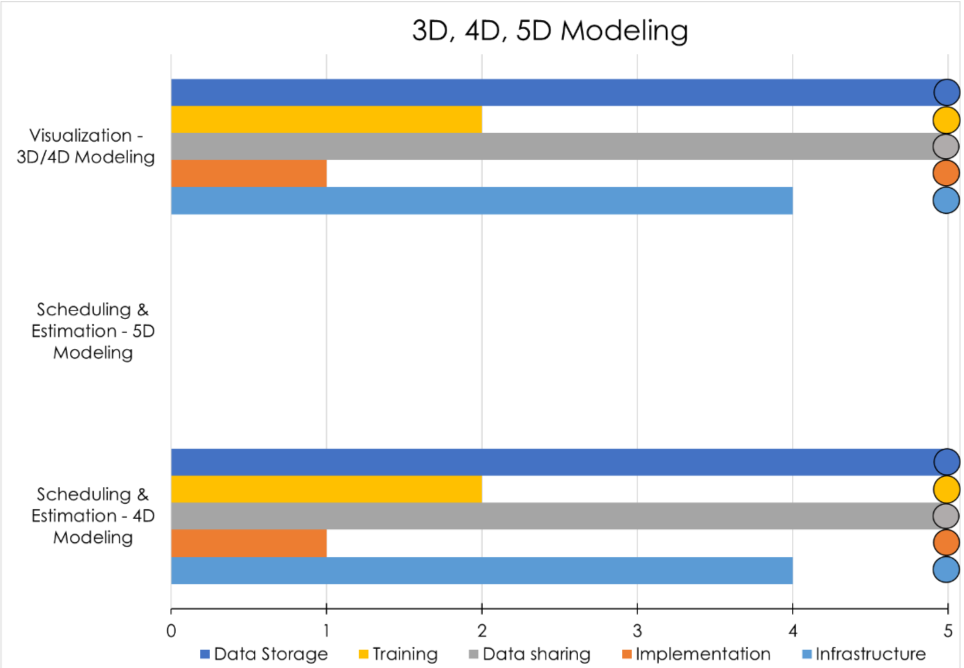



**Figure E.18 Project Delivery Project Mgmt. 3D/4D/5D Usage for Various Functions**

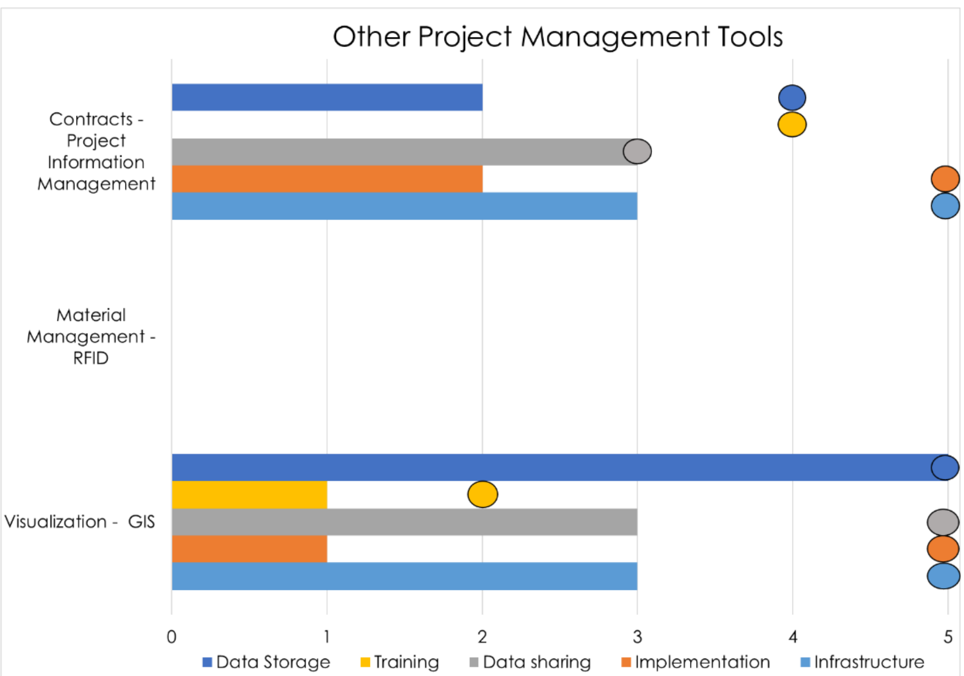



**Figure E.19 Project Delivery Project Mgmt. Other Tool Usage for Various Functions**

# Asset Management

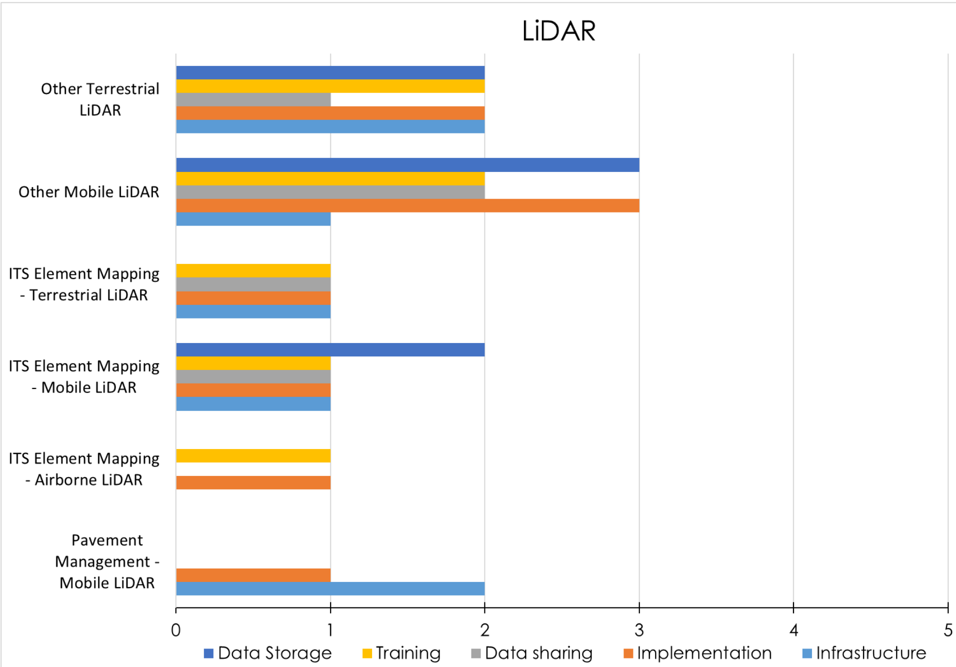



**Figure E.20 Asset Management LiDAR Usage for Various Functions**

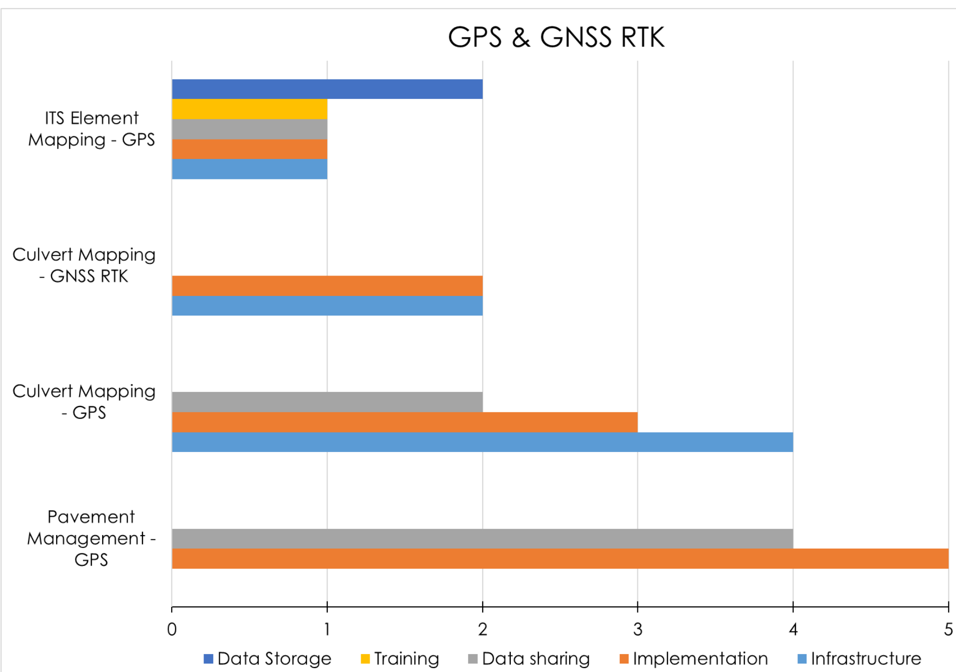



**Figure E.21 Asset Management GPS/GNSS Usage for Various Functions**

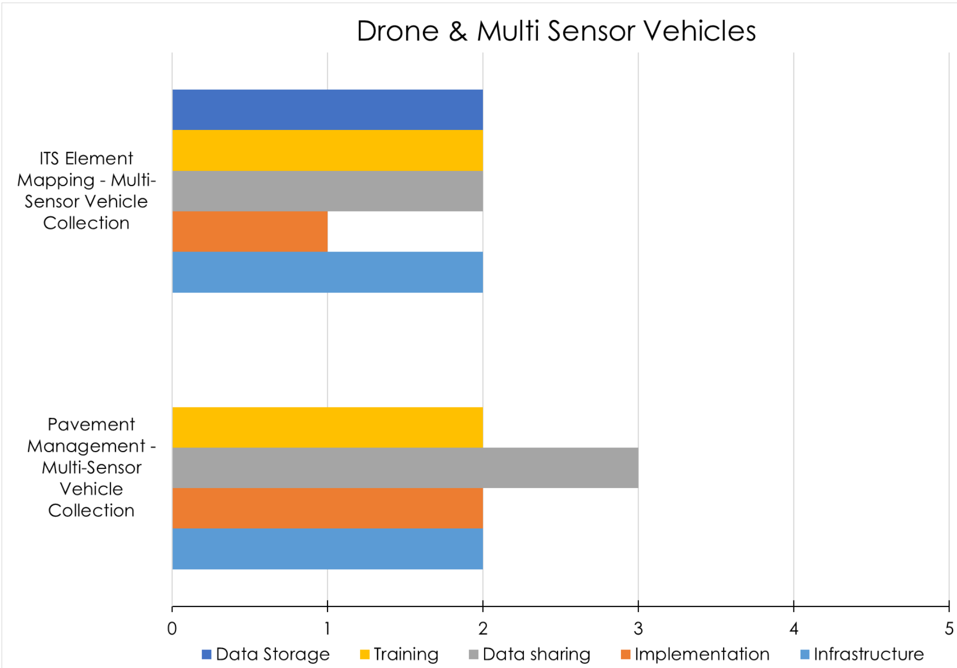



**Figure E.22 Asset Management Drone & Multi Sensor Vehicle Usage**

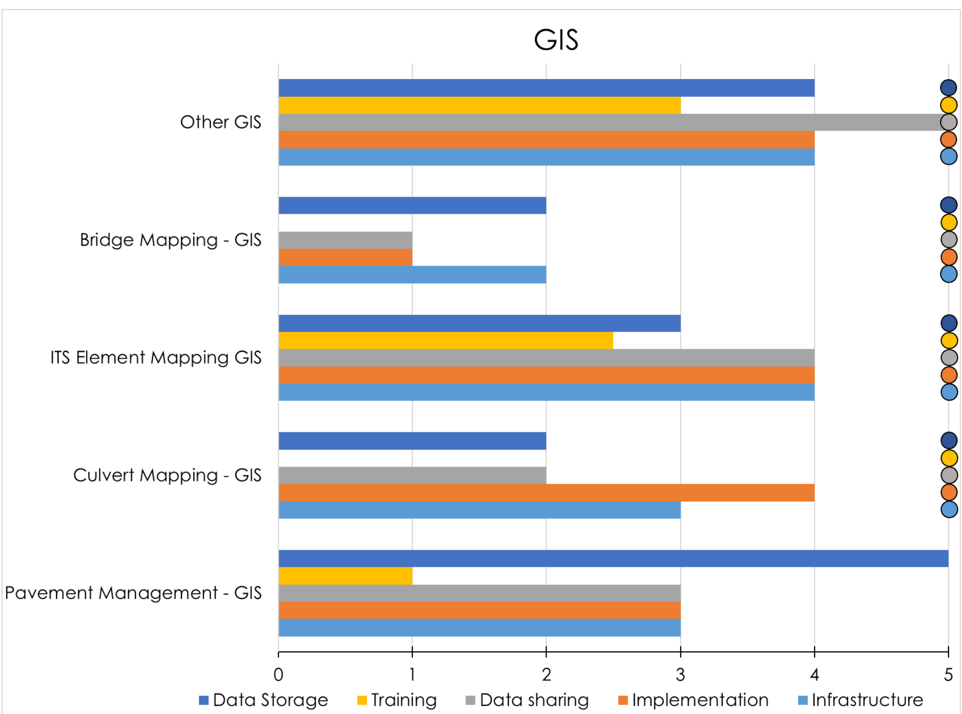



**Figure E.23 Asset Management GIS Usage for Various Functions**

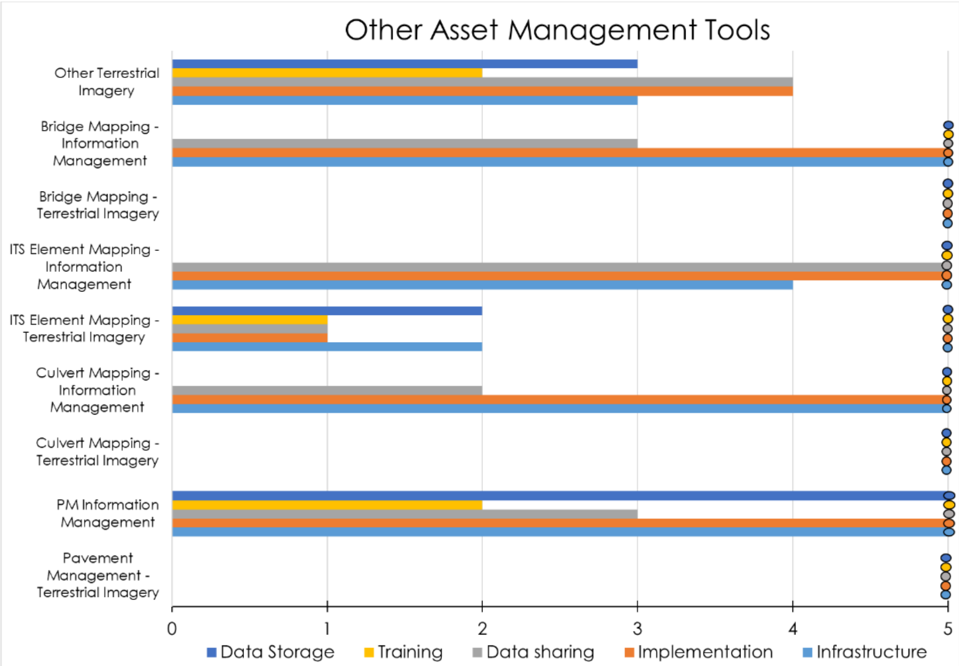



**Figure E.24 Asset Management Other Usage for Various Functions**

# Maintenance

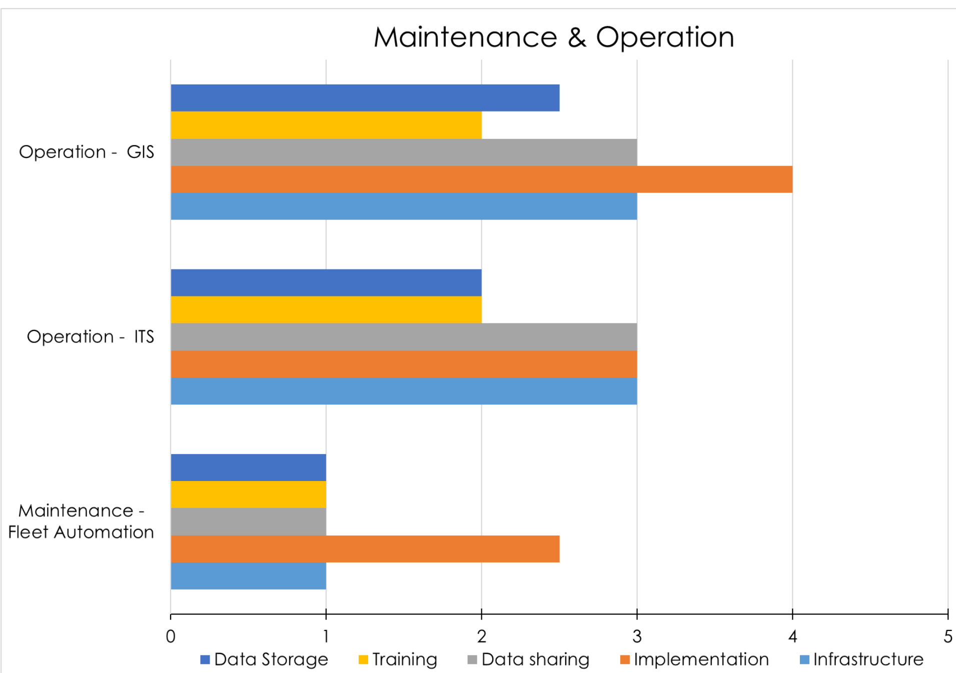



**Figure E.25 Maintenance & Operations Tool Usage for Various Functions**

# Appendix F: Integrated Project Delivery Recommendations

This appendix contains recommendations and information contributed by Caltrans D4 that shows specific examples of how software and systems can be applied.

## Environmental EDMS, Design EDMS, Construction EDMS:

The current industry best practices for Environmental and Engineering Document Management Systems, as part of an Integrated Project delivery project development work flow, are the following implementations;

- Bentley ProjectWise 365[36]
- Autodesk Vault 2020 (Project Sync)[37]
- eBuilder cloud-based, planning, design and construction Program Management Information Solution (PMIS)

## Environmental Database & GIS:

The industry solution is currently based on cloud based Integrated Project Delivery (IPD) work flow, which allows each discipline to keep their data sources in their native forms as well as utilizing ESRI GIS geodatabases and story board and insight to provide a collaborative environment during the "K" and "0" phase of the PAED process.

[36] Bentley ProcjetWise 365 (https://www.bentley.com/en/products/brands/projectwise#services)

[37] Autodesk Vault 2020 (https://knowledge.autodesk.com/support/vault-products/learn-explore/caas/CloudHelp/cloudhelp/2020/ENU/Vault-New/files/GUID-AB77C01B-811E-4E29-8A48-36EFE55DFA3B-htm.html)

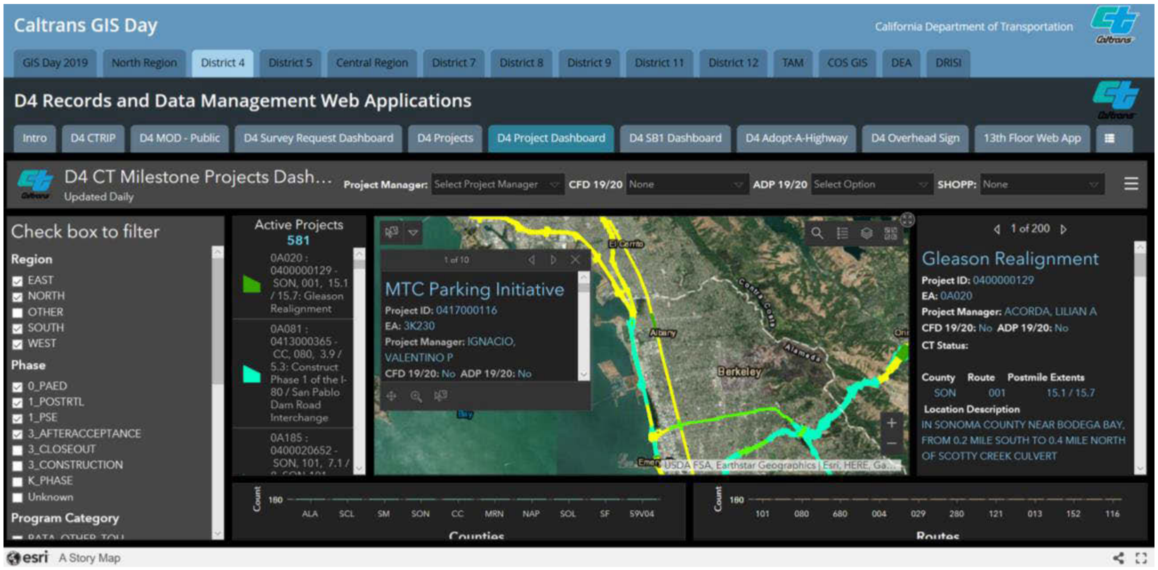


**Figure F.1 Caltras D4 Records and Data Management Web Applications**

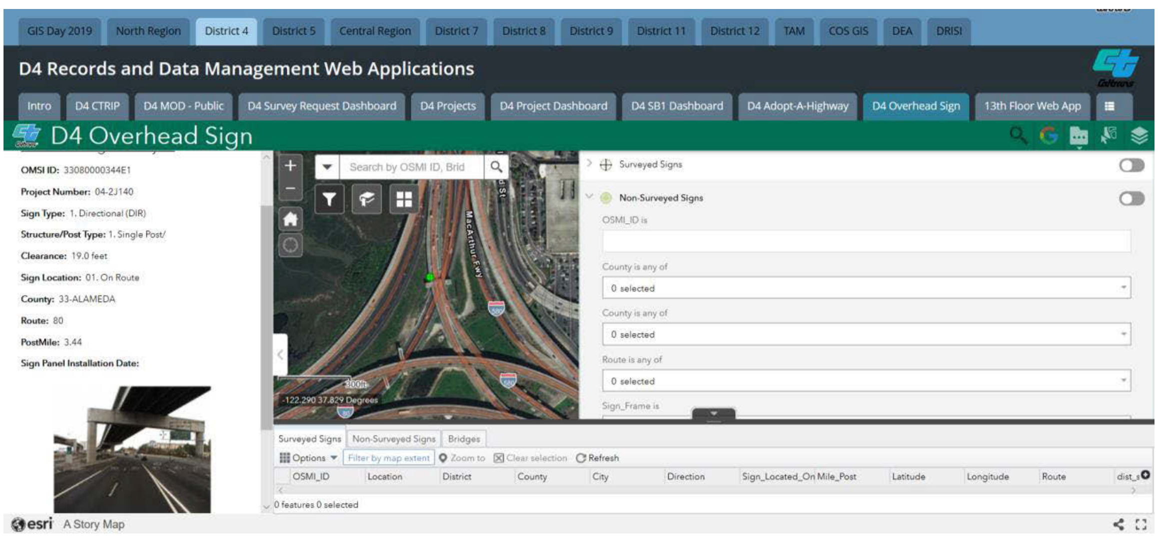


**Figure F.2 Caltras D4 Records and Data Management Web Applications**

# Surveying Mobile LiDAR:

The combination of DTM 3D survey chains, TIN and point cloud data provide a 3D immersive virtual environment that allows the design team to take full advantage of 3D modeling during the PS&E process as shown in Figure F.3. This translates to better, more accurate design and decreases the number of CCOs caused by design error.

The collaborative approach effort between the Design and Survey Divisions at the HQ and District levels is to ensure both divisions are committed to 3D modeling during project delivery. Since Survey provides the initial 3D Digital Terrain Model (DTM) for the Civil3D environment. It is the responsibility of the project engineer to ensure per-project scope required 3D modeling. When MTLS and STLS are used in the survey data collection, 3D point cloud data should be delivered to the design team in a format compatible with MicroStation and Civil3D environments. Having the 3D point cloud data empowers the design team to deliver the 3D Digital Design Model (DDM). Point cloud data ensures the slope stake notes for Survey Engineer File (SEF) and any potential Request For Information (RFI) is analogized in a 3D environment thus providing quality feedback.

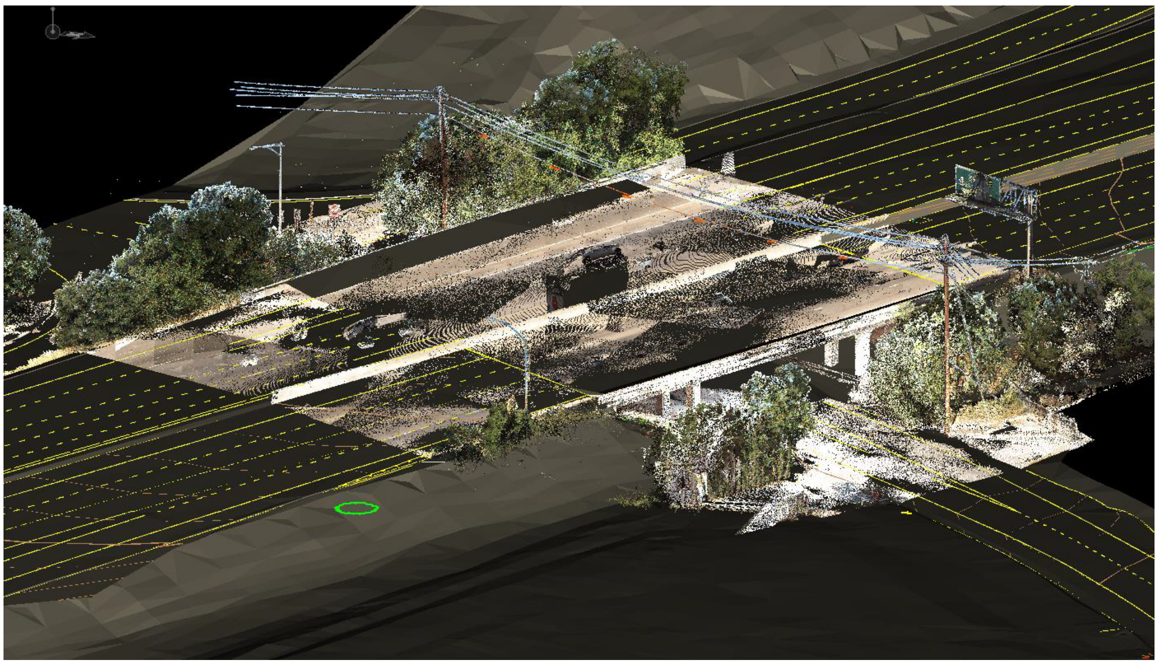


**Figure F.3 Route Alameda 680 Express Lane Project Digital Terrain Model and Lidar Data Set**

# Surveying Airborne LiDAR:

Establish better standards for classification tables of airborne data for in-house processing protocols. Incorporate detailed airborne LiDAR classification and registration standards into the task order contract for mapping consultants.

# Design (roadway & structure):

- Bentley's iModel with the BIM workflow [192]
- Autodesk Integration Project Delivery
- Hybrid solution with a combination of tools from Bentley & Autodesk

# Design Collaboration:

Challenge:

- Complex field conditions can present challenges as you try to accurately represent existing conditions during civil infrastructure project development. To help plan and design transportation projects, a broad collection of data must be accessible and usable.

Solution:

- Import and process data from a wider variety of sources for existing conditions, survey field crews can be better equipped and plan to execute the survey plan before leaving the office.
- Aggregate CAD, GIS, terrain, raster, LIDAR, and more, into a highly accurate 3D in context model using real-world coordinate systems.
- Improve data quality using automated tools, such as drawing cleanup and data classification.

# Construction Mobile Devices:

Trimble (SiteVision) and other AR devices will be a vital part of the information transfer from model to site (Digital Twin), examples are shown in Figure F.4, and Figure F.5.

**Figure F.4 Geometry positioning**


**Figure F.5 Model size limits**

# Construction CM/GC:

Developing standard language to include IPD & VDC with 3D & 4D modeling for incorporation into every CMGC contract is recommended. Particularly since the high-end contractor community is advanced in the area of standardized terms faster than the design sector. For example, in the SM-101 Express lane project, the design team utilized 3D modeling from the PAED phase all the way through the PS&E phase. The model and the Survey Engineer File by-products will be used for construction. An example 3D visualization is shown in Figure F.6.

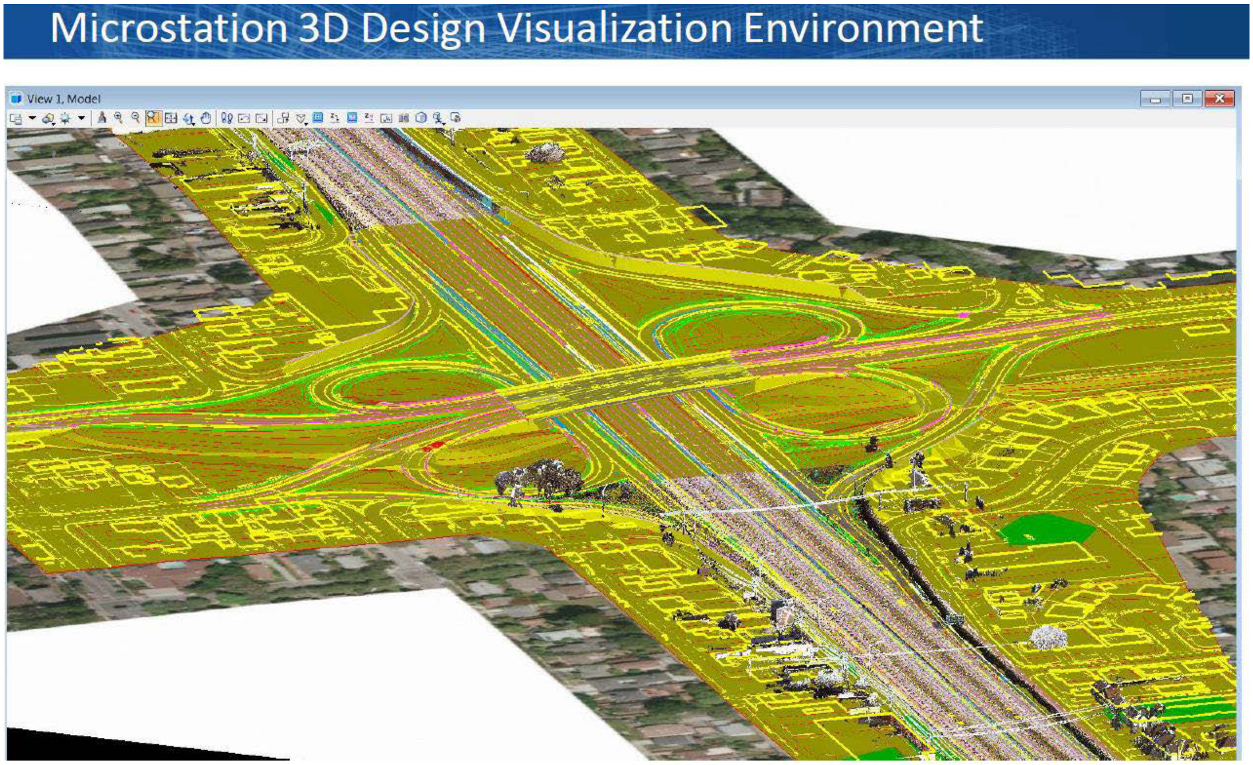



**Figure F.6 Microstation 3D Visulization Originally Presented at AEC Next[38]**

# Maintenance GIS:

GIS should be part of the design tool chain in the VDC frame work. Currently, the department is mainly utilizing GIS for cartography, Geodatabse, and ArcGIS online applications. More emphasis is needed on ArcGIS Pro platform and WEBScene technology to implement BIM in GIS.

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[38] Kourosh Langari originally presented this slide as part of a presentation titled "21st Century Infrastructure Project Execution/Redefining Project Phases" at the 2018 AEC Next Expo and Conference.

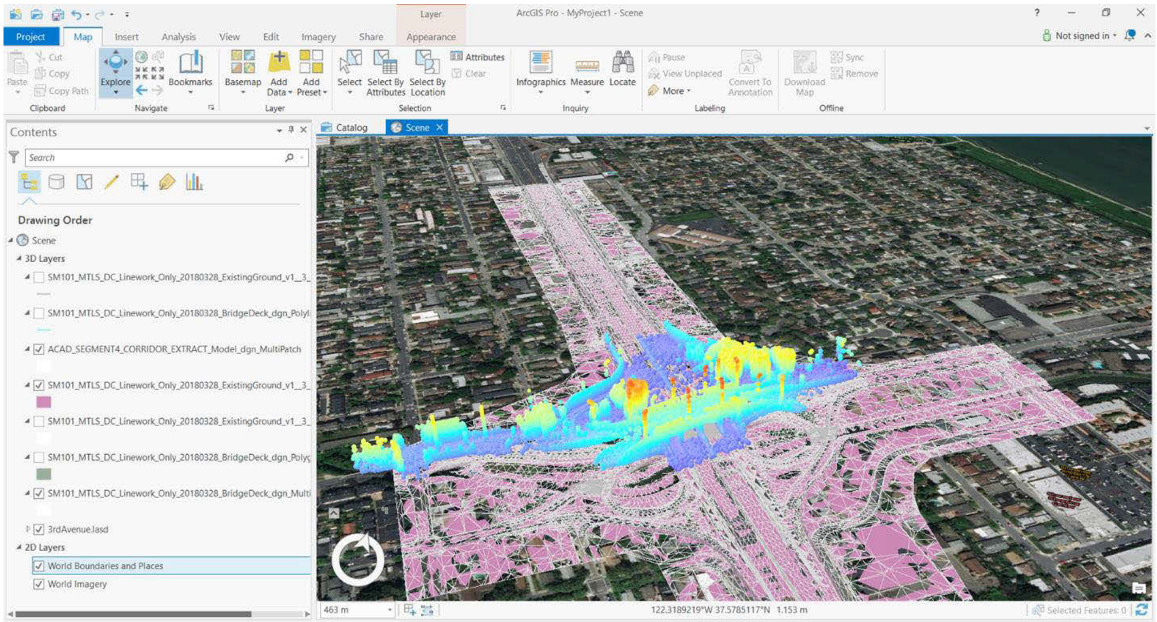

**Figure F.7 ArcGIS Pro Environment with 3D BIM design data from MicroStation & Civil 3D Environment for SM-101 project during the PAED & PS&E process.**

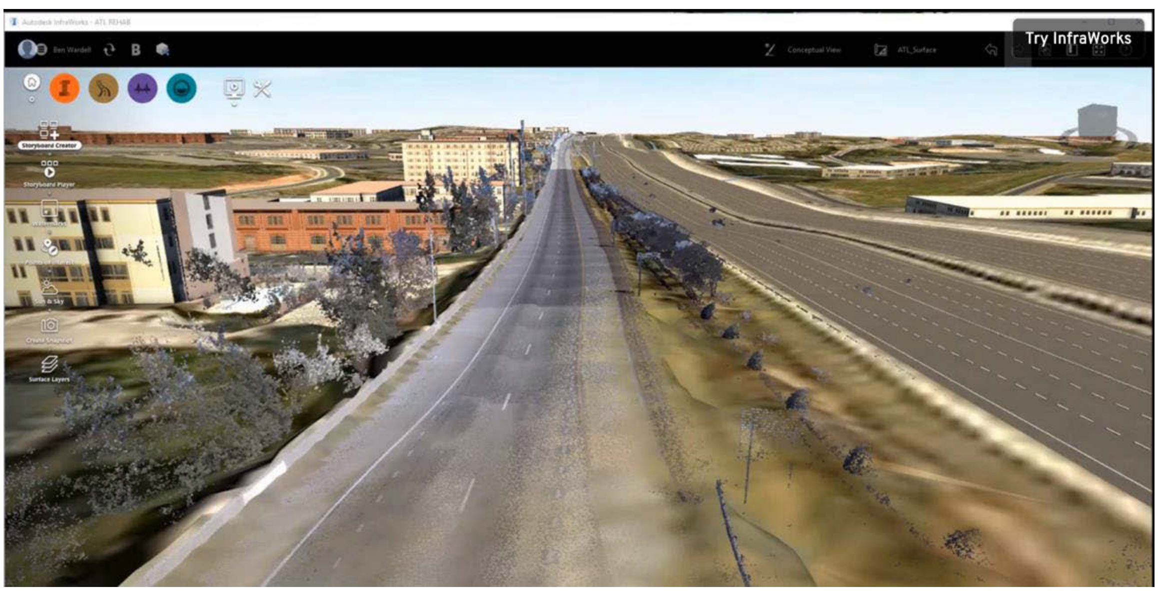


**Figure F.8 WebScene technology in Infraworks and ESRI environment for SM101 corridor**