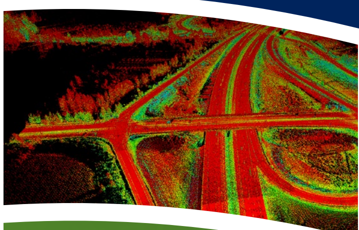
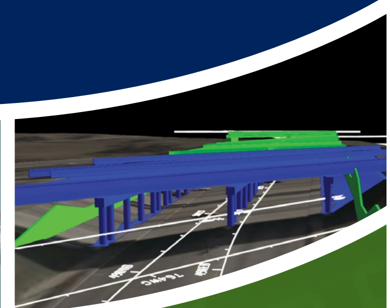
Guide for

Optimizing Survey Data for 3D Design

Spring 2017





3D Engineered Models:

Schedule, Cost, and Post-Construction

*An **Every Day Counts** Innovation*

U.S. Department of Transportation
Federal Highway Administration

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Optimizing Survey Data for 3D Design

Introduction

Digital project delivery is a paradigm that can enable the State Transportation Agency (STA) to make effective decisions throughout the project lifecycle. All project delivery starts with a sound understanding of the existing site conditions. The closer that understanding is to the actual field conditions, the more meaningful the decisions made during design will be, leading to a more efficient and effective design and construction process. The challenge of getting a complete picture from this valuable information is mainly due to a lack of data governance protocols and descriptive information about the data itself. Accessibility to the survey information is further complicated if the data is housed within hardcopy documents, such as field books, or in a legacy (or proprietary) format incompatible with current systems, thus making the data largely unusable. This poses difficulty in effectively using data that may in fact be valuable for 3D design.

Moreover, organizations such as STAs do not leverage the full value of survey data and expertise throughout the project delivery spectrum. This is evidenced by limited investment in and attention to survey data up-front in the design process and deferring risks into construction. In fact, lower confidence and high uncertainty in the use of survey data widen the gap between estimated and actual construction costs. A successful strategy easily employed by STAs to reduce this uncertainty and elevate confidence is building and nurturing collaborative relationships between design staff and survey staff. This ensures survey-related opportunities are considered and acted upon early in the design to confidently reduce risks in construction.

Figure 1. Helicopter LiDAR[1] Survey Dataset for Roadway 3D Design[2]

1 Light Detection and Ranging

2 Image courtesy of Missouri Department of Transportation

Some transportation projects span many years and create unavoidable uncertainty in the reliability of the base map from which the design is created. Several considerations, which are outlined in this document, need to be taken into account before moving ahead with design or construction after such a long delay. Hence, there needs to be a process that evaluates the base map for accuracy and reliability at key milestones. This Guide discusses four key principles—risk management, agility, collaboration, and metadata—to help the designer optimize survey data for 3D design. This information will help designers understand the risks associated with base map data and to work with the resident engineer in addressing potential risks prior to construction.

This document provides general guidance intended to allow organizations to take a risk-based approach to investing in preconstruction survey. Understanding the risks and mitigation measures will allow STAs to better control the project costs and quality before construction begins.

Overview of Survey Data

Figure 2. Triangulated Irregular Network (TIN) Model Superimposed on Project Site Photograph[3]

Surveying is a key process in the design and construction of highway projects through determining property boundaries for both public and private land, mapping the existing terrain conditions, and laying out the location of future roads and bridges. Survey technologies collect data actively (e.g., LiDAR sensors) or passively (e.g., total stations or global navigation satellite system (GNSS) receivers) and can be georeferenced (e.g., grid coordinates) or localized (e.g., ground coordinates). Typically, a combination of surveying technologies is used to collect survey data and is subsequently developed into a base map in a process referred to as data fusion. Survey data is the foundation for successful use of 3D models in construction projects.

The designer needs to know what survey data is available to start the design and needs to understand certain characteristics of the data. There are many sources of survey data with varying levels of accuracies, densities, and applicability, but understanding the key terms described in Table 1 will help limit exposures to risk.

3 Image courtesy of Certainty 3D

Table 1. Key Terms Related to Survey Data

Term	Description
Accuracy	**Absolute accuracy** means the deviation of measurement from the National Spatial Reference System (NSRS) network of primary control. **Local accuracy** means deviation of measurement from the local network of secondary control. ***Limitations:*** Homogeneity of multiple data sources is limited with varying levels of accuracy. Appropriate use of survey data is driven by the accuracy of the data.
Coordinate Systems	**Coordinate systems** are reference systems used to specify the position of a point either geographically or on a projected surface. **Grid coordinates** are referenced to a projected planar surface defined by a datum, i.e., state plane coordinate system or low-distortion projection. **Ground coordinates** are derived from grid coordinates by applying a combined factor. ***Limitations:*** Project design should never mix grid and ground coordinates. Make sure to communicate the approved coordinate system basis of the design before the survey data is collected. Consult with appropriate survey staff for assistance.
Datum[4]	**A datum** is a mathematical reference model used to approximate positions on the Earth. **A "horizontal" datum** (Cartesian x- and y-axis) defines coordinates. **A "vertical" datum** (Cartesian z-axis) defines elevations. ***Limitations:*** Datums not currently maintained by the National Geodetic Survey (NGS) or other designated authority pose significant risk to project success due to absolute accuracy uncertainty and unreliable datum relationships.

Furthermore, incorrectly applying assumptions with using survey data, i.e., requesting high-accuracy survey data for design elements that do not need it, will increase the likelihood and severity of cost overruns because the survey data costs are directly proportional to accuracy level. This underscores the importance of partnering with survey staff early in project development, so unnecessary expenditures are avoided through constructive discussions on meeting the needs of the design. Survey data classifications and associated risks are listed in Table 2.

Table 2. Survey Data Used in 3D Design and Risk Potential

Survey Data Classifications	Survey Data Type	Potential Risks	Potential Risk Impact
Cadastral Data (2D)	points and lines	Change in ownership, right-of-way acquisition, communicating project limits to construction staff	**\$-\$\$**
Mapping Data (2D/3D)	points, lines, and surfaces	Age or source of original survey, original accuracy no longer appropriate for application, etc.	**\$\$-\$\$\$**
Control Data (3D)—Primary and Local	points	Primary—variable horizontal/vertical datum references and absolute accuracies Local—density needs, critical structure locations, and variable local accuracies	**\$\$\$-\$\$\$\$**

Progressive and strategic involvement with appropriate survey staff early in the project will help with addressing project accuracy needs, identifying supplemental needs in current survey data, and receiving new or proper updates for continued development of the 3D model.

Impact of Survey Data on Design

Designers are exposed to survey data either when working with their original base map data or during subsequent updates to their base map. The impact of how well the survey data meets the needs of the designer resonates throughout the remainder of the project design and construction, so it is imperative that deliberate steps to mitigate risk are taken in

4 In 2022, NGS will be replacing horizontal and vertical datums with a 3D datum, which will affect transportation projects. For more information on the upcoming datum, see *https://www.ngs.noaa.gov/datums/newdatums/* .

the early stages of project development. Those risks that cannot be addressed early should maintain visibility to the designer and resident engineer, so they can be responded to at the appropriate time.

The base map data serves as the foundation from which the design is built, so the more accurate this data, the more robust and effective the design will be. In addition to knowing what survey data is contained within the base map data, the designer also needs to understand how to read and comprehend metadata as well as the surveyor's report. Metadata and the surveyor's report bring awareness and insight into the critical details necessary to make informed decisions regarding risks and opportunities.

Base map data should include:

- 2D land boundary data
- 3D planimetric data
- 3D alignment data
- 3D surface data with contours and breaklines
- Aerial imagery

Modern, parametric design tools enable designers to quickly propagate design changes through the design documents. This gives the designer greater flexibility through data fusion in working with survey staff to vary both the collection method and the collection time. In this way, high accuracy can be acquired only where needed and at a time in the design process when the footprint is established and the likelihood of change in the field conditions before construction is lower.

Role of Survey Data in Risk Management

Many agencies have formalized risk mitigation and planning for some project types. This process can be used to identify, assess, and mitigate the risks associated with geometric design in construction, which can improve workflows and result in more effective, efficient, and safer project delivery. An example of a risk management approach[5] is illustrated in Figure 3.

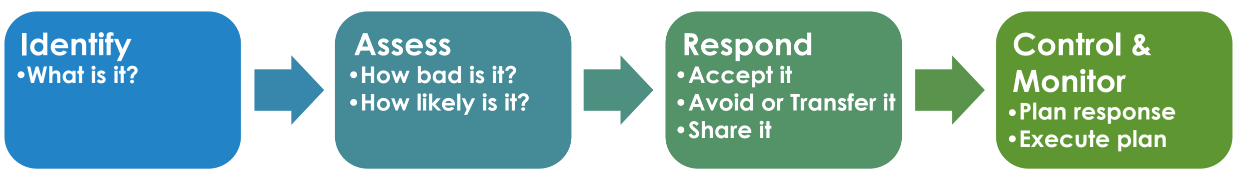


Figure 3. Traditional Risk Management Approach

Risk Assessment During Design

A risk assessment is recommended to identify the high-risk design elements that are more susceptible to failure if the survey data does not accurately represent field conditions as close as practicable to when the construction phase begins. Evaluating the likelihood of a risk event occurring and the severity of the impact will inform mitigation efforts. The types of risks that arise if the survey data does not accurately reflect the field conditions in construction are quantity differences, constructability issues, and unclear design intent. The impacts vary by feature and may vary along a feature. Some examples are shown in Table 3.

Table 3. Example Impacts and Potential Costs

Impacts	Potential Cost
Quantity deviations	$$-$$$
Requests for Information (RFIs)	$$
Field-fits	$-$$
Redesign	$-$$
Rework	$-$$
Delays	$$$
Disputes	$$-$$$
Change orders	$-$$$
Claims	$$-$$$$
Safety hazards	$-$$$$

5 Minnesota Department of Transportation. (n.d.). Minnesota Department of Transportation Project Management Guidance. Retrieved November 15, 2016, from Minnesota Department of Transportation website: *http://www.dot.state.mn.us/pm/documents/project-risk-management.docx*

Thus, it is critical to identify the features that pose the biggest threat. Figure 4 offers some insight into where to focus mitigation efforts for a given data classification.

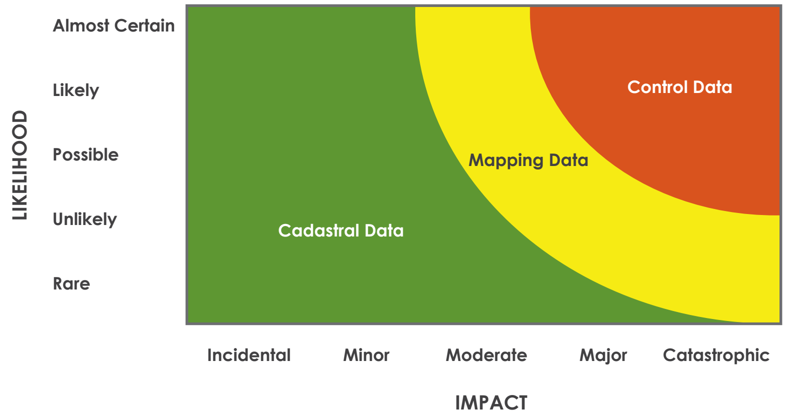


Figure 4. Example Survey Data Risk Heat Map

Responding to Risk During Design

The probability of a risk can be reduced by collecting high-accuracy survey before completing design, but that is not worthwhile if the cost of data collection is higher than the impact of the risk. That represents a case where risk can be accepted or managed in construction. Many risks are acceptable in construction, but can lead to issues if the resident engineer is not aware of the risk and has not had time to formulate a response plan. Figure 5 illustrates what margin of error may be acceptable or unacceptable during construction.

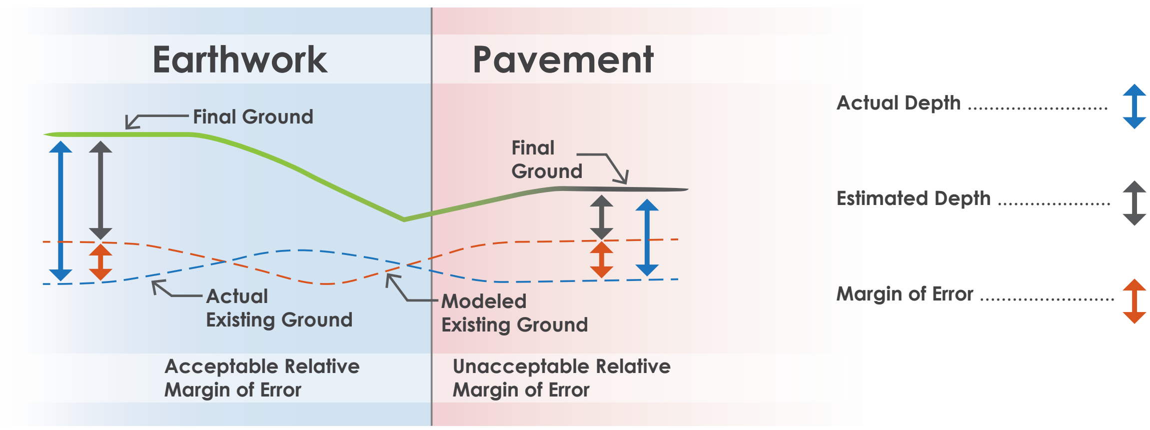


Figure 5. Margin of Error Depends on Project Feature Tolerances

There are many strategies that the designer can use to reduce risks, mainly by communicating the base map certified accuracies and the data confidence levels.[6] For references related to defined confidence levels, please consult the Federal Highway Administration's Utilizing 3D Digital Design Data in Highway Construction final report.[7]

Also, because risks are more likely to occur when the uncertainty of the survey data varies by feature and location, it is critical to work with the resident engineer to identify the features that pose the biggest threat for creating major delays that result in costly change orders and high road user costs. These strategies succeed in bringing transparency to the process and addressing limitations with insufficient survey data.

6 The intent of introducing "confidence levels" is so designers will be more risk-aware and measure their effort in refining geometric designs in the context of the confidence they have in the basis of the design matching construction field conditions, as well as the impact on construction if field conditions are different.

7 Maier et al., November 10, 2016. Utilizing 3D Digital Design Data in Highway Construction [Live Webinar]. FHWA. Recording retrieved from *https://connectdot.connectsolutions.com/p5yulbzt2hk/*

Using an iterative approach to respond quickly to needs and issues during design, using milestones such as preliminary design, right-of-way certification, and final plans, can reduce risks proactively. Using modern design software and 3D design processes, making updates to the 3D design is less time consuming as changes propagate dynamically to the plan sheets. The designer should perform multiple review iterations of the base map to control quality following a rigid process that highlights deficiencies and escalates the issues to the relevant stakeholder(s). The events that help ensure the base map data is being reviewed and/or interrogated for accuracy and reliability include, but are not limited to:

Scheduled events:

1. Start of new project phase
2. Start of milestones, i.e., 30%, 60%

Unscheduled events:

1. Change in existing conditions
2. Project schedule changes
3. Change in scope

Changes in existing conditions require supplemental survey data for the original survey data, which changes the design intent. This is a common occurrence with large and complex design projects in urban settings, where changes in land developments occur frequently. Furthermore, existing conditions also change as a result of natural or man-made disasters, which may have a significant impact on the original schedule and budget for data collection (not necessarily the accuracy). Nevertheless, any time the data collection method is changed, the accuracy requirements should be reviewed to ensure there are no negative impacts. Scope changes are another trigger for necessary design updates. A scope change is in essence a modification of the design intent, which may require new survey data.

Proper response planning for constructability risks will highlight survey data needs up-front in the design so these areas can be evaluated before construction begins. At minimum, the designer and resident engineer should sit down with the surveyor during the final design to outline specific areas of the project that have uncertainty in order to quantify any impacts that are likely to occur in construction. Awareness is key to defining the most appropriate response.

Controlling and Monitoring Risk in Using Survey Data

There are a number of opportunities throughout the preconstruction process that project managers can capitalize on to ensure that only managed risks enter construction. Quality gates, much like the aforementioned review iterations, are an effective mechanism to build into the project milestone schedule and measure effectiveness of using survey data.

Quality Gate 1: Collaborative Planning Sessions for Survey Data Collection

Formal or informal planning sessions set up the survey data collection campaigns for success through well-defined criteria and a mutual understanding of expectations. Taking this proactive step in building a collaborative environment for the survey staff, design staff, resident engineer, and the project manager to communicate risks early in the project ensures opportunities are harnessed and threats are addressed. All parties to the Data Integration Team should come to the initial meeting with the necessary questions and materials to convey expectations and requirements.

Planning sessions should not stop after the planning stages. They should occur regularly throughout the design and construction process. The more collaborative and robust these meetings are, the better the chances for project success.

The goal here is to spur discussion and drive thoughtful reflection on not only meeting the current requirements, but also looking forward in the project lifecycle to mitigate risks that may affect construction. An output from this process is a mutual understanding of what data is needed, as well as some initial ideas on the technology to use. However, the service provider has the responsibility to select the right collection tool that meets the data needs of the designer (or resident engineer). It is important to focus on the requirements, as opposed to the methodology, in order to avoid unnecessary costs and misunderstandings. Furthermore, focusing on requirements for design or construction will ensure the methodology is appropriate, which results in a higher degree of confidence.

Quality Gate 2: Receiving Survey Data for Design

The designer must seek to understand certain characteristics of the survey data to ensure effective decisions can be made on its use. Visual review and inspection of the data is insufficient to make the necessary decisions regarding risk mitigation and data use. Focusing on the survey data characteristics provides more insight into the data and allows the designer to evaluate appropriate use and ensure fused datasets are in alignment (position and accuracy).

Figure 6. Data Integration Team[8]

The characteristics of the survey data should be captured in ISO-compliant metadata and the surveyor's report. If no metadata or surveyor's report was provided, ask for it! All survey data needs to have documented evidence of prescribed criteria so all users understand the data. Some considerations that will assist the designer when evaluating the risk associated with the survey data are outlined in Figure 7.

8 Image courtesy Geoff Werbicki, WSP | Parsons Brinckerhoff

Accuracy and Integrity

- **What is the horizontal and vertical datum? Are these the most current systems maintained by NGS or other designated authority?** Knowing the coordinate system, projection, and elevation datum is critical to geospatial data integration.
- **What are the absolute accuracies of the dataset (or subset)?** Understanding the accuracies will help determine appropriate use.

Source and Accessibility

- **What is the origin of the dataset?** Having access and understanding the data source will help define data characteristics and risk potential.
- **How old is the dataset?** Older data increases the severity of the risk.
- **Potential data sources:** photogrammetry surveys, terrestrial LiDAR Surveys (mobile and static), aerial LiDAR (network- and project-level), field topographic surveys, and unmanned aircraft systems (UAS).

Consistency and Clarity

- **Are the file types well-defined and usable? Are there any conflicts with proprietary systems?** Understanding the interoperability of the data will help maximize the value of the data and reduce conflicts.
- **Is it clear what the data represents?** Accurate representation of field conditions is the main objective of the base map and survey data. It is important for the graphics to show the design intent.

Completeness

- **How many data sources are in the dataset?** Data fusion has become an economical method for increased accuracy in critical areas. Proper documentation is critical for managing risk.
- **Who should verify the dataset for completeness and accuracy?** A qualified surveyor is the appropriate professional to verify completeness of a dataset. This individual should have the expertise to review metadata and understand data characteristics. The dataset(s) should represent the existing field conditions within specified tolerances.

Figure 7. Considerations in Reviewing Data Characteristics

Quality Gate 3: Pre-Construction Checks

Original surveys may meet pre-design specifications but may not necessarily be sufficient for 3D construction. With automated machine guidance (AMG) construction, the layout occurs in real time as the machines do not require physical markers nor suitably equipped inspectors. While this creates an opportunity to explore in advance of any potential issues with tie-ins and quantities, it also creates an obligation to verify the base map data.[9]

Preconstruction quality control for 3D data involves checking the accuracy of the original ground and/or subsurface features where necessary and determining the impact and need for design revisions where there are differences.[9] Design revisions are necessary when high-risk elements are present or when more data is required to increase the confidence level of the design.

During pre-construction, the Data Integration Team should convene and lay out an action plan for the pre-construction quality control that aligns with the overall quality control plan for the project. This action plan will outline the steps necessary to verify control is of sufficient quality and stability for construction means and methods, to update the base map after clearing and grubbing, to review and spot check tie-in locations for sufficiency, to strengthen data transfer between team members, and to address any other areas of uncertainty before construction starts.

9 Maier et al., 2016. Utilizing 3D Digital Design Data in Highway Construction: A Case Study. Draft Final Report.

Conclusion

Survey data is foundational to 3D design and construction, but understanding the lineage and data characteristics will enable the designer and resident engineer to make meaningful, risk-informed decisions. Much effort is spent making refinements to designs; these decisions are more meaningful if the designer is aware of how accurately the survey data reflects the actual field conditions. Taking a risk-based approach to identifying the locations where accurate survey data adds value to the 3D design can ensure STAs are being good stewards of the taxpayers' money. By using an iterative approach throughout the project delivery lifecycle, risks will be identified early in the process and responded to quickly. All stakeholders strive to reduce risk during the design process in order to accurately forecast costs before construction starts, thus making effective use of survey data a critical project consideration. Figure 8 offers a maturation guide for organizations seeking to optimize survey data during project delivery.

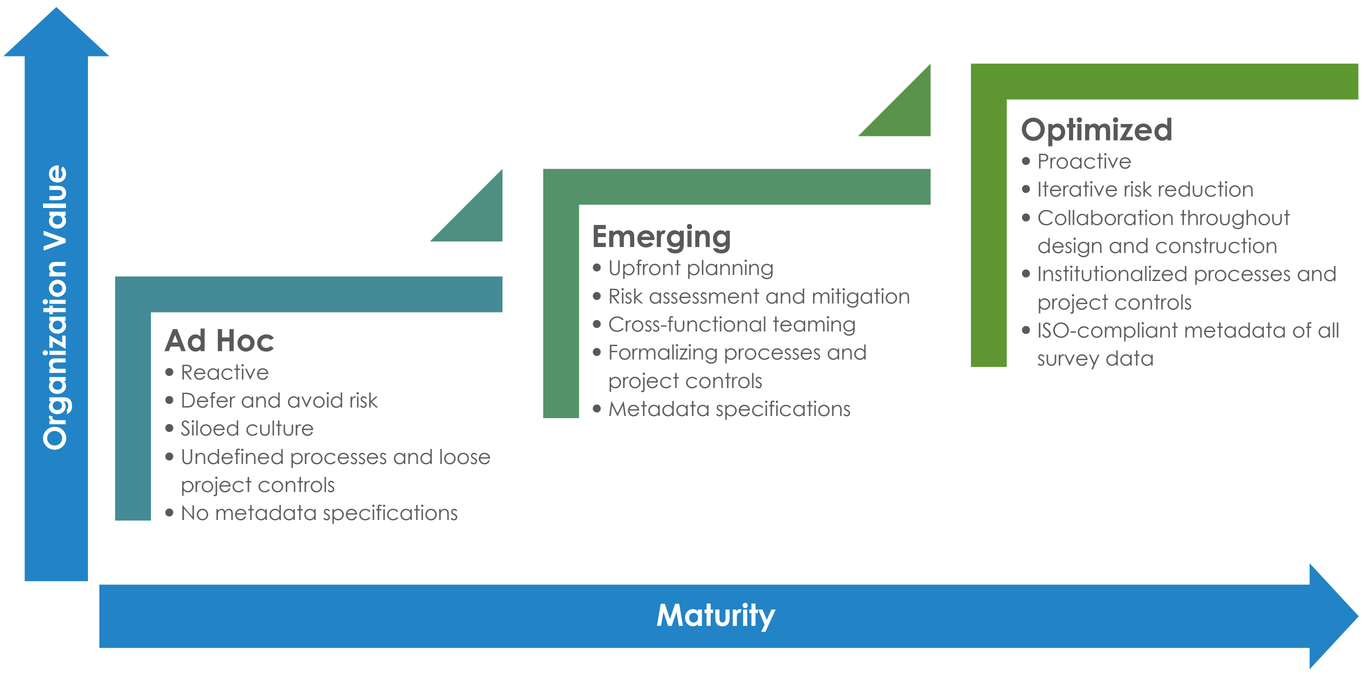
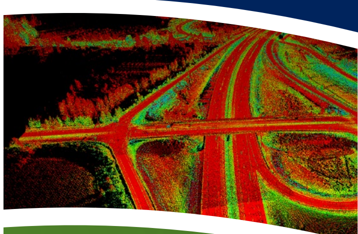
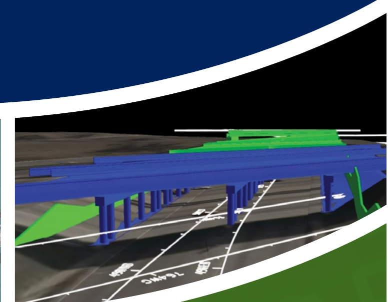


Figure 8. Optimization Maturity Model

***Every Day Counts**, a state-based initiative of the Federal Highway Administration's Center for Accelerating Innovation, works with state, local and private sector partners to encourage the adoption of proven technologies and innovations to shorten and enhance project delivery.*



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FHWA-HIF-17-030