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Update to AASHTO's Visualization in Transportation: A Guide for Transportation Agencies

FINAL GUIDE

PREPARED FOR NCHRP
TRANSPORTATION RESEARCH BOARD
of
THE NATIONAL ACADEMIES

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Abstract

The purpose of this project was to update the *AASHTO Visualization in Transportation: A Guide for Transportation Agencies* (Guide). The AASHTO Technical Committee on Environmental Design (TCED) developed the Guide in 2001 and updated it in 2003. Those documents have provided valuable assistance to State Departments of Transportation (DOTs) across the country that are seeking sound information, guidance and technical assistance on visualization.

The usage of visualization within transportation agencies is now more widespread and established, and visualization technologies and processes have advanced considerably. The need for context-sensitive solutions for transportation projects requires visualization tools that represent those projects accurately and realistically in their intended environments. The concept of transparent communication of project goals and impacts has lead agencies to embrace visualization for stakeholder communication. Visualization tools foster better communication and collaboration, which can lead to mutually-acceptable results faster, while achieving better project outcomes.

This updated Guide represents research into new technological advancements, processes, techniques and includes applicable case studies. It is intended that this Guide will become a valuable reference for the transportation community — a current, nationwide publication that will provide comprehensive technical and practical guidance for visualization in transportation.

Executive Summary

The AASHTO Technical Committee on Environmental Design (TCED) developed the AASHTO Guide for Visualization in Transportation in 2001 and updated it 2003. The guide has provided valuable assistance to State Departments of Transportation across the country that are seeking sound information, guidance and technical assistance on visualization.

Visualization has become an important tool in understanding and conveying a project area's existing context which forms the basis for all transportation solutions. Better communication and understanding of existing conditions in context with proposed solutions aids project planners, designers, constructors, administrators and the general public to more effectively collaborate towards mutually acceptable results faster while achieving better project outcomes.

Visualization has also become wide-spread in all aspects of transportation. Visualization technology is dynamic, accelerating at a rapid pace and is constantly evolving. Because of these important factors, the TCED has recognized and determined that it is necessary to update the *Visualization in Transportation* guide. The need for a current, nationwide publication that provides comprehensive technical and practical guidance for visualization in transportation is great. Visualization has become a core tool through-out project development and delivery and has become a premier technology for communicating alternatives as a project advances.

The much used AASHTO visualization guide became a standard reference document within the transportation community for developing visualization work deliverables. However, the guide has become out of date as a result of incremental but rapidly accelerating technological, imaging and other media advancements that have taken place over the past few years.

As a result, this updated guide contains the inclusion of new technological advancements, processes, techniques and applicable case studies. The Guide's content and information value is vitally important for a transportation agency's ability to better plan, estimate, develop and deliver important infrastructure projects. This Guide may also be used to improve communication and collaboration among project developers, transportation officials and the general public necessary for advancing a project.

Introduction

Visualization tools, once the sole domain of graphic artists and three-dimensional (3D) computer modeling specialists, is now being utilized by transportation professionals within the planning, design and construction processes of state and federal transportation agencies.

What are these visualization tools, how are they being applied and why has the need for them increased? These are the primary questions being asked by transportation professionals, as they strive to comprehend and integrate visualization into their production processes.

Visualization is the process of representing abstract business or scientific data as images that can aid in understanding the meaning of the data. [1] In the transportation industry, data can range from design information to a Geographic Information System (GIS) database. Visualization's purpose is to convey complex issues created by this data, in terms that the average person can understand, so that more informative and effective decision-making can occur.

In the past, transportation professionals utilized these tools primarily for outreach to enhance the communication process with stakeholders and the general public on projects. Today, these tools are beginning to be applied within the planning, design and construction processes of transportation agencies. The challenge facing these agencies is to understand and develop processes and guidelines for its use.

This document will define the multiple tools and uses of visualization. It will explain the processes involved and provide case studies as a reference as to how these processes can be applied.

Figure-01 – 3D rendering of Presidio Parkway in San Francisco, used for public outreach and stakeholder communication. Image courtesy SFCTA

1. What is Visualization?

Visualization could be defined at its simplest as the simulated representation of a design concept and its contextual impacts or improvements. [2] To assist in the development of a simulated representation, there are a plethora of visualization tools that a transportation professional can use. Determining the best tool and process for a project can be a challenge. Several factors are involved within the decision-making process from funding, production schedule to the desired output required. Visualization tools can be as simple as a hand drawn rendering or be as complex as 3D Building Information Modeling (BIM).

Figure-01 represents a high-level workflow matrix, which presents the basic tools that are available, and to how they integrate within the production process. The matrix stresses the need to fully understand the ultimate deliverable for the project, as this will determine, which visual tools will be utilized. Each project has its own unique constraints and requirements. As a result, multiple visualization tools are typically utilized, as there is no one universal visualization tool or solution. Consideration must also be given toward the aptitude of the staff involved on the project. To implement a visualization solution, trained personnel are required. Otherwise, this type of work will have to be outsourced. Careful planning is required upfront if visualization is to be an effective tool in the overall project lifecycle. This Guide will go into detail on how these visual tools are selected and used within the various production processes.

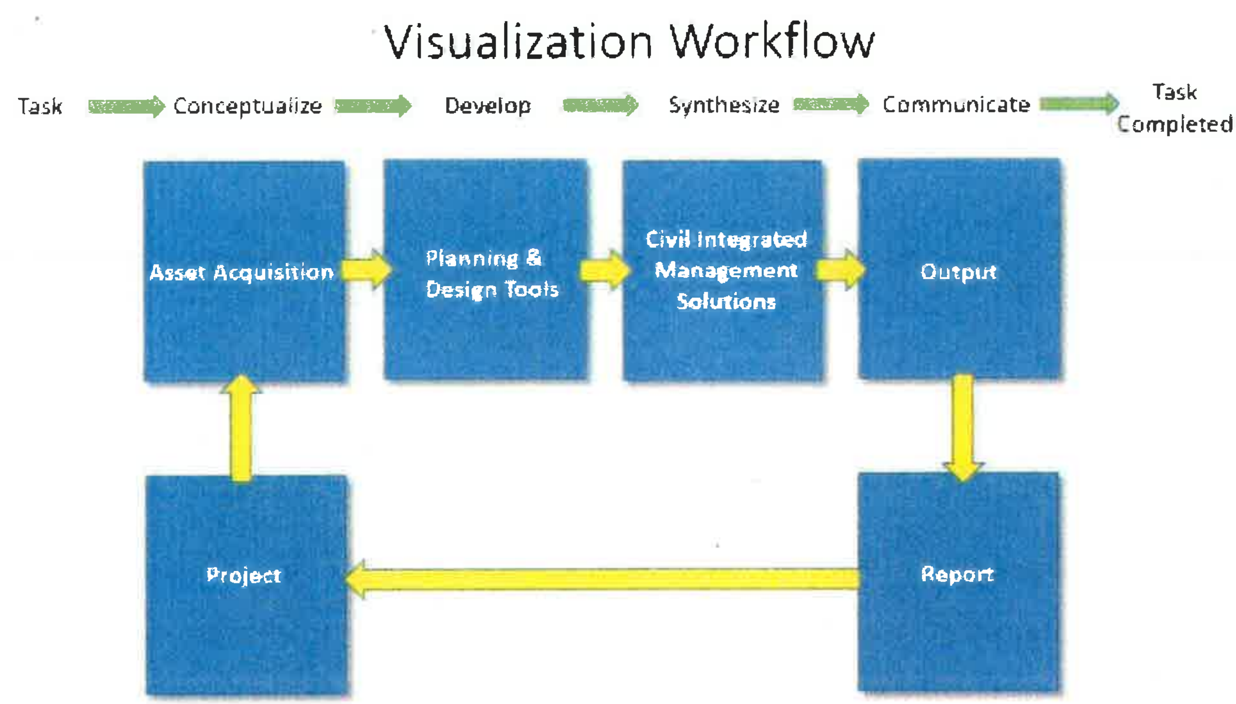

Figure-02 – Visualization Workflow Matrix

What are the General Uses and Results of Visualization?

There are a broad variety of uses for Visualization. Since its inception, it has been primarily used as an outreach tool. For **stakeholders**; its value is in the conceptual stages of a project, where more informative decisions can be made with issues such as line-of-sight, aesthetics and site impacts. For the **general public** and other interested parties, visualization is a powerful tool that can help to convey complex planning and design scenarios in a context that the average person can understand.

Figure-03 – Typical project public meeting, image courtesy Parsons Brinckerhoff

By improving the communication process with stakeholders and the general public, projects tend to achieve faster approval and acceptance times. This thought process was addressed within a 2007, joint AASHTO/FHWA Context Sensitive Solutions Planning Process Summary Report. "Context Sensitive Solutions (CSS) is a collaborative, interdisciplinary, holistic approach to the development of transportation projects. It is both process and product, characterized by a number of attributes. It involves all stakeholders, including community members, elected officials, interest groups, and affected local, state, and federal agencies. It puts project needs and both agency and community values on a level playing field and considers all trade–offs in decision making. Often associated with design in transportation projects, Context Sensitive Solutions should be a part of all phases of program delivery including long range planning, programming, environmental studies, design, construction, operations, and maintenance.[3]"

As planning and design continue to migrate toward being 3D driven processes, visualization has the ability to perform a more pivotal role in the conceptual design phase of a project. Designers have the ability to review multiple design scenarios, determine conflicts or interferences with visual tools. Concepts such as constructability, project workflows and construction phasing can all be more effectively comprehended by using visual tools. Visualization also enhances project communication as design scenarios are more readily conveyed and understood. Ultimately, with a more efficient decision-making tool applied in the early stages of a project, the overall design quality is approved. By enhancing the quality process, cost savings are generally achieved.

Visualization tools have evolved from being an output tool of planning and design, to becoming a component of the planning and design process.

Why the Need for Visualization?

SAFETEA-LU Requirements

Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) establishes that Metropolitan Planning Organizations (MPOs), "to the maximum extent practicable, employ visualization techniques to describe plans." (Source: SAFETEA-LU, Public Law 109-59)[4]

The Federal Highway Administration (FHWA) and Federal Transit Administration (FTA) have jointly issued rules for MPOs to follow in order to meet the requirements established in SAFETEA-LU. The FHWA and FTA define "visualization techniques" as "methods employed by states and MPOs in the development of transportation plans and programs with the public, elected officials, and other stakeholders in a clear and easily-accessible format." This is intended to "promote improved understanding of existing or proposed transportation plans and programs." The FHWA and FTA language is intentionally vague in regards to the types of visualizations that are appropriate or expected. As a result, each MPO is allowed the flexibility to meet visualization requirements in a way that most "appropriately [illustrates] the projects or plans."

Public Involvement

Since the early 2000's, the general public has become more engaged in transportation projects. Previous methodologies at outreach resulted in transportation agencies having to defend projects to the public. This is largely due in part to the outreach tools being used at public workshops and meetings, which were tools that were more reactionary during this phase. This reactionary approach often led to the public not fully comprehending the project impacts in terms that they could understand. With the advent of Context Sensitive Solution (CSS) processes, transportation agencies are now engaging the public earlier, garnering support versus contention. With a more upfront approach of outreach, visualization tools and processes have become more effective in their use. This is partly due to the significant enhancement within their performance and capabilities. Powerful visual tools that once required a specialist to create content, can now be utilized by most transportation professionals with Computer-Aided Design (CAD) or computer graphic experience.

Visualization is also addressing a generational issue. Generations Y (1980-2000) & Post Millennials (2001-present)[5] have grown up with computer graphics being ingrained within their lives. Movies, television, the web and video games all have produced compelling 3D computerized graphics. These generations expect those same types of graphics to be utilized for projects that require public involvement. These generations also have a heavy background with computer gaming and now are expecting to see imagery in real-time versus renderings or computer animation. Transportation agencies need to recognize that the public is no longer receptive to some of the traditional visualization methodologies used in the past.

Social media / networking have also accelerated the need for visualization tools. Project websites and other social media resources, such as blogs and webcasts have become common place since the early 2000's. Much of the content on these sites is graphical. Transportation agencies have been challenged with developing and supporting this type of outreach using content that the viewer can clearly understand and relate to. Many of these networking utilities also provide agencies with real-time feedback, which assists with the CSS process.

Contractors & Constructors

The push to utilize visualization tools is being primarily driven by contractors and constructors, who value the use of 3D design processes during the construction phase of a project. It improves the quality of their projects, while reducing the costs to produce them. This "push" has resulted in transportation agencies throughout the country evaluating the need for 3D design processes and visualization tools within project development. As a result, the Federal Highway Administration (FHWA) created the Every Day Counts initiative. Every Day Counts (EDC) is designed to focus on a finite set of initiatives. Teams from the Federal Highway Administration will work with state, local, and industry partners to deploy the initiatives and will develop performance measures to gauge their success.[6] The EDC initiative fosters collaboration and innovation and visualization tools and processes compliment this directive. EDC is helping to drive the use of visualization for transportation projects.

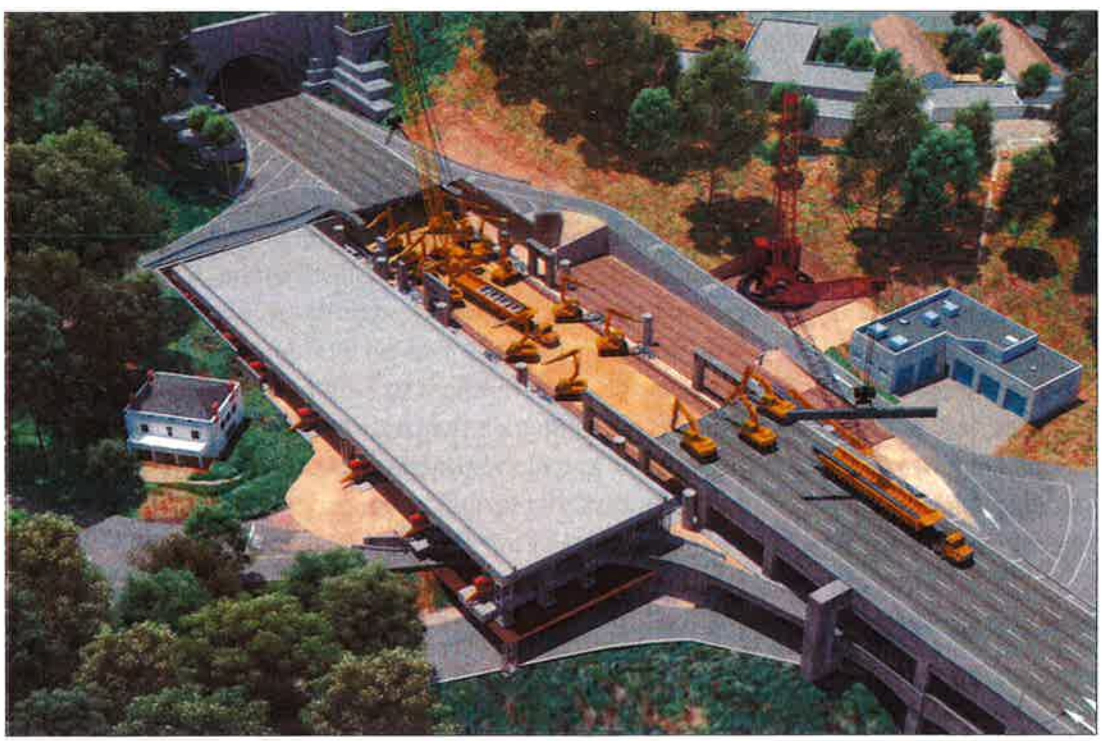

Figure-04 – 3D rendering of complex demolition activities during bridge closure; the rendered sequence illustrated equipment locations and movements. Image courtesy Bay Area Toll Authority.

Three-dimensional (3D) modeling in transportation construction is a mature technology that serves as the building block for the modern-day digital jobsite. The technology allows for faster, more accurate and more efficient planning and construction. Through the use of 3D modeling, visualization is becoming part of the process, not a by-product of it.

For example; Contractors, recognizing the vast opportunities to reduce costs with Automated Machine Guidance (AMG), are taking advantage of these technological advances. State agencies expect AMG to make more efficient use of already limited resources for construction. Industry-leading departments of transportation (DOT) recognize that potential advantages and cost savings are abundant, and have found that bid prices are minimized when the complete model is included in the bid package, available to prospective contractors, and controls the project.[7]

The push to utilize AMG and other 3D processes during the construction phase has resulted in transportation agencies implementing it within the planning and design phases of a project. Several mandates exist for its use within the planning stages of a project. For example, the National Environmental Policy Act (NEPA) requires Federal agencies to prepare Environmental Impact Statements (EIS's) for major Federal actions that significantly affect the quality of the human environment. An EIS is a full disclosure document that details the process through which a transportation project was developed, includes consideration of a range of reasonable alternatives, analyzes the potential impacts resulting from the alternatives, and demonstrates compliance with other applicable environmental laws and executive orders.[8] 3D planning and design tools, along with visualization are utilized within the EIS, as they significantly improve how alternatives are selected for detailed study, the reasons why some alternatives are eliminated from consideration and how the alternatives meet the need for the project and avoid or minimize environmental harm.

3D Model Based Design Processes

The use of visualization has increased due to the continued adoption of 3D model based design processes. Various evolutions of these processes have been referred as Building Information Modeling (BIM) within the architectural industry, Virtual Design & Construction (VDC) within the design/construction industry and Civil Integrated Management (CIM) and Bridge Information Modeling (BrIM) within the transportation industry. The term '4D' model, '5D', even '6D' and beyond, are becoming more commonplace in the design community as references to time based, or schedule-linked 3D model simulations. '4D' has different meanings depending on the context and application. 4D+ models are discussed in more detail later in Section 4, and in the Glossary. Regardless of how these processes are labeled, they are all based upon a process that leverages parametric 3D models with extended intelligent information attached to them. To assist transportation professionals, the FHWA developed the on-line resource titled "3D Engineered Models" as a reference for 3D, (and 4D/ 5D) design processes. https://www.fhwa.dot.gov/construction/3d/design.cfm

Building Information Modeling (BIM) is a process involving the generation and management of digital representations of physical and functional characteristics of places. Building information models are files (often but not always in proprietary formats and containing proprietary data) which can be exchanged or networked to support decision-making. Current BIM software is used to plan, design, construct, operate and maintain diverse physical infrastructure. Because BIM is such a general tool and has many factors at play, a decision can be made to approach the process in piecemeal fashion—using separate definitions or micro-BIM definitions. Here are a few;

- Populating a 3D model with intelligent, parametric objects, so that each contains information such as Manufacturer, Part #, size, type, gauge, voltage, and so on.
- Collision detection and coordination.
- Stage visualization and schedule modeling.
- Data management and Infrastructure.

There are two general approaches toward using BIM processes

- Leads to determining the value of the product, i.e. the 3D model for use in construction (by contractor and owner)
- Backs into whether an agency has all the ingredients necessary to have a valuable product.

Things to consider are:

- Does the project have the survey resolution needed to build a model that can be used for the intended applications? This adds to the decision on how much detail to add to the 3D model.
- Will the data be consumed? If it's unlikely that inspectors or contractors will use the data, then agencies should not generate more than is needed for plans and estimates.
- Will the project utilize a 3D design tool? This is perhaps the biggest question; in most cases, transportation agencies are already migrating toward 3D design processes. However, not every agency is applying the technology. If 3D is truly an extra for the design process, then its effectiveness is diminished.

The architectural community uses BIM Execution Planning to manage the discussions at a project-level on how much to build in 3D and at what level of detail to produce elements in 3D (LOD). The American Institute of Architects (AIA)[9] references Penn State University as an on-line resource for BIM guides and templates, http://www.bim.psu.edu/. These templates have been customized for highway design.

Virtual Design and Construction (VDC) is the management of integrated multi-disciplinary performance models of design-construction projects, including the product, work processes and organization of the design - construction - operation team in order to support explicit and public business objectives.

The primary goal of VDC is to ensure efficient construction of facilities and roadway corridors. The VDC process involves close cooperation of all project stakeholders, at all project stages in order to facilitate cooperative decision making. Some of the benefits of the VDC process are:

- Assists in visualizing a project, therefore reducing change requests during construction.
- Ensuring elements are coordinated and are constructible, before construction starts.
- Validating and shortening construction schedules through schedule simulations.
- Minimizing construction waste through accurate quantity take-offs and detailing.

Civil Integrated Management (CIM) - is the collection, organization, and managed accessibility to accurate data and information related to a highway facility. The concept may be used by all affected parties for a wide range of purposes, including planning, environmental, surveying, construction, maintenance, asset management, and risk assessment.[10] It is a lifecycle approach in which all of the transportation disciplines are integrated within a single process.

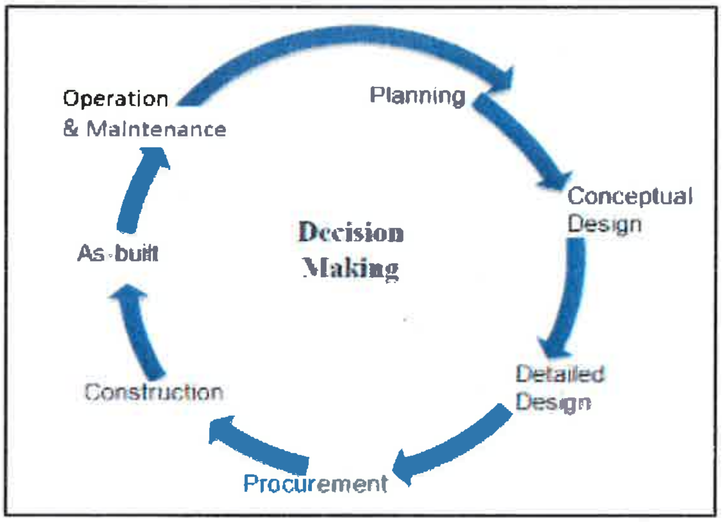

Figure-05 – Decision Making Process for CIM (ref. NCHRP 20-68A, 13-02)

Benefits include;

- Faster project completion with improved quality and safety
- Increased Productivity
- Reduction of manual tasks and machine-like precision
- Effective real-time control and monitoring of movement and location

The National Cooperative Highway Research Program (NCHRP) 20-68A sponsored the Unites States Domestic Scan Program for Civil Integrated Management (CIM) 13-02.[11] The findings of this Domestic Scan Program will assist agencies in identifying when and where to effectively employ intelligent construction technologies. The results will also identify successful partnering techniques being used by state DOT's, consultants, contractors, and materials suppliers in utilizing intelligent construction technology.

Agencies will benefit from this scan by gaining knowledge of the use of CIM practices and tools in highway construction projects utilizing emerging intelligent construction technologies and partnering for the fast, efficient, and safe delivery of projects.

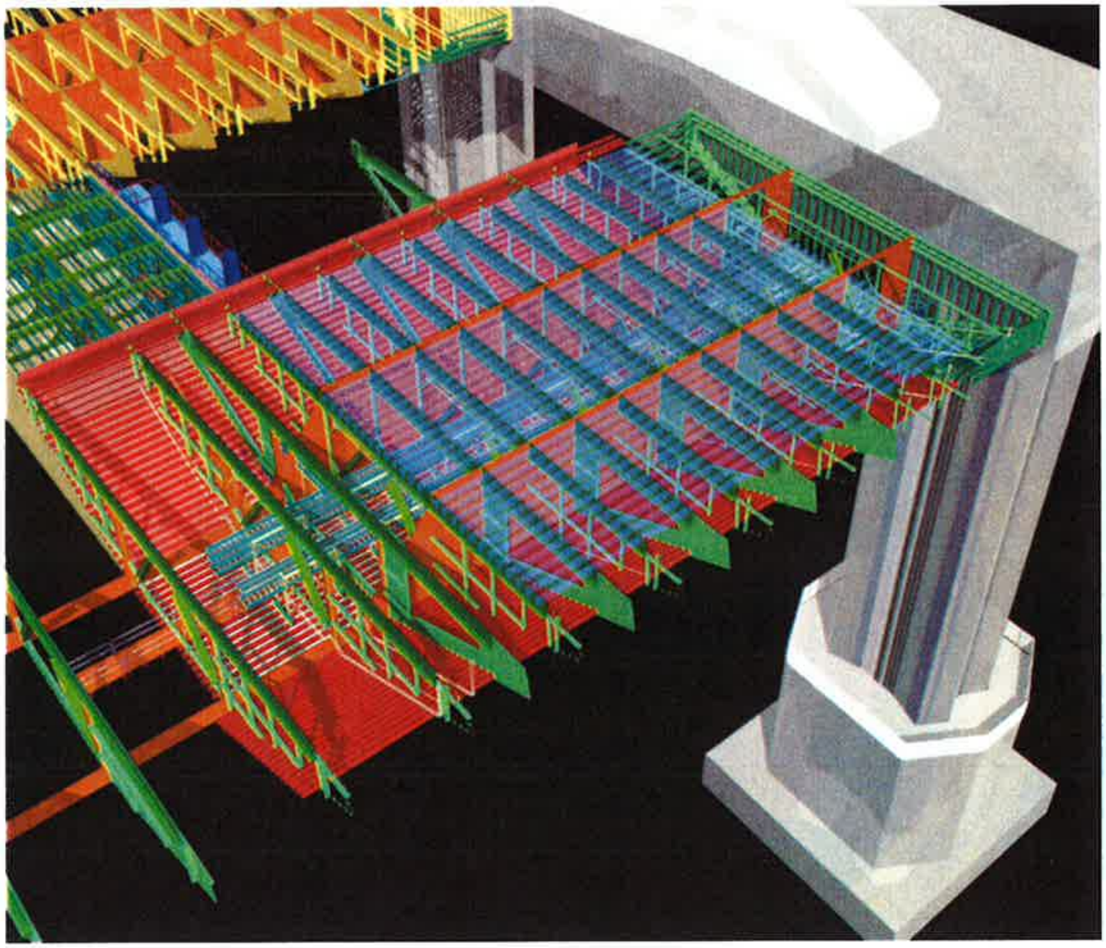

Figure-06 – 3D bridge (Brim) model, San Francisco – Oakland Bay Bridge, CA. Image courtesy BATA

Bridge Information Modeling (BrIM) **-** Within the bridge design and construction community, the term Bridge information modeling (BrIM) is sometimes used as a hybrid term of Building information modeling (BIM). According to Stuart S. Chen, the BrIM process uses 3D conceptual and applicable data in all three phases of bridge structure design. The model allows deployment and real-time utilization of data in the bridge lifecycle as conditions are modified. Bridge information modeling encourages the use of data information not only in the design phase but beyond it. BrIM promotes the reuse and sharing of project information assets.

http://aucache.autodesk.com/au2012/sessionsFiles/1529/3109/handout_1529_CI1529%20-%20Bridge%20Information%20Modeling.pdf Page 10 includes a graphic developed by Dr. Stuart Chen that references different software tools for different phases of the project lifecycle.

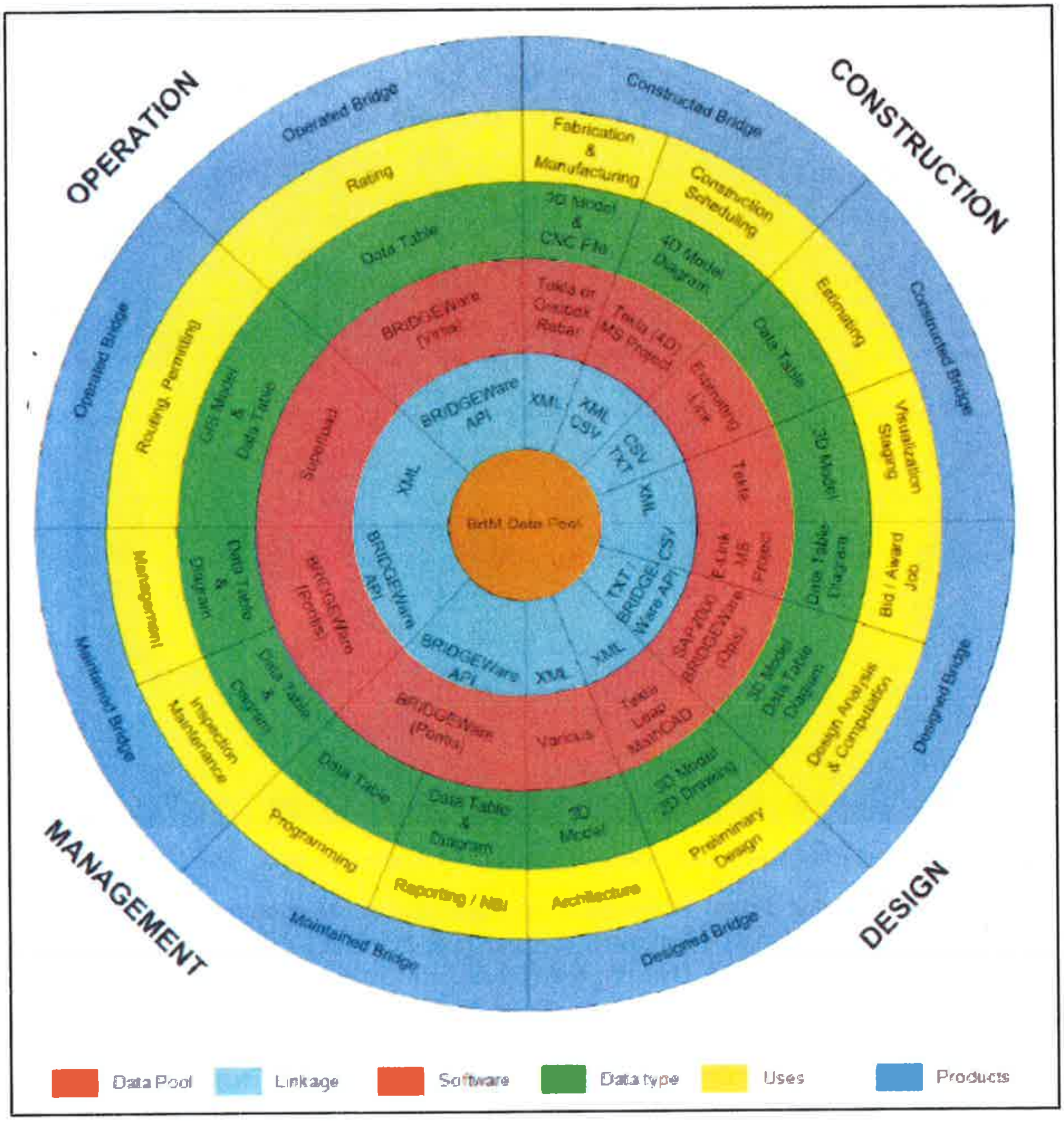

Figure-07 – Bridge Lifecycle Processes and Products (FHWA Contract DTFH61-06-D-00037)

An effective BrIM solution depends entirely upon the structural engineer's investment in the process and in exploring the potential to accurately layout the bridge in three dimensions in their preferred product; then exporting a solid or mesh model that can be used either directly to produce plans or to guide the development of plans. BrIM depends greatly on the structure type and how the data will be used.

Data Visualization

Data Visualization involves the creation and application of the visual representation of data, meaning "information that has been abstracted in some schematic form, including attributes or variables for the units of information". A primary goal of data visualization is to communicate information clearly and efficiently to users via the information graphics selected. [12] Often the term "Big Data" is used to describe visualization of large datasets. Big data is an all-encompassing term for any collection of data sets so large and complex that it becomes difficult to process them using traditional data processing applications. By visualizing this data in different ways, patterns and trends can be more readily identified. Data Visualization is being applied more and more within the planning and design processes of transportation agencies.

Data Visualization has driven the development and application of new and innovative visualization tools. Data that once was conveyed either with spreadsheets or simple graphs and charts, is now being presented with an assortment of visual tools. For example, the Center for Advanced Transportation Technology CATT Lab at the University of Maryland[13] develops visual analytics and information visualization tools for transportation agencies that lead users to insights that would usually be difficult, if not impossible, to discover through traditional data analysis techniques.

The American Society of Civil Engineers (ASCE) has a Visualization, Information Modeling, and Simulation (VIMS) Committee[14] whose purpose is: to increase the appropriate use of databases and information management technologies in civil engineering teaching and practice. Included in the committee scope are the representation, management, storage and retrieval of civil engineering information, product and process modeling, data/object/knowledge repositories and interoperability standards, and information infrastructure issues.

Geographic Information Systems (GIS)/Geodesign

Geodesign brings geographic analysis into the design process, where initial design sketches are instantly vetted for suitability against a myriad of database layers describing a variety of physical and social factors for the spatial extent of the project.

Through the use of Geodesign processes, transportation agencies can improve the planning, design and construction processes and contextual outcomes to improve the quality of projects and livability of our built environment. This set of processes helps tie-in 3D design, information modeling, analysis, visualization and collaboration throughout the project lifecycle (conceptualization, capital planning, project planning, design, construction, operations and maintenance). For guidance on implementing GIS/Design solutions at a transportation agency level, please reference the Iowa Department of Transportation GIS Implementation Plan;
http://www.intrans.iastate.edu/reports/gis_implementation_plan.pdf

Design and construction impacts can be examined through geospatial technology (simulations, modeling, visualization, communication of design and constructions impacts, and an information model used throughout the project lifecycle) and be immediately fed back into the evolution of design, construction and operations to support the integration of information models (3D design, visualization, construction models, and asset management).

The American Association of State Highway and Transportation Officials (AASHTO) sponsors the annual GIS for Transportation Symposium[15] or GIS-T. Concepts such as Geodesign and Data Visualization are presented at this symposium.

Traffic Simulation

Traffic simulation or the simulation of transportation systems is the mathematical modeling of transportation networks (e.g., freeway junctions, arterial routes, roundabouts, downtown grid systems, etc.) through the application of computer software to better help plan, design and operate transportation systems. It can study models too complicated for analytical or numerical treatment, can be used for experimental studies, can study detailed relations that might be lost in analytical or numerical treatment and can produce visual demonstrations of present and future scenarios.

These simulation programs rely on visualization tools to convey output. Visual output formats include real-time traffic data; computer animated traffic simulation for proposed transportation projects or advanced driving simulator technologies, such as the National Advanced Driving Simulator sponsored by the University of Iowa.[16]

Advanced Technologies

Laser Scanning - a technology increasingly used for providing 3D as-built data for various applications, including land surveying, architecture, bridge structures, and highway construction. These scanners use advanced laser measurement technology capable of obtaining thousands of point measurements per second. They generate a highly detailed data set, which can then be used to create an accurate and comprehensive 3D Computer-Aided Design (CAD) model. 3D laser scanners provide survey data that would otherwise be difficult or impossible to measure using traditional surveying instruments.

Figure-08 – LiDAR point cloud of highway interchange, image courtesy Caltrans.

Laser scanning can be classified into several types including; aerial (or airborne), terrestrial, mobile, desktop (or bench-top), and hand scanning. Aerial scanning is performed from airplanes or helicopters (and soon from unmanned aerial vehicles, or UAV's), and usually involves mapping and terrain surveys over a large area. Terrestrial scanning is a broad category involving capture of accurate 3D data for a wide variety of applications such as industrial as-builts, mining, archaeology, and surveying. Mobile scanners are designed to operate from moving vehicles traveling at standard highway speeds. Desktop scanners are designed to accurately capture smaller objects for inspection, replication, and other purposes. Handheld scanners acquire 3D data when the operator sweeps it over an object.

Visualization tools and processes are increasingly using laser scanned 'point clouds' as an existing conditions base for 3D models. The scanner systematically sweeps and measures an area or room until it has a complete picture of the 3D space round it. This point cloud is a true to scale, accurate data set from which we can extract valuable information and 3D models.

The ASCE has a technical paper titled, "Cost-Benefit Analysis of Mobil Terrestrial Laser Scanning Applications for Highway Infrastructure"[17]. It presents a cost-benefit analysis of mobile terrestrial laser scanning, specifically in highway infrastructure applications. The NCHRP Report 15-44 "Guidelines for the use of Mobile LIDAR in Transportation Applications" has a companion website that outlines details about every aspect of mobile LiDAR: http://learnmobilelidar.com/

Automated Machine Guidance (AMG) - provides construction efficiencies through enhanced location referencing. AMG involves using construction equipment mounted with onboard computers. A combination of 3D modeling data along with global positioning system (GPS) technology, AMG provides horizontal and vertical guidance in real-time to construction equipment operators. AMG assists agencies and contractors in finishing projects in less time and with lower overall cost while providing higher quality and safety.

Between location awareness, cloud-based data connectivity and telemetry, AMG products create, manage and consume vast quantities of data to optimize the productivity and safety of heavy civil construction. The challenge, as an industry, is leveraging that data for the owner to manage their assets. Two FHWA Every Day Counts 3[18] activities will start to scratch that surface; one for the extension of 3D modeling into post-construction and the other for e-Construction. Visualization tools will provide an important role in these activities.

Photogrammetry - for transportation planning and design can be divided into different categories according to the types of photographs or sensing system used or the manner of their use as given below:

- Terrestrial or ground photogrammetry - When the photographs are obtained from the ground station with camera axis horizontal or nearly horizontal
- Aerial photogrammetry - If the photographs are obtained from an airborne vehicle. The photographs are called vertical if the camera axis is truly vertical or if the tilt of the camera axis is less than 3-degrees. If tilt is more than (often given intentionally), the photographs are called oblique photographs.

Photogrammetry is extensively used by transportation agencies for both planning and design. There is an inherent push to utilize Visualization tools to help convey the results of photogrammetry. There are a variety of resources on photogrammetry including the Photogrammetry and Remote Sensing web site sponsored by the Washington State Department of Transportation.
http://www.wsdot.wa.gov/Mapsdata/Photogrammetry/3DTL.htm

3D Printing is a manufacturing process that builds layers to create a three-dimensional solid object from a 3D digital model. 3D printing requires that the model be 'watertight' as the industry refers to it, the geometry must be comprised of completely closed solids. There are tools and vendors that will take 3D geometry, check it for 'holes', and cap any missing surface to create a printable model. Currently most printers are relatively small, and models must be printed in sections. The technology is changing rapidly and supporting more varied kinds of materials. Ultimately we will see concrete based printers that will print structures directly from 3D models!

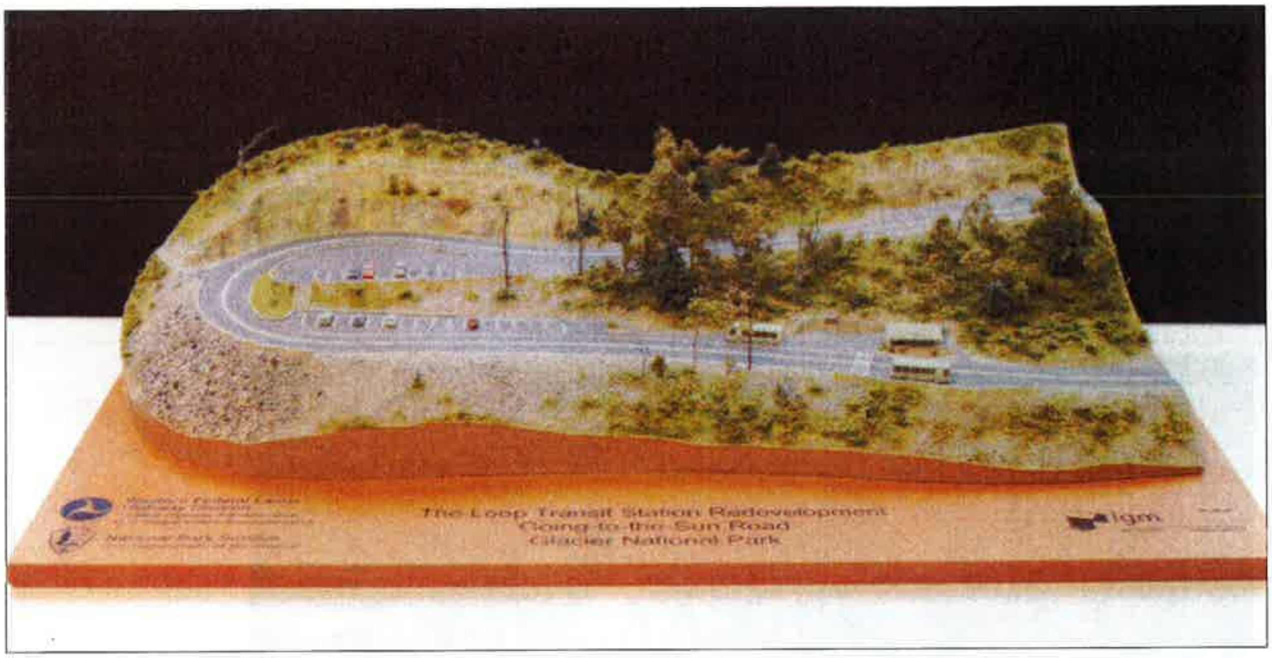

Figure-09 – 3D model print of Going-to-the-Sun Road, MT. Image courtesy WFLHD

There have been use cases for 3D printing in the transportation industry. North Carolina State University's traffic researchers used 3D printers to make a tactile map that helps the blind navigate through a busy roundabout http://www.ncsu.edu/huntlibrary/create/. As 3D printing technologies mature within the transportation industry, it will become another output resource available for transportation professionals.

Virtual Reality/Augmented Reality – Virtual reality refers to 3D interactive models that keep track of head movements as a viewer looks around to present a more immersive experience of the 3D model. Augmented reality is the use of technology to overlay digital information on an image or video stream being viewed through a device (such as a smart tablet or phone camera). Mobile devices now have the ability to track viewer location and orientation and thus have become great platforms for location based virtual reality and augmented reality platforms. 3D modeling applications now allow users to track their position in the virtual environment of the model, and present it to the viewer in the actual real world location, aligning the 'virtual camera' with the view on the device. This technology is having a huge impact on construct site management and inspection, the devices can keep track of where the user is and present location aware information and views of the model.

By leveraging mobile device applications with state-of-the-art game engine technology, transportation agencies have access to tools that allow outreach programs to reach a wider, more technology focused audience. The San Francisco-Oakland Bay Bridge (SFOBB) detour closure application, 'Bay Bridge Explorer', was distributed via the Apple I-tunes store. The game-like application allowed users to literally 'drive' on the Bay Bridge before and after an upcoming closure for a detour change[19]. The tool allowed users to experience the detours first hand by first viewing overhead renderings that compared the two configurations, and then allowing them to drive on the detours one at a time. More importantly, the tool allowed Caltrans and the Bay Area Toll Authority to reach and inform a larger local audience of the upcoming closure.

Figure-10 – Virtual Reality Driving Simulator, San Francisco - Oakland Bay Bridge, courtesy Bay Area Toll Authority

2. The Visualization Process

Understanding the Project Delivery Process

To understand the best uses for visualization tools, transportation professionals need to have a fundamental understanding of the Project Delivery process. "In order for Federal funding to be authorized for the construction of Major Projects, the Project Owner must demonstrate to the FHWA that the project has been carefully planned out, i.e. costs have been estimated as accurately and meticulously as possible; risks have been carefully considered and mitigated; funding requirements and strategies have been clearly defined; and the implementation of the project delivery has been carefully planned.[20]" Currently, there are two types of project deliverables being used by transportation agencies; Design-Bid-Build (DBB) and Design-Build (DB). The DB process can be augmented by Public-Private Partnerships (P3). P3's are contractual agreements formed between a public agency and a private sector entity that allow for greater private sector participation in the delivery and financing of transportation projects.

It is important to understand which project delivery process is being used, as there are different workflows for each.

- The Design-Build process is more fluid during the design phase as it is in concert with the construction phase. Often, the DB process produces more frequent design changes. If visuals are required during this phase, the transportation professional will need to determine a cut-off point for producing content. Good communication will also be required to advise Project Managers on the accuracy/state of the visuals.
- In a Design-Bid-Build (DBB) environment the main driver is the design team and their communication with the stakeholders and owner. The need for visualization is usually very clear and the goals more straightforward.

"A majority of state departments of transportation (DOTs) are using alternative contracting methods (ACM) for project delivery such as Design-Build, and several are using Construction Manager/General Contractor, in place of the traditional Design-Bid-Build method on certain transportation projects. In addition, Federal Highway Administration's (FHWA) Every Day Counts 2(EDC-2) initiative also supports and promotes the national use of ACM for accelerated project delivery in an efficient and cost effective manner (http://www.fhwa.dot.gov/everydaycounts/). Some of the reasons for this trend include a desire to deliver projects more quickly, a need to deliver an increased number of projects during short-term periods of expanded funding (such as the recent American Recovery and Reinvestment Act), and to take advantage of documented benefits such as improved constructability, controlling cost growth, early cost certainty and contractor innovation. NCHRP Synthesis 4021 "Construction Manager-at-Risk Project Delivery for Transportation Programs" states that there is a need to provide agencies with a better understanding of these project delivery methods, so as to be able to make an informed decision as to the potential benefits of each. NCHRP 20-7, Task 1722 , "Recommended AASHTO Design-Build Procurement Guide" recognizes that DB is not appropriate for all projects, and should only be used on projects where the benefits will outweigh the additional costs. This project is intended to build off of these earlier efforts".[21]

To assist in how to implement a DB project deliverable, the FHWA is conducting a study, DTFH61-13-C-00024, "Quantification of Cost, Benefits and Risk Associated with Alternative Contracting Methods and Accelerated Performance Specifications".

The document can be found here: https://www.fbo.gov/index?s=opportunity&mode=form&id=e33aa0a332b25e387b53710afda86c76&tab=core&_cview=1. Note also that the opportunity number is C-00024, but the award number is C-00026.

The following Figures (8 & 9), provide an overview of both the Design-Bid-Build and Design-Build Delivery Process.

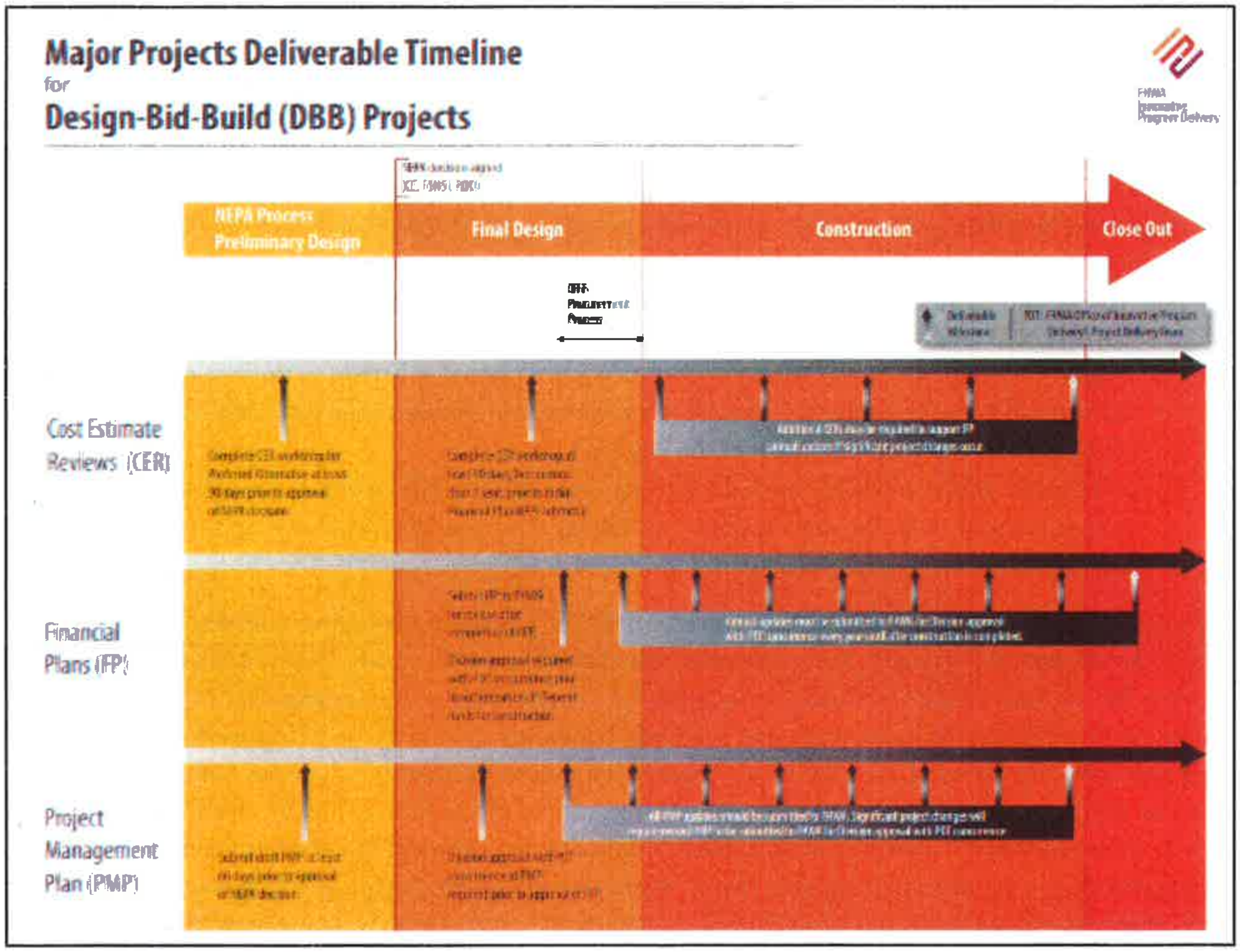

Figure-11 – Major Projects Deliverable Timeline, Design Bid Build, courtesy FHWA

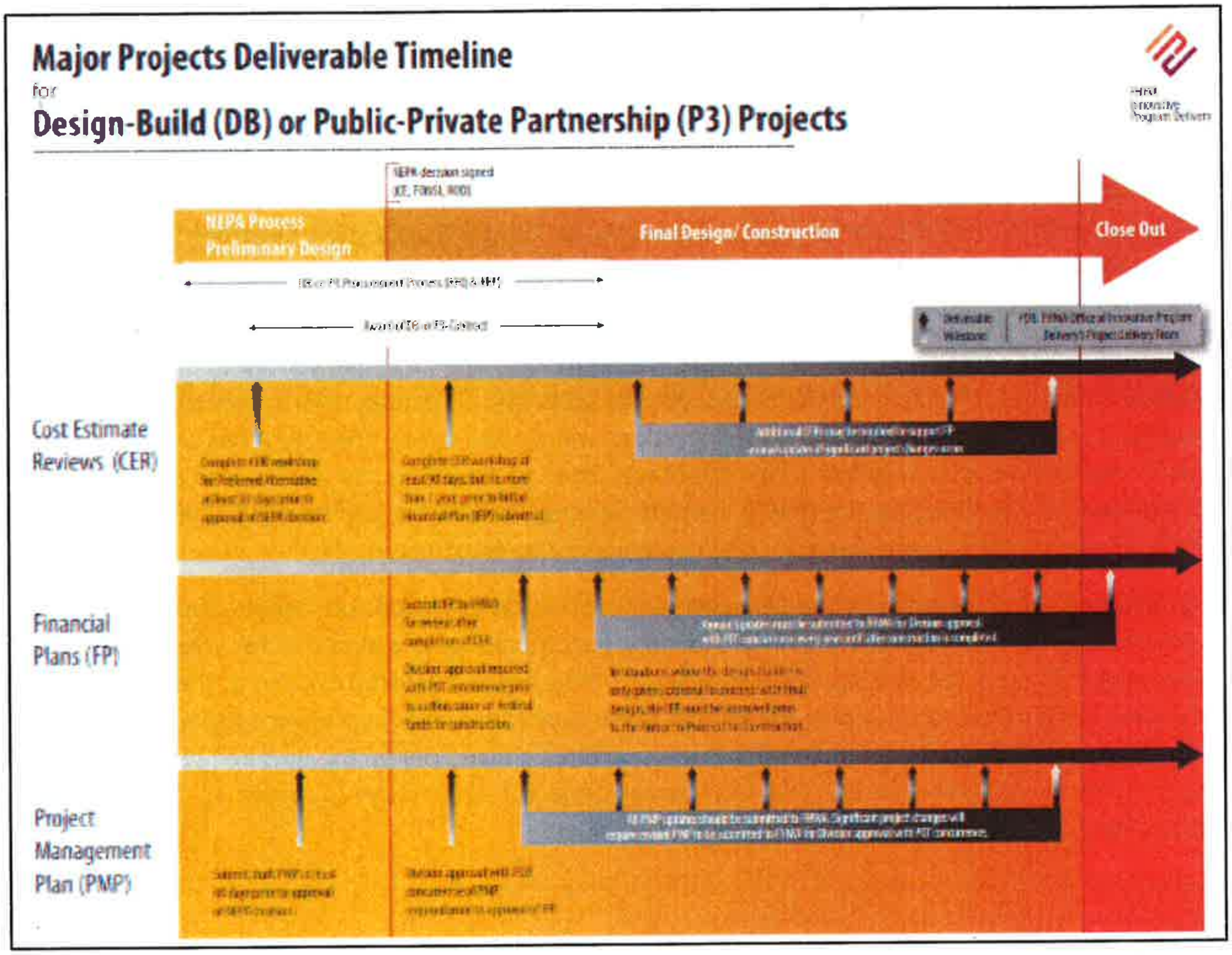

Figure-12 – Major Projects Deliverable Timeline, Design Build, courtesy FHWA

Within the Project Delivery Process, it is important to know which phase that the project is in. Often, the phase determines which visual tool would be most effective. For the Visualization process, there are four basic phases that impact decision-making;

1. Planning
2. Design
3. Construction
4. Operations and Management

For example, if visuals are required within the Planning phase, the content utilized to create the visuals is often conceptual. The Transportation Professional needs to be aware that the content being used for the project at this stage is not always accurate and needs to plan accordingly. Typically, this will add time to the production schedule, as the person creating the visuals will have to make certain assumptions and create content that is currently not fully designed. It could also result in a visualization deliverable that is not entirely accurate. However, not being fully accurate can be acceptable during the Planning phase of a project.

Visualization in Planning – The FHWA has set up an internet site to assist transportation professionals to learn about noteworthy practices and innovative uses of visualization for transportation planning, and who to contact in FHWA about questions or issues on visualization in planning. The site can be accessed at; http://www.fhwa.dot.gov/planning/scenario_and_visualization/

Visualization for Design – The FHWA has also set up a web portal for implementing visualization within the design process. This site can be used as a resource for Design Visualization, Electronic Data/Geometric Drafting, Mechanistic Analysis, US Specifications/Standards and International Specifications/Standards. The site is located at; http://www.fhwa.dot.gov/construction/3d/design.cfm

Visualization in Construction – In recent years, transportation agencies have started to plan and design roads in 3D because they understand the possible benefits that 3D models offer in construction. The benefits include improved productivity of operations and worker safety. The FHWA has created a web site for implementing visualization within the construction process. This site can be used as a resource for Automated Machine Guidance (AMG), Remote Sensing, Earthworks, and Paving & Construction. The site is located at; http://www.fhwa.dot.gov/construction/3d/construction.cfm

Visualization within Operations and Management – Visualization models provide the foundation for additional benefits through the use of 4D modeling (incorporating time elements for staging and scheduling), 5D modeling (linking cost components to the modeled structures), and as the project nears completion, 6D modeling (including the as-built specs, operations and maintenance (O&M) information, and other project life cycle data). The FHWA has published a tech brief on the uses and results of visualization on the Wisconsin DOT Zoo Interchange project. The tech brief is located at; http://www.fhwa.dot.gov/construction/pubs/hif13050.pdf

Visualization Workflows

Once the Transportation Professional understands where the project stands within the Project Delivery process, other considerations can be addressed. Key components of the workflow process are:

1. Staffing
2. Defining the Scope of Work
3. Production Schedule

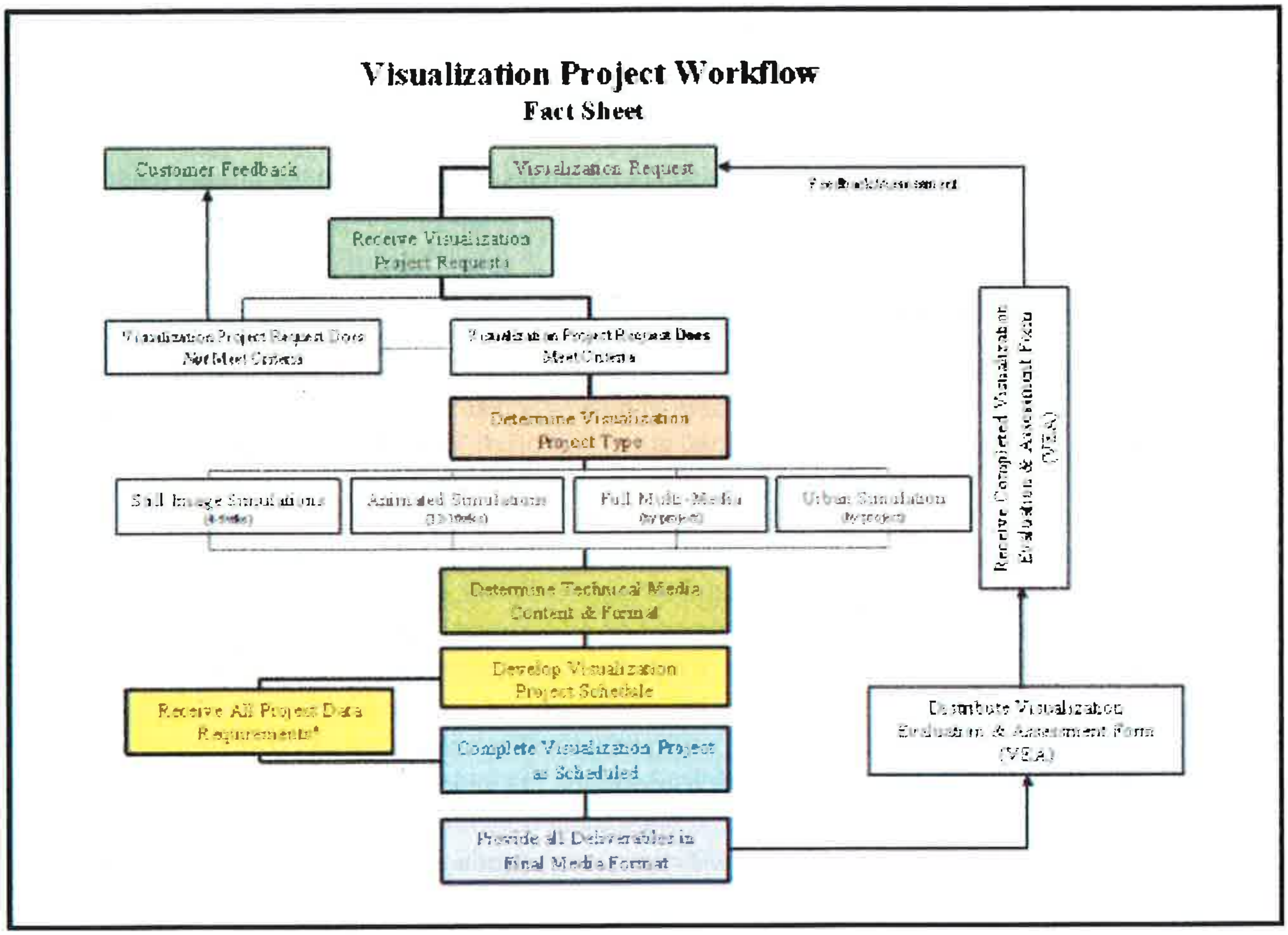

Figure-13 – Sample Visualization Project Workflow, courtesy NYSDOT

Staffing – For a successful visualization project to occur, a thorough understanding of staff proficiency with visualization tools and processes is required. In conjunction with proficient staffing, there is a need for effective communication with Project Managers and agency leadership.

Management

To implement a visualization program within a transportation agency, adoption and acceptance of the use and need of visualization by upper management is critical. The tools and production processes of visualization are often different than those of traditional transportation planning and design workflows. Often, the computer hardware and software required to produce visuals falls outside the defined specifications set forth by the Information Technology (IT) Department within transportation agencies. Typically, special approvals are required to acquire the necessary tools to produce visuals. Therefore, the Visualization Manager needs to have an understanding of the procurement processes and policies within a transportation agency. Without the support of upper management, it will be difficult to provide staff with the proper tools necessary to create visual content.

Having a Visualization Manager (VM) is also a key to a successful program. The VM needs to have good lines of communication with senior management to properly operate the program. He must also have the ability to foster growth and development with staff. The Visualization Manager needs to understand the skill set and aptitude of each visualization support person, as this will determine what type of visual tool is selected. If a project requires a specific type of visualization process that staff is not proficient in, then consideration will need to be made to utilize an outside source to complete the task. As important, the Visualization Manager often acts as the liaison between technical staff and the project team. Communication is critical to a projects' success to keep it on schedule, within budget and produced to the satisfaction of the Project Manager.

Key Components for Visualization Production Staff:

- *Able to understand and read plan reports and design plans* - The most fundamental component for producing visual content is to be able to understand and read plan reports and design plans. These typically are the content provided during a project. To achieve this, the visualization professional will need to be proficient with CAD applications.
- *Must work seamlessly with the planning or design team.* Understanding the experience or knowledge of the Project Manager (PM) will impact production. The more knowledgeable the PM on visualization processes, the more efficient the production flow will tend to be. Often, the PM does not understand the production schedule required to produce a visual product. Excellent communication is required to set expectations up-front. Often, the project schedule is the most important requirement to a PM. Therefore, the visual tool selected will be based on the schedule. For example, if the PM advises that he has only two weeks to produce content, then Visualization Manager will need to inform the PM which visual tools and output can be used within that specified timeframe. It is also beneficial for Staff to have a solid understanding of the project production staff. This will improve the production flow for obtaining content or seeking consultation.
- *Knowledgeable with an array of visualization tools* – To produce visualization content, often several visual tools are required. For example, when producing a 3D Photo-Simulation, the Visualization Professional will need to have skills sets in 3D modeling and photo-editing. Most Visualization Professionals have a primary application in which they are expert. However, they also need to have a fundamental understanding of several other applications.
- *The artistry needs to come from within* – The final results of a rendering are the combination of the visual tools used and the artistry of the visualization professional. Elements such as lighting and perspective are dependent on that professional. Visualization managers need to understand that they can provide training for tools and applications. However, the artistic ability of staff members will be something that is intangible and difficult to teach.

To implement a successful Visualization program at a transportation agency, consideration should be given to developing specific job descriptions for a Visualization Professional. Creating job descriptions will assist in; recruitment, career development and improve the procurement process for obtaining the tools required to produce visuals.

See Appendix B – Sample Classified Position Description, Courtesy of the Washington DOT and Appendix-02 – Sample Visual Engineer Job Description, Courtesy of the Georgia DOT

Defining the Scope of Work – Obtaining a thorough understanding of why visuals are required for a project is highly important. Several factors will need to be considered during the scoping process;

1. The intended use of the visuals?
2. What is the final output required?
3. What assets are available to develop the visuals?
4. What is the production schedule/deadline?
5. What is the level of Development/Detail required?

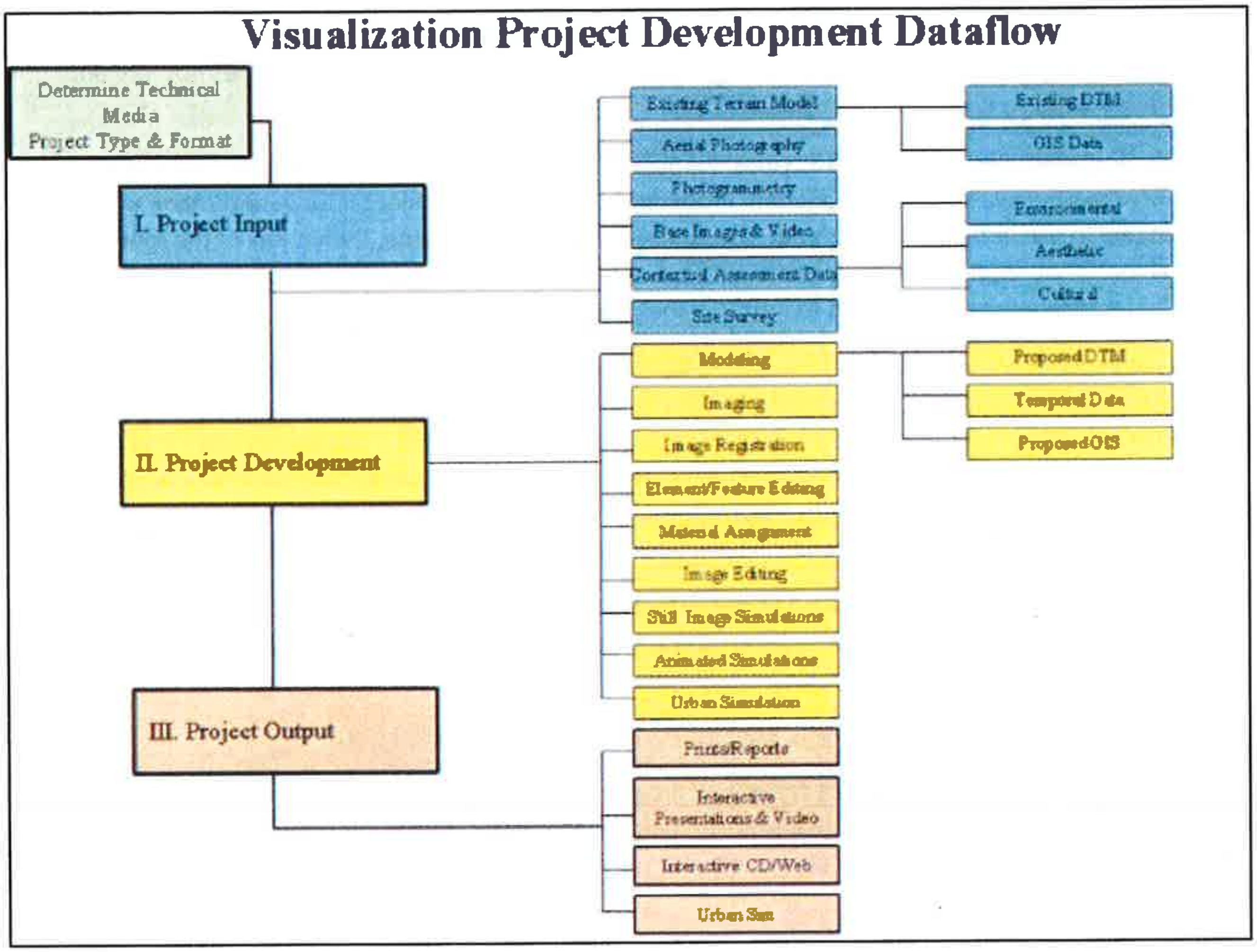

Figure-14 – Sample Visualization Project Development Dataflow, Courtesy NYSDOT

Intended Use – It is important to know what the intended use of the visuals will be. This will aid in the selection of visual tools. Are the visuals required for a public presentation? For a Stakeholder meeting? Design review session? These are a few of the basic questions that need to be asked. For example, if visuals are required for a design review session, they will tend to be more focused on technical detail versus aesthetic quality. Therefore, the visualization professional should expect a greater effort on 3D modeling specific details within the design.

Final Output Required – The Visualization Professional should meet with the Project Manager/Decision-maker to discuss the anticipated output required. Each type of visual tool has different production processes. Knowing upfront the output required, will result in better scheduling and production flow. For example, the final output required for a project is a 1-minute computer animation. The Visualization

Professional will have to account for rending time during the production process. This extra time will impact how much 3D modeling can be accomplished.

Available Assets – Properly assessing the level of effort required to produce visual content is dependent on the knowledge of the existing assets that can be used on a project. Assets can range from a photograph to a 3D BIM model. Visualization Professional should attempt to acquire as many assets as possible as they have the potential to reduce production time. Consideration should also be given to the quality of the assets. For example, obtaining a complex 3D BIM model to utilize for a real-time application might cause additional work due to the complexity of the model, which does not function effectively within a real-time application.

Production Schedule/Deadline – It is critical to meet with the Project Manager/Decision-Maker to identify the time available for production. Production time will be a major factor in determine which visual tool to use. If the schedule to develop content is a short timeframe, then many of the more robust visual tools that require time to develop will be eliminated. Meeting up front will set expectations with the Project Manager and also lead to better management of the visual workflow.

Level of Development/Detail (LOD) – Knowing how much detail to create for a visualization project is essential, as it will impact the production schedule, budget and output required. Expectations need to be set early in the workflow process, so that the Project Manager/Client understands what the final deliverable will be. When generating 3D content, there are often misconceptions on the LOD between the visualization professional and the client. Does every bolt on a bridge need to be 3D modeled or just the major components of the super-structure? This is the line of questioning that should be considered.

For example; the American Institute of Architects (AIA) has established Levels of Development/Detail (LOD) for BIM related projects. These level designations can be used for modeling within the transportation design workflow as well.

(Reference; http://www.aia.org/groups/aia/documents/pdf/aiab078868.pdf).

Level of Development/Detail (LOD) definitions progress from the lowest level of conceptual approximation, to the highest level of representational precision. The AIA determined that five levels, from conceptual through as-built, were sufficient to define the progression. They are as follows:

100. Conceptual

200. Approximate geometry

300. Precise geometry

400. Fabrication

500. As-built

Figure-15 – Level of Development/Detail Examples

Careful consideration should be given when selecting, which LOD is to be used as it determines scope and budget. As equally import, communicating this information early in the visualization workflow process needs to be accomplished.

Level of Development (LOD)	Model Content Requirements	Authorized Uses
LOD 100	Overall massing indicative of height, volume, location and orientation. May be modeled in three dimensions or represented by other data.	Limited analysis Aggregate cost estimating High-level staging
LOD 200	Elements are modeled as generalized systems or assemblies with approximate quantities, size, shape, location and orientation. Attributes may be attached to model elements.	Preliminary Analysis High-level cost estimating High-level scheduling
LOD 300	Elements are modeled as specific assemblies and are accurate in quantity, size, shape, location and orientation. Attributes may be attached to model elements.	Construction documents Detailed analysis Project controls
LOD 400	As per LOD 300 plus complete fabrication, assembly and detailing information	Model-based fabrication Actual cost tracking Look-aheads Virtual mock-ups
LOD 500	Elements are as-constructed assemblies accurate in quantity, size, shape, location and orientation. Attributes may be attached to model elements.	Maintenance and planning of future construction

Figure-16 – AIA Definitions of LOD

The Production Schedule – With the production deadline set, the Visualization Manager/Professional will then need to develop a production schedule. When developing the production schedule, several factors need to be taken into account;

1. Aptitude of Staff to produce the visuals
2. Special requirements for the deliverable.
3. Rendering & Post-production time
4. Existing workload

Aptitude of Staff – This is an important factor to understand during the scheduling process. Often, the Visualization Professional is not proficient in every visual tool required for a project. Therefore, there might be a need to shift workload, so that it will match up to staff abilities and availability. In cases where there is not in-house expertise, then outside consulting services might be required. Having existing relationships with consultants is important, as they have the potential to provide additional resources for workload. Not having proper staffing will result in missed deadlines and/or a project deliverable that does not meet expectations.

Special Requirements – Each project has unique constraints that the Visualization Professional needs to be aware of when scheduling work. Are there specialty services required for the deliverable? For example; GIS, video production, web development or programming. These specialty services potentially will require support from outside of the visualization group. Careful coordination will need to be factored into scheduling, since workload will be produced by personnel that report to others within the transportation agency.

Rendering, Post-Production – When scheduling a project, time must be accounted for post-production activities such as; the number of review sessions required, rendering time, publishing or programming. When generating computer animation, rendering time is a major consideration. Typically, a render farm is used to generate the renders needed to produce a computer animation. The time required to generate these renders will need to be factored into the schedule. If it is estimated to take 4-days to create the renders, then 3D modeling production will need to be completed at a minimum 5-days before the production deadline. If post-production is factored in, that time might even be longer. It is important to establish upfront how many review sessions are required during the schedule and to the scope of edits allowed. This process is important to help avoid scope creep on a project.

Existing Workload – Current workload must be taken into consideration when scheduling a visualization project. The visualization professional/staff must have availability to work on a project in order to meet schedule/deadline. If staffing is insufficient, then other options will need to be considered. For example, can the deadline be extended? Is overtime allowed? Can staff outside the visualization group be utilized? Should an outside consultant be hired? Existing workload must be accounted for when setting up a production schedule.

3. Types of Visualization

Visualization can be loosely divided into three categories of visual types; two dimensional (2D) visuals, three dimensional (3D) modeling and rendering, and Intelligent Design solutions (BIM/VDC/CIM or 4D, 5D, 6D). Determining which format best fits the project needs is dependent on factors ranging from budget, schedule, project phase, and output requirements.

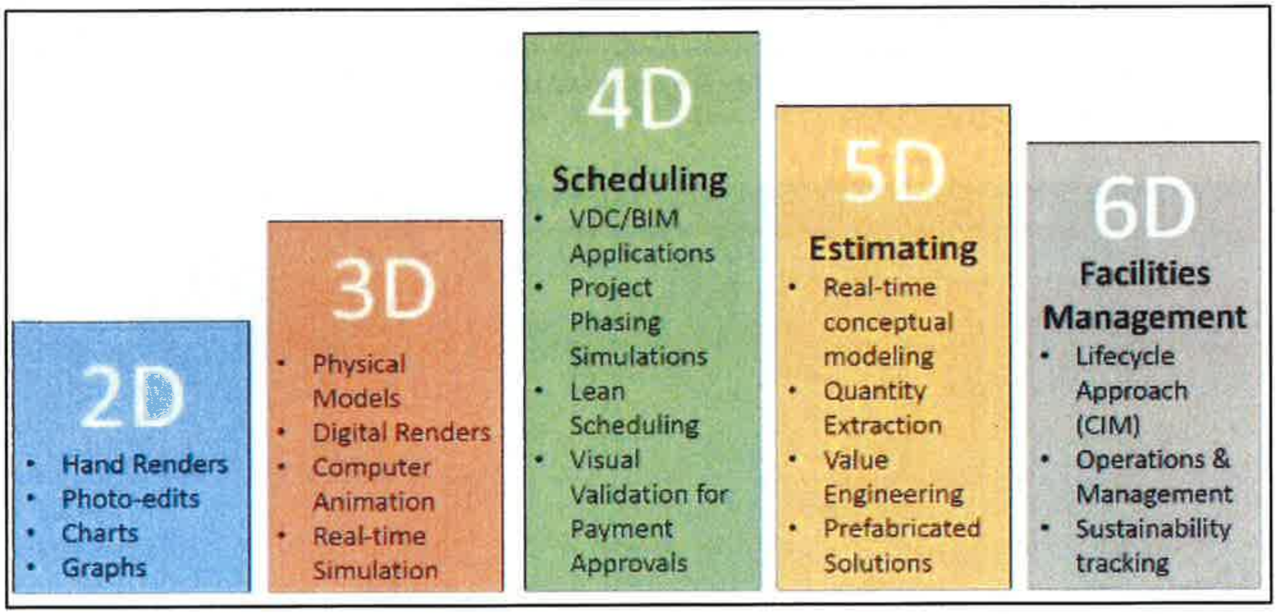

Figure-17 – Types of Visual Formats Chart

Two-Dimensional (2D) Images

2D imagery includes illustrations, photo-based images, and graphics such as charts and digrams. A 2D image has dimensions of height and width only and its elements are organized in terms of a flat surface, especially emphasizing the vertical and horizontal character of the picture plane. It is derived from printing and drawing technologies, such as typography, cartography, technical drawing, advertising, etc. In those applications, the two-dimensional image is not just a representation of a real-world object, but an independent artifact with added semantic value; two-dimensional models are therefore preferred, because they give more direct control of the image than 3D computer graphics (whose approach is more akin to photography than to typography).[22]

2D graphics are mainly used in applications that were originally developed upon printing and drawing techniques. Two-dimensional imagery is often used when project schedule and budget are both limited. In general, producing 2D imagery takes less time. Example applications would be; 2D Graphic Editors, Image Editors and Word processing.

A hybrid that spans between 2D and 3D imagery is photo-simulation, a visualization tool that has supported transportation outreach and communication for many years. Photo-simulation is the addition of design imagery over a photograph (almost exclusively done with digital imagery though there was a time when artists painted designs in oil over paper photographs). This can be 'paint' imagery, added with digital painting tools, or a combination of 3D project components rendered from the same vantage point as the original camera and touched up with paint. A simple 3D model of existing context is used to 'camera match' the model to the original photograph. Once this is done, 3D elements added to the context model are accurate within the photo-simulation view. 2D image libraries of vehicles, people and vegetation are available to support this process. Photo-simulations can be very accurate, realistic, and very cost effective. The limitation is that they are restricted to the viewpoint of the original camera view- hence 2D.

Figure-18 – Photo-simulation example. The roadway and wall outlines were created from a 3D wireframe model, the materials and textures were all 'painted' in. Courtesy Caltrans

Three-Dimensional (3D) Models

A Three-dimensional (3D) model displays a picture or item in a form that appears to be physically present with a designated structure. Essentially, it allows items that appeared flat to the human eye to be displayed in a form that allows for various dimensions to be represented. These dimensions include (X, Y & Z axis) width, depth, and height. 3D modeling is the process of developing a mathematical representation of any three-dimensional surface of an object (either inanimate or living) via specialized software. The product is called a 3D model. The engineering community uses 3D computer aided design (CAD) programs to create three dimensional models of surfaces and structures.

There are several types of 3D modeling; Primitives, Polygonal, NURBS, Splines & Patches.

Primitive Modeling - The first and most basic is known as the "primitive" modeling method. This is the simplest way of modeling 3D objects, and involves the use of geometric basics such as cylinders, cones, cubes and spheres. The forms here tend to be mathematically defined and precise. Primitive modeling is mainly used in developing 3D models of technical applications.

Polygonal Modeling - A slightly more advanced approach, makes use of what is known as the "polygonal" method. Polygonal modeling involves connecting line segments through points in a 3D space. These points in space are also known as vertices. Polygonal models are very flexible and can be rendered by a computer very quickly. One cannot, however, create an exact curved surface using polygonal 3D modeling technique, which limits its usefulness in certain applications.

NURBS Modeling - Non-uniform rational B-spline modeling, also known as the NURBS method, is one of the best ways for developers to create truly curved smooth surfaces. Unlike polygonal modeling techniques, which can only approximate curved surfaces using numerous polygons, NURBs modeling actually does "bend" the space. This style of modeling is widely used across most platforms.

Splines and Patches Modeling - A more advanced form of NURBS modeling is the "splines and patches" method. This type of program allows developers to use curved lines to identify and project the visible surface. It often takes more time to build and execute commands in this category.

3D Modeling can be output to a variety of sources. Most common are 3D renders and animation. In 3D graphic design, rendering is the process of add shading, color and lamination to a 2D or 3D wireframe in order to create images on a screen. Rendering may be done ahead of time (pre-rendering) or it can be done in on-the-fly in real time. Real-time rendering is often used for 3D video game engines, which require a high level of interactivity. Pre-rendering, which is CPU-intensive but can be used to create more realistic images, is typically used for high definition renders or animation.

Animation has been included in the 3D model section as it is a primary capability and direct output from most modeling applications in use today. Historically, animation was sometimes referred to as '4D', time being the 4^{th} dimension referred to. The term '3D modeling and animation' has become much more commonplace, and animation is almost always a component of a 3D modeling effort. The term '4D' has now become more commonly used to describe schedule linked simulations, these are described in the next section.

Porting 3D geometry between applications is now supported on most platforms. The standard workflow is to produce models in the most familiar 3D modeling application that allows the needed level of detail, and then if needed port to an application that supports the level of rendering quality and animation needed. Some projects, especially in the planning or design phase need lower level of detail than projects in later phases. The level of detail and realism needed in the model is driven by the message being communicated and to what audience it is being illustrated to. More and more, visualization modelers are using 3D CAD data directly from the designers as a starting point. As 3D design processes become more common this will become a standard workflow.

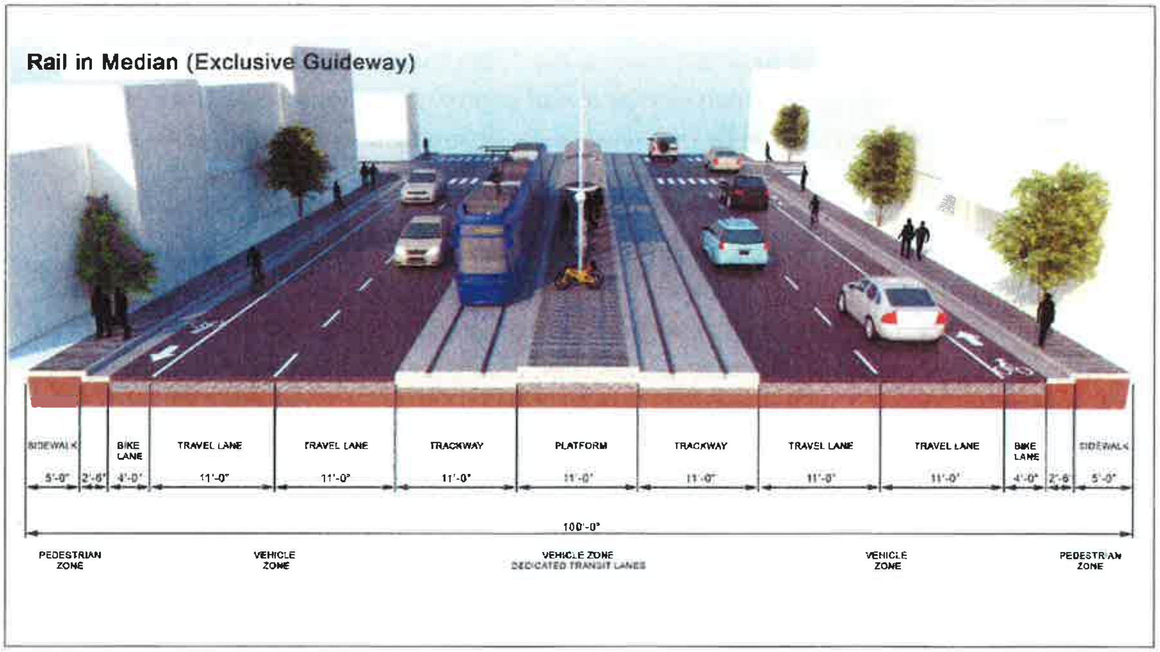

Figure-19 – Conceptual 3D model illustrating lane configuration alternatives. This low level of detail is more cost effective to produce and focuses the attention on the planning concepts being conveyed.

Figure-20 – Detailed 3D model illustrating final project condition. This high level of detail and realism is more effort to produce and focuses the attention on design details, landscaping, and final experience of the project

Computer Animation occurs in two primary ways; Keyframe Animation and Motion Capture.

Keyframe Animation - or keyframing, is the most well-known and oldest style of animation. Keyframing techniques date back to the early 1900's cartoons created by animation pioneers such as, Walt Disney. However, most of the basic principles used by Disney still apply today. Keyframing is essentially changing the shape, position, spacing, or timing of an object in successive frames, with major changes to the object being the key frames. In traditional 2D animation, each frame is usually drawn by hand. When frames are shown in succession, as in a movie, the slight differences in each frame of animation create the illusion of motion.

Motion Capture - or 'mocap', whereas keyframing is a precise, but slow animation method, motion capture offers an immediacy not found in traditional animation techniques. Mocap subjects are attached with sensors that record motion. The data is then linked to a 3D object or character and translated into animation by 3D software.

Another form of 3D is the creation of physical models. Physical models are small objects, usually built to scale, that represents in detail another, often larger object. A preliminary work or construction that serves as a plan from which a final product is to be made: (i.e. a clay model ready for casting). Used in testing or perfecting a final product. Physical models can be created by hand or generated by 3D printing technologies.

Intelligent Design (4D, 5D & Beyond)

Intelligent Design is essentially the combination of 3D modeling with other data associated with 3D elements. It refers to the intelligent linking of individual 3D CAD components or assemblies with all aspects of project life-cycle management information[23]. The models created during this process are parametric and integrated with data. Since the planning and design process is in 3D, visualization is a logical extension of project deliverables.

The terms 4D, 5D, 6D, *(...nD?)* are beginning to take on more specific meaning within the AEC communities. While '4D' was once used to describe the addition of movement, or animation, to 3D objects, that use of the term has diminished significantly. The use of the term '4D' to refer specifically to 3D models linked to planning or construction schedules has become much more ubiquitous with the advent and common use of software applications that produce these schedule-linked simulations somewhat automatically. As these tools allowed the addition of additional data associated with construction activities (cost, resources, materials, etc.) the community began to refer to these additional data associations as new dimensions. For example, adding cost information to 4D model construction activities would constitute a '5D' model. Cost information can be displayed over time with association to specific activities in the schedule. Each new attribute added to activities in the 4D model could constitute a new dimension (6D...nD). *This author maintains that these additional data are attributes, or extended parameters of the 3D/4D activity based objects, but the dimensional terminologies are starting to become more commonly used.*

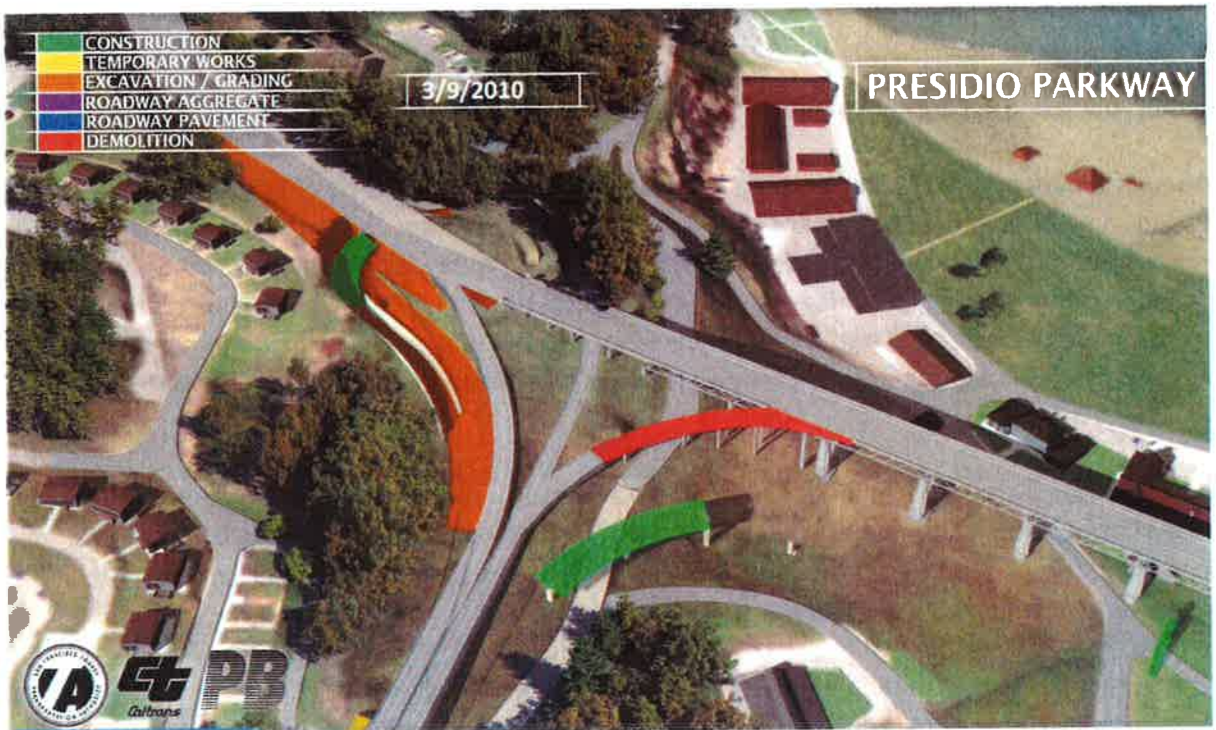

Figure-21 – 4D schedule-linked model snapshot. The color of the geometry is changed over time to represent construction activity types based on the contractor's schedule. Image courtesy SFCTA

The term '5D' is being used by more and more AEC communities to refer specifically to cost loaded 4D models. As part of the Every Day Counts (EDC3) initiative, the FHWA is using the term '5D' to specifically refer to cost loaded 4D models: https://www.fhwa.dot.gov/everydaycounts/edc-3/3d.cfm.

In conjunction with the efforts of the FHWA & NCHRP, the National Institute of Standards and Technology (NIST) researchers and their industrial partners aim to add a new dimension to manufacturing and design capabilities. In a new project, they will demonstrate the feasibility—and benchmark the advantages—of using standardized, three-dimensional (3D) models for electronically exchanging and processing product and manufacturing information all the way from design through inspection of the final part, a tightly integrated, seamless string of activities that manufacturers are calling a "digital thread".[24] The terminology used to define 4D, 5D, 6D, and beyond is often misunderstood. The NIST intends to specifically define and standardize these terms.

Virtual Design and Construction (VDC), Building Information Modeling (BIM) emphasizes those aspects of the project that can be designed and managed, the organization that will define, design, construct and operate it, and the process that the organization teams will follow. These models are logically integrated in the sense that they all can access shared data, and if a user highlights or changes an aspect of one, the integrated models can highlight or change the dependent aspects of related models. The models are multi-disciplinary in the sense that they represent the Architect, Engineering, Contractor (AEC) and Owner of the project, as well as relevant sub disciplines. The models are performance models in the sense that they predict some aspects of project performance, track many that are relevant, and can show predicted and measured performance in relationship to stated project performance objectives.

To address Intelligent Design, The Federal Highway Administration has developed Civil Integrated Management (CIM), which is the collection, organization, and managed accessibility to accurate data and information related to a highway facility. The concept may be used by all affected parties for a wide range of purposes, including planning, environmental, surveying, construction, maintenance, asset management, and risk assessment. A US Domestic Scan Program has been sponsored by the National Cooperative Highway Research Program (NCHRP) and is titled; Scan 13-02 "Advances in Civil Integrated Management (CIM). This scan is being conducted as a part of NCHRP Project 20-68A, the U.S. Domestic Scan program and is scheduled to be published July 2015. The program was requested by the American Association of State Highway and Transportation Officials (AASHTO), with funding provided through the NCHRP. The purpose of the scan and Project 20-68A as a whole is to accelerate beneficial innovation by:

- Learning about a state's successes, challenges, steps to overcome challenges
- Facilitating information sharing and technology exchange among the states and other transportation agencies
- Identifying actionable items of common interest

Expected benefits of implementing a CIM solution are; more effective decisions, open data access and improved communications. To help educate transportation professionals on implementing CIM techniques, the FHWA has set up the 3D Engineered Models web portal. The site provides web based training, workshops, webinar series and field demonstrations. It can be accessed at; http://www.fhwa.dot.gov/construction/3d/

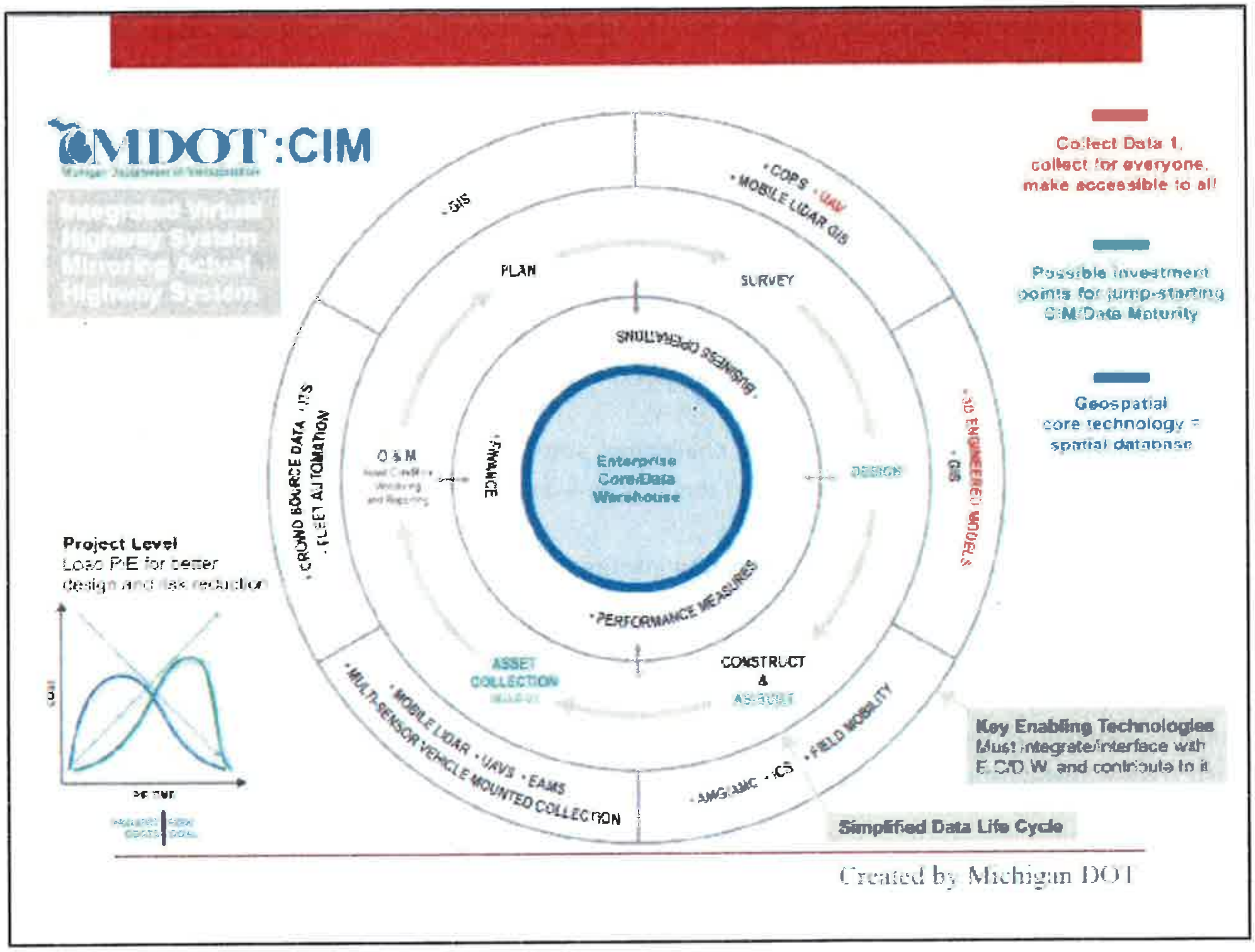

Figure-22 – Civil Integrated Management (CIM), Courtesy of Michigan DOT

The Florida Department of Transportation is one of the first DOT's to start the process of utilizing 3D design techniques for the project delivery process. FDOT will sunset support for legacy 2D Design tools. The last major update, was in July 2014, and will be the last FDOT release to include 2D criteria. All new projects will utilize 3D design techniques. The benefits include; productivity improved by up to 50%, survey costs cut up to 75%, reduced fuel consumption and greenhouse gas emissions by up to 40 percent and increased precision results in smoother surfaces. Details are contained with the FDOT Course Guide, located at;
http://www.dot.state.fl.us/ecso/downloads/documentation/FDOTCorridorModeling/FDOTCorridorModeling.shtm

4. The Benefits of Visualization

The use of Visualization tools and processes has made significant impacts and benefits within the transportation planning and design community. Once having been a specialized service for public involvement, visualization has become a part of the project delivery process within most transportation agencies. Overall, the project delivery process has been improved through the use of Visualization.

Figure-23 – Public Involvement meeting, courtesy Parsons Brinckerhoff

Primary Benefits of Visualization include:

1. Improved Project Communication
2. Improved Project Understanding by Stakeholders and general public
3. Enhances the Project Acceptance/Approval Process
4. Improved Risk Management
5. Improved Comprehension and Understanding of Data
6. Improved Design Quality
7. The Potential to Reduce Costs

Improved Project Communication – As the transportation project delivery process continues to trend toward the use of Design-Build and Public Private Partnerships (P3), there will be a heightened need for increased and more effective communication. Visualization tools and process can assisted with the communication process through; accelerating the decision-making process, improving design consensus, providing highly technical information to a non-technical audience, construction sequencing and most importantly engaging the public. Visualization methodologies have created greater consensus and understanding, versus traditional methodologies such as plan sets and spreadsheet information. This occurs because these dated methods do not fully convey impacts in basic terms that the average person can understand.

Project Acceptance – Visualization and 3D modeling enhances the project acceptance process both for stakeholders and the general public. By providing a visual feedback methodology, planners and engineers can more easily convey complex issues. While 3D visualizations have become commonplace on big-budget transportation and land development projects, industry professionals continue to find new applications for the technology, which is continually gaining more functionality while becoming more affordable. No longer limited to niche experts working on megaprojects, visualizations are increasingly being developed by a wide range of professionals on projects of all sizes. The results are being viewed interactively in new formats, and often help answer questions from skeptical members of the public.

Improved Project Understanding by Stakeholders and general public – Visualizations of projects are much easier for the non-technical audience, including stakeholders and decision-makers, to understand than plan and section drawings. All stakeholders are 'seeing' the same view of the project and gaining a better understanding of project intent, goals, and potential impacts.

Improved Risk Management –Avoiding, mitigating or capitalizing on opportunities resulting from the visualization applications, help to reduce planning and design impacts. 3D Modeling and Visualization methodologies have many inherent benefits over working in 2D. Product visualization and presentation are improved, parts and drawing views update automatically and accurately, and interference and collision checking provides an automated, error-free way to check for interferences and collisions before constructing the project.

Improved Comprehension and Understanding of Data – Visualization of data (DEMs, DTMs, structures, etc.) is the core of higher-end 3D visualization and is at the heart of accuracy, reliability and thus credibility issues and concerns. 3D modeling and visualization has become part of the planning and design process through the implementation of BIM, VDC and CIM. The Building Information Modeling (BIM) Project Execution Planning Guide was developed to aid owners as they develop strategic, implementation, and procurement plans for BIM integrating in their organizations. This resource presents a structured approach to effectively plan the integration of BIM within an organization. Three planning procedures are presented: Strategic, Implementation and Procurement Planning. The Guide can be accessed at; http://bim.psu.edu/Owner/default.aspx

Improved Design Quality – 3D Modeling & Visualization solutions provides a variety of benefits. From a productivity standpoint, it increases the level of drawing automation, increases design accuracy. Engineers can develop applications to support and assist more complex modeling tasks, significantly shortening the learning curve required to achieve productivity. Because engineering time can be wasted looking for drawings and other documents, this increased automation boosts productivity and improves the efficiency of engineering design. Importantly, the 3D Modeling & Visualization offers a unified, multi-disciplinary environment in which you can learn how to use common tools spanning multiple disciplines. For example; Traffic analysis has been improved by allowing traffic engineers to integrate traffic simulation data within a 3D model through an automated process. Constraints, queuing and other issues that were often not identified with past methodologies are now readily seen.

The Potential to Reduce Costs – Throughout the project lifecycle visualization tools have the opportunity to achieve savings either through shortened approval times, enhanced production, improved design quality, reduce in-the-field changes, reduce contract change orders and accelerated the overall project schedule.

Penn State University has developed a Project Execution Planning Guide for the Use of BIM. The Guide provides a structured procedure, for creating and implementing a BIM Project Execution Plan. Many of the uses of BIM can be related to and/or referenced to Visualization and 3D modeling processes. Within the Guide, benefits for BIM have been identified as different tasks, which can benefit from the incorporation of BIM. These benefits are documented as BIM Uses. The guide includes twenty-five uses for consideration on a project (reference Figure-20). The complete guide can be referenced at; http://bim.psu.edu/Project/resources/download_thank_you.aspx

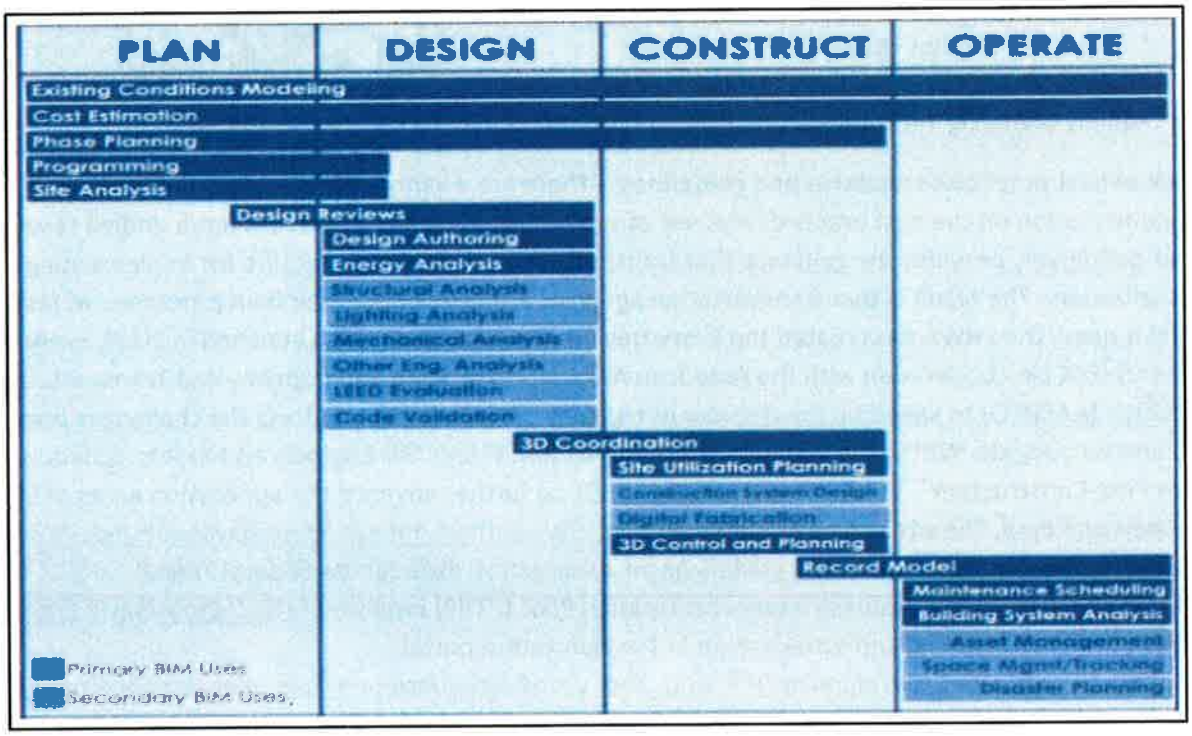

Figure-24 – BIM Uses throughout a Building Lifecycle, courtesy Penn State

To assist in the understanding of the benefits of Visualization and the 3D modeling process; Caltrans conducted a survey on "Advanced Modeling Techniques for Enhanced Constructability Review: A Survey of State Practice and Related Research". Caltrans was interested in learning how other state departments of transportation (DOTs) are employing 3D modeling and other types of advanced modeling techniques for developing highway infrastructure improvements. To aid in this effort, this Preliminary Investigation presented the results of a survey that explored the state of the practice in transportation agencies' use of advanced modeling. To supplement survey findings, Caltrans also examine domestic and international research and federal guidance related to the use of advanced modeling techniques to enhance project delivery. The full report can be accessed at; http://www.dot.ca.gov/newtech/researchreports/preliminary_investigations/docs/enhanced_constructability_review_preliminary_investigation.pdf

5. The Constraints of Visualization

Visualization tools and processes provide many benefits. However, there are constraints for its use that a transportation professional must be aware of. These constraints will impact the use/need for visualization, as well as determine the type of visual methodology used. Careful consideration to the constraints of visualization should be taken into account during the decision-making process for its use. Constraints include:

Figure-25 – FHWA, Every Day Counts logo

1) Lack of Best Practices, Standards and Guidelines
2) Staffing
3) Production Scheduling
4) Support from Senior Leadership
5) Budget
6) Rapidly Changing Technologies

Lack of best practices, standards and guidelines – There are a variety of resources, web sites and documentation on the best practices and use of visualization. However, there is not a unified resource that definitively provides the guidance that transportation professionals require for implementing visualization. The result is that transportation agencies are developing their own processes. In response to this need, the FHWA has created the Every Day Counts (EDC) web site. Launched in 2009, Every Day Counts (EDC) in cooperation with the American Association of State and Highway and Transportation Officials (AASHTO) to speed up the delivery of highway projects and to address the challenges presented by limited budgets. Within the web site, there is a section titled; "3D Engineered Models: Schedule, Cost and Post-Construction". The FHWA is working in EDC to further advance the application areas of 3D models and data. The site can be accessed at; http://www.fhwa.dot.gov/everydaycounts/edc-3/3d.cfm. Other sources for information and guidelines on visualization include; the Federal Transit Administration's Public Transportation Participation Pilot (PTPP) program. http://choosingviz.org/, the FHWA Scenario Planning and Visualization in Transportation portal; http://www.fhwa.dot.gov/planning/scenario_and_visualization/scenario_planning/scenpractices.cfm the FHWA, Federal Lands Highway Division | Design Visualization Guide http://www.efl.fhwa.dot.gov/guides/dv/default.aspx and the TRB Visualization in Transportation Committee (ABJ95) portal: http://www.trbvis.org/

Staffing – Several key factors must be taken into account concerning staffing.

- Currently, (most) transportation agencies do not have a defined position plan or group for a visualization employee. This impacts
    - *Hiring the proper personnel* (with appropriate knowledge and skillsets) Difficult to obtain upper management support, without a defined position plan. Reference Appendix-01 and Appendix-02 for sample position plans.
    - *Assigned Hardware & Software*. Most transportation agencies have stringent guidelines for computer hardware and software allocation, which is based primarily on defined position plans. Most agencies "bundle" visualization professionals within another job

description because there is not a defined position. A significant amount of visualization hardware and software requirements fall outside the existing parameters of other position plans. The result is that it is often difficult for the visualization professional to obtain the proper equipment.

- *Pay grades*. It becomes difficult to hire the proper skilled person because pay scales are typically not in alignment with other firms and agencies that hire visualization professionals.
- *Performance Reviews.* It is difficult for management to properly review visualization professionals because there is not a defined position plan and measures. This results and a poorly defined career path for the visualization professional.
- *Training* – Obtaining the proper training is difficult without a specific position plan. This problem is compounded by the limited resources offering training. Asides from direct vendor training, there are few options for outside training on visualization tools. Many agencies augment training by having personnel attend conferences or webinars. For example, through the EDC initiative, the FHWA has sponsored several webinars on 3D Engineered Models for Construction. A series of eight webinars have been developed to assist in adopting the technology. The webinars are given in a "cradle to grave" sequence. Participants will hear how contractors incorporate 3D engineered models in their workflow of bidding and preparing to execute construction. http://www.fhwa.dot.gov/everydaycounts/edctwo/2012/3d_webinars.cfm

- Recruitment
  - Most transportation agencies have hired visualization personnel from within the agency. These people typically come from the landscape architecture or GIS groups and tend to already have some visualization experience. Without a specific position plan, it is difficult to recruit and hire the proper person from outside of the agency.

Production Scheduling – Visualization projects within transportation agencies tend to be more reactionary, as they are not typically planned or discussed early within the project development process. The consequence is that the allotted schedule to develop visuals is limited, which results in adjustments to the visualization approach to a project. By discussing visualization options early within the project development process, transportation professionals can make more proactive decisions on its use.

Support from Senior Leadership – Since there are no unified national standards and guidelines, it is often difficult to garner acceptance from senior leadership on the use of visualization. Visualization processes often fall outside the standard practices implemented during project development, which makes it difficult for senior leadership to understand and determine its use. The perception from leadership is that visualization, while an effective tool, it is not vital within the project development process. However, as BIM, VDC & CIM practices continue to develop and expand, visualization processes will become more ingrained within project development.

Budget – Most transportation projects have limited funding and often, little to no monies set aside for visualization. Thus the use of visualization tends to be limited to large scale projects. Since the majority of small to mid-sized projects do not account for visualization in the early planning stages, there is a lack of funding for its use. Larger projects have a tendency to absorb the reactionary costs of visualization. Upfront planning for the use of visualization within the project development process will relieve some of these budgetary constraints.

Rapidly Changing Technologies – Transportation Visualization groups and personnel have historically been at the forefront of leveraging technology to assist in the project development process. However, as the need for innovative solutions grows, the technology options multiply, and funding streams diminish. Transportation professionals are under increasing pressure to rapidly adapt to the impacts of changing technologies and expectations. The pace and complexity of change has become so rapid over recent years, that traditional approaches to visualization have become outdated. Transportation engineers, planners and decision makers need to develop better insight into the nature of change, as well as the range of conditions they may encounter in the future. Consideration needs to be given as to when to adopt technology and the investment in it.

Figure-26 – Innovative 3D interactive public involvement viewing device which presents future plans via a mobile device embedded in a unique viewing platform. The device uses augmented reality to show future designs in context, image courtesy OWLized.

6. Output Delivery Methods

When considering visualization, there is a need to determine what the final output of the project will be. Determining the output will be based on several factors: needs of the project, budget, schedule, staff capabilities and assets available to complete the work. There are several types of output methodologies, each with its benefits and constraints. Careful upfront planning is required when selecting which output option to utilize. The primary output methods are:

1) Analog Deliverables
2) Digital Deliverables
3) Project Deliverables

Analog Deliverables – When people think of visualization, they often think of high-end computer animation and graphics. However, the traditional methods of analog deliverables are still an effective tool to utilize by the visualization professional. Deliverables include; print materials (photography, sketches, renders) and physical models.

Creativity and innovation play vital roles in the engineering design process. Prototyping is a potential aid that can support designer cognition and thereby spur novel ideas. Designers often use physical models in the idea generation process. Physical models range from very simple models used for the visualization of the idea to complicated three dimensional and fully functional prototypes. Physical models can be produced by traditional hand created techniques or through 3D printing technologies. 3D printing is a process of making three dimensional solid objects from a digital file typically from a 3D CAD resource. 3D Printing technology is advancing rapidly and diminishing in cost. This technology will rapidly evolve into a standard method of producing deliverables to support design and outreach.

Figure-27 – 3D Printed Model Examples, courtesy SFCTA

Digital Deliverables - Title 23 Section 106(j) of MAP- 21 defines "Advanced Modeling Technology" as an available or developing technology, including 3D digital modeling that can; accelerate and improve the environmental review process; increase effective public participation; enhance the detail and accuracy of project designs; increase safety; accelerate construction, and reduce construction costs; or otherwise expedite project delivery with respect to transportation projects that receive Federal funding. The overarching goal is to improve the project delivery process. Output deliverables in a digital format help to achieve this goal. Several DOT's have begun the process of implementing a digital delivery process. The Oregon DOT as of January 1, 2015, requires delivery of roadway digital data bidding reference packages. http://www.oregon.gov/odot/hwy/3drdm/pages/index.aspx

There are several types of digital deliverables to consider:

- *Electronic file formats* – include digital renderings from 3D CAD & Modeling applications, video production, photo-simulation and animation. Essentially, it is content that is generated by a computer program and then outputted to print or media. A detailed listing of file formats and usage can be located in the FHWA Communications Reference Guide, Chapter 8 – Electronic Publishing. http://www.fhwa.dot.gov/publications/research/general/03074/qrg08.cfm

- *Real-time Simulated Models* – are 3D models that can be interactively navigated through, via a wide variety of devices and applications. With these virtual reality based tools, participants can request in real-time, that specific locations and scenarios be observed, enabling them to obtain greater understanding. Real-time simulation is a powerful tool for analyzing, designing, and operating complex systems. It is a cost-effective means of exploring new processes, and provides a method for checking design impacts interactively, helping to produce results faster than traditional digital file formats. Gaming engines are now being utilized for planning and design to provide real-time feedback on projects.

  Driving Simulators are utilized for some transportation planning projects. They provide a mechanism for exploring research that is infeasible, too costly, or unsafe in the real world, including assessing cognitive or physical ability, gaining understanding of driver performance and behavior, testing vehicle design in virtual proving grounds, and training drivers. Driving simulators come in variety of options from a portable PC system, to a more advanced CAVE facility or a sophisticated motion based system. The University of Iowa's National Advanced Driving Simulator employs a suite of driving simulators and instrumented vehicles to conduct research studies for the private and public sectors. https://www.nads-sc.uiowa.edu/

Figure-28– Driving Simulator, courtesy University of Iowa

Other unique real-time simulated tools include; augmented reality applications, virtual reality based headset technologies and output devices that utilize 180 or 360-degree viewers. It is a non-linear stretching technique that adjusts the viewing ratio of the displayed video with minimal distortion. It achieves this by stretching the video image on the edges of the screen, leaving the center of the screen unaffected.

- *Web Applications* – The heightened used of social media has pushed the need for informative web sites to keep stakeholders and the general public informed. Project based web sites and applications have become common tools used by transportation professionals. The Internet offers transportation agencies a relatively inexpensive and widely accessible channel to distribute information to current and potential customers, employees and vendors and to other stakeholders. Web sites can be used as a resource for a project, or as a reference tool for training. Many of these sites use visual tools for imagery. The FHWA's National Highway Institute (NHI) has developed the, "Web-Based Training (WBT) Developer Toolkit". The guide was developed to provide NHI contractors with guidance in developing web based training applications. The toolkit can be accessed at; https://www.nhi.fhwa.dot.gov/resources/wbt_developer.aspx

- *Mobile Applications* – For many years, access to databases, networks, web services, and various other computing resources at public transportation agencies was largely limited to transportation agency staff. As computing technologies have evolved, the term "cloud computing," commonly referred to as "the cloud," has emerged to describe a way of linking these resources via the Internet, to provide information to both internal and external users. The cloud also enables agencies to share processing and visualization tools. This allows agencies to present data in a more interactive manner than with traditional data-sharing mechanisms, presenting opportunities for expanded sharing of geospatial information. Public agencies are increasingly turning to cloud technology to help streamline workflows and allow data sharing among a broader audience. In particular, transportation agencies are beginning to use cloud computing to more easily store, manage, manipulate, analyze, and share geospatial data and business information. Cloud technology can replace traditional data-sharing mechanisms such as File Transfer Protocol (FTP) sites by displaying data in an interactive manner. Even modest efforts to use cloud technology have led agencies to ask fundamental questions about how transportation agencies will conduct business in the future. The public sector is increasingly adopting cloud technology to streamline workflows and to allow data sharing among a broader audience. Traditionally limited to GIS experts or displayed on static maps, transportation agencies are moving geospatial data to cloud-based formats to adapt to new mobile technologies and an increased general expectation for on-demand and interactive access to information.[25]

The pervasive use of mobile devices has increased the need for transportation agencies to address the utilization of mobile applications and devices. Uses range from Automated Machine Guidance (AMG) with GPS based mobile systems, to handheld devices that synchronize field data with database servers. Outreach uses include web feeds and blogs to keep the public informed on a project.

Figure-29 – Mobile Device in the field, courtesy Parsons Brinckerhoff

Project Deliverables – The process that transportation agencies utilize to deliver a project is evolving from many different directions. Visualization processes need to evolve with them. As planning and design continue to migrate toward 3D database driven applications, the visuals required for those projects will become imbedded into that process. Visualization professionals will need to learn how to integrate their applications within the BIM, VDC, GIS and CIM workflows.

Summary

The State of Visualization

There has been significant progress in the use of visualization tools for the project development process at transportation agencies since the last update to the Visualization in Transportation Guide (2003). What was once the domain of graphic specialists, visualization has become a more accessible tool that most transportation professionals can use. This trend has occurred due to the integration of 3D technologies into the planning, design and construction processes. These processes are changing how visualization is incorporated into the project delivery process. Visuals are becoming more ingrained into the process, not a by-product of it.

The Federal Highway Administration has begun to promote Civil Integrated Management (CIM) into the project delivery process. CIM utilizes multiple tools and process to achieve a lifecycle approach to project development. These tools and processes are based on the development of 3D modeling and database information. The result is that visual tools and output capabilities are becoming part of project development.

The methodologies for project delivery are also changing. Alternative delivery methods such as Design-Build and Public-Private Partnerships (P3) have heightened the need to more effectively communicate. Visual tools have become more essential with the increased need to effectively communicate. Transportation agencies will be challenged to identify those tools and as to how to integrate them within the project delivery process.

As stakeholders and the public continue to embrace social media, real-time data and virtual reality based applications; transportation agencies will be challenged to respond. Agencies will need to identify and develop visual tools to meet this need. Agencies should be proactive in their approach, starting with assigning a Visual Quality Manager/Engineer within their agency.

These trends will continue to increase as the rapid advancement and acceptance of technology driven tools and applications increases. Tools such as mobile applications, cloud based computing and advanced technologies such as laser scanning and 3D printing, all are impacting how transportation projects are planned, designed, constructed and maintained. Similar to the innovative CAD tools developed in the 1980's, the innovative tools today, will change how transportation agencies produce projects in the future.

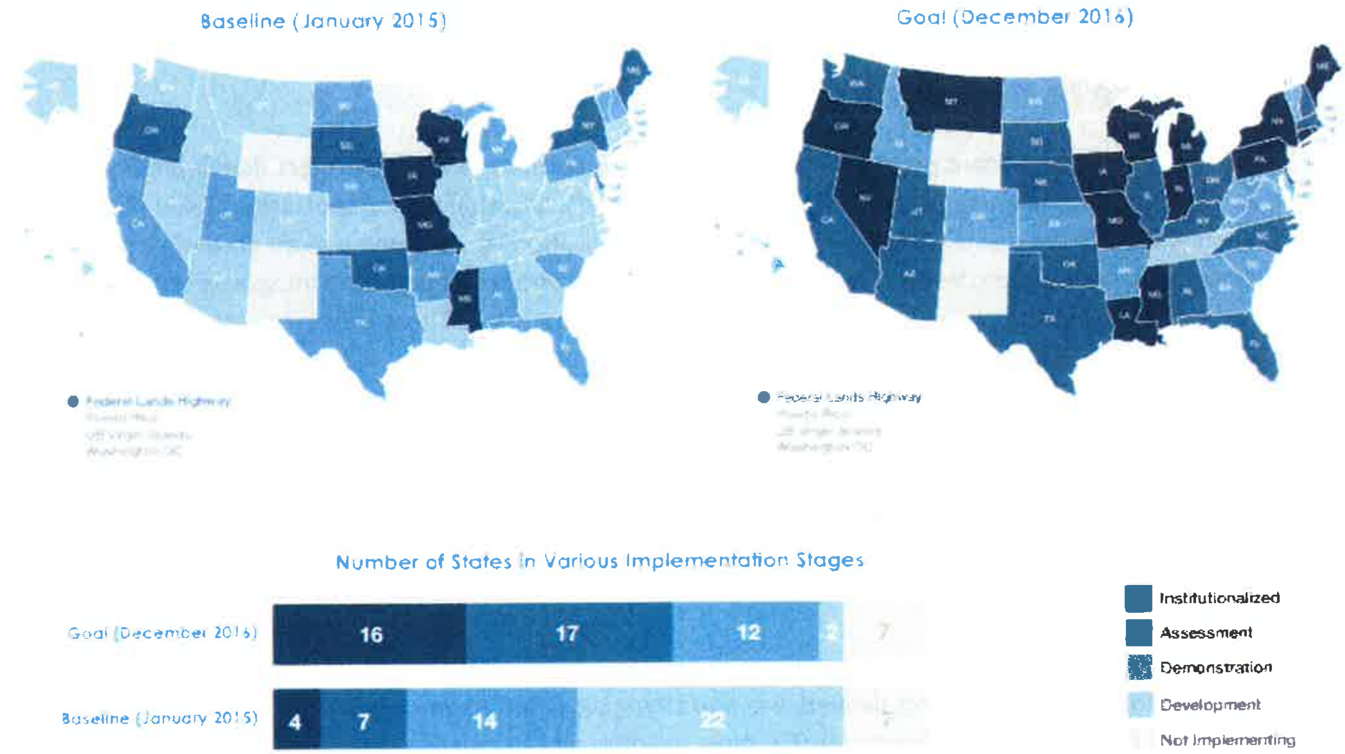

Figure-30 – 3D Engineered Models – Current Status, Courtesy FHWA

Next Steps for Visualization

To assist transportation agencies on how best to incorporate visualization into the project delivery process, several steps need to be explored.

Continued development of national and statewide standards, guidelines and best practices for their use

1) A call for new case studies
2) Identify and resolve gaps in organizational implementation and adoption

Continued development - There are a wide variety of resources available to assist transportation professionals with visualization technologies. The primary issue is, that this information is not centralized or is difficult to locate. The Federal Highway Administration has made great strides in developing the Every Day Counts web portal (http://www.fhwa.dot.gov/everydaycounts/). It is a very good resource for innovation within the transportation community. However, more development is needed as technology continues to advance at a rapid pace.

Case Studies – The advent of new project delivery methodologies such as Design-build, Civil Integrated Management and Virtual Design and Construction (VDC) has caused the need for additional understanding on how visualization technologies integrate with these processes. Supplementary case studies will be needed to help transportation professionals understand the integration process. In conjunction with the changing project delivery process, rapid advancement in technology will increase the need for case studies. Further study will be needed to identify the impacts, benefits and constraints of the rapid pace of change.

Resolve Gaps – A significant obstacle to implementing visualization services within transportation agencies is that visualization is not recognized as an official discipline. Few transportation agencies have developed a formal group producing visuals, nor do they have formal job classifications/titles for visualization professionals. Agencies need a more comprehensive understanding of the discipline of visualization and how best to incorporate that discipline into its workflow.

Glossary of Terms

3D Design - The term is an abbreviation for three-dimensional design, incorporated commonly in design procedures associated with computers and other electronic drawing systems. In 3D design techniques, a designer uses all three axis (x, y and z) to interpret and develop a realistic figure of the desired object.

3D Printing - A manufacturing process that generates three-dimensional solid objects from digital models. To print a 3D object, the manufacturer uses a device that 'lays down' solid material in layers based on the digital 3D geometry of the model.

4D Model - a term widely used in the AEC industry, refers to the intelligent linking of individual 3D CAD components or assemblies with time or schedule-related information. The use of the term 4D is intended to refer to the fourth dimension: time, i.e. 4D is 3D plus schedule (time). The most common use now refers specifically to simulations representing time-based activities derived directly from a planning or construction schedule.

5D (6D...nD) Model – originally referred to any activity associated data (such as cost, materials, or resources) being added to the 4D model, each attribute being considered a new dimension. '5D' has more recently been used almost exclusively to refer to 4D models where cost has been associated with activities. This type of 5D model allows planners to explore what the budgeted/estimated cost of a project might be at any given point in time during construction.

American Association of State Highway and Transportation Officials (AASHTO) - is a standards setting body which publishes specifications, test protocols and guidelines, which are used in highway design and construction throughout the United States. Despite its name, the association represents not only highways but air, rail, water, and public transportation as well.

American Institute of Architects (AIA) - is a professional organization for architects in the United States. The AIA offers education, government advocacy, community redevelopment, and public outreach to support the architecture profession.

American Society of Civil Engineers (ASCE) - founded in 1852 to represent members of the civil engineering profession worldwide. Based in Reston, Virginia, it is the oldest national engineering society in the United States

Augmented Reality (AR) - is the integration of digital information with live video or the user's environment in real time. Basically, AR takes an existing picture and blends new information into it. One of the first commercial applications of AR technology is the yellow first down line in televised football games.

Automated Machine Guidance (AMG) – refers to the use of a CADD generated 'finished' design surface used in conjunction with sophisticated software and construction equipment to direct the operation of machinery with a high level of precision, improving the speed and accuracy of highway construction processes.

Big Data - an all-encompassing term for any collection of data sets so large and complex that it becomes difficult to process them using traditional data processing applications.

Bridge Information Modeling (BrIM) - can be an information definition of the bridge asset, co-created by many people using an array of technology to answer broad-ranging needs. BrIM can benefit the entire bridge lifecycle, project selection through rehabilitation, resulting in the development of new best-practices.

Building Information Modeling (BIM) - a process involving the generation and management of digital representations of physical and functional characteristics of places. Building information models are files (often but not always in proprietary formats and containing proprietary data) which can be exchanged or networked to support decision-making. Current BIM software is used to plan, design, construct, operate and maintain diverse physical infrastructure.

Computer Augmented Virtual Environment (CAVE) - is a multi-person, multi-sided, high-resolution 3D environment that is used for viewing virtual content in an immersive interactive setting. These displays are used in a wide variety of design and research applications in the university, commercial and industrial sectors.

Computer-Aided Design (CAD) - the use of computer systems to assist in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. Its output is often in the form of electronic files for print, machining, or other manufacturing operations.

Computer Animation - is the art of creating moving images via the use of computers. It is a subfield of computer graphics and animation. It is created by means of 3D computer graphics. It is also referred to as CGI (Computer-generated imagery or computer-generated imaging), especially when used in films.

Computer Rendering - Is the process of add shading, color and lamination to a 2D or 3D wireframe model in order to create fully textured images. Rendering may be done ahead of time (pre-rendering) or it can be done in on-the-fly in real time. Real-time rendering is often used for 3D video games, which require a high level of interactivity. Pre-rendering, which is CPU-intensive but can be used to create more realistic images, is typically used for animation and video production.

Civil Integrated Management (CIM) - is the collection, organization, and managed accessibility to accurate data and information related to a highway facility. The concept may be used by all affected parties for a wide range of purposes, including planning, environmental, surveying, construction, maintenance, asset management, and risk assessment.

Context Sensitive Solutions (CSS) - a collaborative, interdisciplinary approach that involves all stakeholders in providing a transportation facility that fits its setting. It is an approach that leads to preserving and enhancing scenic, aesthetic, historic, community, and environmental resources, while improving or maintaining safety, mobility, and infrastructure conditions.

Data Visualization - a general term that describes any effort to help people understand the significance of data by placing it in a visual context. Patterns, trends and correlations that might go undetected in text-based data can be exposed and recognized easier with data visualization software.

Design-Bid-Build (DBB) – The traditional U.S. project delivery method, which customarily involves three sequential project phases: design, procurement, and construction. Design-build is a project delivery method that combines two, usually separate services into a single contract. With design-build procurements, owners execute a single, fixed- fee contract for both architectural/engineering services and construction. The design-build entity may be a single firm, a consortium, joint venture or other organization assembled for a particular project.

Design-Build (DB) – A project delivery method that combines architectural and engineering design services with construction performance under one contract.

Environmental Impact Statement (EIS) - a document prepared to describe the effects for proposed activities on the environment. "Environment," in this case, is defined as the natural and physical environment and the relationship of people with that environment.

Geographic Information Systems (GIS) - A system for capturing, storing, analyzing and managing data and associated attributes, which are spatially referenced to the earth.

Global Positioning System (GPS) - a satellite navigation system used to determine ground position and velocity (location, speed, and direction). A "constellation" of 24 well-spaced satellites that orbit the Earth and make it possible for people with ground receivers to pinpoint their geographic location. The location accuracy is anywhere from 100 to 10 meters for most equipment.

Laser Scanning - is the controlled steering of laser beams followed by a distance measurement at every pointing direction. This method, often called 3D object scanning or 3D laser scanning, is used to rapidly capture shapes of objects, buildings and landscapes. A laser rangefinder is a device which uses a laser beam to determine the distance to an object.

Level of Detail/Development (LOD) - The American Institute of Architects (AIA) established an LOD framework for the AIA G202-2013 Building Information Modelling Protocol Form. It refers to the 'Level of Development' required for model element content. The term 'level of development' is used rather than 'level of detail' in recognition of the fact that a visually very detailed element might in fact be generic and despite appearances might be at a low level of design development.

MAP-21 - the Moving Ahead for Progress in the 21st Century Act (P.L. 112-141), was signed into law by President Obama on July 6, 2012. Funding surface transportation programs at over $105 billion for fiscal years (FY) 2013 and 2014, MAP-21 is the first long-term highway authorization enacted since 2005.

National Cooperative Highway Research Program (NCHRP) - A forum for coordinated and collaborative research, the NCHRP addresses issues integral to the state Departments of Transportation (DOTs) and transportation professionals at all levels of government and the private sector. The NCHRP provides practical, ready-to-implement solutions to pressing problems facing the industry. The NCHRP is administered by the Transportation Research Board (TRB) and sponsored by the member departments (i.e., individual state departments of transportation) of the American Association of State Highway and Transportation Officials (AASHTO), in cooperation with the Federal Highway Administration (FHWA). Individual projects are conducted by contractors with oversight provided by volunteer panels of expert stakeholders.

National Environmental Policy Act (NEPA) - is a United States environmental law that established a U.S. national policy promoting the enhancement of the environment. Additionally, it established the President's Council on Environmental Quality (CEQ).

Non Linear Imaging - denoting digital editing whereby a sequence of edits is stored on computer as opposed to videotape (analog), thus facilitating further editing.

NURBS Modeling - Non-uniform rational B-spline modeling, also known as the NURBS method, is one of the best ways for developers to create truly curved smooth surfaces. Unlike polygonal modeling techniques, which can only approximate curved surfaces using numerous polygons, NURBs modeling actually does "bend" the space. This style of modeling is widely used across most platforms.

Oblique Imagery - is aerial photography that is captured at approximately a 45 degree angle with the ground. The angle, which is inherent to oblique imagery allows viewers to see and measure not only the top of objects but the sides as well. Oblique Imagery more closely resembles how people normally view their landscape compared to traditional orthogonal (straight down) imagery

Parametric Modeling - Using the computer to design objects by modeling their components with real-world behaviors and attributes. A parametric modeler is aware of the characteristics of components and the interactions between them. It maintains consistent relationships between elements as the model is manipulated.

Photo Simulation or Photo Composite – a computer-generated representation of a future project, "rendered" into an actual photograph, making it easy to see the changes to the visual environment. Rendered images can be generated for either 2D or 3D content.

Physical Model - A small object, usually built to scale, that represents in detail another, often larger object. A preliminary work or construction that serves as a plan from which a final product is to be made: (i.e. a clay model ready for casting). Used in testing or perfecting a final product.

Polygonal Modeling - A slightly more advanced approach makes use of what is known as the "polygonal" method. Polygonal modeling involves connecting line segments through points in a 3D space. These points in space are also known as vertices. Polygonal models are very flexible and can be rendered by a computer very quickly. One cannot, however, create an exact curved surface using polygonal 3D modeling technique, which limits its usefulness in certain applications.

Project Life Cycle – the various phases within a project delivery approach. To include; Pre-Planning & Acquisition, Finance, Design, Construction, Operations & Management and Upkeep & Improvements.

Primitive Modeling - The first and most basic is known as the "primitive" modeling method. This is the simplest way of modeling 3D objects, and involves the use of geometric basics such as cylinders, cones, cubes and spheres. The forms here tend to be mathematically defined and precise, which makes it easy to work with in most cases, even for relative beginners. Primitive modeling is mainly used in developing 3D models of technical applications.

Public-Private Partnerships (P3) - A business relationship between a private-sector company and a government agency for the purpose of completing a project that will serve the public. Public-private partnerships can be used to finance, build and operate projects such as public transportation networks, parks and convention centers. Financing a project through a public-private partnership can allow a project to be completed sooner or make it a possibility in the first place.

Raster Graphics – A computer image, which (unlike vector graphics) is made up of small 'tiles' (pixels or dots). When a raster image is enlarged, the pixels or dots give a stair step-like jagged appearance. All video (monitor) screens, dot matrix, inkjet, and laser printers, and scanners are raster image devices whereas a CAD production plotter is a vector image device.

Reality Capture – the combination of high-end laser scanning equipment and aerial photogrammetry equipment to create highly accurate, survey-grade models of the physical space and objects.

Real-time Rendering – Is one of the interactive areas of computer graphics, it means creating synthetic images fast enough on the computer, so that the viewer can interact within a virtual environment. The most common place to find real-time rendering is in video games. The rate at which images are displayed is measured in frames per second (frame/s) or hertz (Hz). The frame rate is the measurement of how quickly an imaging device produces unique consecutive images.

Rendering - rendering is the process of add shading, color and lamination to a 2D or 3D wireframe in order to create images on a screen. Rendering may be done ahead of time (pre-rendering) or it can be done in on-the-fly in real time. Real-time rendering is often used for 3D video game engines, which require a high level of interactivity. Pre-rendering, which is CPU-intensive but can be used to create more realistic images, is typically used for high definition renders or animation.

Render Farm - a group of networked computers devoted to rendering images, used typically in the production of computer-animation.

Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) - With guaranteed funding for highways, highway safety, and public transportation totaling $244.1 billion, SAFETEA-LU represents the largest surface transportation investment in our Nation's history. The two landmark bills that brought surface transportation into the 21st century—the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and the Transportation Equity Act for the 21st Century

(TEA-21)—shaped the highway program to meet the Nation's changing transportation needs. SAFETEA-LU builds on this firm foundation, supplying the funds and refining the programmatic framework for investments needed to maintain and grow our vital transportation infrastructure.

Scope Creep - (also called requirement creep and feature creep) Refers to uncontrolled changes or continuous growth in a project's scope. This can occur when the scope of a project is not properly defined, documented, or controlled. It is generally considered harmful.

Splines and Patches Modeling - A more advanced form of NURBS modeling is the "splines and patches" method. This type of program allows developers to use curved lines to identify and project the visible surface. It often takes more time to build and execute commands in this category, but the results tend to be some of the most vivid and life-like.

Vector Graphics - the use of geometrical primitives such as points, lines, curves, and shapes or polygons—all of which are based on mathematical expressions—to represent images in computer graphics. Vector graphics are based on vectors (also called paths), which lead through locations called control points or nodes. Each of these points has a definite position on the x and y axes of the work plane and determines the direction of the path; further, each path may be assigned a stroke color, shape, thickness, and fill. Vector graphics can be magnified infinitely without loss of quality, while pixel-based graphics cannot.

Virtual Design and Construction (VDC) - is the management of integrated multi-disciplinary performance models of design-construction projects, including the product, work processes and organization of the design - construction - operation team in order to support explicit and public business objectives.

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Appendix A – Case Studies

Case Study-01

Georgia DOT – US-19 / State Route 9 & State Route 60 – 3D Modeling, Photo-rendering

Project Background

The project proposes to reconstruct approximately 0.26 miles of US 19/SR 9 at SR 60 from an existing Y-intersection into a roundabout. CR 84 (Stone Pile Gap Road) also ties in to this intersection. All three roadways have an existing typical section that consists of a two-lane undivided roadway. US 19/SR 9 is a rural principal arterial posted for 45 mph with two 12-foot lanes and grassed shoulders.

CR 84 is a rural minor collector with two 9-foot lanes with grass shoulders. The project will maintain the existing number of undivided travel lanes, speed limits, and the current widths for each roadway but will modify the shoulders of all three. SR 60 will have 8-foot shoulders with 6.5-foot paved due to it and the southern portion of US 19/ SR 9 being part of a designated state bike route (Bike Route 90). The typical section of the roundabout will be consistent with current standards for roundabouts in Georgia. It will have curb and gutter on the exterior edge of the travel lane and contain a raised truck apron with mountable curb on the interior portion. The center of the roundabout will encircle an existing historical feature, a large stone pile that is purportedly a grave site for a fabled Native American, Trahlyta. The legs of the roundabout will feature raised splitter islands to provide speed control and a pedestrian refuge.

The Need for Visuals

Public Engagement – Due to the significant historical impact of the site and to improved roadway safety; a series of public meetings were required to explain the proposed alignments for the complicated intersection. To address the proposed alignment, a series of photo-simulations were created to convey the preferred alternate in terms that the general public could understand.

The Results from the Use of Visualization

For civil engineering projects, the Georgia DOT utilizes Bentley MicroStation and InRoads for drafting and roadway design. Different files are provided to contractors, when the project is let to construction (e.g., existing ground surface, finish grade surface, and primary alignments in LandXML format; end-area and GPS grading reports). However, GDOT's most recent 3D efforts (2013 to 2014) have been focused on visualization for engineering analysis and communication with the public.

Figure 1. Intersection of U.S. 19 / State Route 9 and State Route 60, Lumpkin County, GA (Google Maps).

GDOT's Visual Engineering Resource Group (VERG) and Environmental offices worked together to create 3D models to produce computerized renderings that will be used to better communicate the proposed alternatives to the local tribal leaders. Prior efforts to communicate using 2D plans and layouts had not successfully portrayed how the project would look, or shown that there will be no impacts to the burial grounds.

Figure 2. Street view of triangle at the intersection of U.S. 19 / State Route 9 and State Route 60 (Google Maps).

Project Challenges

Next, GDOT's Visual Engineering Resource Group will be investigating how they can transfer these 3D models from preliminary engineering to their designers in order to facilitate subsequent 3D modeling and design efforts. Similarly, they are going to explore what type of data designers can provide to the Visual Engineering Resource Group in order to expedite and enhance the production of visual deliverables.

Project Information

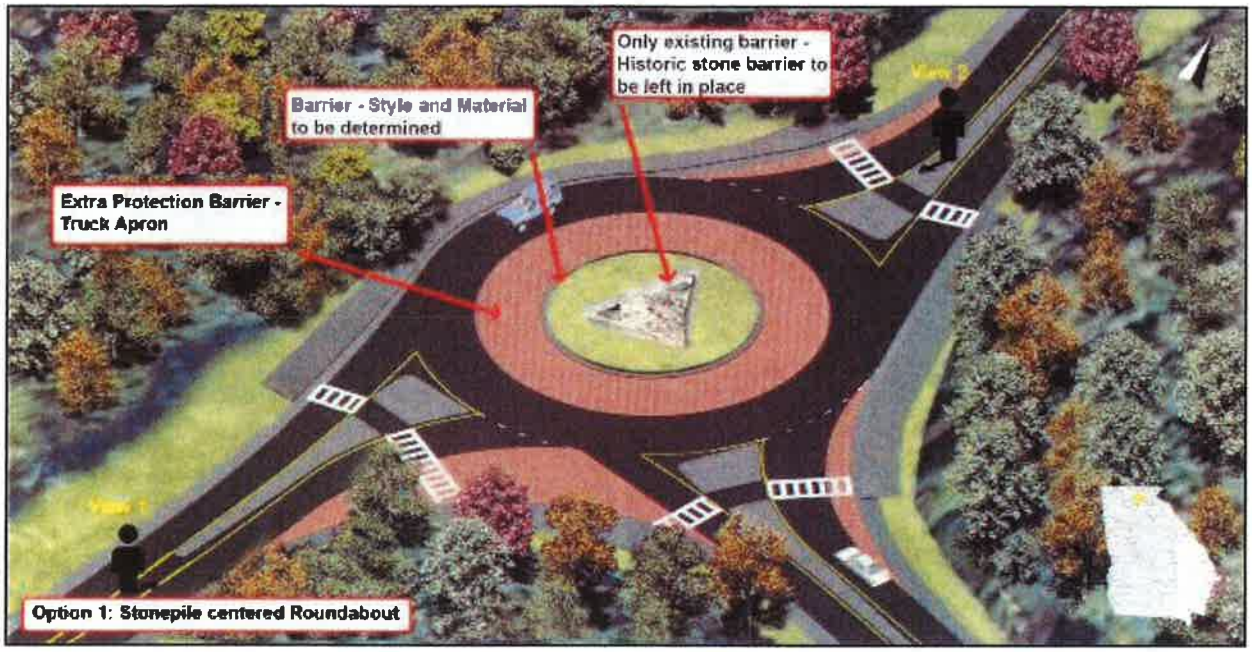

Figure 3. Rendering of Option 1: Stonepile-Centered Roundabout

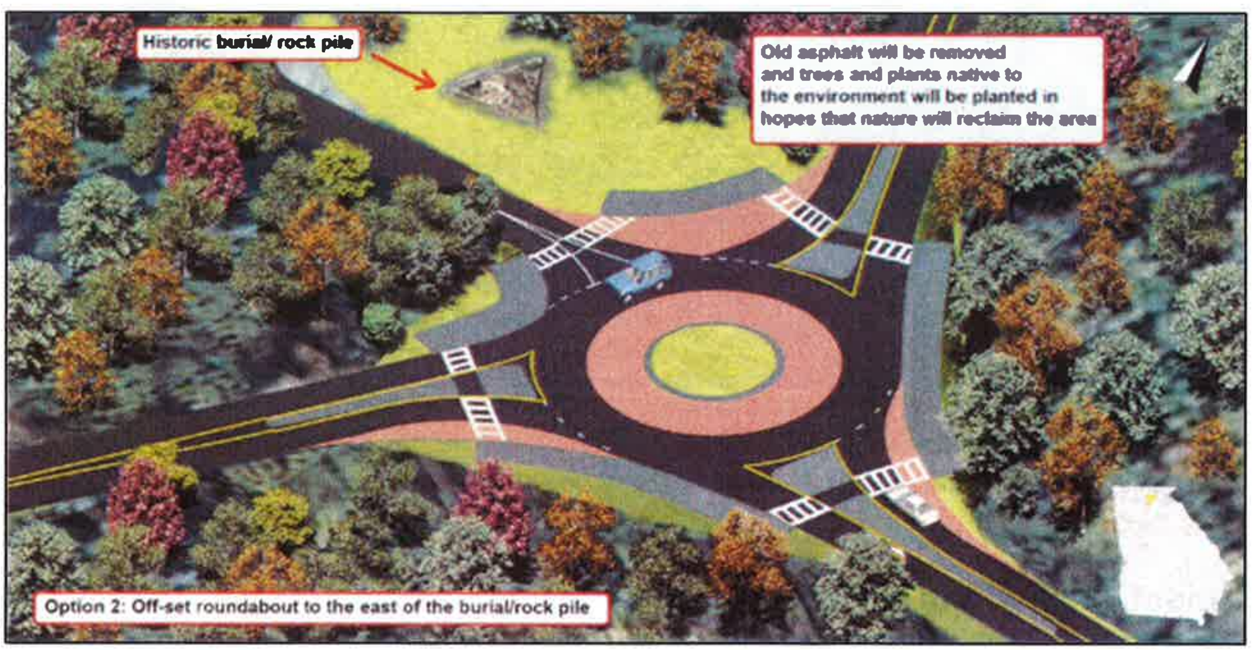

Figure 4. Rendering of Option 2: Offset Roundabout

Case Study-02

Wisconsin DOT – Zoo Interchange, 3D Engineered Models

TECHBRIEF

U.S. Department of Transportation
Federal Highway Administration

3D Engineered Models for Construction

UNDERSTANDING THE BENEFITS OF 3D MODELING IN CONSTRUCTION: THE WISCONSIN CASE STUDY

ABSTRACT

To evaluate the benefits of three-dimensional (3D) design data, the Wisconsin Department of Transportation (WisDOT) calculated the return on investment (ROI) for several components of a reconstruction project. The metric showed an improved efficiency in dirt-moving operations and a greater cost savings during construction of other components such as general structures, drainage and bridges with general use of models for 3D roadway projects.

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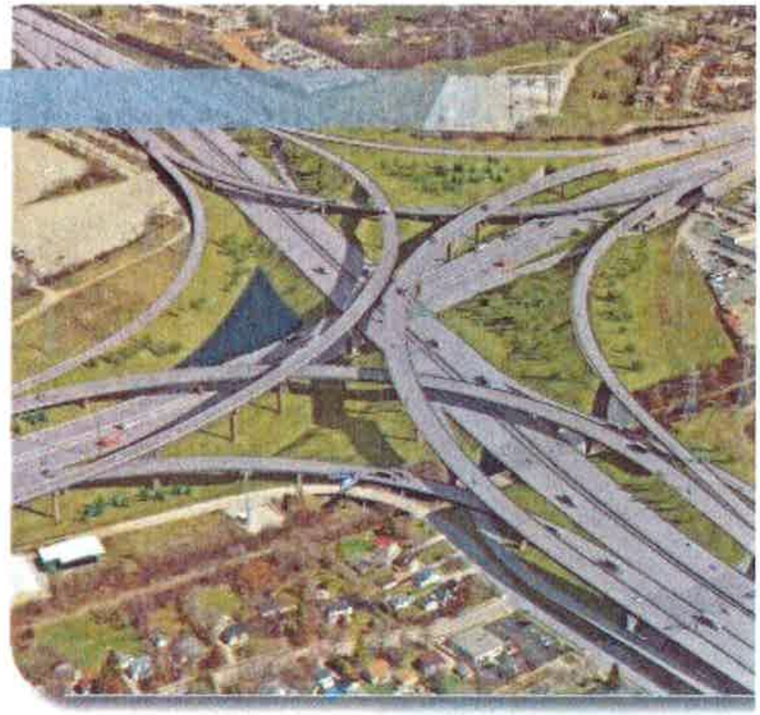
Introduction

Transportation agencies have used three-dimensional (3D) modeling in building construction (also known as "Building Information Modeling" (BIM)) effectively for many years. In BIM applications, designers are able to identify early in the process potential construction issues, such as clashes in future piping, wiring, and HVAC ductwork.

In recent years, transportation agencies have started to plan and design roads in 3D because they understand the possible benefits that 3D models offer in construction. The benefits include improved productivity of operations and worker safety. Using 3D models also enhance the bidding process and allow contractors to use Automated Machine Guidance (AMG) to yield higher quality and less expensive construction. Agencies may provide 3D design data to potential bidders, or contractors may develop their own models for use with AMG during construction.

The Wisconsin Department of Transportation (WisDOT) is at the forefront of the movement toward using 3D modeling in roadway construction. While many States recognize the benefits that 3D models provide in earthwork operations in road construction, WisDOT's Return on Investment (ROI) calculation, using actual project data, shows that 3D modeling can result in even more significant gains during construction of roadway structures and features. WisDOT is currently verifying early ROI projections on the Zoo Interchange Project, a freeway interchange on the west side of Milwaukee.

Engineered Models for Construction (3D modeling) can reduce construction costs during all stages of construction from excavation, earth moving, and compacting and finishing to drainage, bridges, and other features. The modeling offers savings through greater accuracy, efficiency, and reduced resource cost. 3D data not only enhances design through clash detection and better visual representation of the completed project prior to breaking ground, but it also can be used for such downstream applications as AMG.



The benefits of implementing 3D modeling include:

- integrating several design processes together, resulting in better and faster designs at a lower cost.
- improving engineers' inspection capabilities and enhancing quality assurance, thereby increasing efficiency and optimizing resources.

Costs

- Training Costs – WisDOT design staff must complete a 100-hour web-based training program.
- Development Costs - Staff must complete separate web-based training programs in Plans Production, Survey, R/W Plats, and Construction Administration.
- Software Costs – Purchase of software and licenses for staff is required.
- Design Office Transition Costs – Transitioning from 2D to 3D design shops may take a few years to fully complete.

CASE STUDY - ZOO INTERCHANGE, MILWAUKEE, WISCONSIN

The Zoo Interchange, located west of Milwaukee, forms the junction of I-94, I-894, and US 45. The Zoo Interchange is the busiest corridor in Wisconsin, with traffic volumes averaging 350,000 vehicles per day. The $1.7 billion project, which began in 2007 and is scheduled for completion in 2018, will implement operational, safety, and capacity improvements and reduce congestion throughout the corridor.

DESIGN MODELING: The Zoo Interchange Project makes significant use of 3D models as well as components that allow users to view schedule and cost information along with the 3D design. Time planning components for staging and scheduling are called "4D modeling." Cost information linked to the modeled structures is 5D modeling. Incorporating project life-cycle data is 6D modeling. The Zoo Interchange Project primarily uses 3D and 4D modeling. The scope and complexity of this effort makes for a variety of challenges, many of which are addressed or reduced via modeling.

DESIGN-BID-BUILD: WisDOT awarded the Zoo Interchange Project as Design-Bid-Build (DBB) contract. DBB is a relatively traditional project delivery method versus design-build or other newer methodologies. The DBB process makes the use of design documents for "Bid and Build" vital in order to accurately reflect the owner agency's priorities and be constructible and free of design clashes. Using 3D modeling can ease or even automate the process of design clash detection.

WORKFLOW AND DATA COMPATIBILITY: To achieve the potential benefits of 3D modeling, all project parties needed appropriate access to the models. This open access required a methodology and a workflow for sharing, editing, and approving the models between the owner agency, the designer(s), and the contractors. Sharing and benefitting from the models also required data interoperability between different systems.

DATA COLLECTION: Data accuracy in all three dimensions is a prerequisite for achieving all the potential benefits of 3D models. For the Zoo Interchange Project, designers used 3D LiDAR technology to survey data via an integrated survey and data fusion. Designers located and plotted underground utilities in three dimensions. After collecting 3D data, the project team integrated the staging and scheduling information for the temporary roadways and structures to create a 4D model to support maintenance of traffic.

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CLASH DETECTION: Clash detection is the process for identifying physical conflicts or collisions between two elements in the model occupying the same space. This process takes place prior to construction in the field, and is also known as spatial coordination. Clash detection tools typically produce two types of results or "products" from these 3D design models: clash jobs resulting from automatically comparing the various models and visualizations of these models. A June 2012 Clash Detection Review Meeting allowed utilities on Zoo Intersection Project to identify clashes in signals, freeway traffic management systems, lighting, signing, and drainage components at 108 locations. Project designers dealt with these clashes early in the process, eliminating a significant number of contract change orders and subsequent design issue notices (DINs) during construction. Figure 1 shows screen captures from the clash detection process that compare various design standards during model development.

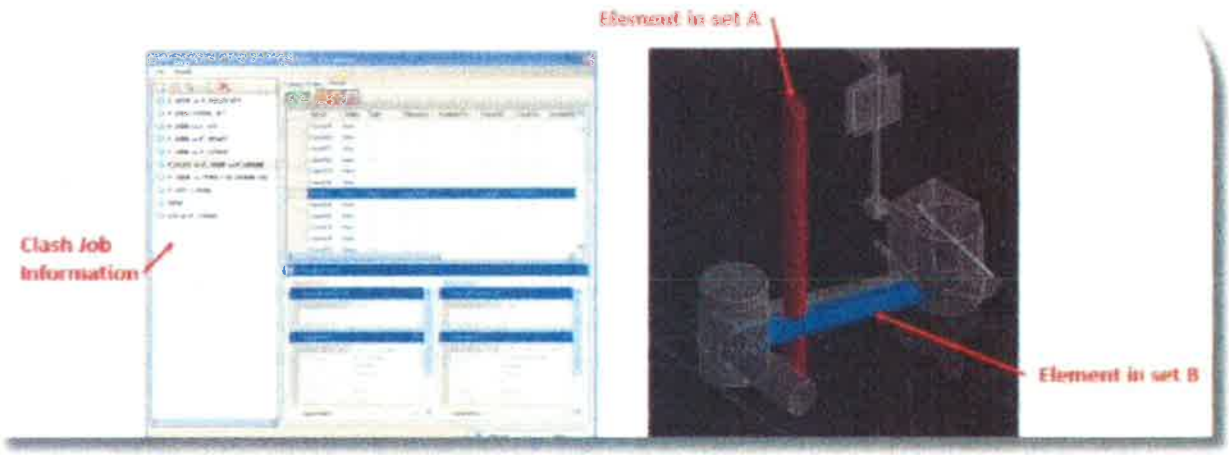

Figure 1: Screen captures from clash detection software.

BUILD FASTER AND MORE AFFORDABLY: In addition to clash detection, 3D modeling is helping WisDOT accelerate and improve the Zoo Interchange Project. It also provided better information to the public via renders and drive-through animations as shown in Figure 2. Plans, specifications, and estimates production used 3D models, incorporating roads, structures, utilities, surfaces and sub-surfaces, signs, signals, lighting, traffic, and landscaping. The 3D AMG model informed both the bidding and construction process.

The Zoo Interchange Project Team also integrated timing components into the 3D models to create 4D models that address project schedules and plans.

OTHER OPPORTUNITI

The Zoo Interchange Project is ongoing. As the project moves forward, 3D models provide the foundation for additional benefits through the use of 4D modeling (incorporating time elements for staging and scheduling), 5D modeling (linking cost components to the modeled structures), and as the project nears completion, 6D modeling (including the as-built specs, operations and maintenance (O&M) information, and other project life cycle data).

Figure 2: Example [illegible] from 3D model.

RETURN ON INVESTMENT

WisDOT recently completed an effort to develop an ROI estimating method for 3D modeling projects using data from the Mitchell Interchange Project as it neared completion. The Mitchell Interchange was part of the larger I-94 North-South Freeway Project, which was intended to improve the outdated design of the interchanges and roads through the addition of medians, shoulders, and consistent exits as well as to increase capacity by adding more lanes. A total of 17 interchanges were updated for ease of use and safety along a 35-mile stretch that includes 3 counties in Wisconsin and crosses into the State of Illinois. The Mitchell Interchange was one of the most complex interchanges being redesigned primarily due to its high traffic volume but also because it included a redesign of 14 bridges, 3 tunnels, 29 retaining walls, several entrance and exit ramps, 7 noise barrier walls, 54 sign structures, multiple utilities, and many other complex factors.

WisDOT originally developed the Mitchell Interchange using traditional two-dimensional plans. However, WisDOT generated 3D models at the completion of the project to investigate the potential impacts of design modeling on cost savings. Because clash detection was not performed during development of the Mitchell Interchange plans, the project provided a good opportunity to more fully understand the potential benefits that 3D modeling could have on large projects. Performing clash detection in advance would have limited the data available to understand the savings in costs of contract change orders and CMs.

WisDOT estimated that modeling could have saved approximately $9.5 million on the Mitchell Interchange if 3D modeling had been used during the planning stages. During this comparison, WisDOT did not consider the cost savings of any issues that would be unavoidable regardless of the use of modeling. For example, bad soil types identified during the project were not included as an opportunity for cost savings based on the use of modeling. Rather, WisDOT focused on specific opportunities for ROI within DIN categories. Design issue notices (DINs) are changes to the design that become necessary due to conflicts or issues identified during construction. Within several DIN categories, WisDOT identified a percentage of potential cost reduction through comparison of the developed 3D model and the actual results achieved during construction. Table 1 below shows the estimated percentage of impact that the use of 3D modeling could have had on each DIN category on the Mitchell Interchange Project. Figure 3 below shows the estimated percent of impact for each DIN category graphically. As shown, 3D modeling results in the majority of gains in categories other than earthwork, such as general structures, drainage, and other features.

DIN Category	Estimated Percent of Reduction	Total Cost ($ millions)	Average Cost Per Issue
General Structures	30.5%	6.8	545,674
Roadway/Drainage	25.5%	5.7	85,631
Wet Utilities/Drainage	11.1%	2.4	27,120
Bridges	8.0%	1.8	15,557
Noise Wall	8.0%	1.8	125,909
Retaining Wall	7.7%	1.7	21,818
Earthwork	4.5%	1.0	59,220
Electrical/ITS/FTMS	2.6%	0.6	15,557
Traffic	2.1%	0.5	18,174
Sign Structures	0.1%	0.02	738

Table 1. Estimated Cost Impact from the Use of 3D Modeling on the Mitchell Interchange Project

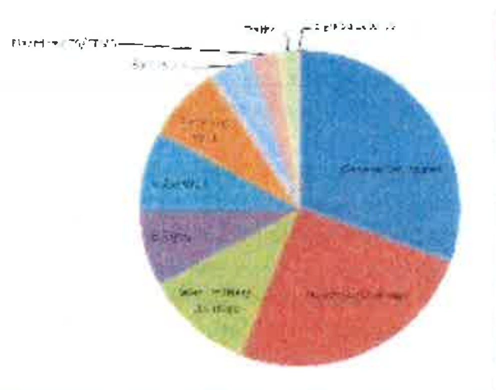

Figure 3: Estimated return using 3D modeling using DIN Categories on Zoo Interchange ROI Analysis

WisDOT found through this examination of ROI for 3D modeling on the Mitchell Interchange Project that the majority of the gains are possible in general structure and roadway/drainage components. And while earthwork is often thought of initially for significant gains in return on investment using 3D, it makes up only a small percent of the return that can be realized through the use of 3D modeling. WisDOT is looking to realize these potential ROI gains using 3D modeling on the Zoo Interchange Project. WisDOT staff is also leading development of a Transportation Research Board paper to further detail the results of their ROI effort related to the Mitchell Interchange and the Zoo Interchange projects, which will be available in fall 2015.

LESSONS LEARNED

- 3D modeling is increasingly being used by transportation agencies across the country to reduce costs and time needed to complete roadway projects.
- 3D data can enhance not only design through clash detection and better visual representation of the completed project prior to breaking ground but it can also support downstream applications such as AMG.
- A methodology and work flow for sharing, editing, and approving 3D model files is critical to success.
- Cost gains achieved through the use of 3D modeling can be more significant during general, drainage, structural, and feature design categories than during earthwork and excavation alone.

GLOSSARY / TERMS

- 3D model – graphical representation incorporating the depth, breadth, and height
- 4D model – linking 3D model components to incorporate time/ schedule information
- 5D model – linking 4D model components to incorporate cost-related information
- 6D model – upgrading an as-built model to incorporate facilities management or project lifecycle information, such as O&M manuals, specifications, and warranty information
- Automated Machine Guidance (AMG) – 3D modeling data combined with global positioning system (GPS) technology to provide horizontal and vertical guidance in real time to construction equipment operators.
- Contract Change Orders – changes required by the project owner to roadway construction plans during project execution.
- Design Bid Build (DBB) – project delivery method in which a transportation agency contracts for development of the design, and construction of a roadway
- Design Issue Notice (DIN) – notification issued by transportation agency to recognize and alter the design of a roadway element, based on an issue or problem identified during construction
- LiDAR (Light Detection and Ranging) – a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light
- MOT – maintenance of traffic
- O&M – operations and maintenance
- ROI - return on investment

U.S. Department of Transportation
Federal Highway Administration

FHWA-HIF-13-050

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Case Study-03

Minnesota and Wisconsin DOTs – St. Croix River Crossing

Project Background

Located near Stillwater, Minnesota; the St. Croix River Crossing project is replacing the Stillwater Lift Bridge, which spans the St. Croix River, which is designated as a Wild and Scenic River. Consideration of a replacement bridge crossing over the St. Croix River near Stillwater began in the early 1970s. By 1995, a Final EIS was completed for a replacement bridge. However, because the St. Croix River was designated as a National Wild and Scenic River, the National Park Service (NPS) evaluated the project under Section 7(a) of the Wild and Scenic Rivers Act. The NPS and found that the project, as proposed, would have a direct and adverse effect on the river. As a result of the finding, the project was not allowed to proceed. Following this finding, an independent Stakeholder review of the project was conducted to analyze potential bridge alignment alternatives.

The St. Croix Crossing has been decades in the making, partly because of the many historic, cultural, threatened and endangered plants/animals and other environmental features along the St. Croix National Scenic Riverway. There has been extensive public and community involvement on both sides of the river to determine whether a bridge should be built, to select the best location/design for the bridge, and provide a mitigation package to offset any impacts to the environment that the project may have.

The Need for Visuals

In 2002, the need for visualizations became apparent due to the public's misunderstanding or misinterpretation of standard MnDOT plans, layouts and cross-sections. A long term vision of using visualizations from preliminary design through construction on the St. Croix Crossing Project was comprehended by the Project Coordinator.

Due to these comprehensive needs for more effective outreach methodologies; the St. Croix River Crossing project enabled the Minnesota DOT to create a Visual Imaging Group. Under the direction of Todd Clarkowski, P.E., who is the Minnesota Department of Transportation (MnDOT) St. Croix Crossing Project Coordinator; Marv Hondl, Senior Engineering Specialist and Kai-Jurgen A. Huot-Link, Transportation Program Specialist from the MnDOT's Visual Imaging Group have been able to develop and apply visualization techniques over the entire project lifecycle of the St. Croix River Crossing Project.

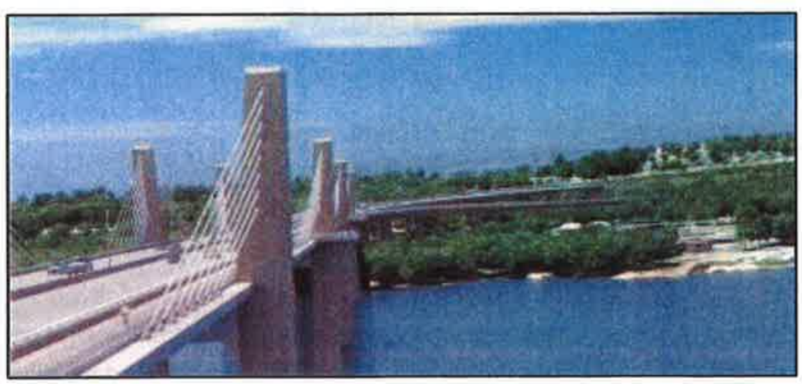
From 2002 to 2004, the Visual Imaging Group created visualizations from the plans, layouts and cross-sections. A rough, black and white, version of the visualizations was used in 2004 at the Supplemental Draft EIS Public Hearings to present the many river crossing bridge and road alternatives.

After public and Stakeholders narrowed down the location of the new river bridge, the Visual Quality Review Committee considered three concepts for further refinement and comparison for the new river bridge. Bridge design options that were being considered were consistent with an "extradosed" bridge because that bridge type fit best within the National Scenic Riverway. Extradosed bridges have relatively short towers above the bridge with cables extending from the tower to the bridge surface.

In 2005, the St. Croix Visual Quality Review Committee (VQRC) and Project Team (Wisconsin DOT, Minnesota DOT and Consultant Team) enthusiastically chose the "Organic" architectural extradosed bridge concept for further development. This concept successfully balanced engineering and functional criteria of cost, maintenance and construction means with visual, aesthetic and architectural project criteria. Of the three concepts presented at the mid-September Open Houses, the public also preferred this concept.

In 2006, the Supplemental Final EIS identified the preferred alternative package of the new river bridge location/design, the roadway improvements in both states, the future use of the lift bridge and a mitigation package. The Visual Imaging Group updated the visualizations and animations to reflect this preferred alternative.

The Results from the Use of Visualization



At one point when the stakeholders convened, they set aside the question of whether a bridge should be built and focused instead on what it should look like if it were built. A bridge architect, who was also an artist, was invited to the meeting to talk about configuration and design possibilities for a new bridge. The architect was able to translate the stakeholders' visions of a new bridge into sketches. "What ensued," reflected Dale Keyes, "was a dynamic give and-take interchange between the architect and the stakeholders and among the stakeholders; at the end of the session, everyone left knowing a lot more about bridges and being able to conceptualize what a new bridge could look like on the St. Croix. And

almost everyone was excited about the possibilities." Thus, the visualization was a major turning point. Perhaps the most important moment in this phase came when the stakeholders began discussing bridge design. In none of the previous attempts to find a solution were the stakeholders permitted to wrestle with the aesthetic questions in the way they did in this mediation. Removing constraints, ignoring old assumptions, and freeing the stakeholders' imagination allowed them to break new ground and move toward a solution that could be acceptable to everyone" Source:
http://www.udall.gov/documents/ECRForum/StCroixRPT.pdf

The Visual Imaging Group developed 3D models and animation for all of the proposed alignments and loop trail.

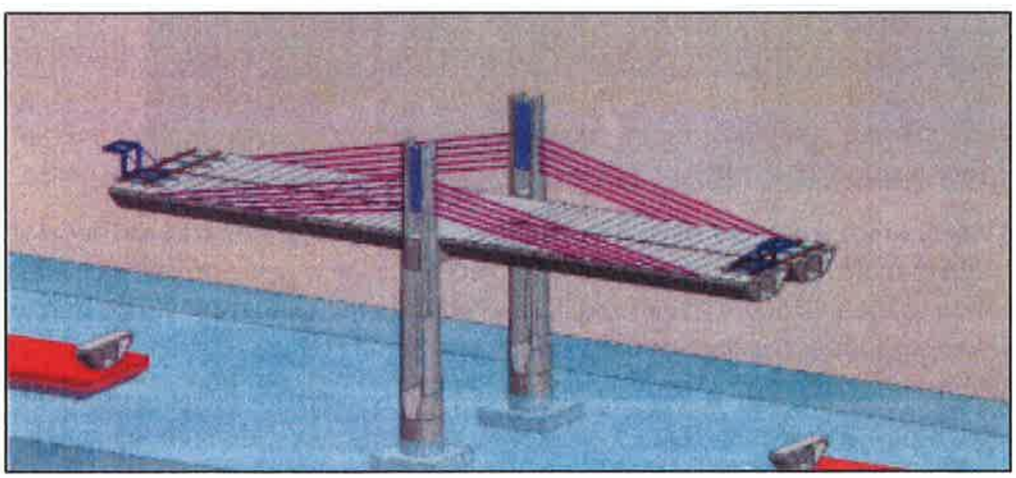
The models and animation were used throughout the National Environmental Policy Act (NEPA), legal challenges and public involvement processes, which ultimately resulted in the selection a preferred alternative. Once the preferred alternative was chosen, the Visual Imaging Group created additional animations depicting the details of the proposed project including aesthetic treatments. The final product was computer generated animated videos that depicted the project's [referred alternative package. . www.dot.state.mn.us/metro/projects/stcroix/vqpp.html

The animated video, which presented views from the river, the roadways, loop trail and aerial views, included narration that provided information on the project and as to why the project elements were chosen. In addition to the animation, Visual Imaging staff also created a variety of visuals that were included in the project's Visual Quality Manual.
www.dot.state.mn.us/metro/projects/stcroix/vismanual.html

As the St. Croix River Crossing project progresses, the Visual Imaging Group has continued to develop and update the visualizations/animations for the project.

Project Challenges

- No definitive guidance from NEPA on when and how much visualization to use.
- Initial insufficient computer hardware to produce computer animation. Missed a few deadlines due to lengthy rendering times.
- Time sensitive - visualization deliverables must fit within NEPA process.
- Not having a clearly defined scope for the animation flight path(s) increased the workload and budget.



- The scripting process for the video production was much lengthier than originally anticipated.
- Lack of computer hardware, software and new visual practices. Having a proactive Visual Manager (Todd Clarkowski) vastly improved the approval processes needed to garner computer hardware, software and develop new visual practices. Agency management support is imperative.

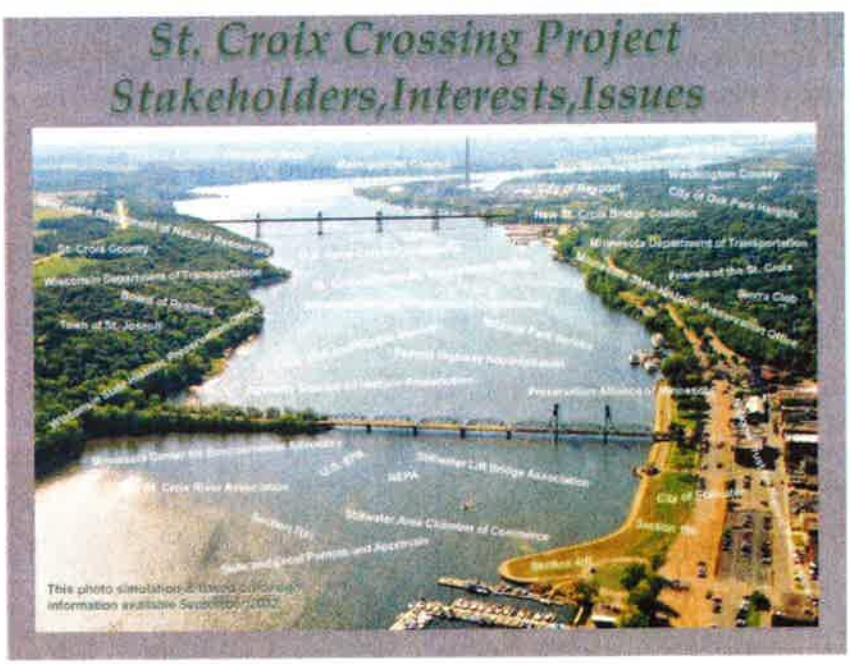
- Lack of standard MnDOT procedures and policies for the use of visualizations.

The Benefits of Visualization

- Visuals helped the DOT to develop a "partnership" relationship with the multiple agencies and organizations that had a stake in the project during the pre-construction phases
- By using visualization from the onset (basic sketches, low resolution black and white renders, high resolution, etc.), effective planning occurred; producing a more efficient workflow, thus reducing costs.
- Developed best practices and processes for the use of visualization for other MnDOT projects.
- Effective tool during the NEPA and legal challenge processes to help explain mitigation efforts to reduce impacts for environmental concerns.
- Improved alternative design understanding helped to move the project forward through the project development processes.
- The visuals created for the St. Croix River Crossing project helped to generate a great deal of discussion regarding the project's design and facilitated decision-making. For example, draft visuals helped committees make design decisions.
- Visualizations during construction assisted in describing the staging of the work on the new river bridge.
- The 3D model is planned to be used for bridge maintenance and operation via a BIM.
- The successful use of visualization on the St Croix River Crossing Project has led to an increased demand for use on other MnDOT projects and created a more standardized process.

Project Highlights

This joint project between the Minnesota Department of Transportation and the Wisconsin Department of Transportation addresses the congestion and safety issues by replacing the 80-year-old Stillwater Lift Bridge with a new four-lane bridge and connecting expressways on both



sides of the St. Croix River while minimizing impacts on the area's historic and natural resources. Work includes:

- New 5,000 foot long extradosed bridge crossing
- Reconstruct 3 miles of Minnesota Highway 36 and Highway 95, including a new interchange
- Build three-mile, four-lane connection to Wisconsin Highway 64 from the new bridge
- Construct Wisconsin Highway 35 overpass, the Wisconsin Highway 35/County E interchange and the pedestrian/bike path
- Create extensive trail facilities and preserve historic Stillwater Lift Bridge for use by bikes/pedestrians, with trail connections between the new river crossing bridge to the historic lift bridge

- Total project = $580 million to $646 million
- Construction began in 2012 and is expected to be completed in 2016, with the new river bridge open to traffic. Mitigation items have also occurred "before/during/after" construction. The historic lift bridge will be converted to a pedestrian/bicycle facility in 2017.
- St. Croix Crossing Project website is at http://www.dot.state.mn.us/stcroixcrossing/

Case Study-05

3D/4D Modeling and Visualization for the I-95 New Haven Harbor Crossing Corridor Improvement Program

The use of intelligent computer models and processes such as Building Information Modeling (BIM) and Civil Integrated Management (CIM)* is transforming the delivery of transportation programs. Owners, designers, and contractors are using these processes to design, build, and simulate projects virtually before executing them in reality. The use of virtual modeling increases communication and coordination among project stakeholders by providing an easily accessible vision of the entire project. 3D and 4D models (where time is the 4th dimension) reduce risks, errors, and inefficiencies which are common to more traditional forms of project management.

Interstate 95 New Haven Harbor Crossing

With the support and foresight of the Connecticut Department of Transportation (CTDOT), the program management team is utilizing 3D/4D modeling on the I-95 New Haven Harbor Crossing Corridor Improvement Program, a multimodal transportation project that features public transit enhancements and roadway improvements along 7.2 miles of I-95 in New Haven, Connecticut. This stretch of roadway runs through a densely developed urban area and is part of the heavily traveled northeast corridor between New York and Boston. Constructed in the late 1950s, the highway and bridges in this area accommodate traffic volumes in excess of 140,000 vehicles per day, more than three times the amount for which they were designed. The project includes capacity improvements as well as the replacement of the existing Pearl Harbor Memorial Bridge, known locally as the Q-Bridge ("Q" for Quinnipiac River). The new Q-Bridge will accommodate ten lanes of traffic and is the first extradosed cable-stayed bridge in the country.

Figure 1. Overview of the 3D model of the project showing final condition

CTDOT began studying remedies for the area's traffic congestion in 1989. Construction began in 2000 and the entire project is expected to be finished in 2016. Parsons Brinckerhoff is CTDOT's Program Manager on this project, coordinating 28 separate construction contracts for various portions of the program. To support this effort, the project team is using both 3D and 4D project models for construction planning, project collaboration, and program communication.

Construction Challenges

Three highways converge as you approach the Q-Bridge on the west side and the project has numerous ramps and access roads that feed into a complicated interchange, but during the reconstruction of the bridge and interchange, traffic had to be maintained. Several temporary ramps accommodated traffic during construction of the permanent roadways and structures. Throughout the project, traffic was being shifted between these temporary or finished sections and any closures or shifts on I-95 and associated ramps was limited to very small windows and had to occur on very specific and inflexible dates. As a result, the overall project schedule and all the various construction activities were driven by these traffic shifts. The Q-Bridge itself was also built in sections, with traffic detoured to a new span followed by the demolition of the original existing span. Therefore, a large part of the ongoing public outreach program was the communication of the timing and details of these traffic shifts. This was a highly successful aspect of the project.

Figure 2. Graphic produced from the 3D model showing closures/detours

The sheer complexity of this project's scope was one challenge; the large number of interrelated construction activities was another. The physical area of the contracts sometimes overlapped at transition points—at the western approach to the Q-Bridge for example—and the contractors had to work in very close proximity to each other. Space was very limited because the new ramps and roads were being built in-between existing structures. These tight quarters required careful and precise construction logistics, planning, and sequencing.

Virtual Construction

To support construction planning and management, the project team developed 3D and 4D models using several BIM software solutions, including AutoCAD® Civil 3D®, Autodesk® 3DS Max® Design, and Autodesk® Navisworks® Manage. The team used these models for technical analysis, project communication, visualization of construction sequences, and illustrations for the public's better understanding of the project. Renderings and animations produced from 3D models showed stakeholders the ultimate plan and vision for the completed project.

Figure 3. Detailed 3D rendering showing complex construction activities during closure

The 4D model pairs project design elements with construction activities to virtually display the progression of construction over time. Originally the 4D model was developed as a visual aid for contractors bidding on the project, using very high-level schedule activities to illustrate basic construction sequencing. But once construction began the team started adding more detailed elements and construction activities. These 'construction-worthy' models validated and illustrated the many traffic shifts, detours, and associated road closures which constituted the construction process, and supported the planning and communication of proposed construction activities and equipment logistics.

Creating the 3D Models

To accurately simulate the construction process, including demolition of existing structures, the team needed to model proposed project elements (the permanent and temporary roadways, ramps, and bridges) as well as the *existing* infrastructure.

For the existing conditions the team imported survey data, digital terrain models, 3D as-built design data such as roadway centerlines, GIS data, and conventional 2D drawings into Civil 3D to combine and re-build the data in 3D. The Civil 3D model was then moved to 3DS Max Design, a software solution specifically for 3D modeling and photo-real rendering and animation. Using 3DS Max Design, the Team enhanced the model by adding details such as signs, vehicles, landscaping, and realistic materials. In addition, geospatial data such as aerial imagery and building footprints were imported and optimized in 3DS Max Design to provide surrounding context.

Next, the team created 3D design models of the project. Drawing on a variety of sources again, the team imported 2D and 3D data, including contour data of interim and final surfaces, into Civil 3D to create the 3D model, and clean up and reconcile the data sources. The model was moved to 3DS Max Design for additional modeling efforts, surface editing, and addition of materials and finishes.

These models are the basis for the hundreds of still images and animation simulations posted on CTDOT's project website (www.i95newhaven.com). These high-end project visualizations helped the public, the client, and other project stakeholders easily grasp the details of this complicated construction program as well as the day-to-day traffic and detour changes.

Figure 4. Snapshot of the integrated project 4D model showing detailed construction activities and equipment locations

Adding the 4th dimension

For 4D modeling, the team moved the 3D models to Navisworks Manage. Over 2000 individual activities in the two primary contractors' schedules are linked to individual elements in the Navisworks model for construction planning and simulation. As construction progresses, the 4D model is used by the extended project team to help visualize and better understand the complexities of the design and the construction process. Some of the major contractors on the project were separately using Navisworks, or other 3D modeling systems, to evaluate equipment locations and clearances, and convey their means and methods. In some of those situations, the models were incorporated into the overall team model, resulting in a shared 3D/4D resource that benefited everyone by improving communication between contractors and program managers.

Latest Developments

CTDOT and the project team continue to innovate on this project and have begun using LiDAR point cloud management tools such as Bentley Descartes and Civil 3D to create 3D models from laser scans. For example, one area of the project is particularly tight, where three levels of existing highway ramps (that were eventually demolished) were just a few feet away from an historic building. To plan the demolition, the team needed to accurately model the ramps and the building. The team incorporated point-cloud data captured by the contractors into the overall 3D model, and used it to extract model elements accurate to within inches.

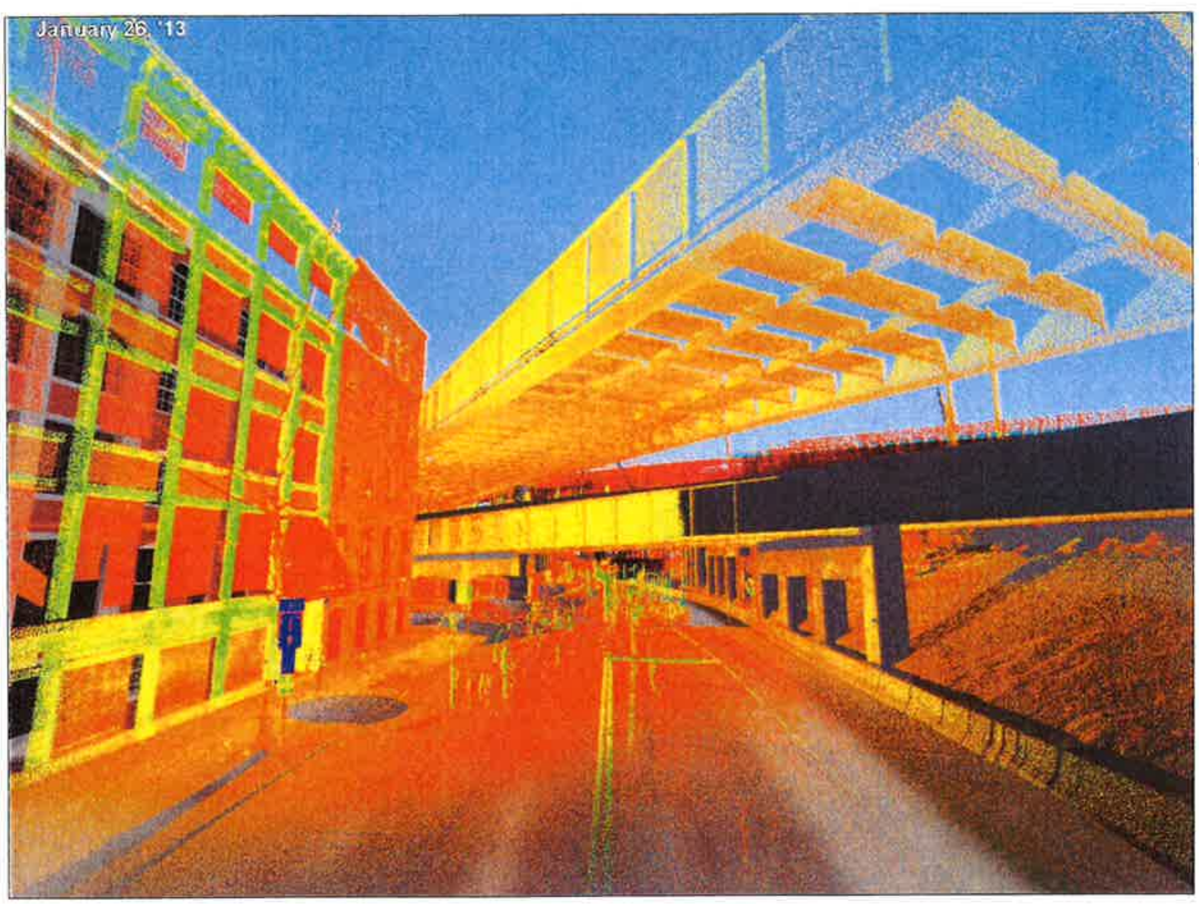


Figure 5. LiDAR point cloud of historic building and stacked steel structures slated for demolition.

Results

The I-95 New Haven Harbor Crossing Corridor Improvement Program is on schedule for completion in 2016. To date, the CDOT Team has produced over 200 still and graphic images and over 5 hours of animation files for the project. 3D and 4D models have allowed the team to virtually build the project, enabling them to check staging/construction sequences and schedule logic much earlier in the process, better manage site logistics, and more closely synchronize multiple activities.

"Using these tools and processes to increase communication and coordination among all project stakeholders greatly increased the level of confidence in the design, the schedule, and the overall execution of the program. The end result is reduced project risk, rework, cost, and schedule." - Team Project Manager

For DOTs, working with consultants to design and deliver projects using tools and processes such as BIM and Civil Integrated Management is definitely where the transportation industry is headed. The I-95 Corridor Improvement Project represents a great first step by CTDOT in that direction.

**Civil Integrated Management or CIM is a term now being promoted by the FHWA under the 'Every Day Counts' Initiative*

Case Study-05

New York DOT – Tappan Zee Bridge Replacement

Project Background

The project is located 13-miles north of New York City near Tarrytown & Nyack, New York. The existing Tappan Zee Bridge, which is over 50-years old, is a 3-mile long Hudson River crossing. The bridge is part of Interstates 87 and 287 and with an annual average daily traffic of 140,000 vehicles, reaching 170,000 vehicles a day during major holidays, and is considered heavily travelled. This is significantly more than the 18,000 vehicles the bridge averaged daily when it went into service in 1955.

The new Tappan Zee Hudson River Crossing is designed for a 100-year service life. It will feature twin three-mile structures, each with 1,200-foot cable-stayed main spans and 350-foot steel girder approach spans. The new bridge provides eight general traffic lanes, emergency lanes, extra-wide shoulders for express bus service, a dedicated bicycle and pedestrian path on the northern span, and scenic overlooks.

The first span of the new twin-span bridge is scheduled to open in 2016, and the new bridge should be complete in 2018.

The total cost of the New NY Bridge project is $3.9 billion. The bridge is being designed and built by Tappan Zee Constructors, LLC (TZC), a consortium of design, engineering and construction firms, including Fluor, American Bridge, Granite, and Traylor Bros., along with key design firms HDR, Buckland & Taylor, URS, and GZA. TZC is working closely on the project with a team of employees from the New York State Thruway Authority and the State Department of Transportation.

The Need for Visuals

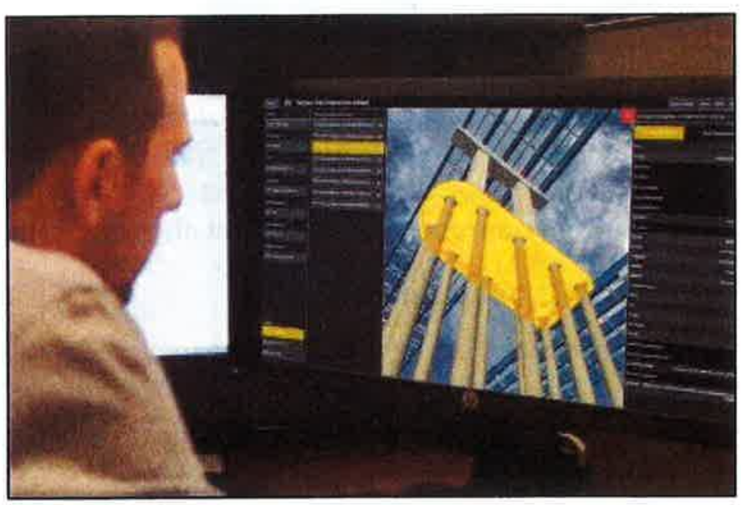
Public Engagement - Plans for a new bridge to replace the Tappan Zee were first discussed in 1999, and over the next 11 years, 430 meetings were held, 150 concepts were considered without the project moving forward. In October, 2011, new design-build legislation was enacted, and the project finally moved forward.

To address the significant need for public outreach and support, a Visual Quality Panel (VQP) was instituted. The New NY Bridge Visual Quality Panel was established early in the project to provide aesthetic guidance and support to TZC, while ensuring that the public's voice is heard and incorporated in the ongoing development of the design. The panel consists of one chair appointed by the Thruway Authority, a visual quality manager from the design-build team and 13 public representatives.

The members of the panel are:

- Brian Conybeare, VQP Chair, Special Advisor to Governor Cuomo, Thruway Authority
- Darrell E. Waters, Design-Build Team Visual Quality Manager, Tappan Zee Constructors
- Heather Sporn, Thruway Authority Visual Quality Manager, NYS Dept. of Transportation
- David Aukland, Tarrytown Planning Board
- Suzanne Barclay, Town of Orangetown
- John Bonafide, Division for Historic Preservation, NYS Office of Parks, Recreation, and Historic Preservation
- Ed Burroughs, Westchester County Planning Commissioner
- Jerry Faiella, Executive Director of Historic Hudson River Towns, former New Castle Town Administrator
- Robert Fellows, Rockland Center for the Arts
- Barbara Hess, Hess Architects
- Andrew Klemmer, President of Paratus Group and Scarsdale resident
- Richard Kohlhausen, Rockland County Community College Board, Capitol Risk Management
- Elma Reingold, Irving Resident, Assistant Principal of the High School of Art and Design, NYC
- Alison Spear, Ennead Architects
- Thomas Vanderbeek, Rockland County Planning Commissioner
- Victoria Weisel, MS, LMSW, Irving Neighborhood Association

Advanced Design Tools - The scale and complexity of the New NY Bridge project led the TZC to utilize 3D Database Driven (3DD) modeling processes such as Building Information Modeling (BIM), Virtual Design and Construction (VDC) and Bridge Information Modeling (BrIM) for the project. This technology approach aided in the identification of potential design conflicts early in the process and allowed designers to discover efficiencies that assisted in the reduction of costs and improved construction scheduling. This effort was overseen by Robert Allen, HDR Vice President and Design Services Manager during Construction and Ken Coulter, Manager, Interactive & Visual Design at HDR.



The 3D database design model also helped to quantify and organize the materials. By utilizing this method, calculations have the potential be more quickly solved and visually enhanced through 3D modeling versus the traditional CAD design process.

3DD has allowed designers and constructors to organize the vast amount of data generated by a project of this scale and manage design and construction, including scheduling and tracking of each element of the bridge's construction progress.

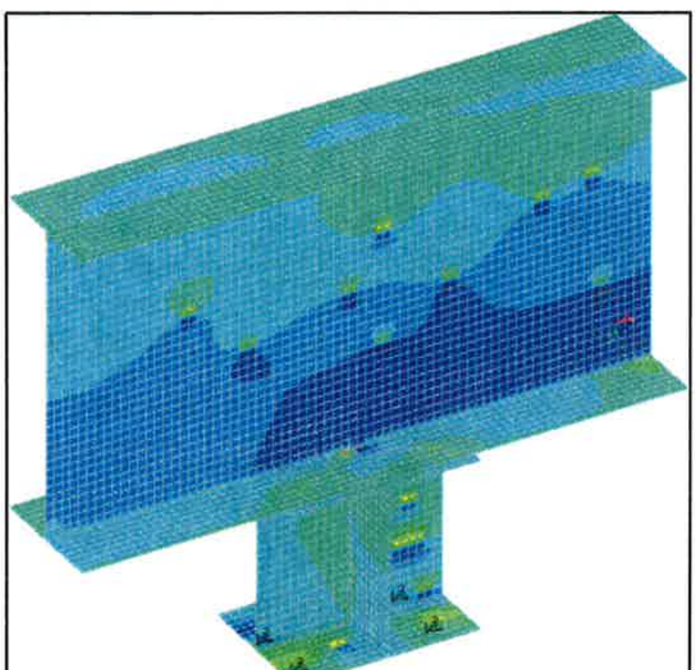
3DD technology also is used being used to ensure that construction proceeds in strict accordance with design plans, serving as a visual log book. To date, engineers have already matched and linked documents and photos to different parts of the virtual bridge. This highly efficient record keeping, gathered in a single source with no duplication.

A Lifecycle Solution - It is intended that the 3DD processes used during design and construction will continue to serve the Thruway after the bridge is completed. Future maintenance teams will need to quickly access and analyze the data that has been collected in the 3DD database. Utilizing video game-based technology, the TZC team developed a user-friendly viewer program that displays the bridge model in a realistic and interactive virtual manner. Each of the approximately 500,000 bridge elements can be viewed with links to pertinent design and maintenance information. Maintenance crews will be able to view the model from mobile devices, laptops or desktop computers, allowing them to see every piece of the bridge at every possible angle.

"While the BIM model certainly enhances design and construction, the 3D technology will also be invaluable to Thruway engineers in the planning and execution of its maintenance program for the New NY Bridge," said Larry Soeller, a Thruway Authority senior highway maintenance engineer.[1]

The Results from the Use of Visualization

For the New NY Bridge, the Tappan Zee Constructors, LLC (TZC), consistently sought to minimize overhead costs, while offering the team and the public a single source of responsibility with design-build and integrated project delivery. The TZC utilizes work sharing and workload balancing to



operate projects efficiently, while maintaining project costs and accelerating delivery schedules. By using these civil design, collaboration, and information mobility tools it is projected that this approach saved $3.1 million in project costs over 15 months, increased efficiency with simultaneous design practices, and saved hundreds of hours of CAD management and production.[2]

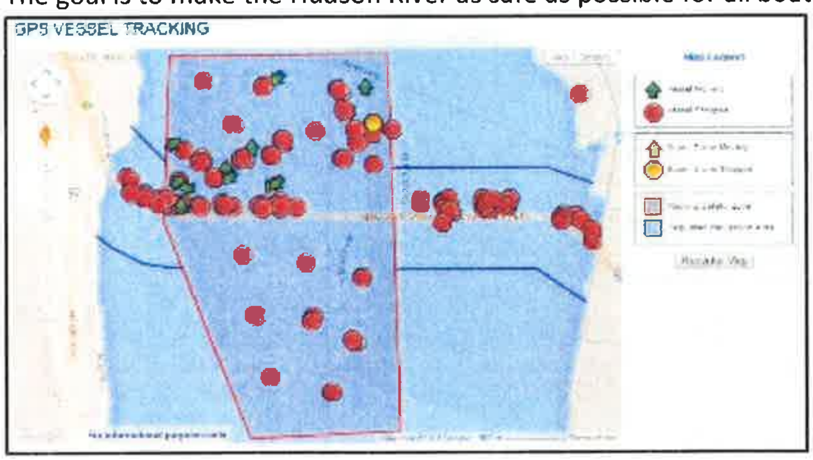
Finite Element Analysis - The project also provided an opportunity to address a long-standing problem of cracking in the fabricated steel bearing stools supporting the stringers in the West Deck Truss. This involved the replacement of 500 steel stub columns, or stools, in the superstructure that are cracking. The TZC utilized three-dimensional (3-D) Finite Element (FE) modeling for the analysis of these overstressed structural components. The stool components were modeled both globally as one span of the truss structure, and locally as the stringer with its stool connections to determine the overall solution to the problem. Over the years, engineers had stiffened the columns in an attempt to prevent further cracking; however, the computer analysis determined that an opposite approach was necessary. A connection detail was designed that includes elastomeric bearing pads and slotted bolt holes to increase the flexibility of the columns' connections. The new connection details enable the columns to continue to support the same vertical elements, but also allow them to flex with the bending movements that the bridge experiences. [3]

A combination of 3D database driven design tools, visual analysis and enhanced communication between the bridge owner, designers, fabricators and the contractor resulted in up to 18 deck panels were replaced during one nightly work shift, without incurring morning traffic delay.

Improved Safety – During the construction phase, as many as four dozen Tappan Zee Constructors vessels are active within the project area on the Hudson River. During peak periods, 100 or more vessels could be in the active work zone. Crew boats, tug boats, barge mounted cranes and barges – as well as temporary fixed platforms – are in the area and may be moved at any time.

To maintain safety for the project and for the general public, TZC vessels and barges on the site are being tracked by GPS technology. The Thruway Authority and Tappan Zee Constructors have also applied for a new safety zone around the 16 construction barge mooring locations at the site. No vessel traffic will be allowed in the safety zone. Displayed on an interactive map, the GPS system offers real-time updated information on the status and movement of construction vessels on the water.

The goal is to make the Hudson River as safe as possible for all boaters during the project. The area around the Tappan Zee Bridge is currently a very active construction zone and will continue to be throughout the project.



Hudson River Boat and Yacht Club President Scott Croft said: "The Hudson River Boat and Yacht Club appreciates everything the Thruway Authority and Tappan Zee Constructors are doing now and in the future to help boaters stay safe during bridge construction. [4]

Project Challenges

Visualization Staffing - A project of this magnitude requires that the TZC ensures that the project fits within the unique environmental, social, aesthetic and physical character of the region and the river corridor within which the Project is located. The design solution shall fit the contextual character and all corridor and site conditions. The Design-Builder shall be responsible for ensuring that all aesthetic aspects shall comply with the requirements laid out in the Environmental Documentation. The Design-Builder shall be responsible for ensuring that suitable communication between visual design staff and construction staff is established during build-out, to ensure that visual aspects of the design intent are implemented as appropriate.[5]

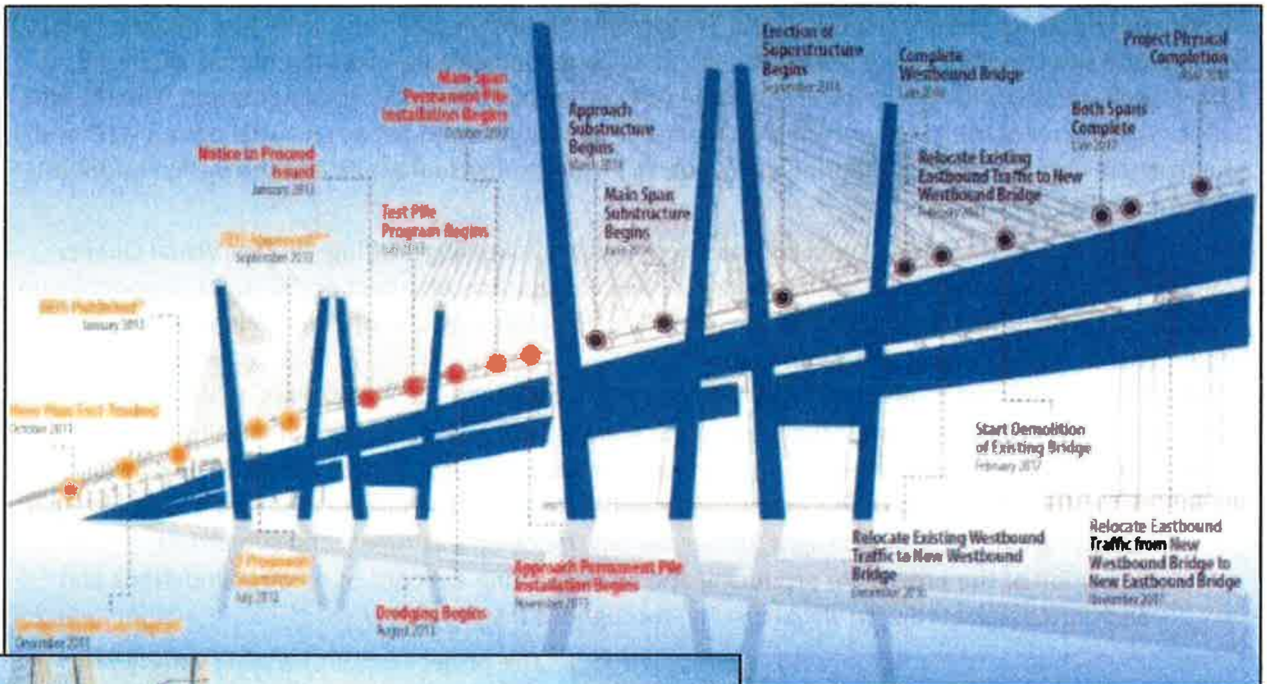
The requirements of the design-build contract required the following staffing; Project Visual Quality Manager, Project Architectural Lighting Design, Project Landscape Architect and Graphic Support Team. To focus TZC visualization staff and sub-consultants, a Visual Quality Management Plan (VQMP) was implemented. The VQMP required at minimum;

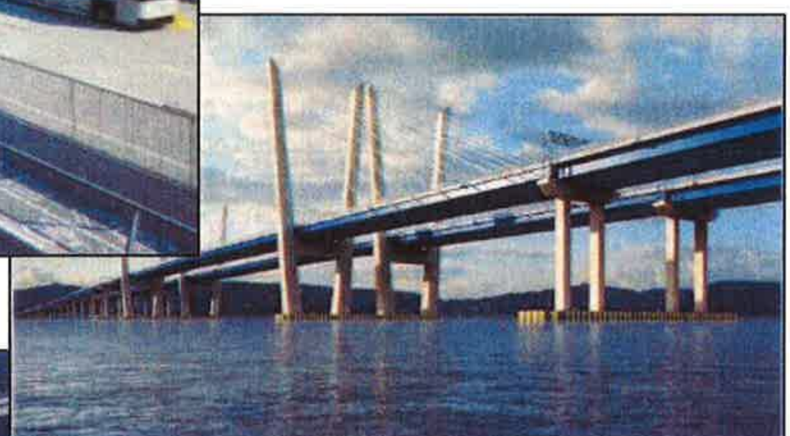
- Process and methods for coordinating and interacting with the Authorities' visual quality panel.
- Strategies for identifying, maintaining and enhancing the visual quality of existing conditions.
- Identification of schedules for visual quality meetings, project benchmarks and deliverables.
- Definition of the responsibilities of the Design-Builder's visual quality manager in overseeing and reviewing overall bridge designs, design details, mock-ups, samples, and submittals.
- Definition of the process of producing and disseminating a record of recommendations and decisions associated with visual quality, throughout the Project.

The project requires a wide variety of visualization output from photo-simulation to computer rendering and animation. Detailed requirements are identified within the Tappan Zee Hudson River Crossing Project, Design-Build Contract Document-Part 3, Section 13: Visual Quality (New York State Thruway Authority, 21 November 2012).

All these requirements have led to the implementation of a comprehensive Public Involvement Program (PIP), which major goal was to "ensure that all possible opportunities are explored to engage a diverse group of public and agency participants, seeking and using their views, and providing timely information throughout the design and construction process". The result of this goal is that a significant amount of visuals have been required for the project.

Project Information


Main Span Permanent Pile Installation Begins
October 2013
Notice to Proceed Issued
January 2013
Test Pile Program Begins
September 2012
January 2012
October 2011
July 2012
Dredging Begins
August 2013
December 2011
Approach Permanent Pile Installation Begins
November 2013
Approach Substructure Begins
March 2014
Main Span Substructure Begins
Erection of Superstructure Begins
September 2014
Complete Westbound Bridge
Relocate Existing Eastbound Traffic to New Westbound Bridge
Both Spans Complete
Project Physical Completion
Start Demolition of Existing Bridge
February 2017
Relocate Existing Westbound Traffic to New Westbound Bridge
December 2016
Relocate Eastbound Traffic from New Westbound Bridge to New Eastbound Bridge



FACT SHEET

Visual Quality Panel

THE NEW NY BRIDGE

A 16-member Visual Quality Panel (VQP) composed of community leaders and design professionals collaborates with the New NY Bridge project team on aesthetic features of the New NY Bridge.

The VQP ensures the local community has a voice in decisions related to the appearance of the New NY Bridge and provides aesthetic guidance to the project team. The panel considers topics that include design of the shared use path for pedestrians and bicyclists, belvederes (or scenic overlooks), landscaping, gateways, lighting, and historical/cultural installations.

The panel is chaired by Brian Conybeare, special advisor to the Governor, with one representative from the Thruway Authority, one from design-builder Tappan Zee Constructors, LLC, and 13 volunteer community representatives.

To get more information about the VQP and its members, visit NewNYBridge.com/news/2013/2013-02-15-vqp.htm.

Based on public input, the VQP chose chamfered top towers for the New NY Bridge. Above image: Rendering of new chamfered-top towers.

VQP members tour the existing bridge to get a firsthand experience of views, walking distances, noise, wind, and other environmental factors affecting the shared use path and belvederes.

VQP members Barbara Hess, Heather Spom, and David Aukland conferring on belvedere options.

NewNYBridge.com | info@NewNYBridge.com | 1-855-TZBRIDGE (892-7434) | @NewNYBridge

Endnotes

[1] The New NY Bridge, "Virtual First, Actual Second Building Digital 3D Models Helps Refine Design and Organize Construction" The New York State Thruway Authority (web site). (17 February 2015). Site address: http://www.newnybridgegallery.com/updates/virtual-first-actual-second-building-digital-3d-models-helps-refine-design-and-organize-construction/ (accessed 12 March 2015).

[2] ENR Events, "Bentley, BIM and Real World Advantages of 3D Modeling with HDR", ENR (web site) (17 December 2014). Site address: http://video.webcasts.com/events/pmny001/viewer/index.jsp?eventid=47410 (accessed 15 March 2015).

[3] Structure Magazine, "Accelerated Bridge Construction Keeps Tappan Zee Bridge Open", Structure Magazine (1 October 2009). Site address: http://www.structurearchives.org/article.aspx?articleID=971 (accessed 8 March 2015).

[4] News, "New NY Bridge Project Enhances Boater Safety; U.S. Coast Guard Expands Regulated Navigation Area", The New NY Bridge (web site) (26 March 2014). Site address: http://www.newnybridge.com/news/2014/2014-03-26-boater-safety.html (Accessed 1 April 2015).

[5] Referenced, Tappan Zee Hudson River Crossing Project, DB Contract Documents-Part 3 (New York State Thruway Authority, 21 November 2012) 112.

Appendix B – Sample Position Descriptions

Sample Classified Position Description for Visual Quality Manager/Engineer, Courtesy of the Washington DOT

10%	project visualization and video production scoping meetings to define project goals and direction for client understanding and consent. Author project scope of work (SOW) agreements with clients. Maintain project relationships to ensure that final product expectations are met on budget and in a timely manner. Plan and coordinate aerial imagery sessions. Manage the production of project visualization media. Directs survey crew and traffic control personnel while obtaining visual communication support data. Manage and evaluate the character and nature of video projects. Provide leadership and direction in project video scripting, storyboarding and production shot-schedule. Conduct final QA/QC of all media productions.

23. **Essential Job Functions:** List the essential functions of this position. Functions listed in this section are primary duties and are fundamental to why the position exists. They must be performed with or without reasonable accommodation (do not assign percentage of time in this section).
Ability to communicate effectively at all levels within the agency, with the public and with local governments. Ability to develop visual communication projects and programs within WSDOT and with WSDOT partners. Ability to lead, motivate and manage others. Ability to supervise work. Ability to strategically & collaboratively plan for program growth. Thorough understanding of commercial digital photography in all light conditions. Thorough understanding of video production. Thorough understanding of 3-D modeling and animation. Ability to edit sound and video to produce a finished end product. Ability to use and operate surveying equipment in support of project visualization exercises. Ability to use department's computer aided design and drafting tools. Ability to use animation, virtual environmental and image manipulating software. Ability to plan, coordinate and conduct aerial (helicopter) imagery gathering flights. Ability to plan, develop, and layout aesthetically pleasing end products for presentation. Ability to work in areas where there may be heavy traffic and considerable noise. Ability to enter/exit man lift equipment including bucket.
24. Essential job knowledge, skills and abilities <u>and</u> degree, license, and or special certification required by position (kind and length of time)
Management experience leading a diverse statewide group of highly specialized technical experts. Manage the production of project visualization media. Directs survey crew and traffic control personnel while obtaining visual communication support data. Manage and evaluate the character and nature of video & 3D modeling-visualization projects. Provide leadership and direction in project video scripting, storyboarding and production shot-schedule. Conduct final QA/QC of all media productions. In depth knowledge of civil engineering design to include structures and roadway design. In depth knowledge of urban planning, architecture and architectural landscaping related projects. Knowledge of 3D CADD (MicroStation) and the ability to detail and draft, in a 3D CADD environment, all forms of WSDOT design projects. Knowledge of 3D modeling/animation software (3D Studio Max & Sketchup), virtual environment software (Vue 6) and Adobe Photoshop for visualizing transportation engineering related projects. In depth knowledge of creative application of 3D modeling - visualization for civil infrastructure change management. Experience with video production that includes, but not limited to: scoping, scripting, storyboarding, video shooting and post editing. Knowledge of roadway survey operations and the ability to function as any part of a survey crew. Management experience in directing commercial digital photography sessions. Management experience in directing helicopter flight - aerial photography operations. Associate Degree in Civil Engineering with 2 years experience equivalent to a Transportation Engineer 4 with 3 years communication-based skill experience OR, Bachelor Degree in Civil Engineering with 3 years communication-based skill experience OR, Bachelor Degree in Communication with 2 years equivalent experience to a Transportation Engineer 4.

Washington State Department of Transportation

General Service Classified Position Description

See Instructions Next Page — *SHADED AREAS ARE COMPLETED BY HUMAN RESOURCES*

1. Position Number 00819	2. Employee Name (Last, First, MI)	3. Submitted By ☐ Agency ☒ Employee	4. Position Type 1. Full-Time
5. Division/Region/Section/Unit PDD/GeoMetrix/VERG	Org Code 303080	6. Submitted For ☒ Update ☐ Reallocation ☐ Establishment	
7. Present DOP Class Title Transportation Engineer 4	DOP Class Code 530N	Proposed DOP Class Title Transportation Technical Engineer	DOP Class Code 530P
8. Working Title (if different than class title) Visual Engineering Resource Group (VERG) Manager & Supervisor	12. Approved Class Title (FOR HR USE ONLY)		Class Code
9. Employment In Current Position 20 Years 7Months With Present Duties 4Years 3 Months	13. Effective Date	14. Work Period Designation	15. Pay Range
	16. L&I Risk Codes		
	17. Reviewed By / 18. Date	19. Approved By	20. Date
10. Immediate Supervisor's Name	Phone Number	Immediate Supervisor's DOP Class Title WMS 03GeoMetrix Manager	Position Number OW034
11. Location Of Employment (City) Tumwater			

Position Objective

21. Discuss in a few sentences what the position is required to accomplish. Summarize the scope of impact, responsibilities, and how the position supports/contributes to the mission of the organization.

The VERG manager presents, consults, outreaches, develops and produces highly specialized visual communications media for agency decision makers and other WSDOT partners. As a state wide, headquarters based, technical program specialist, this position is responsible for providing strategic communication assistance for program and project accomplishment. This position supports the WSDOT mission by: researching viable department wide projects and programs that can benefit from visual communication; establishing and maintaining an effective corporate understanding throughout WSDOT of project visualization, commercial photography and video production; educating executive leadership in the dynamic capabilities of visual communications; and keeping VERG technical skills commensurate with visual communication industry standards.

22. % of Time ☐ Day ☐ Week ☐ Month ☒ Year	Key Work Activities (Percentage of time should = 100%)
60%	The VERG manager presents, consults, outreaches, develops and produces highly specialized visual communications media for agency decision makers and other WSDOT partners. As a state wide, headquarters based, technical program specialist, this position is responsible for providing strategic communication assistance for program and project accomplishment. This position supports the WSDOT mission by: researching viable department wide projects and programs that can benefit from visual communication; establishing and maintaining an effective corporate understanding throughout WSDOT of project visualization, commercial photography and video production; educating executive leadership in the dynamic capabilities of visual communications; and keeping VERG technical skills commensurate with visual communication industry standards.
30%	Interact with WSDOT executive management and other state agencies to establish an understanding and use of visual communications. Conduct outreach efforts with WSDOT partners with respect to the use of visual communications. Provide direction to maintain a high degree of team technical growth commensurate with visual communication industry standards. Define VERG program direction, organize visualization related training, assign work projects and review final drafts for approval. Research, evaluate and adopt methods and protocols in producing project visualization, video production and commercial photography media. Conduct

Selective certification requiring demonstrated knowledge of:
MicroStation
3D Studio Max
Sketchup
Vue 6
Adobe Photoshop
Digital Photography

25. Supervisory or Lead Worker Relationship

Is this a Supervisory Position? ☒ Yes ☐ No (Conducts performance appraisals)
Is this a Lead Position? ☐ Yes ☒ No (Assigns and reviews daily work, does not conduct performance appraisals.)

(If either applies, attach current Organization Chart.)

26. Supervision Required By Position

☐ Close, Detailed ☐ Limited ☒ Little – Employee Responsible for Devising own work methods

Signatures

☐ If not in agreement with employee submitted package, check here and provide statement of explanation.

☐ The job duties above are an accurate reflection of the work to be performed by this position. All necessary attachments are included, i.e. organization chart for supervisory/lead positions, assessment of observed performance for reallocations with incumbent.

27. Signature of Immediate Supervisor	28. Title	29. Date
30. Signature of Appointing Authority	31. Title	32. Date

As the incumbent in this position, I have received a copy of this position description.

33. Signature of Employee	34. Title	35. Date

Sample Visual Engineer Job Description, Courtesy of the Georgia DOT

Visual Engineer Job Description
Georgia Department of Transportation

Title: Visual Engineer

Description:
This position would be responsible for producing a variety of visual deliverables including photo-simulations (ie: photo-paste, photo-matching), 3D animations, videos, etc. A civil engineering background is preferred since this position will need to have knowledge of roadway design methodologies and will need experience in 3D modeling. The candidate needs to be able to: (1) Work well in a team environment: (2) Be willing to work beyond normal hours to meet deadlines; (3) Learn new tools and techniques quickly; (4) Be self-disciplined in meeting project deadlines.

Skill Set:

- 3D Modeling in Bentley MicroStation (Proficient: 1 2 years)
- Adobe Photoshop (Proficient: 1-2 years)
- Adobe Premiere (Novice)
- Applying materials and lighting to MicroStation scenes (Proficient: 1-2 years)
- Bentley InRoads (Proficient)
- Creating camera views and animations in MicroStation (Proficient: 1 2 years)
- Image manipulation in Photoshop (Proficient: 1-2 years)

Responsibilties:

Provide engineering expertise to visualization projects

Possesses a working knowledge of roadway design methodologies. Uses existing civil design software to develop, modify, and review alignments, profiles, and other geometric elements. Ensures that decisions about the deliverables are practical and applicable for the context of the project and that they are in compliance with standard engineering practices/principles based on sound engineering judgment and engineering experience. Coordinates with Project Manager and Designer related to development of project deliverables to ensure the deliverables are what is needed to properly communicate the project or aspect of the project in question. Participates in public information meetings, arriving on time when and where required, and represents the Department in a professional and courteous manner when in contact with the public and other offices.

Maintain knowledge and proficiency in technology

Maintains knowledge of current trends in visual engineering and related software and tools. Evaluates and makes recommendations for new technology (ie: software and hardware). Provides technical knowledge and expertise to Department personnel/Consultants. Ability to learn new tools and techniques quickly.

Produce visualization products

Produces products requested by customers using the available tools/software, as well as standard methodologies. Understands how to leverage engineering data to aid in the production of models. Uses 3D modeling techniques to produce solids, surfaces and meshes. Performs material application to models for realistic effects. Understands rendering methodologies and output requirements. Creates animations and videos and provides any required post-production work.

Participate in product and project delivery

Produces reasonable timeframes and schedules for assigned work based on customer's needs and project deadlines. Delivers required products within the established timeframes and deadlines such that delays are not incurred on the project. Produces all deliverables on the menu of services including photo paste, photo match, renderings, animations, etc. Produces products that are consistently of high quality and meets requirements specified by customer. Provides regular status updates to the manager and customer. Produces man hour estimates on Consultant projects as required.