NCHRP SYNTHESIS 361

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Visualization for Project Development

A Synthesis of Highway Practice

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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Visualization for Project Development

A Synthesis of Highway Practice

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SUBJECT AREAS
Planning and Administration and Highway and Facility Design

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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This synthesis is dedicated to the late Greg Herrington. His infectious enthusiasm and tireless efforts to champion the use of visualization have helped to improve and increase its usage within transportation agencies throughout the United States.

Cover photograph: The 390-ft span Virgin River Arch Bridge in southern Utah, final rendering.

FOREWORD

By Staff
Transportation
Research Board

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

This synthesis presents information on visualization; the visual representation of proposed alternatives and improvements and their associated effects on the existing surroundings. It focuses on the best practices and experiences to date within transportation agencies that are developing and incorporating visualization into the project development process. The report provides an overview, details case studies, addresses the challenges of visualization, and compares the results with a similar study from 1996.

This synthesis report was developed by conducting interviews with various transportation agencies, universities, and consultants throughout the United States. A survey questionnaire was distributed in advance of the interviews to assist in the preparation.

Charles L. Hixon, III, Bergmann Associates, Rochester, New York, collected and synthesized the information and wrote the report, under the guidance of a panel of experts in the subject area. The members of the oversight panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

VISUALIZATION FOR PROJECT DEVELOPMENT

SUMMARY

Visualization is the visual representation of proposed project alternatives and improvements and their associated impacts on the existing surroundings. The technology uses a vast array of tools to assist transportation agencies in the decision-making process for planning and design.

Traditionally, visualization has been used to convey the final design to decision makers, stakeholders, and the public. Today, some transportation agencies are finding new ways to integrate visualization into the project development process.

This synthesis focuses on the best practices and experiences to date of leading transportation agencies that are developing and incorporating visualization into the "preconstruction" component of the project development process.

Information was acquired through interviews with various transportation agencies, universities, and consultants across the United States. A survey questionnaire was sent to the agencies in advance of the interview to assist in preparation for the interview. Additional information was acquired by means of the Internet and by a review of previous AASHTO and TRB documentation concerning the uses of visualization.

For more than 20 years, computer graphic technologies have advanced the production and accuracy of the project development process. The greatest impact of these technologies has been with computer-aided drafting and design (CADD). Initially considered a two-dimensional (2-D) drafting tool, CADD has matured over the years to become a viable three-dimensional (3-D) design tool. The use of 3-D CADD technology has provided transportation agencies with the capability to use new visual tools to help with planning and design. These visual tools are becoming more widely used within the planning, design, construction, stakeholder approval, and public involvement processes.

The rapid progression of these visual tools has exceeded the organizational capacity of many transportation agencies. This rapid progression is the result of in large part the decreasing costs of computer hardware and software and the increasing processing capacity of desktop computer systems. Agencies struggle with basic decision-making questions: When should visualization technologies be used? How should they be used? What visual technologies should be used?

The current state of visualization within the transportation community is one of eagerness to use the technology, but minimal organization for its implementation. Transportation agencies throughout the United States are looking for guidelines and best practices for its use.

A majority of the current use of visualization occurs at the grass-roots level within transportation agencies. Most of this use is driven either by a specific project or by a project manager. The result is that most transportation agencies are reactive to visualization versus being proactive in its development. People with minimal to no experience with visualization are determining its use or nonuse for their project(s). Because the use of this technology is being driven by people with a lack of experience, clear standards or guidelines need to be developed or adhered to by transportation agencies. Because there are no accepted guidelines,

research and development for visual tools is limited to job-related experience and trial and error. With the exception of the Minnesota Department of Transportation, Metro District, and the New York State Department of Transportation, most of the agencies interviewed for this synthesis have informal groups or individuals who produce visuals. None of these groups has any structured organization or recognition by their respective transportation agencies. Basic guidelines such as job descriptions, application development processes, or best practices are not being followed by these groups or are being informally written and executed.

Despite the lack of focus and direction, the use of visual tools by transportation agencies is increasing. This increase is primarily the result of outside forces, such as the need for project acceptance from the public for controversial design issues. Almost every large-scale project today uses some form of visualization capability. Visualization is becoming "expected," especially for high-profile projects requiring extensive public involvement.

Because of the extent of hardware and software applications currently available, it would be extremely difficult to determine which product(s) should be used for best practices or for cost–benefit analyses. However, developing sound standards and guidelines for the use of these products is attainable. The most effective way for visual tools to be implemented and standardized is to institute them within the planning and design process as a logical extension of CADD. Three-dimensional CADD tools are already in place; however, transportation agencies have been reluctant to use them because of the expense of training and additional staff-hours required for 3-D production.

To meet the increasing demand for visualization, the transportation agencies interviewed for this synthesis would all like to see guidelines, best practices, and cost–benefit analyses compiled for the use of visualization. The goal would be to have transportation agencies formally recognize visualization as a core service within the project development process.

CHAPTER ONE

INTRODUCTION

PURPOSE OF SYNTHESIS

Following is a definition that has been used to describe the technology known as visualization:

> Using the computer to convert data into picture form. The most basic visualization is that of turning transaction data and summary information into charts and graphs. Visualization is used in computer-aided design (CAD) to render screen images into 3-D [three-dimensional] models that can be viewed from all angles and which can also be animated (*1*).

This definition, although useful, is just one of many definitions that have been used for the term. Varying definitions have led transportation planners, designers, and engineers to interpret visualization differently. To combat this confusion, transportation agencies look to other agencies for help in addressing their needs for visualization. This synthesis focuses on the best practices and experiences with leading transportation agencies that are developing and incorporating visualization into the "preconstruction" component of the project development process.

The information gathered from the case study agencies will address (but not be limited to) the following topics:

- Business drivers who started the process of adopting visualization technologies;
- Evolution of the process of adopting visualization technologies;
- Integration of visualization with other agency processes (in particular, other processes using spatial data);
- Visual interviews with key individuals (i.e., testimonials);
- Hardware and software used to generate applications;
- Activities for which visualization is being used, including design/build, context-sensitive solutions, and homeland security;
- Staffing and training (e.g., in-house versus contracted, centralized versus decentralized, and number of persons doing visualization);
- Costs (e.g., costs relative to overall project costs);
- Benefits (e.g., reduced change orders and litigation, improved public buy-in to projects, and streamlining of processes);
- Examples of successful use (e.g., for internal design coordination and for public involvement);
- Lessons learned (i.e., what worked and what did not work);
- Institutional issues, including upper management support; and
- Ways to sustain visualization production capability.

In summary, this synthesis report provides transportation agencies with a concise set of case studies that highlights the best practices and experiences of using visualization within the project development process.

SCOPE OF WORK

This synthesis report has been generated by conducting interviews with various transportation agencies, universities, and consultants throughout the United States. The interview questionnaire for this synthesis appears as Appendix G. Interviews were conducted from March 2005 through June 2005 and included the following agencies and organizations:

- New York State Department of Transportation (NYSDOT)
- Utah Department of Transportation (UDOT)
- California Department of Transportation (Caltrans)
- FHWA—Eastern Federal Lands
- Minnesota Department of Transportation (Mn/DOT)
- Florida Department of Transportation (FDOT)
- TRB—Transportation Safety
- State University of New York (SUNY) at Buffalo
- Illinois Institute of Technology
- Bentley Systems, Inc.
- URS Creative Imaging Group.

To augment and assist in the preparation of these interviews, additional information was acquired through the Internet and the review of previous TRB and AASHTO documentation concerning the uses of visualization.

This report focused on obtaining case studies of the best practices and experiences of visualization within transportation agencies. Its intent is to describe the uses of visualization in an effort to develop standards and guidelines. Currently, there are no national standard visualization guidelines that transportation agencies follow.

ORGANIZATION OF SYNTHESIS

This synthesis is presented in five chapters. This first chapter details the synthesis purpose and scope.

Chapter two provides an overview of visualization. Topics include the definition of visualization, the history of visualization within the transportation design community, the need for visualization (e.g., for cost savings, production schedule, increased communication, and better design), the uses of visualization (e.g., for design review, interference detection, construction sequencing, approval, public involvement, and homeland security), and the applications used in visualization.

Chapter three details case studies recommended by the panel from state DOTs; the FHWA; and other agencies, consultants, and vendors referred by the state DOT and FHWA interviewees. The case studies focus on the best practices process, which includes initiating a visualization program, obstacles, goals, benefits, costs, savings, shortcomings, lessons learned, and next steps.

Chapter four addresses the challenges of visualization. It focuses on how transportation agencies are integrating visualization into the design process and how there is a need for a cost–benefit analysis to assist that need. The chapter also investigates the personnel involved in the visualization process. It describes how decision makers, technicians, and project managers interact with each other during the design process. Staffing, training, funding, and approvals awareness and visualization tools are presented. The issues of standardization and guidelines are also discussed.

Chapter five compares the results of this synthesis study with the results of a similar 1996 study. It describes how the use of visualization has changed in the past decade, including what has worked and what has not worked. Chapter six presents the conclusions. It summarizes opportunities to advance visualization in transportation, presents additional findings, and provides concluding remarks.

CHAPTER TWO

VISUALIZATION OVERVIEW

WHAT IS VISUALIZATION?

> Visualization is a simulated representation of proposed transportation improvements and their associated impacts on the surroundings in a manner sufficient to convey to the layperson the full extent of the improvement (*2*).

The use of visualization to understand complex issues such as proposed designs is not a new phenomenon. It has been used in maps and drawings for centuries. A famous example of this is Charles Joseph Minard's map of Napoleon's invasion of Russia in 1812 (Figure 1). This map clearly conveys troop movement, size, and loss of life during the campaign into Russia (*3*).

Visualization can accelerate conceptual approvals, identify less-than-obvious design flaws or opportunities, and ultimately reduce development costs before commencement of construction. It has the ability to help with the analysis of multiple design elements, such as proposed buildings, roadways, and underground utilities. Seeing the proposed design in three-dimensional (3-D) instead of a series of two-dimensional (2-D) plans and elevations increases overall understanding, which can translate into schedule and budget savings. The nature of the technology provides the capability for quicker response times in implementing design changes. The technology can be used throughout the life cycle of a project plan—from the process flow of value engineering, to the project development and environment study phase, to design and construction. Visual tools can provide greater communication and concise understanding, which in turn can lead to quicker acceptance or approvals.

A major strength of visual tools is their ability to clearly convey design issues. Designers will have the ability to view their concepts from multiple viewpoints, including viewpoints that are not feasible with standard photographic methods. Critical issues such as roadway aesthetics, vertical and horizontal alignment fit, traffic flow, and line of sight can be identified. The general public can also obtain a greater understanding of the project by viewing the proposed changes from a potentially unlimited number of viewpoints. Public outreach and support can be more effectively achieved. Although traditional methods of presenting 2-D design plans and charts for high-profile projects have often created additional misunderstanding because these methods do not fully convey impacts in basic terms that the average person can visually understand, 3-D and other new visualization tools allow participants to better view specific locations and their proposed alternatives to obtain greater understanding.

HISTORY OF VISUALIZATION WITHIN TRANSPORTATION DESIGN COMMUNITY

As the transportation design community matured during the 20th century, visuals were used to convey proposed roadway designs. Before the advent of computers, traditional artist hand renderings and physical models (Figure 2) were created and used primarily for stakeholder approvals. Although effective, hand renderings only provided a limited number of viewpoints for the project. They were also based on artistic interpretation and thus were only approximate in their accuracy. Physical (i.e., scaled) models provided an excellent and accurate representation of the overall project site, but lacked the detail necessary to fully comprehend the design. They were also time consuming to create, expensive to build, and inflexible to deal with the changes of a typical project.

Since the inception of CADD (computer-aided design and drafting), computerized visuals have been created by the transportation design community. The CADD discipline can trace its beginnings to the Sketchpad system developed by Ivan Sutherland in 1963 (*4*). Sutherland was able to connect the display capabilities of the cathode ray tube with the computational abilities of the computer, and the interactive process with the light pen made it possible to create a system for designing mechanical parts. Sutherland's system prompted automotive and aerospace companies to take notice and start their own projects to try to harness the power of the computer for their design needs. The late 1960s saw a flurry of activity in the CADD-related sector. Turnkey companies such as Calcomp, Computervision, and McAuto started creating and marketing software or hardware for this industry. These CADD-based visuals ranged from simple 2-D plots of plans and sections to 3-D renderings of proposed elevations.

By the mid to late 1970s, CADD modeling was available through such programs as Intergraph's Interactive Graphics Design Software (Figure 3). These applications ran on expensive mainframe systems. Because of the limitation of hardware processing speeds (68k), software capabilities, and the expense to operate these systems, 3-D visuals were difficult to achieve. The results were simple, shaded models that

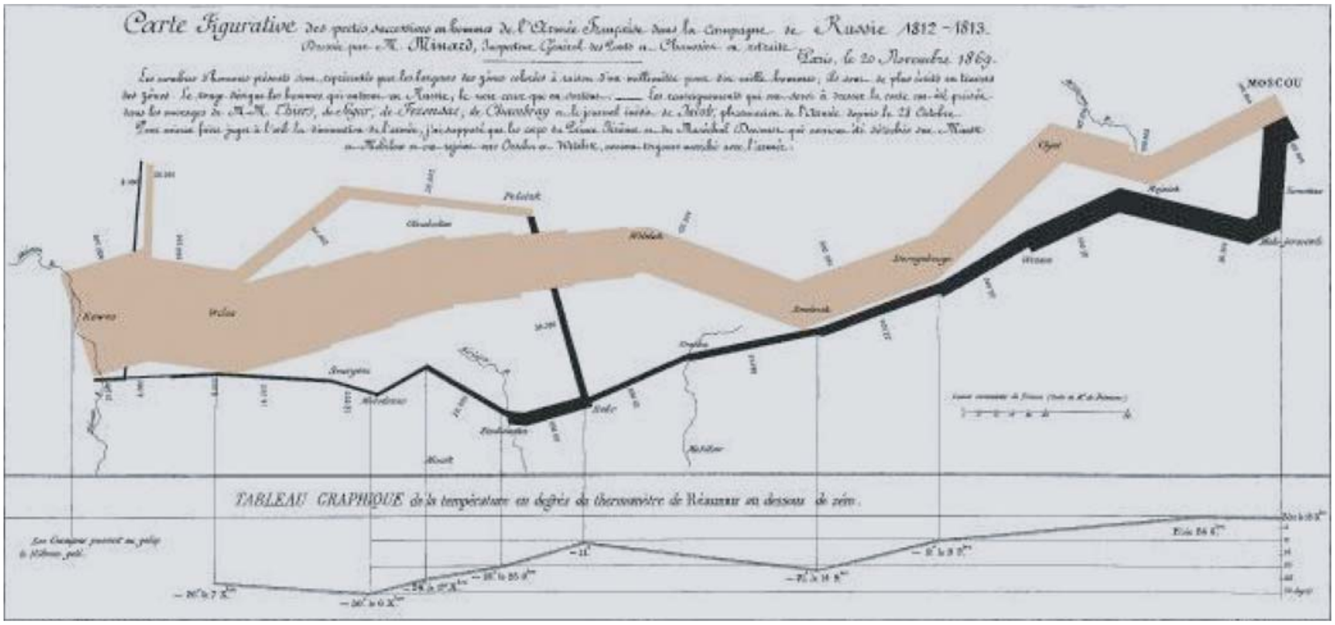

FIGURE 1 Charles Joseph Minard's map of Napoleon's march to Moscow during The War of 1812. (*Courtesy*: Graphics Press.)

could only be created by an experienced CADD operator. Throughout the 1980s, CADD primarily ran on mainframe computers.

In the early 1990s, hardware and software technologies rapidly advanced. Personal computers (PCs) were slowly replacing the mainframe-based workstations. PCs primarily used the Microsoft Windows operating systems, which helped enable software manufactures such as Autodesk and Bentley Systems to develop CADD applications for the PC. For the first time, designers and engineers could create CADD drawings and renderings on an affordable workstation platform. As the hardware technologies for desktop PCs advanced, new software tools were being developed that made it easier to create computerized visuals. By the early 2000s, CADD applications became more sophisticated, allowing users to design and model much more effectively in 3-D. Autodesk's 3-D Studio and Bentley Systems' MicroStation, combined with other vendors, now offered integrated and affordable advanced 3-D modeling and rendering capabilities.

To complement the CADD modeling, rendering, and animation capabilities of transportation agencies, other software applications have been written. Presentation graphic programs have simplified and improved how presentations are created and shown. For example, they have simplified the process of creating 35-mm slides and presenting them in a slide presentation. The steady advancement of other programs such as photo-editing applications has enabled visualization specialists to create seamless photo-simulations that blend the

FIGURE 2 Physical model of the Corning Bypass project. (*Courtesy*: Bergmann Associates.)

FIGURE 3 Intergraph workstation—1978.

3-D CADD model into a photograph. Today's transportation planner has an extensive portfolio of affordable hardware and software applications to use for computerized visualization.

WHY THE NEED FOR VISUALIZATION?

The need for visualization within the transportation community can be traced back to two factors: (1) improvement to the design process and (2) public and stakeholder involvement. Both of these issues have driven the advancement and use of the technology.

Improvement to Design Process

CADD technology was initially devised to improve the drafting process by automating mundane routines such as border creation and text input. Vendors strived to improve the process so that higher-quality work could be produced with less labor. In the mid-1980s, cost–benefit analyses were conducted to justify the up-front expense of hardware and software needed to implement CADD. The investment for mainframe computers, workstations, and software utilities regularly exceeded $100,000 (*5*). To justify these expenses, analyses were conducted that measured and compared the performance of design production on a drafting table with the performance of a CADD system. The testing proved that using CADD, even with the sizable up-front costs, was warranted. Two-dimensional CADD (see Figure 4) greatly improved the drafting and design process. Benefits included the following:

- Elimination of the need for tedious redraw (CADD could be used for productive design and analysis functions);
- A common electronic database;
- Reduced retrieval and print times for documents through a document management solution;
- Improved information flow with workflow and e-mail tools;

FIGURE 4 2-D CADD roadway alternative plan.

- Improved conformance with the ISO 9000 or Occupational Health and Safety Administration regulations through better document control procedures;
- Fewer lost, damaged, and misfiled documents;
- Immediate availability of accurate information;
- Streamlining of the change process;
- Improvement in time to market; and
- Improved quality.

The success of 2-D CADD has led developers to improve CADD capabilities by incorporating 3-D tools within the software. Three-dimensional design was the next evolution of the CADD process. By initially generating the design in 3-D, the process of design can be improved, achieving better quality control, improved process flow, and a natural extension to developing visuals from the design. If the project is initially designed in 3-D, then creating renderings, animation, or simulation will be a logical progression rather than an add-on application. Incorporating 3-D into the design process will lead to increased demand in the use of visualization tools. These visual tools translate into a variety of potential cost savings, including the following:

- Increased quality control, which leads to fewer construction changes and improved production schedules.
- Better and more cost-effective design. Because visual tools help to understand the design alternatives more effectively, better design decisions can be made.
- Increased communication and understanding. It is far easier to convey design ideas or options with visuals. The old adage "A picture is worth a thousand words" holds true with visualization.
- Improved timetables for approvals. When the understanding of a project is improved, acceptance by stakeholders or the public can be obtained more efficiently. Garnering rapid approvals or reducing approval times can be invaluable to costs savings on transportation design projects.

Public and Stakeholder Involvement

Public and stakeholder involvement is seen as a major reason for the need for visualization tools. The general public, resource agencies, and other stakeholders are continually exposed to 3-D computerized renderings and animation. Computerized visuals are used in the daily activities of most people, from the entertainment community (in which visualization is used for television commercials, print advertisement, movies, and much more) to industrial uses such as computer numerical control (*6*) machining and geographic information system (GIS) applications. Computerized visuals dominate the public eye today. With this mindset, the public expects and demands to see similar visuals at public presentations. This pressure has driven transportation agencies to develop and implement visual tools for public outreach.

USES OF VISUALIZATION WITHIN TRANSPORTATION DESIGN COMMUNITY

People use visualization in ways that vary widely from discipline to discipline. Within the transportation agency community, several uses of visualization are in application today.

- **Design.** As shown in the case studies in this synthesis, visualization enables planners and engineers to design more effectively and efficiently. Critical issues such as line-of-sight and site impacts can be better understood through the use of visual tools. Because engineers are currently charged with the task of designing 3-D projects, it seems particularly practical to use 3-D tools (see Figure 5). Completing the design using 3-D visualization tools enables engineers to better understand the design and construction process and to identify design flaws early in the process instead of during the construction phase, where expensive overruns usually occur or where it may be too late to remedy the design flaw.
- **Human factors assessment.** Visuals assist planners and designers in identifying the full range of human factors and interfaces (e.g., cognitive, organizational, physical, functional, and environmental) necessary to achieve an acceptable level of design and meet the functional requirements of the project. Results are realized in improved acquisition decisions, reduced training and maintenance costs, fewer human errors, improved safety, a higher probability of system success, and improved user acceptance.
- **Impact analysis.** Visuals allow planners and designers to "see" project impacts before anything is built. Visuals that help explain or justify certain aspects of a project are usually incorporated into one of two documents: (1) the environmental impact statement (EIS), which is a document produced during the project development and environment process that describes all likely impacts that will result from the project, or (2) the project-specific aesthetic guidelines or visual quality manuals that some agencies have, such as the guidelines of the Mn/DOT (*7*).
- **Construction sequencing.** Visualization can be used to help planners comprehend complex construction sequencing issues (see Figure 6). Construction overruns are common and affect project budgets significantly. Almost all construction claims for overruns are based on design problems, usually because contractors claim that their jobs required more work than was outlined in the original plans. These design problems lead to more work and can be reduced or even eliminated through the use of 3-D CADD design and visualization.
- **Interference detection.** If the design process is being completed in 3-D, a variety of visualization tools can automatically identify interferences during the CADD process. This process can be complicated, involving a significant number of plan sheets. Often it is difficult for the designer and decision maker to fully understand the impacts of a project because many plan sheets need to be cross-referenced. Three-dimensional applications can improve the overall understanding of the design by automating the process of identifying interferences

FIGURE 5 3-D rendering. (*Courtesy*: Bergmann Associates.)

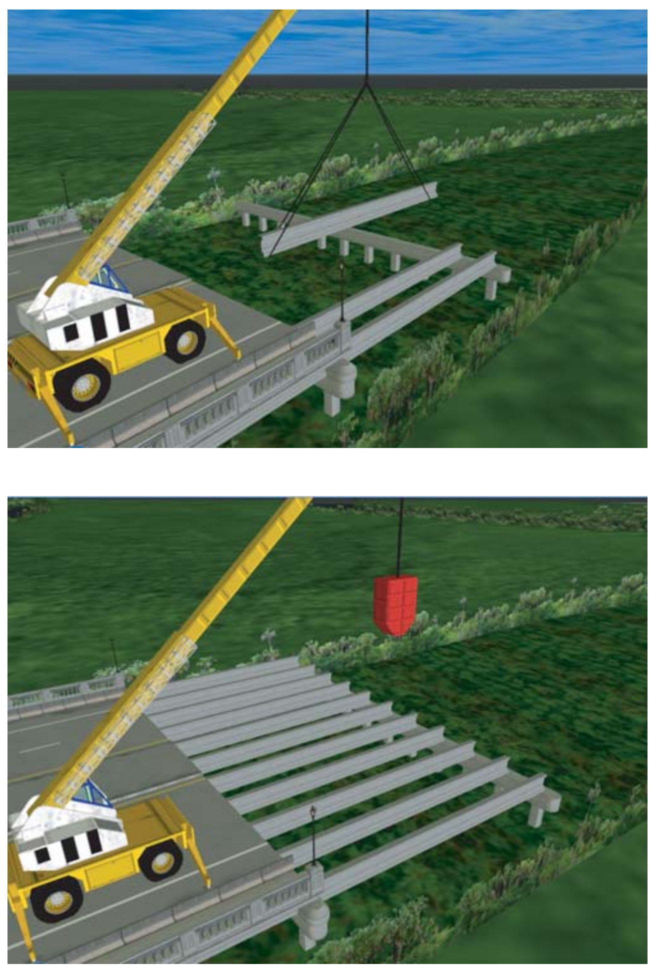

FIGURE 6 Construction sequencing.

and conflicts. For example, often details for piping or electrical components can reside on one set of plan sheets whereas the overall structural components for the project reside on another sheet. Traditional methods require constant referencing between those sheets. Three-dimensional interference detection improves this process. Three-dimensional software applications can also automatically call out constraints for interference detection or calculate sequencing processes. These visual tools assist the engineer in providing real-time feedback on the design. This visual feedback tool greatly improves the quality and accuracy of the design.

- **Funding and approval.** To start the project planning process, transportation agencies need to garner funding and support from state agencies, such as metropolitan planning organizations, and federal agencies, such as FHWA. To assist in the funding process, visuals can be used to help stakeholders and decision makers better understand the overall project goals and impacts.
- **Public and stakeholder involvement.** Used during the public involvement process, visualization can play a key role in acquiring support for the project; help citizens and stakeholders to make informed decisions; and foster enhanced relationships between transportation agencies, stakeholders, and the public. Many projects are ultimately decided by public acceptance. Because a significant portion of public opinion is driven by a misunderstanding of the project or by apprehension, it is important to make sure the public understands the design. Visualization improves understanding by better conveying to the public complicated design issues (see Figure 7). This improved understanding often leads to project consensus and approval.
- **Homeland security.** Homeland security is a relatively new use for visualization. It has been greatly accelerated since September 11, 2001. Visuals created for a project can assist planners and security agencies in understanding security issues such as line-of-sight and structural integrity. Three-dimensional visuals combined with database applications such as GIS add a level of intelligence and detail to visual data. Visuals are now being used as vital planning tools instead of being a byproduct of the design process.

FIGURE 7 Visual rendering of proposed site improvements at a U.S. Coast Guard Border Crossing Facility in Buffalo, New York.

VISUALIZATION TOOLS

Key Factors in Determining What Tools Are Used

The foundation of most computerized visualization tools is CADD data. CADD data can be derived from a variety of sources, such as survey data and field measurements. The data can be in 2-D or 3-D formats and can be simple or complex in design. Visual tools are used to enhance the CADD design and to convey it in a variety of formats. Key factors in deciding which visual tool to use include, but are not limited to, the following:

- **Project goals.** The most important factor in deciding which visual tool to use is the project goals. Visuals need to have a purpose or else they do not serve a viable function. For example, if the project requires an interactive public outreach tool, web development tools would be used instead of static photo-simulations. The right tool is needed for the right job. Visualization can be critical to addressing conflicting objectives and/or values between the agency, stakeholders, and the public.
- **Project schedule.** Another important factor in deciding which visual tool to use is the project schedule. The shorter the schedule, the less complex the visual tool needs to be. However, having a short schedule does not mean that the visual tool will be less effective; it simply implies that a different approach to conveying the design is required.
- **Project budget.** Once the project schedule and goals have been determined, project budgets can be set. These budgets are normally determined by the project manager. Currently, little to no formal information exists for project managers to access to help determine the visualization portion of the overall project budget. Project managers rely on information obtained either from experienced transportation agency members or through consultants associated with the project.
- **In-house knowledge and experience.** To successfully create visuals for a project, experienced visualization specialists are required. These specialists need to have a diverse array of knowledge about a variety of visualization tools. Project goals cannot be met unless the staff available has the correct skill set.

Types of Visual Tools

Hand Rendering

Hand rendering is the oldest visual tool used within the transportation design community. A hand rendering can be created by drawing or painting freehand images or tracing over existing CADD plans or elevations (see Figure 8). Although considered a "low-tech" visual solution, hand rending is still quite an effective tool. Many engineers and architects would argue that the traditional method of hand rendering gives the drawing a human touch, whereas computerized rendering tends to look somewhat plastic. This argument has some validity, and only an experienced individual can produce electronic renderings that will satisfy the preferences of an experienced traditional renderer.

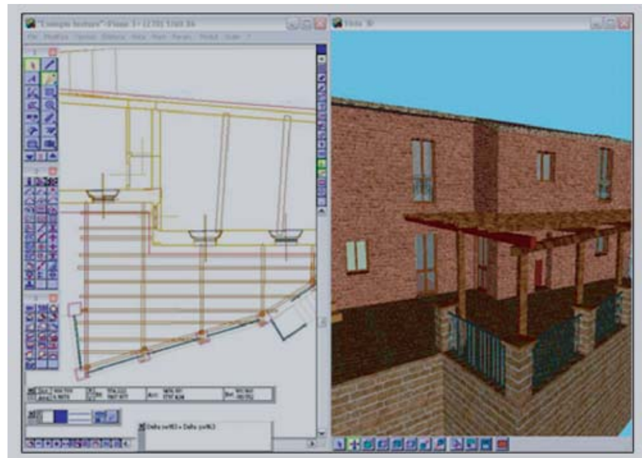

FIGURE 9 2-D CADD file and associated rendering.

Two-Dimensional Graphics

Two-dimensional CADD data, graphics, and photography can be applied to a variety of visual applications (see Figure 9). Most meetings and public presentations rely on 2-D graphics to convey everything from demographics to budgets. This visual tool can be output to print mediums, web development, or electronic multimedia presentations. Two-dimensional graphic models may combine geometric models (also called vector graphics), digital images (also known as raster graphics), text to be typeset, mathematical functions, and more. These components can be modified and manipulated by 2-D geometric transformations such as translation, rotation, and scaling. Two-dimensional simulations or photo montages can be very efficient and effective on some projects.

Computer Renderings

Computer rendering can be used after the 3-D model has been completed. Once completed, the model is inserted into a rendering program, where it is assigned variables that assist in adding realism to the model. Elements such as color, texture, lighting, reflectivity, and shadow are defined within the model. The rendering program then computes these elements and produces a realistic rendering (see Figure 10). Inserting these variables into a rendering program and creating realistic output takes an artistic eye and can be one of the most time-consuming portions of creating visuals. Often, multiple versions of the rendering are created until the proper "look" is achieved. The final product is a realistic rendering that can include environmental elements such as particles, lens flare, and subtle lighting and shading.

Photo-Simulation

Once the 3-D rendering has been created, it can be incorporated into an existing photograph using a photo-editing package (see Figure 11). The goal of the photo-simulation is to educate the observer while at the same time creating a seamless composite, whereby the computer graphics blend into the picture. Photo-simulation can provide the realism that the general public and the design industry expect to see in visuals.

Computer Animation

Computer animation is the art of creating moving images by using computers. It is a subfield of computer graphics and animation. Increasingly, computer animation renderings are

FIGURE 8 Hand rendering; the oldest visual tool used within the transportation design community.

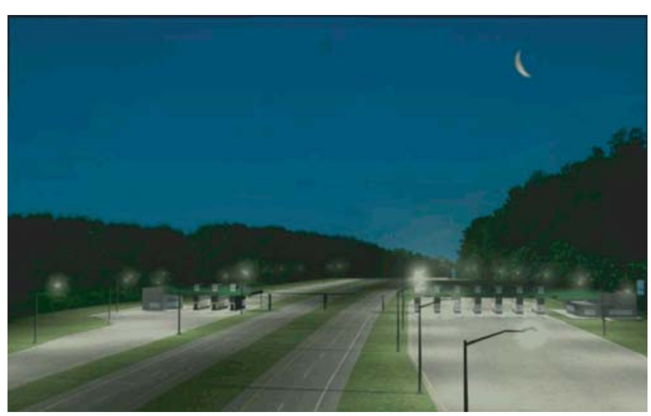

FIGURE 10 Toll plaza rendering. (*Courtesy*: SUNY at Buffalo.)

FIGURE 11 Photo-simulation of existing conditions (*top*) and proposed conditions (*bottom*).

FIGURE 12 Computer animation of Virgin River Arch Bridge. (*Courtesy*: Utah DOT.)

created by means of 3-D computer graphics, although 2-D computer graphics are still widely used. Sometimes the target of the animation is the computer itself; sometimes the target is another medium, such as film.

Essentially, computer animation is a series of computer renderings that are strung together (see Figure 12). Time constraints need to be considered when deciding to use computer animation, because rendering can be a time-consuming process. The computer systems must generate all the renderings necessary to create an animation, and it takes 30 frames (that is, renderings) to generate 1 s of computer animation (see Figure 13). Thus, for example, if it takes 5 min to generate one rendering, it will take 150 min to generate 1 s of computer animation:

- 5 min to prepare each rendering.
- 30 renderings to create each second of computer animation.
- $5 \times 30 = 150$ min to prepare each second of animation.

If the project requires 60 s of computer animation, then, based on the 5-minutes-per-frame calculation, it will take 9,000 min, or 150 h, to render all the frames necessary to produce the animation:

- 150 min to prepare each second of computer animation.
- 60 s of computer animation required for the project.
- $60 \times 150 = 9{,}000$ min to prepare computer animation.
- $9{,}000/60$ min = 150 h.

Production houses, consulting firms, and some transportation agencies use render farms or network-distributed rendering to improve processing and production time. A render farm is a computer cluster that renders computer-generated imagery. The rendering of images is a highly parallelizable activity because each frame can be calculated independently. The main communication between processors is the upload of the initial models and textures and the download of the finished images. Network-distributed rendering is the process of aggregating the power of several desktop computer workstations to collaboratively run a single computational task in a transparent and coherent way so that the workstations function as a single, centralized system. This form of rendering is used when a render farm is not practical or feasible. Instead of purchasing and maintaining a render farm, desktop workstations available on a network are used. Usually these workstations are accessed during the evening hours so as not to prohibit other uses of the workstations during the day.

Overall, when using computer animation, careful consideration needs to be given for the production schedule owing to the amount of potential rendering time.

Real-Time Simulation

Based on virtual reality, real-time simulation is a graphical database technology that allows for interactive navigation

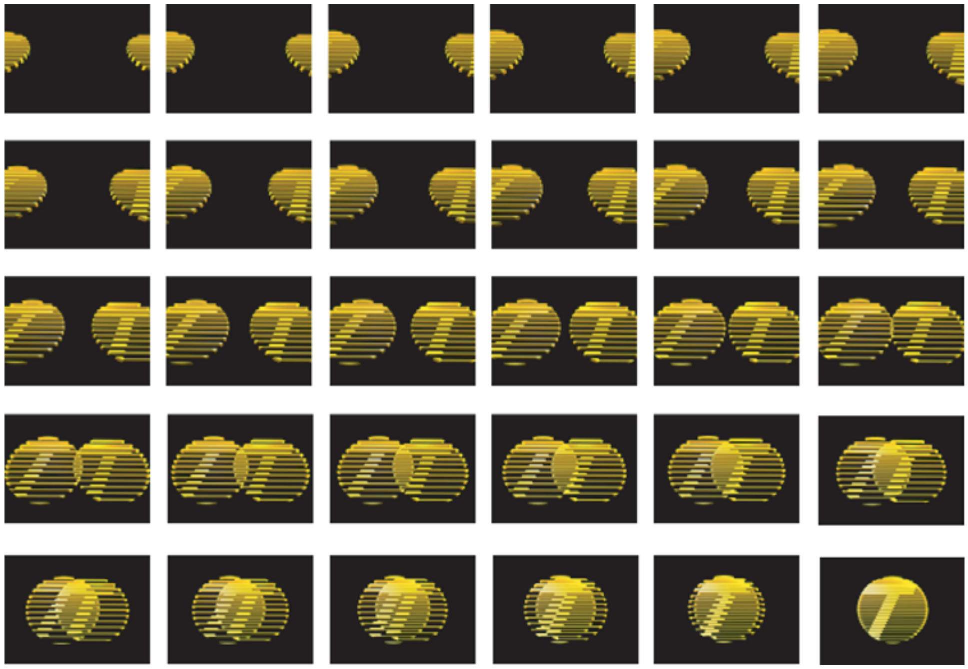

FIGURE 13 Frame count needed to generate 1 s of computer animation.

throughout a digital model. This visual database has the ability to foster rapid conceptual approvals, help identify design flaws, and reduce development costs before the commencement of construction. This technology has been pioneered by the U.S. military for flight and combat simulation and is rapidly becoming a key tool for the urban design and planning community. Cities such as Las Vegas, Nevada, and Cerritos, California, are currently using the technology to help with planning and design issues (*8*). Although traditional visualization methods have been used as a presentation tool, real-time simulation streamlines the complex phases of planning and designing a project by integrating multiple sets of plans and elevations and allowing the viewer to see them simultaneously instead of one sheet at a time.

Being a database itself, real-time simulation can be linked to other databases, such as GIS applications, traffic simulation utilities, or facility management utilities. Without real-time simulation, these other databases are stand-alone and cannot be linked together. However, real-time simulation can view these database formats simultaneously and allow the user to navigate interactively throughout the digital model, thereby making the database "intelligent." By dynamically linking real-time simulation to other databases, decision makers will have the ability to analyze various types of information. If the simulation is set up properly, it can interactively display tax base information, utility and building statistics, traffic simulations, and more.

Real-time simulation technology has the added ability to interactively analyze multiple design options. Objects such as proposed buildings, roadways, and underground utilities can be toggled on and off. This ability increases overall understanding, which can translate into schedule and budget savings. The nature of this technology allows for quicker response times in implementing design changes.

Real-time simulation can be a key master planning tool. Because it is a database, it can be modified for years to come. As changes occur to the project, the database can be updated. Additional features, such as a proposed building or roadway conditions, can be incrementally added to the database. Ultimately, the database can be expanded to contain large metropolitan areas. The technology can be used throughout the life of a master plan, providing greater communication and concise understanding, which in turn will lead to quicker acceptance or approvals.

The strength of real-time simulation lies within its interactivity. Designers will have the ability to view their concepts interactively. Critical issues such as building aesthetics and line of sight, which are security issues, can be easily identified. The general public can also obtain a greater understanding of the study by viewing the proposed changes from many perspectives. Public outreach and support can be more effectively achieved. Other visualization tools for high-profile projects have often created additional misunderstanding because these methods do not fully convey impacts in basic terms that the average person can understand. With real-time simulation, participants can interactively move around a site to see every angle and obtain greater understanding (see Figures 14–17).

Real-time simulation is a unique planning tool that can produce greater levels of communication and understanding. Users of this technology need to be aware that, unlike

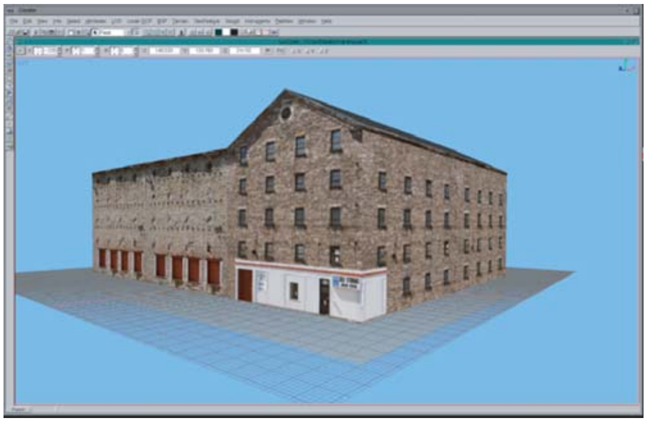

FIGURE 14 One angle of a 3-D simulation model of a building.

computer animation, real-time simulation cannot render multiple light sources, shadows, or reflectivity. These capabilities are currently available only with computer rendering or animation. They are commonly used to provide greater realism to the computer model or when lighting or shadow studies are required for a project. Therefore, if the goal of the project is to show any of these details visually, real-time simulation should not be used.

Web Development

The Internet has revolutionized how information is conveyed and shared. The transportation design community has recognized web development as an important part of the overall project development process. Several categories of websites can be produced, including, but not limited to, the following:

- **Promotional sites.** These sites typically serve as an online brochure to help increase public awareness for pending, upcoming, or active projects. They are usually static in content, but may involve some dynamic elements, such as information-gathering forms and database-driven elements.
- **Project-based sites.** These sites allow the project to be managed from multiple and even remote locations by means of the Internet. Management tools such as project scheduling, e-mail, and file management can all take place on the Internet. Various levels of security can be assigned to ensure data integrity and accuracy. With one common site, data for the project can be located quickly. Past problems of multiple file versions can also be eliminated by a common project-based website.
- **Public outreach.** These sites enable the general public to both access up-to-date project information and voice its opinions and concerns (see Figure 18). As the project progresses, the website can be updated with such information as project milestones, present and future traffic impacts, alternative transportation solutions, published meeting reports, and schedules.

FIGURE 15 One angle of a real-time 3-D simulation model of a proposed roadway.

FIGURE 16 One angle of a real-time 3-D simulation model of a proposed public safety building.

Multimedia Development

Multimedia systems support the interactive use of text, audio, still images, videos, and graphics. Each of these elements must

FIGURE 17 One angle of a real-time 3-D simulation model of a proposed building.

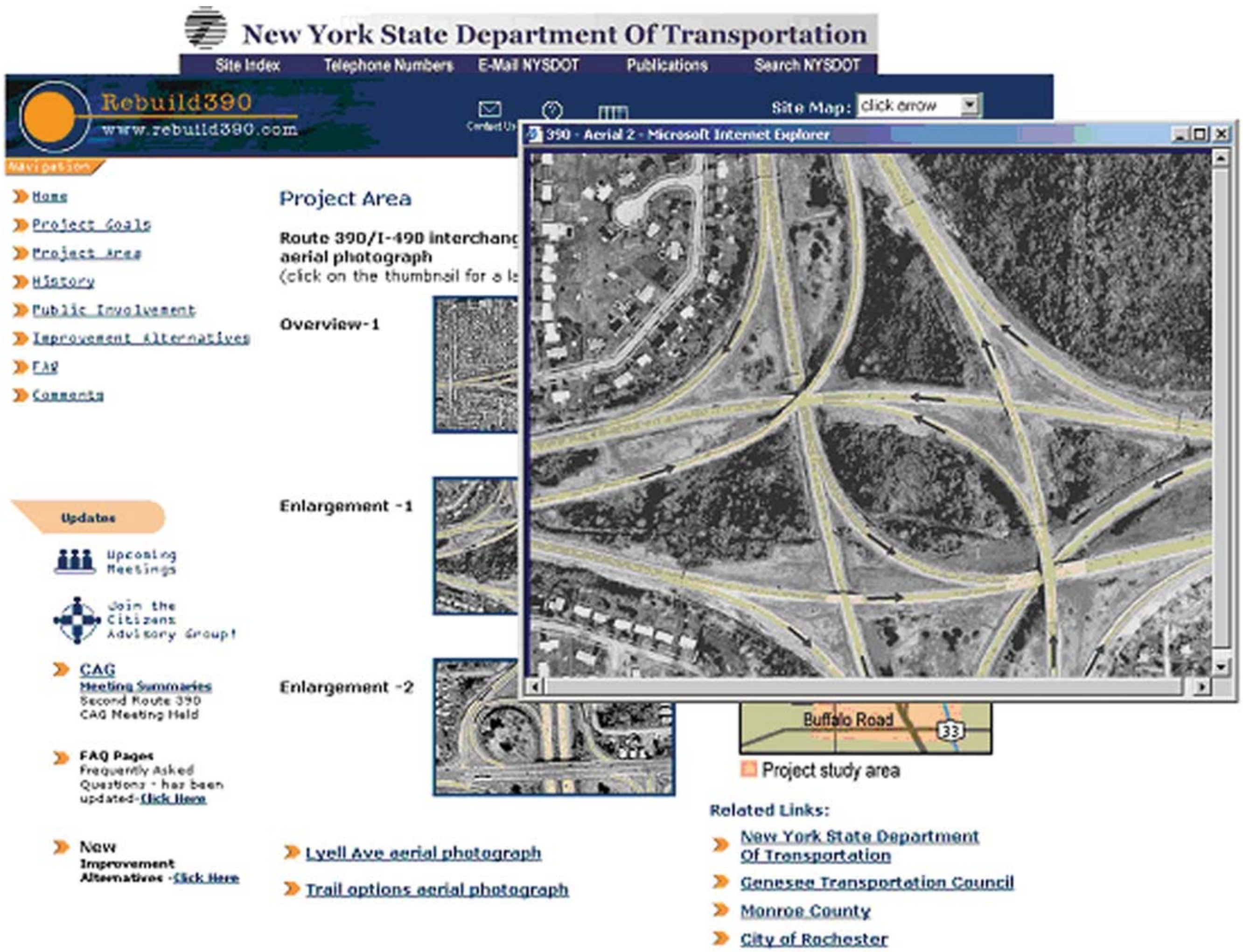

FIGURE 18 Public outreach website.

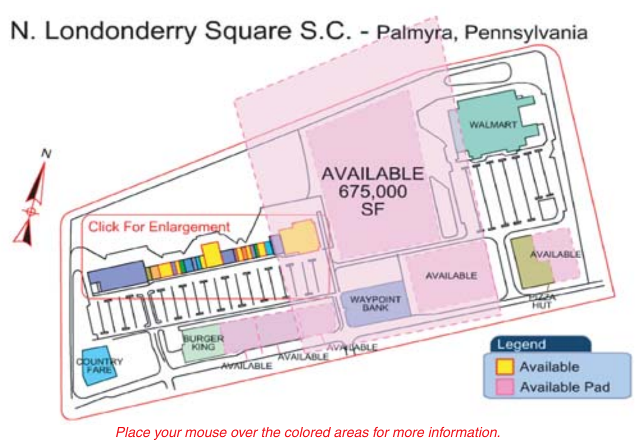

FIGURE 19 Multi-media graphic with “roll-over” capabilities. Roll-over capabilities allow the viewer to select an image within the graphic to see alternative images and text.

FIGURE 20 Scene from a video production that combines photo-simulation, 3D digital modeling and animation, and computer-generated graphics.

be converted in some way from analog form to digital form before they can be used in a computer application. Thus, the distinction of multimedia is the convergence of previously diverse systems. Commonly, multimedia elements are considered applications that are executed from a CD-ROM. The key advantage of this visual tool is its interactivity. The user has the ability to navigate at will throughout the multimedia system, using such features as “roll-over” capabilities to access alternative images, audio, or text (see Figure 19). Examples of multimedia tools include self-paced tutorials, informative project pieces, and outreach tools for stakeholder or public involvement.

Video Production

Video production combines the visual tools of photo-simulation, 3-D digital modeling and animation, and computer-generated graphics to create an informative depiction of a project (see Figure 20). The final product is an effective outreach tool that can be shown multiple times and from most locations. Video productions can be aired on local cable access, and copies can be made available at various municipal facilities in a variety of formats, including VHS, DVD, CD-ROM, and Beta-SP. Video production is the art and service of producing a finished video product to a customer’s requirement. Videos can satisfy a wide range of demands, from demonstrating safety features in dangerous environments to providing training. An example of a more everyday application is a television news article. Video producers take an outline, produce a script, create storyboards, and begin production. This process often includes experts ranging from CADD staff to computer graphics technicians. The production is created, put on broadcast-quality tapes, edited, and presented in a draft or “guide” form. Sound tracks and visual effects are then added, and the final video is presented. With the increasing use of video in a wide range of commercial and government functions, video production is a fast-growing industry.

CHAPTER THREE

CASE STUDIES

This chapter details case studies from several transportation and governmental agencies, consultants, manufacturers, and other agencies. These case studies focus on why visualization has been used, how it has been applied, and what the lessons learned from its use are.

CASE STUDY 1: UTAH DEPARTMENT OF TRANSPORTATION

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Salt Lake City, UT 84119-0100

Organization

The use of visualization technologies is overseen by a group of engineering technology support (ETS) personnel, including four individuals who have visualization experience. The visual team is actually part of the overall information technology (IT)/CADD group (which has nine people) for UDOT. Although the ETS personnel do not yet have a formal business plan, guidelines, or job titles for visualization, the group is actively completing a variety of visualization projects and conducting research and development on the technology.

Why the Need for Visualization at UDOT?

The ETS group is highly motivated to use visual technologies and is driven by a combination of in-house directives and requests from UDOT's project managers. The primary purpose of generating visuals has been for public involvement projects where there are controversial issues and where decisions with significant ramifications need to be made. Unless the visualization project is completed as an in-house research project, the need for visuals is directly linked to the project manager. The group has been recognized throughout UDOT for generating visuals. Project managers regularly consult with the group on whether or not visuals should be used on their projects. However, there is no formal procedure in place for a project manager to use when determining if visuals are needed for their projects.

Implementation Plan

Research and Development

The UDOT visual team, recognizing the value of visualization technologies, has for the past 10 years researched and implemented its use within design projects (see Figure 21). A requirement for all research is the compatibility of visual tools with UDOT's primary CADD application, MicroStation. Currently, there are no formal research and development directives at UDOT for visualization. To facilitate the research and development effort, the group's engineering technology support manager for IT participates on the TRB Task Force on Visualization in Transportation (ABJ95T) (*9*). This task force has helped to formulate alternatives and keep the group current on visualization technologies. The support manager also relies on hardware and software vendors to keep informed on current and future technologies. UDOT also relies on consultants for visualization support services. To organize a pool of qualified consultants, UDOT submitted a request for qualifications, "Standard Requests for Qualifications—Visualization Pool" (see Appendix B). This request for qualifications was authored by the support manager and others to properly assess the capabilities and qualifications of consultants. The ultimate direction of which visual technologies to use is determined by the UDOT ETS group and the project manager. The group regularly creates visuals in the following formats: 2-D and 3-D renderings, photo-simulation, and animation.

The past 2 years have seen the UDOT ETS group begin to use virtual reality-based, real-time simulation technologies for its projects. The group would like to see visual tools used more during the design process, specifically using 3-D CADD. The group observes that most visuals are created after important design decisions are made. For example, visuals are requested for a public presentation of previously designed projects. Although visuals are effective in helping to educate the public, they are an added expense to a project. If 3-D CADD were implemented, visuals would be part of the process from the beginning and would be easier and less costly to produce.

There is no ongoing base visualization budget at UDOT. A project level budget is created, and specific visualization hardware and software needs are expensed as part of the project. This process is relatively new at UDOT. No longer are there separate budgets for planning, design, construction, and so

FIGURE 21 UDOT visual technologies web page. (*Courtesy*: Utah DOT.)

forth. All budgetary issues are now under one budget, the overall project budget. This has helped in funding visualization projects; eliminating the need to approach each individual discipline for funding requests. The final decision is made by the project manager in consultation with the ETS manager for IT.

Because there are no standards or guidelines, the group receives additional support from UDOT's IT group. When hardware or software requests are made, the IT group uses a matrix developed for CADD to determine purchase, configuration, and set-up.

Internal Approval Process for Visualization

Funding and support for visualization research and development has varied. Although management at UDOT has supported the group in developing visual technologies, each succeeding department manager does have a different policy concerning visualization. Each new manager must educate decision makers and project managers on the value of visualization. With no strategic visualization policy or guidelines, the task of educating has been difficult.

Staffing

With no officially endorsed, department-wide visualization training procedures, standards, or guidelines, staffing has proven to be a difficult task. Staffing consists of CADD technicians who have an interest in visualization. These staff members are self-motivated and usually assist in the research and development process.

Because visualization is still in the technology adoption phase, there are no formal training courses for the CADD technicians at UDOT. In-house mentoring is achieved when individuals attend seminars on specific applications and projects. The staff also relies on its software vendors for education on the latest techniques for CADD visualization. The group is proposing to incorporate 3-D CADD into the department and is receiving some resistance from CADD technicians who would be required to learn it. This resistance is partly the result of the difficulty of learning 3-D CADD and partly the result of the additional design time required for the project.

Visualization Benefits

UDOT has measured dramatic cost and productivity savings when visualization is used on projects. The support manager conservatively projects a 15:1 return on investment when using visual tools.

The reduced change orders, construction cost savings, and more efficient use of materials that resulted from use of visualization were tracked while designing the Virgin River Arch Bridge project near the communities of Hurricane and La Verkin, Utah (Figures 22 and 23) (*10*). Along with improved design and cost savings, the visuals produced for the public presentations helped secure the project approval. The support manager is confident that as more projects use 3-D design, the return on investment might exceed 30:1. This support manager stated that

> The principles that we discovered during this process led us to believe that the value of 3-D design and visualization were not just as tools for large, very complex projects, but that it would bring us significant value on almost every project (*10*).

CASE STUDY 2: CALIFORNIA DEPARTMENT OF TRANSPORTATION

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Chief, TASAS Branch
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Sacramento, CA 95814

FIGURE 22 Virgin River Arch Bridge, early test rendering.

FIGURE 23 Virgin River Arch Bridge, final rendering.

Organization

Caltrans, like many DOTs, is organized into separate regions, or districts. California has 12 districts, each operating independently from the others. Visualization services apply the same structure to its purposes and uses as well. The result of this organization is that Caltrans currently does not have a cohesive and uniform visualization group or policy for the agency. Despite their independence, districts normally provide services (including visualization) to other districts, primarily for engineering services. Some districts are much more active in the use of visualization because of population densities and volumes of active projects.

Currently, each district is promoting the use of visual tools in various forms and disciplines. Some districts will use visual tools immediately on projects, whereas others only react to a given project. Particular focus for the use of visualization has been given to the landscape architecture and structure architecture disciplines. Informally, visual members from some of the districts meet annually and discuss how each has been using the technology.

In the 1960s, Caltrans initially mandated an offering of visuals to projects for public awareness and approvals. By the mid-1970s, visualization was being incorporated into the environmental process. Initial visuals were physical models and hand renderings. Visuals were predominantly used by landscape architects to help with aesthetics. In the late 1980s, Caltrans began using computers for CADD and graphics. Initially, during the transition from paper to CADD, Caltrans attempted to centralize the support. This attempt was not successful and subsequently led to the organization that is in place today.

In the mid-1990s, the bridge architecture group had eight people creating CADD and related visuals. At the time, only one staff member was considered proficient in the field of visualization. This visualization group focused solely on visuals for the bridge architects and engineers and steadily improved its skill sets with visualization. The group remains in operation.

Why the Need for Visualization at Caltrans?

The public ultimately drives the needs for visuals at Caltrans. Visuals are created primarily for public presentations and in-house meetings. For the most part, 3-D renderings, photosimulations, and 2-D graphics are created for these presentations. The use of computer animation is infrequent and not considered a strength of the group.

Project managers are the other source of demand for visualization. The visual groups will work closely with the project manager to determine what types of visuals are needed, how many are needed, and so forth. Projects that are large and high-profile, controversial, or having significant environmental impacts usually require visuals.

Implementation Plan

Research and Development

There are no formalized research and development programs at any of the districts within Caltrans. Research is determined by lead technicians within each group. These lead technicians inform the other staff members through in-house training and mentoring. Because of the nature of these lead technicians' workflow, which is very busy, it is difficult to find time to conduct research. Approximately 95% of all production schedules are within 1 week. These schedules for visualization are very fast. Another factor is limited budgets that have cut training, conference attendance, and professional association attendance.

Another avenue for research and development is the use of vendors. When specific needs are required, Caltrans will also bring in its hardware and software vendors to make presentations on potential solutions.

Internal Approval Process for Visualization

The project managers are responsible for the use of visual tools. There is no formal budget for hardware, software, or staff-hours. These issues are all absorbed within the overall project budget. Caltrans computer budgets for the past few years have been very tight, with limited funding for visualization tools. The groups use workstations and applications that are not current—in some cases, the systems are 3–4 years old. The older software applications and hardware systems have helped to restrict the development of visualization. On larger projects, some visual tools can be purchased and absorbed into the project budget; however, these projects are the exception. The Caltrans IT department is approaching support globally, not for niche services such as visualization. Therefore, unique hardware and software requisitions usually are not approved. This approach is causing a disconnect between the visual groups and IT, which leads to further inefficiencies.

Because there are no formal standards or guidelines, each project determines what visual applications and standards will be used.

Staffing

There are no formalized job descriptions for visualization technicians at Caltrans. Alternative titles with special classifications, such as bridge assistant or associate, are given. Staffing primarily comes through the CADD ranks. New hires (primarily college graduates) are made, and they are the ones who are pushing the use for newer technologies. It is hard to keep these new hires, because they eventually take jobs with consultants. The workflow process involves the senior-level person—for example, the chief of that particular discipline—negotiating with a project manager to complete a visualization project. In turn, the senior-level person mentors and manages junior-level people who create the visuals. Projects that require advanced uses of visualization, such as animation and simulation, are completed by consultants when requested by project managers.

There are no formal training classes for visualization. Instead, periodic seminars and classes are offered for particular software applications. People attend these sessions and then pass down the information to other members within the group.

Visualization Benefits

Production Improvements

Visuals have improved the public involvement process and added credibility to the design process. Its usage has dramatically increased over the past 2 years. Because every large design project in California is controversial, visuals are used to help the project manager and stakeholders properly convey the design. For example, during the planning and design phase of the San Francisco–Oakland Bay Bridge project, the District 4 director stated that visuals helped to ensure that the public bought into the high-profile and complex project and that the design team was designing it properly (Figure 24). Caltrans needed to design a structure that met strict seismic guidelines and be visually appealing to the stakeholders and public, who wanted a streamlined and elegant looking bridge. Visuals improved the communication process between the various resource agencies, engineers, and stakeholders during the design. The final design met all the engineering criteria and visually appealed to stakeholders and the public. The director stated that visuals are considered for every Caltrans project. Although there is no formal procedure in place to implement visualization, the director noted

FIGURE 24 Visuals of the San Francisco–Oakland Bay Bridge.

that common sense was generally used by project managers in determining its usage. In the typical process, the project managers approach the in-house groups for visuals. Some groups have established reputations in producing certain types of visuals, such as photo-simulation.

The visual groups at Caltrans are striving to add accuracy and credibility to the visuals created for these processes. The landscape architecture group regularly uses visuals as part of the EIS with the visual impact assessment reports. Although the EIS is traditionally not part of the design process, some of the visuals created for the EIS have affected and changed the design.

Little work has been completed using high-end visual tools, such as animation. Some limited 3-D modeling has been completed, but primarily it has been used for digital terrain modeling (DTM). The lack of 3-D modeling is linked to limited computer budgets that have generated aging hardware and software. 3-D design is still cost-prohibitive. Until Caltrans can reduce the costs associated with 3-D design (e.g., hardware, software, training, and initial increased production times), such design will continue to not be used in-house. Almost all animation or high-end computer graphics are being completed by consultants.

When accepting new assignments, the visual groups have learned to be cautious in attempting new things. The aptitude level of the technicians plays an important role in the selection of the visual tool and output.

Productivity Savings

The controversial Devil's Slide Project in San Mateo County successfully used visualization to assist with the design and approvals (see Figures 25 and 26) (*11*). For the past 50 years, the project has been studied, designed, and redesigned. To help convince the California Coastal Commission to move forward with the project, visuals were required to show how the proposed tunnels would blend into the unique landscapes along the California coast. Critical viewpoints were determined from the EIS, including several tunnel perspectives

FIGURE 25 Devil's Slide Project location graphic, San Mateo County. (*Courtesy*: Caltrans.)

and maintenance building mitigation. Initially created for understanding and approvals, the visuals (renderings incorporated into photographs) became part of the design process. Large retaining walls were required for the tunnel entrances and were a serious concern of the California Coastal Commission.

Once the initial visuals were created, the commission rejected the design primarily for aesthetic reasons and concerns over the portals for the tunnels. Working with the visualization technicians and engineers, the Coastal Commission had the design revised to match the surroundings and to provide safer conditions from mud slides. Several versions were then generated with visual tools to convey the modified designs. The project was finally approved and is currently under construction.

CASE STUDY 3: MINNESOTA DEPARTMENT OF TRANSPORTATION

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St. Paul, MN 55155-1899

FIGURE 26 Photo-simulation presentation board Devil's Slide Project, San Mateo County. (*Courtesy*: Caltrans.)

Organization

Photo-simulation and computer visualization technology has been an evolving process at Mn/DOT since the mid-1980s. During that time, hand-rendered photo-simulation and 3-D physical models were created by staff within the Landscape Architecture Unit. In the early 1990s, the graphic artist's skills transitioned to the computer using Adobe PhotoShop 2.0. This 2-D paint-and-composite process, although quick and effective, encountered limitations when needing to simulate detailed structures (walls, ramps, bridges, and so forth) and alignments. As a result of demonstrating the importance of elevating Mn/DOT's visualization process to 3-D and engineering accurate levels, a Visualization Unit was established in the mid-1990s with a one-time start-up budget of $250,000. This new centralized unit developed standards, guidelines, and job responsibilities while producing 3-D projects. The Visualization Unit provided a statewide service until 2003, when the group was disbanded because of restructuring during department cutbacks. This cost-cutting measure was partly enacted because there was not a clear cost–benefit analysis in place for the use of visualization technology as a central office function. However, the need for visualization continued as a vital tool on a large number of controversial metro area projects. Recognizing the benefit of having this service within the organization, Mn/DOT's Metro District absorbed part of the old visualization staff and aligned it with experienced MicroStation modeling staff, forming a strong visualization team with expertise in 2-D, 3-D, and 4-D technology (*12*). This three-person Mn/DOT team currently uses an eight-processor rendering farm for their animation production. Two other staff members with good visualization expertise are located in the Central Office Landscape Architecture Unit. Many within these Mn/DOT units believe that more investment of time and resources up-front in project development through visualization will save time and money overall, while reducing rework cycles. As one individual stated, "Better design takes time, but poor design usually takes longer."

Why the Need for Visualization?

Project managers are the primary users of visualization technology. Their primary needs are for public involvement issues (an estimated 70% of all visualization work) and the EIS portion of project development. Newer project managers tend to embrace the technology, whereas senior-level project managers often resist it. Most project managers do not have a good perception of the level of effort and time needed to produce visualizations.

Another result of using visuals for the public involvement process is the discovery of necessary design revisions and the avoidance of design flaws. Adjustments are presented to the project manager, who addresses them on a case-by-case basis.

Implementation Plan

The typical workflow has visuals requested by a project manager, who consults with the district's visualization supervisor. The Visualization Unit will advise the project manager on which visual tools should be used, how they will be presented, and the schedule needed to complete them. A typical production schedule lasts approximately 4 weeks. CADD data and photography are the basis for all visuals. The district project managers or staff also commonly request smaller visualization projects or tasks from the Central Office Landscape Architecture Unit.

Research and Development

There is no formal research and development process at Mn/DOT. However, it does conference with other DOTs such as the NYSDOT for visualization development. There is also some limited support from hardware and software vendors. Many visualization technicians come from universities and art schools that teach various 3-D applications. These individuals are helping to push the advancement of visualization. In the metro district, 90% of all visualization work is produced in-house by the three-person unit.

Internal Approval Process for Visualization

There is no formal visualization budget at Mn/DOT. Budgets are generated straight from projects that the groups are involved with. It is difficult to analyze visual expenses because they are incorporated into the overall project budget and are not tracked separately. When projects are assigned, the only budgetary concerns are the schedule and the staff-hours needed to accomplish the task. The approval process is through the project manager. Larger projects tend to support more visualization objectives.

For the past several years, the Minnesota state budget has been limited for investments in computer technology. Budget limitations were one of the reasons for dissolving the centralized group (the intent was to be a cost-saving measure). With limited budgets there has been minimal training. Travel restrictions are in place, so attending out-of-state conferences and seminars is not possible. There is concern that with continued budget constraints the visual groups will not be able to advance the visualization process.

Staffing

Although all eight Mn/DOT districts have the ability to implement visualization, only a few actually use the technology. The Metro District is the leader. There has also been some visual job sharing between the districts. Staffing is small, with one to three members at each district. Because of the former centralized group, Mn/DOT has visual technicians who are versed in advanced 3-D tools such as computer modeling and animation. Mn/DOT has filled this technology gap by promoting CADD technicians who have art backgrounds and are self-motivated to learning applications on their own. The group has determined that although all technicians have a passion for technology, the individuals with art backgrounds make a noticeable difference with the outcomes. As one individual stated, "You cannot force someone to become an artist; at least not a good artist."

The aptitude level of the technician plays an important role in the selection of the visual tool and output. It has been observed in some cases that someone with less aptitude, expertise, and artistic ability does a less than compelling job.

Visualization Benefits

The most successful uses of visualization continue to be with photo-simulation technology. Mn/DOT believes that this trend will continue for the next few years. Visualization continues to be a communication tool instead of a design tool. 3-D CADD is not a consideration at this time. The objective for now is to refine the tools already in place by adding more realism into the digital images created (e.g., inserting 3-D traffic and people into the models). The goal of the Metro office and other participating districts is to have visualization be incorporated into the design process. The visualization technician needs to become part of the design group assigned to a project early and continuously. There is no current directive to use 3-D design at Mn/DOT.

Visualization is being used on larger projects for public involvement and on smaller projects for existing and proposed analysis.

The St. Croix River Crossing Project is one of the largest projects currently taking place in Minnesota. This $350 million project is attempting to relieve traffic congestion and safety problems by providing a new river crossing. To achieve this goal, there is a large stakeholder group (28 different agencies) that needs to review and approve the proposed design. The project involves very sensitive natural and cultural resource concerns. Early in

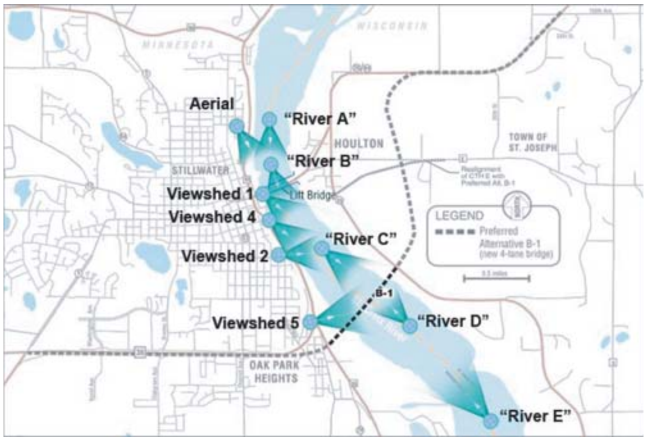

FIGURE 27 Project location map for a proposed alternative for the St. Croix crossing. (*Courtesy*: Mn/DOT.)

the design process it became apparent that the stakeholders could not picture the visual impacts that the proposed bridge would have. To address this issue, an additional person was hired by Mn/DOT to help create various renderings, photo-simulations, and computer animation to represent the five proposed alternatives (see Figures 27 and 28).

The initial purpose of the visuals was to garner support for the project. However, as the production progressed, visualization was used for design purposes, specifically to help assess the bluff impacts on the Minnesota side of the project. The visuals helped to eliminate some of the alternatives early in the process. The project manager believed that the visuals were beneficial to the project, because otherwise "people look at plan sheets and they cannot

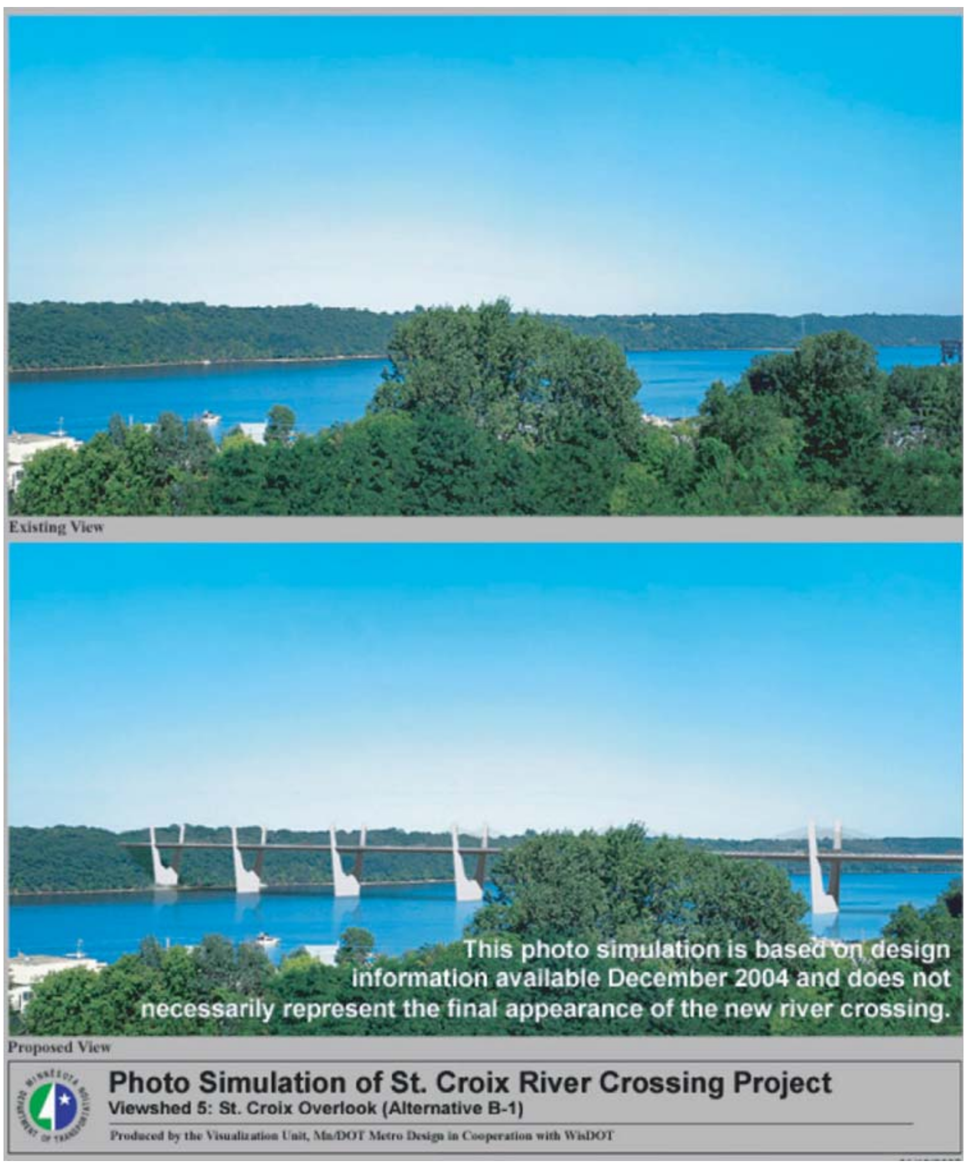

FIGURE 28 Photo-simulation presentation board for proposed alternative for the St. Croix River crossing. (*Courtesy*: Mn/DOT).

fully understand what all the lines mean." He was committed to planning and implementing the visuals, and he believed that visuals would be particularly effective for large design projects.

CASE STUDY 4: NEW YORK STATE DEPARTMENT OF TRANSPORTATION

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Organization

In 1993, the NYSDOT had skilled CADD people working in the Office of Engineering. A think tank was formed, and it was decided to pursue computerized renderings of CADD files. The commissioner at the time was very proactive with visualization technologies and supported the study of visualization. A test was conducted in 1994 on the Heim Road project located in Buffalo, New York. Renderings were created and used at the project's public workshops. A visualization survey was conducted at the workshops asking citizens for their opinion on the effectiveness of the visuals. Overwhelmingly, visuals were preferred over traditional plan sets. They were "far easier to understand." This research project and the subsequent survey led to the commissioner approving the start of a visualization section at NYSDOT. However, in 1995, a new commissioner was installed and all new positions and departments were discontinued. This policy is still in place today.

Implementation Plan

Staffing

Some of the regional offices of NYSDOT have in-house visualization capabilities. In addition, NYSDOT has a centralized group of individuals completing visualization projects; however, they do not have any fully established standards or guidelines and are not formally recognized as a group within the DOT. This lack of recognition has created concern, because there is volatility when a group lacks a definitive identity with definitive career paths for its members. This group completes most visualization projects, but not some projects located in the Buffalo and Long Island regions. All advanced visual applications such as animation and simulation are produced by this central group.

Internal Approval Process for Visualization

The project managers are the ultimate users and decision makers for all visualization services at NYSDOT, both in-house and contracted. To assist project managers in the use of visualization, the visualization group created a Visualization Project Workflow document (see Appendix C). This document assists the project managers with understanding the options available, the assets needed, and the workflow to accomplish the task. To augment the project workflow and help project managers focus on the specific visual tools and the final output required, the group also created a Visualization Request Form (see Appendix D).

The visualization group also established a feedback tool called the Visualization Assessment Form (see Appendix E), which can help justify using visualization and provides guidance to the visualization group.

These feedback tools have helped to increase the demand for visualization services. The majority of work comes from project managers who have used the visualization group's services in the past. The Visualization Request Form acts as a performance agreement once the initial meeting and consequential "scoping" occur.

The criteria for establishing a project's priority are

1. Degree of complexity;
2. Potential for impact: environmental, economic, etc.;
3. Potential for controversy;
4. New facilities; and
5. Statewide significance.

The rating for each criterion is high, moderate, or low.

The feedback forms have greatly increased the need for visualization technologies. They have also helped to improve the quality of the product and increased the project managers' satisfaction.

The investment, maintenance, and spending habits for the visualization group are part of the overall DOT engineering budget, which has a 3-year-long cycle. However, there is no specific budget for visualization. Purchasing and training happen on an as-needed basis only. The visualization group primarily produces 3-D photo-simulations for public involvement projects. More advanced visual tools such as animation and simulation are not often selected because of the production costs involved (i.e., staff-hours). However, the group is actively creating animation and simulation for multiple projects.

Research and Development

There is no formal research and development process at NYSDOT. Most of the research is conducted either by individual group members on their own initiative or through group members' associations with other agencies, such as the TRB Task Force on Visualization in Transportation

(ABJ95T) and the AASHTO Highway Subcommittee on Design (*13*). Both of these organizations provide invaluable resources for visualization.

Visualization Benefits

The group has been successfully operating for the past 10 years, just not as an official group but rather as part of the Landscape Architecture division. In 2005/2006, the visual group will be merging with the GIS, Photogrammetry, Survey, and Data Modeling groups to form the Terrain Data Services group. This reorganization should make visuals a part of the design process. The group will become a centralized technical resource center for specialized 3-D design services. The long-term goal is to have visualization become officially recognized as a design service. To further incorporate visualization into the design process, the visualization group would like to see 3-D design adopted as part of the CADD process. With the short-term budgetary conditions, it is anticipated that this adoption will not take place for several years.

The Latham Traffic Circle in Colonie, New York, was constructed in 1934. A frequent accident site, this old-style, large traffic circle forms an interchange between two busy state highways. Total reconstruction of the circle would have been prohibitively expensive; however, NYSDOT found other ways to improve its safety, including adding new approach signs and pavement markings on all legs of the circle to provide clear paths for negotiating the circle and to minimize driver confusion.

The visualization group at NYSDOT did an extensive amount of animation for the traffic circle project. Both the existing and proposed conditions were visually created to depict conflicts within the circle (see Figure 29). NYSDOT incorporated video and animation to show the view from the driver's perspective for signage and line-of-sight issues. The project was well done, the results from the animation were very effective, and the finished construction turned out as simulated.

FIGURE 29 Rendering of Latham Traffic Circle, Colonie, New York, using video and animation to depict existing and proposed conditions. (*Courtesy*: NYSDOT.)

CASE STUDY 5: FEDERAL HIGHWAY ADMINISTRATION

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Organization

FHWA is responsible for ensuring the safety, efficiency, and economy of the nation's highway transportation system. FHWA oversees all phases of highway policy, planning, research, design, operations, construction, and maintenance. Two principal programs accomplish this task: (1) the Federal-Aid Highway Program, which works with state DOTs to administer the nation's comprehensive highway system; and (2) the Federal Lands Highway Program (FLHP), which works with federal land management agencies to oversee highway programs and provide transportation engineering services for planning, design, contract administration, and construction of highways and bridges that provide access to or within federally owned lands. The FLHP also provides training, technology deployment, engineering services, and products to other customers.

Visualization technologies were first implemented at FHWA in the mid-1990s in an effort to help the public better understand designs. Visualization was first established in the Eastern Federal Lands Highway Division (EFLHD) and later expanded to the Central and Western divisions. The design visualization coordinator oversees activity in the EFLHD division; the other two divisions do not have a lead coordinator at this time. The design visualization coordinator is the first design visualization specialist in the FLHP. This person is in charge of all design visualization at the EFLHD. Design visualization consists of all graphics, including 3-D and 2-D. The design visualization group resides under the Engineering and Software Support division.

Why the Need for Visualization?

FHWA has found that visualization technology helps the public better understand projects and helps expedite design decisions, thereby reducing design costs. Visualization technologies are being used from the planning stage to post-construction repairs; however, it is not part of the design process.

Implementation Plan

Research and Development

There is no specific research and development program at FHWA. To enhance FHWA's research and development resources, the design visualization coordinator is affiliated with the TRB Task Force on Visualization in Transportation (ABJ95T). This individual also consults with CADD vendors, but has noted that these vendors have not made design visualization a priority.

In an effort to standardize visualization methodologies, FHWA contracted Parsons Brinckerhoff to draft a simplified guideline for design visualization. In 2005, this guideline was made available on the FHWA website at http://www.efl.fhwa.dot.gov/manuals/dv/. The purpose of the guide is to introduce visualization tools and innovative practices to the federal lands highway designer so that these techniques and tools will eventually be integrated into most federal lands highway projects whenever there are design issues or communication needs. The guide helps the designer learn to use commonly available software tools to produce visuals that help the designer better understand and communicate designs.

Internal Approval Process for Visualization

The approval process is determined by the project managers in the Engineering and Software Support division, with consultation from the design visualization coordinator. There is no official policy or guidelines for the use of visualization at FHWA. Each of the three divisions' project managers determines what work should be done and how to approach it.

Design visualization is centralized at FHWA, and the design visualization coordinator calculates a yearly budget for this service. Much of this budget is based on the previous year's activity. There are no standards for budgeting costs for specific projects. Calculations are based primarily on previous experience.

Staffing

At the EFLHD, the design visualization coordinator has the only division staffed for design visualization. The visualization coordinator's official title is Senior Transportation Specialist/Design Visualization Specialist. This individual is in charge of coordinating design visualization for all departments and other agencies and oversees two technicians. Staffing came from departmental transfers from the Preliminary Design Department. In parallel with the design visualization guidelines, training guidelines are being developed. Training is conducted primarily in-house through mentoring. The design visualization coordinator sets a yearly budget for attendance at conferences and seminars. This individual also receives vendor-specific training for the applications that are used at FHWA. FHWA currently does not have the same severe budgetary constraints that state DOTs have.

Visualization Benefits

To date, the most effective visual tool used at FHWA has been photo-simulation, such as that used for the Goshen Creek project (Figure 30). This tool is used primarily because of its low cost and quick production time. The technology is also the most easily understood by project managers and the public.

The visualization group completed design visuals for the National Park Service on the Blue Ridge Parkway traffic barrier study. The use of design visualization clearly showed the different aesthetic treatments for the bridge abutments. The National Park Service was enthusiastic about the visuals, which improved the decision-making and public approval processes for the project.

FIGURE 30 Goshen Creek existing conditions (*top*) and photo-simulation of proposed conditions (*bottom*). (*Courtesy*: FHWA.)

CASE STUDY 6: FLORIDA DEPARTMENT OF TRANSPORTATION

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Organization

Visualization technologies are frequently used in FDOT projects. Their use is determined on a case-by-case basis by the project managers for each project. The type and amount of visualization technology use is based on the project manager's experience with the technology and discussion with various in-house staff, vendors, and consultants. There is no regional visualization division. The FDOT Central Office allows each district to determine how to develop and use visualization. FDOT does not have a centralized strategic plan to develop visualization technologies in-house.

FDOT District 6 has an on-staff visualization technician, but not a formal district visualization section or directive. CADD applications are being used in-house to create photo-simulation, renderings, and animation. To augment the capabilities of the visualization technician, higher-capacity hardware components have been provided. Typically, these hardware configurations are CADD-based systems with larger hard drives and memory components and include advanced graphic cards. The technician is usually dedicated to a specific project and works with the project manager to determine the type of visual tool used and the production schedule to complete it.

Why the Need for Visualization?

District 6 typically has several high-profile projects being conducted simultaneously. Because of the volume of these projects, the district must also rely on consultants and vendors to create the visuals required. These projects usually involve a significant amount of public involvement. Visualization technologies are frequently used for public involvement at District 6 and at most other districts within FDOT. District 6 has used a wide variety of visualization applications for public involvement, ranging from computer rendering and animation to multimedia development and virtual reality simulations.

Implementation Plan

The District 6 value engineering department has recognized the importance of using visualization earlier in the project development process. "Value engineering" is the process by which the federal, state, and local highway agencies work to get the best overall project value for the taxpayer. Project management has determined that through the use of visualization technologies within the value engineering process, several key goals can be achieved, including better project understanding, the selection of more effective alternatives, and cost savings. Simply stated, value engineering is an organized application of common sense and technical knowledge directed at finding and eliminating unnecessary costs or adding functions or features to a project (*14*).

The FDOT value engineering department started using value engineering in the design and construction phases of projects in the 1970s. A few years ago, the department's district value engineering coordinators discussed adding another feature to the program, "value added." This concept caused some initial confusion as to whether to report the additions as negative savings. The issue was resolved by developing a separate tracking function as value added. The consensus was that value engineering was a cost-reduction program, and that program was what was originally tracked.

The addition of the new feature helped change the image of value engineering and opened the institutional mindset to accept concepts such as "value in advance," which is the potential to move value engineering into the planning phase where hard cost estimates are not as readily available. The potential for improving the value of a project in the early stages has always been recognized, and the department's management believed that this potential improvement could now be made on corridor projects. Thus, a planning-level project was selected to explore this new approach.

Value Engineering and Visualization

A value engineering study using visualization technologies was implemented and reviewed for Okeechobee Road (U.S. Highway 27), a six-lane, controlled-access highway. For this project, managers wanted to avoid a common problem associated with many value engineering studies; the problem of not having enough information early enough to make a reasonable decision based on facts. To help fill in the missing information, the value engineering team used GIS databases and visualization techniques. In addition, the project managers initiated a process to improve regulatory agency input early in the project. This new process, called "Efficient Transportation Decision Making," was developed by both the department and its normal review agencies (e.g., the U.S. Army Corps of Engineers, the U.S. Coast Guard, the Environmental Protection Agency, and the U.S. Fish and Wildlife Service) (*15*). Providing interactive visual simulations helped bring timely and pertinent comments for the for Okeechobee Road project (see Figure 31). As a result, the project managers did not miss any time-critical opportunities, and fatal flaws were eliminated.

FIGURE 31 Interactive visual simulation of the Okeechobee Road (U.S. Highway 27) project.

The simulation used during the value engineering study changed perspectives quickly and efficiently to focus on either a specific detail or a larger perspective. The aerial model prevented arguments by allowing users to zoom in on the specific study area and have everyone looking at the same thing at the same time.

The use of visualization was progressive, starting with canned data from GIS information sources. As concepts were developed, standardized typical sections, aerial photography, and general project requirements were added to the visualization. Visualization was an expandable and flexible tool for the value engineering team.

Visualization Benefits to Value Engineering Process

The use of visualization during the value engineering process fleshed out "what if" scenarios for the reviewers. The 3-D layers provided conflict identification points and phasing requirements for maintenance of traffic and construction staging.

The varying degrees of abstraction were important from a value analysis perspective because they provided different levels of information, and the user could alter the constraints of the project by turning on or off levels of information. This function could either aid or stifle the creative process by focusing the user's attention on the "how" rather than the "why." The overlay of the differing layers of information helped in the evaluation and analysis phases by comparing data in a graphical format that showed the combined effects of data (see Figure 32).

The shifting of value engineering to the earlier and perhaps more appropriate phases of the work program is a natural outcome of improved information and techniques that were made more readily available though the use of visualization.

CASE STUDY 7: VISUALIZATION FOR MACHINE CONTROL

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Office of Technical Support
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Minnesota Department of Transportation

ROC 52

The reconstruction design–build project on U.S. Highway 52 ("ROC 52"), located near Rochester, Minnesota, stretched from Highway 63 to 85th Street NW. The project was needed to reduce congestion, improve safety, replace deficient bridges and pavement, and eliminate the confusing mixed frontage road system. It included six lanes from Highway 63 to 75th Street NW; a new interchange at 75th Street NW; new and reconstructed local connecting frontage roads; new overpasses at 65th Street NW and 85th Street NW; and reconstructed interchanges at 6th Street SW, 2nd Street SW, Civic Center Drive, and 19th Street NW.

To enhance this large design–build project and assist with the machine control operations for the earthwork portion of the project, visualization was used (see Figure 33). URS Creative Imaging Group created 3-D DTMs of sections of the project site. The AutoCAD-generated models were then loaded into a software program developed by Ziegler/CAT, and this software program linked the DTMs to geographic positioning systems located on earthmoving equipment.

In 2002, Caterpillar and Trimble signed a joint venture agreement to develop and incorporate global positioning sys-

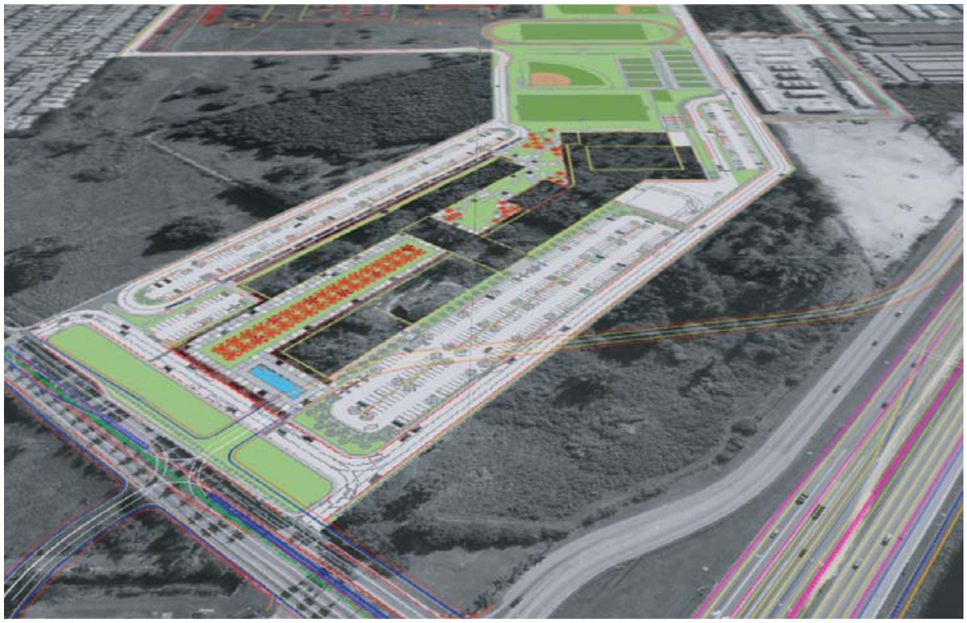

FIGURE 32 Site plan overlay of different layers of information showing combined effects of data on Okeechobee Road simulation.

tem technology into CAT machines. By using this technology, earthwork operations were significantly improved; resulting in faster construction schedules and reduced construction fees.

By relying on the DTMs, machine operators could view the grade control technology program on their machinery while making their grading passes (see Figure 34). This ability eliminated the need for expensive manual surveying, which is traditionally used. When operators use traditional manual surveying, they only know when they are on-grade at the survey stakes; in between stakes, it is guesswork, and most operators will err on the high side to avoid undercutting, which is the most costly mistake. However, erring on the high side leads to an increased number of passes needed to get to final grade. Therefore, the use of DTMs for grading resulted in fewer grading passes, faster grading times, tighter vertical and horizontal tolerances, reduced human error, and increased savings in schedules and budgets. URS Creative Imaging Group calculated a 50% to 70% increase in field performance as a result of DTMs.

In this project, basic 3-D CADD design techniques were used to enhance the construction process. Visualization technologies saved a significant amount of construction dollars

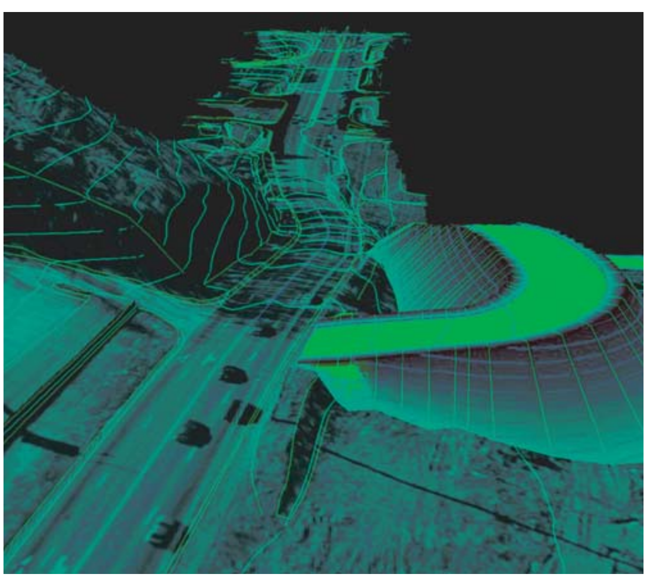

FIGURE 33 Wire frame overlay showing visuals for ROC 52 (U.S. Highway 52) reconstruction design–build project, near Rochester, Minnesota. (*Courtesy*: URS.)

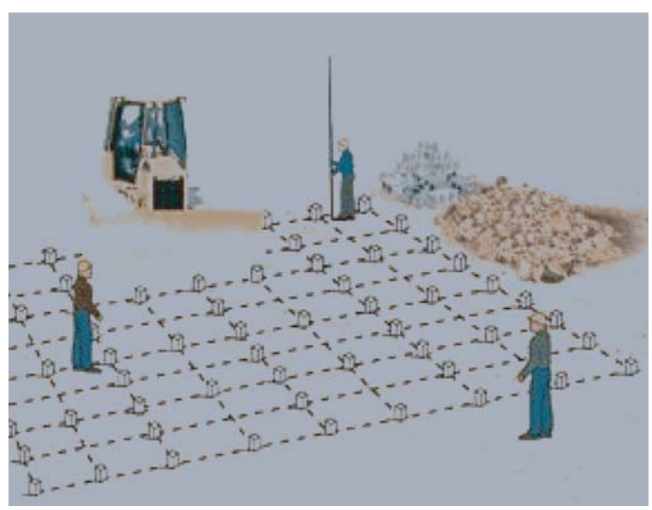

FIGURE 34 Digital terrain model. (*Courtesy*: URS.)

and reduced the overall construction time on this heavily congested highway corridor.

Software for Machine Control

To implement visualization for machine control in projects throughout the department, Mn/DOT has been developing special software in conjunction with Bentley Systems. This software is considered part of the 3-D design process. Although Mn/DOT is promoting the use of the software for machine control, the department is educating personnel to use the software during the design process as well.

Rather than retrofitting modeling, which the DOT is currently doing, the long-term goal is to do the 3-D modeling as part of the design workflow and then generate cross sections from the model. Because one of the products of the new software is a 3-D DTM of the top surface from tie-down to tie-down, 3-D modeling can also be used for visualization. Mn/DOT has numerous other groups besides design (e.g., hydraulics, construction, surveys, and landscape) that have use for the model. Another use for the 3-D model is to check safety features (e.g., passing sight distances and how multiple roadways interface with each other). A designer stated that, "A tool like this would have pointed out the 94-Pascal problem of a few years ago in a matter of minutes, early in the design process."

Mn/DOT is illustrating the potential of its new 3-D modeling software by showing the problems of designs done in the traditional "cross-section" method. Although the new software is still a few years away from common use, Mn/DOT is implementing it on a statewide basis starting in 2006.

CHAPTER FOUR

CHALLENGES

VISUALIZATION AND DESIGN PROCESS

Transportation agencies face many challenges in using visualization technologies, particularly the lack of centralized standards and guidelines. Without such standards and guidelines, visualization technologies cannot be formally integrated into the design process.

Most agencies studied for this synthesis showed that visualization, when used, is usually an independent process performed only at the end of the preliminary design phase, not in the final design phase. During the end of the preliminary design phase—the public involvement period—multiple preliminary design alternatives are presented to the public for approval. Once a preferred alternative selection is made, the final design phase begins and the use of visualization ends. This approach, which most decision makers take, is not ideal. In an ideal approach, visualization would continue into the final design phase, and visuals that were created in the preliminary design phase would be modified and enhanced in the final design phase. In this way, visual tools can add tremendous value to the design process, as has been demonstrated in this synthesis.

During the 1990s, highway design changed rapidly throughout the United States. A new and better way of designing highways evolved based on growing interest in the improvement of highways and their integration into the communities they serve. Whereas the old way was to design, announce, and then defend a project, which led to poor relations between DOTs and the public, the new way is to provide context-sensitive design (CSD) solutions that consider the impact of highways on the environment and communities (*16*).

Visual tools have become part of the CSD process by enhancing the communication between DOTs and the public through the use of the Internet and other mass communication mechanisms. For example, designers have created project websites, such as the Caltrans website for the Devil's Slide project. In time, all DOTs may seek to enhance their CSD solutions through the use of 3-D CADD. By using CSD techniques to improve the design and implementation process, DOTs are reaching out to community leaders and concerned citizens.

COST–BENEFIT ANALYSIS

Because planners and designers need to see data to support the use of visualization, a detailed cost–benefit analysis needs to be conducted on a series of projects to provide measurements. If a project manager perceives that the use of visualization will improve the overall design process, the project manager will probably decide to use visualization in the design process. Because 3-D CADD is a particularly effective way to incorporate visualization into the design process, cost–benefit analyses should pay particular attention to this process.

The case studies for this synthesis have supported the use of visualization; however, they have not provided quantitative measures of costs versus benefits. For example, although visualization played a vital role in the redesign of the Caltrans Devil's Slide project and in getting approvals that have eluded the DOT for years, no cost–benefit analysis was completed for the project. The improvements and savings are valued by the project team, but translating them to non-team members has proven to be difficult. Similarly, in other studies cited in this synthesis, although visualization was determined to aid with various projects, the benefits (design improvements, cost savings, efficiencies, and so forth) were difficult to quantify. A detailed study to measure the benefits of the technology is needed.

The TRB Visualization in Transportation Task Force (ABJ95T) formed a subcommittee to initiate a project to coordinate and assess the systemic use of visualization tools and methodologies throughout the entire life cycle of the proposed Kennedy Center Access Project (*17*). The intent was to generate a detailed cost–benefit analysis on the impacts of visualization on the project. The study was not conducted owing to the cancellation of funding.

The perception of visualization by senior-level managers, decision makers, and project managers will need to change to further integrate visualization into the design process. Many of the interviewees for this synthesis expressed a need for a visualization outreach/educational program directed toward these professionals.

UNDERSTANDING VISUALIZATION TECHNOLOGY

Visualization Decision Maker

Another reason why visualization has not been integrated into the design process is because most designers do not understand its full potential. The case studies in this synthesis revealed that the primary decision makers for its use are the project managers. Most project managers do not incorporate visualization into the design team early in the process. Visualization should be a byproduct of design if it is understood and agreed that "design" begins early in the project development phase. However, most highway departments view design as beginning after the project development phase is complete and after the preparation of final construction plans and documents is underway.

Overall, project managers are not well versed in the visualization process. They have limited knowledge of what technology is available and, more importantly, how it is produced. Their perceptions are mostly that the visualization process is time consuming and expensive. However, there are some examples of project managers consistently reusing the technology for the next project. Several examples within this synthesis show how visualization played an important role in the design or approval process for a project.

Because visualization is not usually part of the design process, it is often misunderstood. The technologies used to implement visualization are not standardized the way they are for engineering or CADD applications. This causes conflict, because management must make decisions concerning its use while having little to no guidance. For example, the software applications used for visualization often require more advanced graphics cards and significant amounts of random access memory. These unique requirements are not standard for purchasing. Because there are no guidelines for visualization, managers often refer to CADD standards for guidelines. However, in most cases, as described in the Caltrans case study, CADD hardware requirements fall short of visualization requirements. The case studies frequently refer to relying on underpowered systems to produce visuals.

Visualization Workforce

Another significant challenge is properly staffing transportation agencies with qualified visualization technicians. The lack of qualified visualization technicians has hindered the development of visualization at these transportation agencies.

Although many agencies do not have qualified visualization technicians, an available workforce is slowly developing as visualization technology matures. Most of the staffing requirements from transportation agencies have been filled by in-house transfers, who typically come from the CADD and landscape architecture departments. The transfers are generally self-motivated and have good CADD skills and art backgrounds. Often, this type of individual is difficult for transportation agencies to find. There is usually a significant investment needed to train these people on how to use visualization technologies.

TRAINING

The case studies convey that training has generally been limited. Mentoring and cascading information are the primary methods used for training. Informal training is frequently done through self-taught or on-the-job processes. By creating proper job titles, career paths with training guidelines can be accomplished. This, in turn, will lead to more accurate budgeting and scheduling for formalized training.

A significant challenge with training is the lack of funding. Limited agency budgets have significantly curtailed the amount of formal training that individuals receive. In addition, there have been significant reductions in travel, which hinders attendance at formal training seminars, conferences, and professional societies. Without standards and guidelines for visualization it is difficult for management to justify training expenses. The current tight funding trend will most likely continue, at least for the near future.

Another training challenge is to determine the type of training. There is a diverse array of visual applications to select from. Training often depends on the software applications that each transportation agency uses. The wide variety of software applications and the lack of standardization for visualization training make it difficult for a supervisor to assist the technician in selecting the correct training regimen.

During the review process for this synthesis, interviewees noted several times that learning 3-D modeling was difficult for most individuals. This difficulty is considered the biggest impediment in the visualization process. Training sources for 3-D vary from software vendors, universities, and technical schools to CADD vendors offering 3-D CADD modeling classes. The transportation agencies interviewed for this synthesis all started the 3-D modeling process using CADD applications, which have built-in 3-D modeling capabilities; therefore, no additional software or hardware investment was needed by these agencies. Once individuals became proficient with 3-D CADD modeling and rendering, other visualization software applications were purchased.

In addition to in-house training and professional seminars, visualization is increasingly being taught by universities and technical schools. However, although these schools produce quality students who know the visual tools quite well, most students do not know how to adequately read design plans and/or understand the design process itself. Significant time is required by transportation agencies for the training of these individuals. In the case of UDOT, it is estimated that an additional 80–120 h of training is required. The training ranges from CADD design to learning specific UDOT design specifications and procedures. The average trainee requires several additional months of on-the-job training to become fully proficient.

Despite the need to provide on-the-job training for new hires, many of the new hires who have recently graduated from colleges and universities have the potential to be good visualization technicians because they have already been trained on 3-D CADD. Most of the visualization technology is done by these new hires, who might otherwise gravitate to alternative employment opportunities if they cannot apply what they have learned.

3-D CADD Training

To assist in incorporating visualization into the design process, 3-D CADD needs to be taught and implemented. Most transportation agencies already have the proper hardware and software assets in place to implement 3-D CADD. Transportation agencies such as NYSDOT and UDOT have used their existing 3-D CADD capabilities to progress to more advanced 3-D CADD applications, such as virtual reality-based real-time simulation. Each of these agencies has concluded that, in addition to budgeting for training, there will be a need to budget time to create content in 3-D. Initially, it will take longer to produce a 3-D plan set than a traditional 2-D plan set. There are no factually based estimates; however, the agencies concur that, on average, it will take one and a half to two times as much time to generate a plan set using 3-D CADD as to generate a traditional 2-D plan set. To fully justify these expenses, the agencies have recommended that a cost–benefit analysis on the efficiencies of visualization be undertaken; there needs to be a distinct return on investment to justify the significant training and production expenses associated with learning 3-D CADD. Many transportation agencies have trained staff on using 3-D visual tools, but none are training specifically for the 3-D design (i.e., 3-D CADD) process. All interviewees expressed a desire to learn 3-D CADD, but none were willing to implement 3-D CADD owing to the upfront costs associated with the training.

In the early 1980s, when CADD programs were first initiated within transportation agencies, there was a tremendous expense to train users. However, because the benefits of the CADD training have outweighed the expenses, CADD design has become prevalent. Many of the people interviewed for this synthesis recognize the benefits of training and using 3-D CADD design and would like to have these benefits documented and verified, preferably through a detailed cost–benefit analysis.

Project Manager Training

A common theme mentioned in case study review was the recommendation of visualization training for project managers. Because they are the primary decision makers for the use of visualization, there should be resources available to inform them of their options. Currently, project managers rely solely on consultations with visualization specialists, consultants, or general opinion. Project manager training can be augmented by having a standardized guideline on visualization, such as the NYSDOT Visualization Project Workflow.

STANDARDIZATION

As mentioned throughout this synthesis, there is a distinct lack of national standards and guidelines for the use of visualization. Instead, there are only minimal guidelines to consult within individual transportation agencies. Many interviewees expressed the notion that standardization is needed to better integrate visualization technologies into the design process. National standards and guidelines similar to the standards developed by NYSDOT (*18*) could be incorporated into the CADD process.

In addition to standardizing the use of visualization, related issues need to be standardized to make visualization a viable tool for transportation agencies.

Official Visualization Department or Discipline

With the exception of Mn/DOT and NYSDOT, no transportation agencies interviewed have formally recognized visualization departments. Visualization is usually incorporated into other departments, such as landscape architecture or structural design. Because of this, there is inadequate measurement of budgeting, expenses, and staff-hour requirements. Senior-level management continues to request a cost–benefit analysis to justify the use of visualization, but such an analysis is difficult without a mechanism in place to measure budgeting, expenses, and staff-hours.

Official Job Titles

Almost all of the transportation agencies interviewed have no specific job titles for their visualization technicians. Such employees are usually lumped into another category. For example, the job title for the lead visualization technician at NYSDOT is Principle Drafting Technician. This title was given to fit the salary structure of the technician to an existing and accepted position within the DOT. However, this nondiscipline title undervalues the role of the technician and also makes a visualization career path within the agency difficult. Not having a defined career path can be detrimental to retaining good staff. Agencies interviewed would like to see proper recognition and titling of the people who create visuals.

Guidelines for Use

Transportation agencies interviewed would like to see a national set of guidelines that could be tailored to their specific agency. These agencies believe that such standards and guidelines are needed if visualization is to become a viable discipline within the design process. The national guidelines should be basic and written to the level of a project manager or decision maker. They should include, but not be limited to, the following:

- Tools available,
- Benefits of using each tool,

- Typical production schedules for each tool,
- Costs associated with each tool, and
- Considerations for creating a budget.

Case studies could be used as the basis for the guideline. Project managers and other decision makers need to be able to associate themselves with the guidelines to fully understand them.

Writing the national standards and guidelines will be difficult, and many issues need to be addressed. How detailed do the standards need to be? What group or organization will be responsible for drafting these standards? How should the standards address the many software applications and output formats that can be used for visualization? How can the standards be flexible enough to apply to the varying policies and procedures at each transportation agency?

FUNDING AND APPROVALS

Without proper standards and guidelines for visualization, funding and approvals will continue to be a challenging task. The transportation agencies participating in this synthesis do not have specific budgets for visualization, making it difficult to track expenses. A cost–benefit analysis for visualization cannot be properly conducted without having official visualization budgets to measure. Most expenses are included within specific project budgets or are part of overall budgets for departments, such as IT departments, or from disciplines, such as landscape architecture. Some agencies, such as UDOT, are actually incorporating visualization expenses into the overall project budget. Although this approach provides a more productive mechanism to obtain approvals and funding, it makes the budgetary process difficult to track. Frequently, the discipline manager or overall project manager is in charge of approving visualization products and services.

IMPROVED VISUALIZATION TOOLS AND COSTS

Another key challenge expressed by project managers interviewed for this synthesis is the cost of using visualization. For example, some applications, such as computer animation, require long production times. These production times depend on variables such as the 3-D modeling required and the length (in time) of animation needed. Visualization specialists conveyed a concern that better visualization applications are needed to help reduce some of these overhead costs. These applications need to make using visual tools easier, provide better functionality, and increase overall productivity.

Automation is one available tool to reduce costs by increasing the accuracy and speed with which 3-D models are created. Some software applications already have the ability to automatically call out design interferences during design and drafting; however, this ability should be added to more applications.

Another cost reduction approach to consider is to integrate multiple functionalities within CADD applications. Currently, most visual technicians model with one software application and render the model in another. The method leads to inefficiencies that, in turn, lead to longer production times. Therefore, eliminating the need to use multiple applications could improve productivity and reduce costs.

Costs can be further reduced if the design is initially done in 3-D. Creating renderings can be a minimal process if 3-D elements are already in place during the design process. CADD can also easily produce traditional plans and sections from a 3-D model.

Another way to reduce costs is for the vendors to decrease the price of visualization applications. Over the past 10 years, software applications specifically designed for visualization have dramatically decreased in cost. However, despite the reductions in cost, software for visualization is still more costly than software for traditional CADD applications. Many interviewees concluded that vendors need to continue to drive down these costs if transportation agencies are to implement the visualization software.

AWARENESS OF AND ACCESS TO INFORMATIONAL RESOURCES

This synthesis study has revealed that most transportation agencies are isolated from one another concerning issues on visualization. This isolation has helped to inhibit the advancement of the technology. Most research and development activities are self-implemented and are limited in their execution, and are primarily done without conferring with other transportation agencies. Many interviewees expressed a desire to have better awareness of societies and organizations that promote the use of visualization. Hundreds of informative user groups and organizations deal with the subject of visualization. Determining which group is best for an agency depends on the personnel within that organization. Many of these organizations are affiliated with a specific application and may be interested in learning about only that application. Two of the leading transportation-related groups that focus on visualization are the TRB Visualization in Transportation Task Force (ABJ95T) and the AASHTO Taskforce on Environmental Design. Both of these groups provide direction and resources for the use of visualization. However, these groups are attended by a finite group of people. One reason for reduced participation in these groups is travel restrictions placed on transportation agency employees. Agencies such as Caltrans expressed the need for alternative outreach methods, such as web-casting meetings.

Better informational access will result in greater efficiencies for research and development, thereby assisting in the process of creating standards and guidelines for visual technologies within transportation agencies.

CHAPTER FIVE

CHANGES IN USE OF VISUALIZATION SINCE 1996

PRIMARY FINDINGS OF *NCHRP SYNTHESIS 229*

To better understand the changes and advancements over the past 10 years, it is both useful and prudent to contrast the findings in this study with those of the 1996 *NCHRP Synthesis of Highway Practice 229*: *Applications of 3-D and 4-D Visualization Technology in Transportation* (*12*). The following statements highlight the findings and conclusions of that synthesis:

> Because there has been no widespread use of 3-D technologies in transportation, it is not possible to reach any valid conclusions with respect to relative effectiveness, the breadth of application within an agency, public acceptance, or other benefits that may accrue from adopting 3-D and 4-D technologies. Three basic questions have been identified that would be of immeasurable value to transportation practitioners if meaningful answers could be found.

Effectiveness of 3-D and 4-D Materials in Design and Communication

- . . . [N]o research has been done to relate various 3-D modeling techniques to the effectiveness and cost-savings achieved for a variety of projects.
- Appropriate research could identify cost-effective production methods, [and] review procedures and processes that could offer significant savings in the design, permitting, and construction processes.

Acceptance and Appropriate Levels of Detail

- . . . there is almost always a concern expressed (by professionals) about the public's suspicion of computer-generated imagery. However, the basis of this suspicion is not well understood.
- . . . there is a need to better understand what types of imagery generate the highest levels of confidence and what levels of detail are necessary to effectively communicate concepts, ideas, and outcomes to a variety of audiences.

Integration of Visualization Technology with Rules-Based Design Systems

- [R]ules-based systems have been developed to evaluate the energy efficiency of buildings based on factors such as fenestration, orientation, season, geographic location, and materials palette.
- The more sophisticated systems are being developed to provide almost immediate feedback on increases or decreases in energy efficiency as design alternatives are tried.
- This same sort of technology is being explored in transportation applications.
- One very important feedback loop in these systems will be 3-D visualization.
- While the value of 3-D visualization tools as a primary feedback mechanism for rules-based design systems can be demonstrated, a great deal of further experimentation and evaluation is needed to create a cost-effective design system.

Transportation Applications

> Clearly, it is not possible to say how long it will be before any of these technologies become commonplace or reach a level of refinement that will make them more economically attractive . . .
>
> [T]hese technologies do represent [a probable] future of the tool base in transportation communication, planning, design, construction, and administration. For these reasons, administrators and professionals charged with the responsibility of developing and operating the computer-based systems of any agency [may wish to] stay abreast of developments in these emerging systems.

WHAT HAS BEEN LEARNED SINCE 1996

From the perspective of technology, the *capability* to develop highly realistic 3-D models, images, and animations for public involvement has significantly improved since the publication of *NCHRP Synthesis 229* in 1996. What was once the domain of powerful minicomputers has now become commonplace using personal computers.

This improved ability, however, remains to be effectively integrated into the CADD hardware and software that provide the foundation of the design process. Also, although the capability to generate the imagery has improved enormously, our understanding of the principles guiding its effective utilization has not.

In many cases, the problems relate to institutional organization, whereas in other cases the problems are more manpower, personnel, and training related. In almost all instances there is a problem with the difficulty experienced by practitioners in moving the design process (most notably CAD) into the world of 3-D. There is a need for widespread recognition of the importance for the adoption of enterprise-wide programs for dealing with spatial data. The "stove pipe" mentality of keeping systems separate and nonintegrated, which characterizes the design process within many state DOTs, needs to change. This need appears to be the case regardless of whether the use of visualization is for public involvement, for project design, or for machine control and stakeout during construction.

FINDINGS IN COMMON WITH *NCHRP SYNTHESIS 229*

There has been, and continues to be, a growth in and diversity of uses of visualization technologies through many aspects of the highway project development process. However, similar to the findings of *NCHRP Synthesis 229*, the primary focus of using visualization in project development has been during conceptual design in support of public involvement.

The case studies contained herein suggest that currently available visualization tools can benefit the interaction between engineers and designers and end users. However, these benefits continue, in large part, to be anecdotal and not substantiated by data. *NCHRP Synthesis 229* specifically noted the inability to "reach any valid conclusions with respect to relative effectiveness, the breadth of application within an agency, public acceptance, or other benefits that may accrue from adopting 3-D and 4-D technologies." The findings of this synthesis provide a better understanding of the breadth of application and acceptance by the public, but there are still no data to support valid conclusions regarding relative effectiveness and benefits of use.

In the years since *NCHRP Synthesis 229* there have been dramatic reductions in the costs associated with the hardware and software required to generate realistic, high-resolution imagery. Despite this phenomenon, state DOTs remain reluctant to invest in this technology. In addition, where investments have been made, there remains a great deal of uncertainty as to how to best organize to take advantage of the new investments.

DOTs are beginning to ask (informally) for both technical training and organizational support on how best to invest, organize, and function with these technologies.

Despite today's heightened awareness of the need for project collaboration and information management the systems used for planning, design, construction, and public involvement remain largely nonintegrated. Visualization can provide a common source of spatial data for the different functions. The Internet, for example, can enable individuals to interact in highly collaborative ways in a visually oriented space and in real time. Still lacking is an effective set of tools to communicate and collaborate effectively in 3-D for transportation engineering organizations, in both intranet and Internet environments.

CHAPTER SIX

CONCLUSIONS

OPPORTUNITIES TO ADVANCE VISUALIZATION IN TRANSPORTATION

As at the time of *NCHRP Synthesis 229*, there are now a number of opportunities (new and underway) that, if more effectively taken, can provide considerable insight to improving the comfort levels of departments of transportation (DOTs) with visualization. These opportunities allow for an orchestrated approach throughout the transportation community:

- **Fill the gaps in knowledge and practice.** The TRB Task Force on Visualization in Transportation (ABJ95T) has developed a comprehensive "Working Research Agenda" that identifies the gaps in knowledge and practice relating to the findings of this synthesis. A current copy of this research agenda has been provided as part of this synthesis and may be found in Appendix A.

- **Create technology transfer initiatives to exploit technology advances from areas outside transportation.** Discussed in the previously noted research agenda, a more comprehensive effort to this effect would prompt a more effective transfer of technologies, and possibly spur the development of new technologies, for the highway project development process.

- **Develop the means to introduce visualization to the engineering curriculum at all levels.** Visualization should be incorporated into all levels of engineering training, from undergraduate to graduate, from bench-level engineer to project and program manager, and ultimately to the highest levels of the profession. There are a number of professional activities to improve the educational process through visual learning environments. Particular attention is being given to the science and engineering communities. Some of the resources to support these improvements are:

  – The National Science Foundation,
  – The Learning Foundation,
  – The Association for Computing Machinery SIGGRAPH Education Committee's *Visual Learning for Scientists and Engineers* (available online at http://www.siggraph.org/education/vl/vl.htm), and
  – The Gordon Research Conference on Visualization in Science and Education.

- **Identify the types of data that need to be collected to document the costs and benefits associated with using visualization in the project development environment.** One approach is to begin with the development of an agreed on "work breakdown structure" that could be used across different project applications. The work breakdown structure can be a basis for a database from which practitioners can derive information on relative levels of effort, costs, and so forth.

- **Define the functional requirements for visualization tools that can significantly increase user friendliness.** Such functional requirements might be used to prompt the industry to respond to practitioner needs in the development of new capabilities and the refinement of existing capabilities.

- **Develop an expert system that can aid the user in identifying and selecting visualization options.** The system should convey the benefits of each option based on project-specific applications and needs.

ADDITIONAL FINDINGS

There are new and strong interests in highway construction for leveraging 3-D models to enable electronic machine control and stakeout processes. The challenge has been that these models need to be created first, and not every DOT is equipped to deliver them. New developments in CADD software are looking to make the delivery of those 3-D models much easier, however the uses of visualization throughout the project design process remain largely nonintegrated. Integration of visualization uses throughout the project design process would support readily available models for contractors.

There is a growing interest to rethink the design process and to make design more interactive in a way that is project-specific. One of the most effective ways of doing this is through the use of immersive and semi-immersive simulators. For years, the effectiveness of this approach has been demonstrated in the defense, aerospace, and automotive industries.

The FHWA's International Technology Exchange Program recently published its findings of a safety scan, *Roadway Human Factors and Behavioral Safety in Europe* (available online at http://trb.org/news/blurb_detail.asp?id=6313). In its findings, the scan team observed a number of progressive methods underway to improve the safety of roadway design, including human-centered roadway analysis and design and driving simulators for roadway design and visualization. The report contrasts the more extensive and integrated use of driving simulators as part of design in Europe with the less extensive and less integrated use in the United States, even though the "level of fidelity (e.g., degrees of motion, image size and quality) at the agencies visited was comparable to the range of simulators in the United States." In the United States, the ease with which DOTs will be able to leverage these tools will depend on

- Improving the frequency and ease with which DOTs can create 3-D models in support of visualization tools and
- Gearing 3-D and 4-D data standards toward the needs of the highway transportation industry.

CONCLUDING REMARKS

Although visualization is certainly about technology, the effective application of visualization is ultimately about effective communication:

- Between those who establish the functional requirements of a system and those for whom the system must satisfy real and/or perceived personal as well as social needs and values;
- Between those who formulate preliminary system requirements and those who must translate those requirements into design;
- Between those who design and those who build and maintain the system; and
- Between those who collectively design, build, and maintain the system and those who ultimately use the system.

Visualization is proving to be an effective tool in facilitating communications. The research outlined in Appendix A could accelerate the continued development of these technologies while ensuring the broadest possible application by groups within the transportation engineering field.

In contrasting the findings of *NCHRP Synthesis 229* with the findings of this synthesis it becomes clear that there has been a considerable increase in the use of visualization technologies on all fronts. Despite these advancements, however, visualization in state DOTs within the United States remains largely an incomplete and minimally organized afterthought with regard to the project development process. This situation, however, is beginning to change.

More and more transportation stakeholders are beginning to see the value of visualization and are starting to insist on it through all aspects of the project development process. This trend is evidenced both in increasing demands of DOTs for 3-D modeling by highway contractors and in recent SAFETEA-LU legislation. The FHWA's "Interim Guidance for Implementing Key SAFETEA-LU Provisions on Planning, Environment, and Air Quality for Joint FHWA/FTA Authorities" states the following (available online at http://www.fhwa.dot.gov/hep/igslpja.htm):

> **Visualization Techniques in Plans and Metropolitan TIP Development:** As part of transportation plan and TIP [transportation improvement program] development, MPOs [metropolitan planning organizations] shall employ visualization techniques (see amended 23 U.S.C. 134(i)(5)(C)(ii) and 49 U.S.C. 5303(i)(5)(C)(ii)). States shall also employ visualization techniques in the development of the Long-Range Statewide Transportation Plan (see amended 23 U.S.C. 135(f)(3)(B)(ii) and 49 U.S.C. 5304(f)(3)(B)(ii)). States and MPOs must employ visualization techniques prior to adoption of statewide and metropolitan transportation plans and metropolitan TIPs addressing SAFETEA-LU provisions.

In the transportation community, visualization is becoming less the special interest that it used to be and more a core requirement within the highway project development process. Transportation agencies need to adapt to this change.

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GLOSSARY

4-D Technology—computerized animated 3-D model that portrays movement through space, over a period of time. An example would be virtual reality-based computer graphics.

Cathode ray tube (CRT)—display device used in most computer displays, video monitors, televisions, and oscilloscopes. The CRT developed from Philo Farnsworth's work was used in all television sets until the late 20th century and the advent of plasma screens, LCDs (liquid crystal displays), and other technologies.

Compact Disc Read-Only Memory (CD-ROM)—version of the compact disc that allows information to be stored and retrieved. Once a CD-ROM is pressed, new data cannot be stored and the disc cannot be erased for reuse. Although CD-ROMs look like music discs, they can only be used with a computer equipped with a CD-ROM drive.

Computer-aided design (CAD)—use of computer programs and systems to design detailed 2-D or 3-D models of physical objects, such as mechanical parts, buildings, and molecules.

Computer-aided drafting and design, computer-aided design and drafting, or computer-aided design development (CADD)—use of the computer to help with the drafting of product plans.

Computer-aided engineering (CAE)—use of computers to help with all phases of engineering design work. Similar to computer-aided design, it also involves the conceptual and analytical design steps.

Computer-aided manufacturing (CAM)—process of using specialized computers to control, monitor, and adjust tools and machinery in manufacturing.

Computer animation—art of creating moving images by means of computers. It is a subfield of computer graphics and animation. Increasingly it is created by means of 3-D computer graphics, although 2-D computer graphics are still widely used. Sometimes the target of the animation is the computer itself; sometimes the target is another medium, such as film.

Computer-generated imagery (CGI)—application of the field of computer graphics (or more specifically 3-D computer graphics) to special effects. CGI is used in movies, television programs and commercials, and in printed media. Real-time computer graphics, such as those in video games, are rarely referred to as CGI.

Computer numerical control (CNC)—technology that has been around since the early 1970s. Before this, it was called NC, for numerical control. A CNC equivalent system can be programmed to duplicate the repetitive and mundane manual labor manufacturing operations in a much more automatic, accurate, and cost-efficient fashion.

Context-sensitive design (CSD)—collaborative, interdisciplinary approach that involves all stakeholders to develop a transportation facility that fits its physical setting and preserves scenic, aesthetic, historic, and environmental resources, while maintaining safety and mobility. CSD is an approach that considers the total context within which a transportation improvement project will exist.

Context-sensitive solutions (CSS)—philosophy wherein safe transportation solutions are designed in harmony with the community. CSS strives to balance environmental, scenic, aesthetic, cultural, and natural resources, as well as community and transportation service needs.

Design–build (D–B)—project delivery method in which the agency or owner holds a single contract with a single entity for both the design and construction of a project. Design–build is owner-driven, and it commonly reduces project delivery time by eliminating lengthy bidding proceedings.

Digital terrain model (DTM)—topographic model of the bare earth that can be manipulated by computer programs. The data files contain the elevation data of the terrain in a digital format that relates to a rectangular grid. Vegetation, buildings, and other cultural features are removed digitally, leaving just the underlying terrain.

Environmental impact statement (EIS)—document that studies all likely impacts that will result from major transportation projects. Impacts include those on the natural environment, as well as those on the economy and society, and those on the built environment of historical and aesthetic significance.

FHWA—federal agency that administers federal highway programs. The agency reviews all Transportation Plans and Transportation Improvement Programs to ensure compliance with federal planning and funding requirements.

Geographic information systems (GIS)—system of hardware and software used for storage, retrieval, mapping, and analysis of geographic data. GIS differs from CADD and other graphical computer applications in that all spatial data are geographically referenced to a map projection in an earth coordinate system. For the most part, spatial data can be "re-projected" from one coordinate system into another; therefore, data from various sources can be brought together into a common database and integrated using GIS software.

Global Positioning System (GPS)—worldwide radio navigation system formed from a constellation of 24 satellites and their ground stations. GPS uses these "man-made stars" as reference points to calculate positions accurate to a matter of meters.

Information technology (IT)—technology required for information processing. In particular, the use of computers and computer software to convert, store, protect, process, transmit, and retrieve information from anywhere at anytime.

ISO 9000—family of standards and guidelines for quality in the manufacturing and service industries from the International Organization for Standardization (ISO). ISO 9000 defines the criteria for what should be measured. ISO 9001 covers design and development; ISO 9002 covers production, installation, and service; and ISO 9003 covers final testing and inspection. ISO 9000 certification does not guarantee product quality. It ensures that the processes that develop the product are documented and perform in a quality manner.

Metropolitan planning organization (MPO)—regional organization responsible for comprehensive transportation planning and programming in urbanized areas. Work products include the Transportation Plan, the Transportation Improvement Program, and the Unified Planning Work Program.

Multimedia development—systems that support the interactive use of text, audio, still images, video, and graphics. Each of these elements must be converted in some way from analog form to digital form before they can be used in a computer application. Thus, the distinction of multimedia is the convergence of previously diverse systems.

Network distributed rendering—process of aggregating the power of several computing entities to collaboratively run a single computational task in a transparent and coherent way, so that they appear as a single, centralized system.

Occupational Safety and Health Administration (OSHA)—branch of the U.S. Department of Labor responsible for establishing and enforcing safety and health standards in the workplace.

Personal computers (PCs)—home or office desktop computer systems that run Microsoft DOS and Windows operating systems.

Pixel—one of the many tiny dots that makes up the representation of a picture in a computer's memory. Usually the dots are so small and so numerous that, when printed on paper or displayed on a computer monitor, they appear to merge into a smooth image. The color and intensity of each dot is chosen individually by the computer to represent a small area of the picture.

Polygon—closed planar path composed of a finite number of sequential line segments. The straight line segments that make up the polygon are called its *sides* or *edges* and the points where the sides meet are the polygon's *vertices*. If a polygon is simple, then its sides (and vertices) constitute the boundary of a polygonal region, and the term *polygon* sometimes also describes the *interior* of the polygonal region (the open area that this path encloses) or the union of both the region and its boundary.

Project managers—person responsible for the planning, coordination, and controlling of a project from inception to completion, meeting the project's requirements and ensuring completion on time, within cost, and to required quality standards. Often, there is a project manager and a consultant project manager.

Random access memory (RAM)—type of computer storage whose contents can be accessed in any order. Computers use RAM to hold the program code and data during execution.

Raster graphics—data file or structure representing a generally rectangular grid of pixels, or points of color, on a computer monitor, paper, or other display device. The color of each pixel is individually defined; images in the red–green–blue (RGB) color space, for instance, often consist of colored pixels defined by three bytes—one byte each for red, green, and blue. Less colorful images require less information per pixel; an image with only black and white pixels requires only a single bit for each pixel. Raster graphics are distinguished from vector graphics in that vector graphics represent an image through the use of geometric objects such as curves and polygons.

Render farm—computer cluster to render computer generated imagery, typically for film and television special effects. The rendering of images is a highly parallelizable activity, as each frame can be calculated independently of the others, with the main communication between processors being the upload of the initial models and textures, and the download of the finished images.

Rendering—the process of generating an image from a description of 3-D objects, by means of a software program. The description is in a strictly defined language or data structure and would contain geometry, viewpoint, texture, and lighting information. The image is a digital image/raster graphics image.

Return on investment (ROI)—calculation used to determine whether a proposed investment is wise and how well it will repay the investor. It is calculated as the ratio of the amount gained (taken as positive), or lost (taken as negative), relative to the basis.

Texture mapping—process of assigning a material to an object similar to the specification provided to the building contractor. To duplicate the object's surface quality, it is necessary to obtain this information in a digital format. One way to create a texture map is by scanning a physical sample material provided by the designer or to scan a photograph.

Value engineering (VE)—federal, state, and local highway agencies are responsible for getting the best overall project value for the taxpayer. Applying the VE process to suitable projects will help one achieve this purpose. Simply stated, VE is an organized application of common sense and technical knowledge directed at finding and eliminating unnecessary costs in a project.

Vector graphics or geometric modeling—use of geometrical primitives such as points, lines, curves, and polygons to represent images in computer graphics. It is used by contrast to the term raster graphics, which is the representation of images as a collection of pixels (dots).

Virtual reality—artificial environment created with computer hardware and software and presented to the user in such a way that it appears and feels like a real environment. To "enter" a virtual reality, a user dons special gloves, earphones, and goggles, all of which receive their input from the computer system. In this way, at least three of the five senses are controlled by the computer. In addition to feeding sensory input to the user, the devices also monitor the user's actions. The goggles, for example, track how the eyes move and respond accordingly by sending new video input.

Virtual reality simulation—real-time simulation is a graphical database technology that allows for interactive navigation throughout a digital model. The database can foster rapid conceptual approvals, identify design flaws, and, ultimately, reduce development costs before commencement of construction. This technology has been pioneered by the U.S. military for flight and combat simulation and is rapidly becoming a key tool for the Urban Design and Planning community. Although traditional visualization methods have been used as a presentation tool, real-time simulation streamlines the complex phases of a planning and designing a project.

APPENDIX A

Working Research Agenda of the TRB Task Force on Visualization in Transportation (ABJ95T)

As of 9/12/2005

The following "working" research agenda was prepared by the Research Sub-Committee of the TRB Task Force on Visualization in Transportation. It represents an initial and ongoing effort to compile the knowledge and understanding of the task force members regarding the related needs in this industry, and to promote research and demonstration efforts in the support of improved and effective advancements of visualization in all modes of transportation.

This Agenda was first presented publicly by Ronald G. Hughes, Ph.D., at the 2005 TRB Annual Meeting in his paper. The research agenda is provided as a part of the present synthesis not as a set of recommendations, but more so as a means of more clearly characterizing what might be/become the major research components in the area of transportation visualization.

TOWARD THE DEVELOPMENT OF A RESEARCH AGENDA FOR THE APPLICATION OF VISUALIZATION IN TRANSPORTATION SYSTEM APPLICATIONS

TRB PAPER NUMBER 05-0230

This agenda has since been modified and the following represents the latest in the efforts of the task force. Comments are always welcome, and the reader is encouraged to contact the task force representatives:

Dr. Ronald G. Hughes, Ph.D.
Co-Chair—Research Sub-Committee
TRB Task Force on Visualization in Transportation
E-mail: rghughes@ncsu.edu
Office: 919-515-8523

Michael A. Manore, P.E.
Chair—TRB Task Force on Visualization in Transportation
E-mail: mike_manore@msn.com
Cell: 512-413-0343

Dr. Richard Pain, Ph.D.
Transportation Safety Coordinator—Staff Coordinator to the Task Force
E-mail: rpain@nas.edu
Office: 202-334-2964

CATEGORY ONE: ESTABLISHING A RESEARCH FOUNDATION (TOPICS 1–5)

1. Visualization Demonstration Project—Getting Started Technically and Organizationally as an Agency or Engineering Consultant

Rationale:

One of the most common statements by transportation agencies and consulting firms regarding visualization is: "We are interested but do not know how to get started." There exists a wealth of knowledge (mostly trial and error) from agencies and consulting firms alike who have successfully applied these technologies. The challenge has been the inability to compile that knowledge and experience into effective, demonstrable guidelines for any organization.

Important elements to focus on should be:

- Capturing the knowledge and experience from the diversity of successful organizations.
- Compiling an employable set of guidelines for both transportation agencies and engineering consulting firms that addresses both the technological considerations and those that are organizational when incorporating visualization.
- Organizing and performing a demonstration effort with transportation agencies and engineering consulting firms to assess the soundness of the guidelines, make appropriate adjustments, and measure the benefits.

2. Areas of Potential Technology Transfer from Aerospace and Military/DOD Applications of Visual Simulation

Rationale:

There is a need for helping visualization practitioners in the transportation field to see beyond the purely military aspect of visual simulation applications within the Department of Defense and to identify the relevance of key technology applications. Recognition of common technology issues and applications can provide transportation agencies seeking visualization expertise a greatly expanded pool of talent to draw on.

Important elements to focus on should be:

- Real-time image generation;
- Visual database modeling hardware and software;
- Distributed computing;
- Networking (local and long haul); and
- Visual fidelity, field of view, scene content limitations, and their effects on performances obtained in driving simulators.

3. The Development of "Guidance" for Visualization Practitioners

Rationale:

There is little or no published guidance for those who develop and use visualization methods and tools at the practitioner level. The need for practical guidance is both for the (software) developer as well as the project engineer. An area of particular need not addressed by current guidance is the effective use of the Internet.

Important elements to focus on should be:

- Distinguishing between different applications and their expected value added,
- Matching scope and project needs and requirements,
- Determining scope of the visualization support effort,
- How to ensure effective application, and
- In-house versus support contractor.

4. Quantifying the Value of Visualization: For Requirements Definition, for Project Design, for Construction, and for Public Involvement

Rationale:

Research is needed that focuses on the benefits and costs of visualization. Research is needed that provides reliable means of collecting the true costs of visualization applications. Even more important is the need for research that documents the real as well as perceived "benefits." The need here is for effective methodology as well as data.

Important elements to focus on should be:

- Distinguishing user needs from design requirements,
- Aligning user needs and values with project requirements,
- Identifying visualization methods that facilitate developer and user focus on values,
- Soliciting user input and comment in a collaborative and measurable environment,
- Quantitative methods for tracking the development of consensus, and
- Visualization applications to constructability and construction phasing.

5. Exploring the Potential for Web-Based Applications of Visualization: System Requirements, Technical Challenges, User Interface Issues, etc.

Rationale:

The Internet is rapidly becoming a chief media source from which individuals seek to acquire information about their world surpassing in many instances radio and television and the printed media. Government agencies that use the Internet to communicate with stakeholders need to clearly understand the technology and its effective use. Effective use is becoming characterized as increasingly interactive. On-line applications are also becoming more prominent as means of facilitating collaboration between those involved in the design process.

Important elements to focus on should be:

- Identifying models of successful and effective application,
- Understanding and overcoming bandwidth obstacles,
- Incorporating on-line user feedback and comment,
- Fostering the collaborative nature of successful project development, and
- Understanding and addressing equity issues.

CATEGORY TWO: MANAGEMENT-ORIENTED ISSUES (TOPICS 6–9)

6. Facilitating the Adoption of Visualization at the State DOT Level: Lessons Learned and Guidance

Rationale:

There remains an outstanding need on the part of practitioners at the state DOT to understand the manpower/personnel, logistics, and organizational factors associated with the acquisition and maintenance of an effective in-house visualization capability.

Important elements to focus on should be:

- Lessons learned on getting started (i.e., staff, hardware and software, facilities, effective organization structure, etc.).
- Integrating visualization into the normal day-to-day work process.
- The importance of a strategic plan for the integration of all aspects of using and managing spatial data tools and resources.
- How to estimate the acquisition and maintenance costs associated with a commitment to visualization.

7. The Definition of Education, Training, and Outreach Requirements

Rationale:

Manpower and personnel challenges associated with the acquisition and maintenance of an effective visualization workforce can surpass those associated with hardware and software acquisition and integration issues.

Important elements to focus on should be:

- In the undergraduate and graduate engineering curricula,
- For the computer graphics practitioner,
- For management.

8. Toward the Development of Visualization "Standards": Source Data, Interoperability, Applications, Fidelity, Accuracy, Ethics, etc.

Rationale:

Interoperability of operations for those involved in the use of spatial data will require a shared understanding of the attributes of that data. The use of metadata will become critical to ensuring a common level of understanding about the data, its method of collection, the conditions under which the data are being displayed, and limitations on inferences that can be drawn from the data.

Important elements to focus on should be:

- Recommended system architectures for ensuring interoperability between different sources of spatial data (e.g., photogrammetry, GIS, GPS, CAD, etc.).
- Ethical standards for acceptable representation of proposed design and system operation.
- The role of metadata in visualization.

9. Using Visualization for the Discovery of New System Concepts in Transportation

Rationale:

New solutions are often dependent on being able to "see" the problem from a different perspective and/or to see solutions that transcend current practice. Visualization may serve not only to see what a final product may look like, but to facilitate improved understanding of the design and engineering principles or processes that make such a product possible.

Important elements to focus on should be:

- Using visualization to think/plan "outside-the-box."
- Exploring innovative, sometimes unconventional concepts and system approaches.
- Keeping exploration closely linked to system effectiveness.
- Using modeling and simulation to explore the range of potential system applications independently of current feasibility/cost limitations.

CATEGORY THREE: THE INTEGRATION OF MODELING AND SIMULATION (TOPICS 10–14)

10. The Visualization of How Things Work Versus How Things Look

Rationale:

Transportation is a dynamic concept defined in large part by its effectiveness (i.e., how a facility "works"). The visualization of process (to include an accurate simulation of its working elements) represents significant technical challenges both from a hardware as well as a computing sense. Research in this area needs to focus on how one achieved functional or operational fidelity in addition to necessary visual fidelity.

Important elements to focus on should be:

- Representing system operation,
- Representing the interaction between manned and unmanned elements,
- Understanding visual fidelity and functional fidelity tradeoffs, and
- Matching application fidelity to project and user needs.

11. Overcoming Obstacles to the Effective Integration of Modeling and Visual Simulation

Rationale:

Research is needed that distinguishes between database generation and the modeling of physical structures and modeling/simulation that focuses on representation of the dynamic nature of the operation of those elements.

Important elements to focus on should be:

- Real-time computing challenges,
- Representing the probabilistic nature of user performance(s),
- Modeling critical interactions between elements,
- Image generation and display system limitations on the real-time representation of the operational traffic environment, and
- Real versus simulated elements.

12. Simulation and Modeling Issues in the Visual Representation of Non-Motorized Traffic (e.g., pedestrians)

Rationale:

Our ability to model (i.e., mathematically represent) the performance attributes of non-motorized traffic elements (i.e., pedestrians) and their interaction with motorized elements is in its infancy. There is both a need for data and for its effective integration within existing models and simulations intended principally for the representation of vehicular traffic.

Important elements to focus on should be:

- Identifying the key attributes and performance characteristics of pedestrians with and without various impairments, bicyclists, etc.
- Information for the effective modeling of interactions between motorized and non-motorized elements (e.g., factors affecting driver yielding performance, factors affecting pedestrian and vehicle gap selection attributes, etc.).

13. Fidelity and Data Accuracy Issues in the Use of Visualization with Respect to Their Effects on Human Performance

Rationale:

There is a need for behavioral research focused on the performance effects associated with our present inability to completely represent all aspects of the visual environment and the means by which they control human performance.

Important elements to focus on should be:

- Understanding visual fidelity limitations (resolution, field of view, scene content, etc.) and their effect(s) on "human-in-the-loop" performance outcomes.
- Understanding the effects of force and motion cueing limitations associated with the use of manned simulation for handling quality evaluations.
- Understanding the stochastic and statistical nature of human performance.

14. Understanding the Practicable Uses for Desktop and Immersive Driving Simulators

Rationale:

The advancements in simulator technologies can provide environments where highway engineers may perform human behavior and safety performance assessments of both final design alternatives and work zone layouts as part of any project. With 3-D geometry captured as part of the design process, and operational performance assessed as part of new visual-centric traffic modeling technologies, immersive and desktop driving simulators would provide project teams with the most comprehensive understanding of the human's perspective of their projects without actually building them.

Important elements to focus on should be:

- Understanding the practical applications of these simulator technologies in both agency and consultant-based environments by synthesizing and assessing "lessons-learned" in the defense and aerospace industries.
- Understanding the interoperability of the data and systems that will need to be combined (3-D geometry, simulated traffic, human-in-the-loop) while building on the fidelity and data accuracy findings captured as part of Problem Statement 13 above.
- Demonstrating the do-ability of applying such technologies, and measuring the actual benefits to the engineering team, the community, and the end-user.

CATEGORY FOUR: UNDERSTANDING THE SOCIAL–PSYCHOLOGICAL AND COGNITIVE ELEMENT (TOPICS 15–17)

15. Assessing User Needs and Values

Rationale:

Research in this area should be thought of as providing both the scientific and practical foundation for the means by which the potential "developer" is able to acquire a design-oriented understanding of basic user needs and values. While conceptually related to the public involvement process, it deals more specifically with the means by which one seeks to understand basic stakeholder needs and values than with guidance as to the manner in which visualization is used to communicate proposed solutions.

Important elements to focus on should be:

- Understanding the relationship between user needs and the context of user values in which satisfaction of those needs must take place.
- Quantitative methods for eliciting and measuring user acceptance in terms of user values.
- Tools/devices for use in soliciting and measuring user input both locally as well as at a distance (i.e., web-based).

16. Understanding the Science of How Persons Acquire System Design and System Operations Information from Visual Displays and Images

Rationale:

There has been no attempt, to our knowledge, to effectively translate what is known from research in the areas of communication and cognitive science into practical guidance to developers and/or practitioners in the area of visualization. Such an effort would need to focus on establishing precisely what it is that we are trying to communicate and achieve through the use of various visualization methods and products, and to relate that specifically to what we know from the cognitive and information sciences toward accomplishing such goals.

Important elements to focus on should be:

- Basic perceptual research on the relationship between visualization elements and the effective communication of system design information.
- Guidance for the practitioner on how to apply these principles to maximize the benefit of visualization applications.
- How to incorporate these principles and methods of effective visualization application into the embedded visualization capabilities of computer-aided design (CAD) applications used principally for design.

17. Visualization in Community Design: Enabling Software Tools and Applications and the Current State of Practice

Rationale:

The use of visualization as a tool to facilitate community design involves techniques and strategies more in common with transportation planners than transportation engineers. Research in this area must address both the technical aspects of the visualization tools employed as well as the communication issues associated with collaborative planning and design.

Important elements to focus on should be:

- Understanding issues associated with the use of visualization at the community or system level versus the level of the isolated facility.
- Achieving consensus versus improving users ability to make informed choices (i.e., to discriminate).
- Understanding the collaborative nature of planning and community design activities.
- Characteristics of effective (visualization) tools that promote effective collaboration.
- The relationship of context-sensitive design and collaborative planning.
- Guidance on the use of visualization for enhancing collaboration (e.g., between stakeholders, between design personnel, between stakeholders and designers, etc.).
- Development of a clear definition of non-tool-specific processes (i.e., from acquisition of source data, processing of source data, feature extraction, database creation, model creation, scenario construction, and scene rendering).

APPENDIX B

Utah Department of Transportation Request for Qualifications

NEW
VISUALIZATION POOL
MAY 2004

Summary Sheet

1. **Project Number:** Not applicable for visualization pool.

2. Location: Statewide.

3. Requested Services: Qualified consultants who can provide the department a medium for conveying conceptual infrastructure enhancements using advanced rendering programs to produce simple yet geometrically realistic representations.

4. **Sources of Funding:** Federal, state, and local.

5. Project Administrator:
Marie Walton, Consultant Services Manager, Utah Department of Transportation, Consultant Services, Box 148490, 4501 South 2700 West, Salt Lake City, UT 84119-5998, Telephone: 801-965-4427, mariewalton@utah.gov

6. Project Management:
Angelo Papastamas, Context Sensitive Solutions, Director, Utah Department of Transportation, 4501 South 2700 West—4th Floor, Box 148380, Salt Lake City, UT 84114-8380, Telephone: 801-965-4561, apapastamos@utah.gov, will be the contact person for the scope of work described in the Pool RFQ.

7. Advertisement Dates: Saturdays, May 1, 8, 15, 2004.

8. Statements (SOQs, Videos, CDs, DVDs) Due-Time: Tuesday, May 18, 2004 before 11:00 a.m. (more information on pp. 14–15).
Four copies of the Statement of Qualifications and, if applicable to your submittal, one Video, CD, or DVD copy shall be delivered to the Utah Department of Transportation, Office of Consultant Services, 4th Floor NE Corner, 4501 South 2700 West, Salt Lake City, Utah 84119-5998 no later than 11:00 a.m. on Tuesday, May 18, 2004.
Statements of Qualifications will not be accepted after the 11:00 a.m. deadline.

9. Type of Statement (SOQ, Video, CD, or DVD) Required: In accordance with Utah Department of Transportation Guidelines for Preparing **Visualization** Statement of Qualifications.
The Statement of Qualifications has a maximum page limit of 10 pages. There are not any restrictions for length regarding Video, CD, or DVD submittals for this Pool Period. However, this may change in the next General Engineering & Local Government Pool period depending on what we receive from this Pool Period.

10. **Selection Review Team Meeting:** Wednesday, June 23, 2004.

Visualization Pool

11. **Oral Interviews Date:** Visualization Pool selection will be from Statements of Qualifications/Videos; however, interviews may be required prior to specific project selection should the Department determine it necessary.

12. **Pre-Negotiation Meeting:** N/A for Visualization Pool.

13. **Project Specific Contract Information from the Selected Consultant Due:** May vary from project to project; but all contract requirements will need to be sent directly to the UDOT Project Manager.

14. **Negotiation Meeting:** N/A for Visualization Pool.

15. **Pool Period:** July 1, 2004 to June 30, 2005. Visualization will become part of the General Engineering & Local Government Pool as a new Work Discipline beginning July 1, 2005. Submittal requirements may change in new Request for Qualifications. The Visualization Pool is held to the same Pool Project and Consultant Caps/Limits of the GE&LG Pool:

Project Cap/Limit (cradle to grave) = $250,000
Consultant Accumulative Pool Period Cap/Limit UDOT Projects = $750,000
Consultant Accumulative Pool Period Cap/Limit Local Government Projects = $600,000.

Consultant Pool Selection Schedule

Date	Action
Monday, April 26, 2004	Advertisement of RFQ to Construction Group
Monday, May 3, 2004	Posting of RFQ on UDOT Consultant Services website
Saturday(s) May 1, 8, 15, 2004	Advertisement of RFQ in local Utah newspapers
Tuesday, May 18, 2004	Statements of Qualifications are due
Tuesday, June 8, 2004	UDOT Selection Review Team (Video, CD, DVD) Viewing
Wednesday, June 23, 2004	UDOT Selection Review Team Meeting
Wednesday, June 30, 2004	Consultant Pool Selection
Wednesday, July 7, 2004	Posting of Pool Selection on UDOT Consultant Services website

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Advertisement

NOTICE OF CONSULTANT SERVICES

The Utah Department of Transportation is seeking the services of qualified Consultants to provide **Visualization** in upcoming statewide Transportation Projects.

If you are interested in submitting a Statement of Qualifications, information on the Request for Qualifications and guidelines for preparing a Statement of Qualifications will be available **Monday, May 3, 2004,** and can be obtained from the Utah Department of Transportation website udot.utah.gov under "Inside UDOT > Internal Groups and Divisions > Project Development > Consultant Services > Project Advertisements" or udot.utah.gov/index.php?m=c&tid=614. **The deadline for submitting the Statement is 11:00 a.m. on Tuesday, May 18, 2004.** The right is reserved by the Department to reject any and all Statements of Qualifications.

The Utah Department of Transportation encourages prime consultants to use DBE/WBE's as sub-consultants where practicable.

Dated this 1st day of May 2004

Utah Department of Transportation
John R. Njord
Executive Director

Introduction

See **Appendix C** which includes:

- Pool Objectives & Tasks
- Contract Requirements
- Department Furnished Items

Required Key Personnel Qualifications

The Consultant shall be responsible to ensure that all personnel proposed under this Request for Qualifications (RFQ) be qualified through training, experience, and appropriate certification for the tasks assigned and shall have a working knowledge of Department standard practices.

The Consultant is expected to complete the form, Proposed Key Personnel to Be Used on UDOT Project (attached as **Appendix B** to this RFQ). Appendix B should state the certification and education levels of the individuals proposed for use on this contract including sub-consultants' personnel. **The completed form must be included in statements but will not count as one of the allowed pages.**

Required Availability of Key Personnel

When Consultants list personnel on Appendix B, Proposed Key Personnel to Be Used on UDOT Project Form, the Consultant is agreeing to make the personnel available to complete work on the contract at whatever level the project requires.

Required Percentage of Work for Prime Consultant

The Consultant must perform work valued at not less than **90%** of the total work, excluding specialized services, with its own staff. Specialized services are those services or items that are not usually furnished by a consultant performing the particular type of service contained in this RFQ.

Required Completion and Acceptance Criteria

Progress payments will be made with a five-percent retainage (escrow) of the invoiced amount for work in progress. Final payment, including any retainage (escrow), shall be made after all of the work has been completed and the final estimate, project records, and documentation have been received and accepted by the Utah Department of Transportation as accurate and complete. Penalties may be assessed for failure to perform in a satisfactory manner.

Applicable Federal and State Regulations

The Consultant shall conform to all applicable state and federal regulations. It is the Consultant's responsibility to know the state and federal requirements and be proactive in making sure that they are followed in every step of each project.

Debarment Certification

Federal regulations require certification by prospective participants (including contractors, subcontractors, and principals) as to current history regarding debarment, eligibility, indictments, convictions, or civil judgments. The selected Consultant will be required to certify in accordance with contract Standard Terms and Conditions.

Authorization to Begin Work

Notice to proceed will be given by Consultant Services as soon as the contract is approved and signed by all parties and returned to Consultant Services. All Notice to Proceed notifications will be in writing from Consultant Services. Failure to follow these standards may jeopardize project funding, reimbursement to Consultants for work done prior to receiving the appropriate authorization to begin work, and may also result in a poor Consultant evaluation.

Required Statement Contents

The Statement from the Consultant should contain the information identified in the attached Utah Department of Transportation Guidelines for Preparing Visualization Pool Statement of Qualifications.

Statement Evaluation Procedures

The Statement shall be evaluated by a Department Selection Review Team in accordance with the criteria described in the Utah Department of Transportation Guidelines for Preparing Visualization Pool Statement of Qualifications.

Conditions of Proposal

All costs related to the preparation of the Statement and any related activities such as interviews, if applicable, are the sole responsibility of the Consultant. The Department assumes no liability for any costs incurred by Consultants throughout the entire selection process.

Disposition of Statements

Statements (SOQs, Videos, CDs, DVDs) become the property of the Utah Department of Transportation, are treated as privileged documents, and are disposed of according to Department policies, including the right to reject all statements. The statement of the successful Consultant shall be open to public inspection for a period of one year after award of the contract. Statements of Consultants who are not awarded contracts shall not be open to public inspection and will be destroyed once the contract is executed with another consultant.

If the Consultant selected for the award has required in writing the nondisclosure of trade secrets and other proprietary data so identified, the Consultant Services Manager shall examine the request in the statement to determine its validity prior to award of the contract. If the parties do not agree as to the disclosure of data in the contract, the Consultant Services Manager shall inform the Consultant in writing what portion of the statement will be disclosed and that, unless the Consultant withdraws the statement, it will be disclosed. If the Consultant withdraws their Statement, the Consultant will not be awarded the contract.

Ownership of Documents

All Videos, CDs, DVDs, tracings, plans, manuscripts, specifications, data, maps, etc., prepared or obtained by the Consultant as a result of working on this contract, shall be delivered to and become the property of the Department. Failure to submit this material in a timely manner may jeopardize Consultant reimbursement, poor Consultant evaluation, or jeopardize future work with the department.

Financial Screening

The Department requires Consultants to be Financially Screened prior to performing work for UDOT. **If a Consultant is selected and has not been financially screened and approved within <u>two weeks</u> after selection, the Consultant will be disqualified unless the delay is due to problems or delays by UDOT.**

The time it takes a Consultant to complete the Financial Screening process varies and therefore the Department encourages Consultants to submit their Financial Screening Application at the same time as their Statement of Qualifications or before.

Consultants may obtain the Financial Screening Application from the UDOT website udot.utah.gov under "Inside UDOT > Internal Groups and Divisions > Project Development > Consultant Services > Forms" or udot.utah.gov/index.php?m=c&tid=287. For questions, contact the Consultant Services Accountant at 801-965-4138 or the Project Administrator as noted on Page 2. A Consultant's Financial Screening status is effective for the period of one year from the time the Consultant is approved.

Pre-Award Audit

In the event that a proposing consultant has failed to pay UDOT monies due to the Department for over-payment on past projects, UDOT has the right to reject and/or disqualify the firm's statement of qualifications and associated materials. Disqualification will be based on the audit findings, determinations, and recommendations made by the Department's authorized agent.

Insurance Certificates

The Consultant is required to provide the Department with Certificates of Insurance referencing the project and naming the Utah Department of Transportation and the State of Utah as additional insureds. Failure to meet the department's insurance requirements may result in immediate action taken against the Consultant by the department and termination of the contract. Minimum insurance requirements are found on the website at http://www2.udot.utah.gov/index.php/m=c/tid=287.

Subscription to the UDOT Consultant Services Update Service

The Department recommends Consultants interested in proposing a Statement of Qualifications subscribe to the UDOT Consultant Services Update Service on the UDOT website udot.utah.gov under “Doing Business > E-Mailing Lists” or udot.utah.gov/index.php?m=c&tid=548&type=1&item=2048&d=full.
If there are any changes affecting the Request for Qualifications, notice will be sent out via an e-mail through the update service.

APPENDIX A
Guidelines for Preparing Visualization Pool Statement of Qualifications

Introduction

These guidelines were developed to standardize the preparation of a Standard Statement of Qualifications (SOQ) by Consultants for Visualization Services on a project and/or Pool, if applicable. The purpose for these guidelines is to assure consistency in format and content in the SOQ prepared by Consultants and submitted to the Department. Preparing a SOQ instead of a detailed proposal reduces the time requirements for the Consultants and simplifies the review process for Department personnel.

The Statement of Qualifications should contain the following information in the order listed with tabbed sections for easy reference:

1. Introductory Letter (Identify e-mail Visualization Pool contact within letter)
2. Project Team
3. Capability of the Consultant (2-D, 3-D, 4-D Graphics)
4. Appendix B.

RECOMMENDED DETAILS AND EVALUATION CRITERIA

1. **Introductory Letter—**The introductory letter should be addressed to:

Marie Walton
Consultant Services Manager
UDOT Consultant Services
4501 South 2700 West
Salt Lake City, UT 84119

In **one** page, express your interest in the Pool Project, state qualifications to do the work, and recount any summary information on the project team or yourself that may be useful or informative to the Department. Include the e-mail address of the primary contact person for this consultant selection process in the introductory letter.

No evaluation points are assigned to this section and the introductory letter will not count as one of the allowed pages.

2. **Project Team—**The evaluation will consider how well the qualifications and experience of the members of the project team relate to the specific project.

   - Project team flow charts including sub-consultants (see sample Project Organization Chart available on the UDOT website udot.utah.gov under "Inside UDOT > Internal Groups and Divisions > Project Development > Consultant Services > Forms" or udot.utah.gov/index.php?m=c&tid=287 under Project Organization Chart and Related Experience Charts).
   - Visualization qualifications and experience of key personnel on project team.
   - Show on a spreadsheet a list of Visualization Projects (transportation or other) you have completed during the last five years. The heading of the spreadsheet should include the following (see sample Related Experience spreadsheet available on the UDOT website udot.utah.gov under "Inside UDOT > Internal Groups and Divisions > Project Development > Consultant Services > Forms" or udot.utah.gov/index.php?m=c&tid=287 under Project Organization Chart and Related Experience Charts.

   Note: Columns may be combined in order to meet the font size and margin requirements.

     - Name of Project Manager
     - Year
     - Type of Visualization Project
     - Project Name
     - Project Location
     - Project Description
     - Visualization Services Performed
     - Client
     - Reference Contact and Telephone Number

A maximum of **40** points is available for this section.

3. **Capability of the Consultant—**The evaluation will consider the Consultant's capability to perform Visualization work.

     - Describe your capability to perform the work. Identify your ability to perform 2-D, 3-D, or 4-D graphics. Refer to the Essentials of Visualization found on the next two pages. If you are submitting 4-D qualifications please include a Video, CD, or DVD with your Statement of Qualifications.
     - Describe any unique qualifications you have to perform this type of work.
     - Describe internal quality and cost control procedures.

   A maximum of **60** points is available for this section.

4. **Essentials of Visualization—**The following definitions are provided for clarification purposes and to distinguish among various visualization components available.

2-D Graphics: Photo-simulations are simulations or images that are representative but may not be accurate. These are any static or 2-dimensional images that portray the spatial relationship of an object with three dimensions.

- Renderings or Artist's Conceptual Simulation—either hand-drawn or prepared using a computer image that is created by drawing or "painting in" proposed new elements on a photographic image or video frame called a "base image" to generate a near photographic image of a proposed transportation feature. Base images can be converted from photographs by using a scanner or image capture boards for video. This process does not use *x*, *y*, *z* coordinate locations or digitally merging composite images.

- Image Paint—a generic term used to characterize computer-based software (such as PhotoShop) that is used to create, modify, or edit digital images. Image editing has application in all 3-D image work and some application in frame-by-frame 4-D editing.

- *Note*: It is very important to understand that painted or edited images by themselves are not based on geometrically accurate elements and that the resulting images may not truly reflect the actual final outcome of the transportation feature it portrays. The quality and level of realism achieved depends on the artistic skill of the artist and the quality of the base image used.

3-D Graphics: 3-D photo-simulations are simulations based on a photographic montage and 3-dimensional modeling of geographic elevation information with other associated pertinent information that is representative and accurate.

- Composite Image Simulation—merging two or more images that have the same viewing station/location defined by *x*, *y*, *z* coordinates and perspective parameters. Composite static images most frequently involve merging photographic or video base images for which the camera location and settings are known and/or calculated. These are then merged or overlaid with a 3-D computer image that has been generated using the real world location and settings for the virtual camera (computer camera). In this process, the background image must be taken so that the geographic location parameter, the viewpoint, the camera settings, and the actual size of some of the objects in the image are known. This is very important in that when changes are introduced (proposed transportation features) they can be matched to provide geometrically and dimensionally accurate images.

- A 3-D computer model is used to generate a perspective using the same coordinate camera location and camera settings as those of the original background or base image. These two images are then overlaid using control points to create the final composite image. This method provides the most visually correct, accurate, and defensible representation possible. With proficiency and care, the range of error is generally less than two percent. (Several other steps are also involved such as material definitions and material rendering to complete the final composite image.)

4-D Graphics: Urban simulations, animated simulations, and real-time simulations are simulations based on motion and/or real-time movement within a virtual model. Animated 4-D incorporates a wide range of dynamic imagery in a series of 3-D images that are sequentially related in space and time. The time reference is defined as the fourth dimension.

- Urban Simulation or "Real-Time" Simulated Graphics—the ability of a computer system to generate, display, and update images in a continuous rendering mode. Real-time provides complete movement within the virtual model without pre-selecting a specified path. Rendering occurs simultaneously as movement is performed.

4-D applications include:

- Video: the unedited recording of existing site conditions using a video camera.
- Simulated Phase Change: the process of illustrating that occurs from an existing base image condition to the proposed composite image condition from the same viewpoint and saved as a video sequence.
- Animation: sequence of composite images that when played at specific speeds will produce the illusion of motion.
- Urban Simulation or "Real-Time" Technology: an innovative tool for interactive urban/transportation planning, consensus building, public education, and conflict resolution. Real-time simulation includes adaptable database management systems and an optimized desk top PC and web-enabled system configuration, all seamlessly integrated under a universal fourth dimension of time. Besides the common real-time 3-D interactive capabilities, real time provides the ability to control the fourth dimension of time and to integrate time-based intelligence with existing information databases, such as GIS and other IT systems.

  Real-time applications are an ideal solution for visualizing dynamic transportation operations that are complex within changing environments. Additionally, real-time applications are extensible with the ability to associate information from databases (such as GIS and Oracle) with the 3-D graphic entities located within the visual database. This enables the user to identify and query an associated database for object attributes via "3-D object picking." URLs and web-enabled applications can also be easily embedded with the 3-D graphic entities. This makes an effective decision support and knowledge management tool to serve the various needs of this undertaking.

5. **Appendix B**—The Consultant is expected to complete the form, Proposed Visualization Key Personnel to Be Used on UDOT Project (attached as **Appendix B** to this RFQ). Appendix B should state the certification and education levels of the individuals proposed for use on this contract including sub-consultants' personnel. **The completed form must be included in SOQ but will not count as one of the allowed pages.**

When Consultants list personnel on Appendix B, Proposed Key Personnel to Be Used on UDOT Project Form, the Consultant is agreeing to make the personnel available to complete work on the contract at whatever level the project requires.

The Department reserves the right to create qualification/ability level categories (2-D, 3-D, and 4-D) depending on the variation of submittals by the Consultants. The overall Consultant Statement of Qualification Score will determine what Visualization Project Work Level the Department determines the Consultant qualified to do.

Note: This is a new focus area for the Department and therefore changes to the selection process and submittal requirements may vary next Pool Period. Visualization may also become a Work Discipline in the next General Engineering and Local Government Pool. Please make sure that you are a "Subscriber" to Consultant Services electronic notifications. You may do so at the following site:

http://listserv.dot.state.ut.us/scripts/lyris.pl?join=consultantservicesupdates.

Video, CD, or DVD Requirements

1. **Video/CDs/DVDs Copies**
Submit 1 copy (for Selection Team to view together). One of these media tools is required for those firms representing Level 4-D graphic experience in your Statement of Qualifications. Please identify media tool submittals with the firm name, a contact, and appropriate contact information.

SOQ Format Requirements

It is very important that submittals be clear, concise, and in the recommended format so they may be evaluated in an objective manner by the Department's Selection Review Team.

1. **SOQ Copies**—Submit 4 copies (number sequentially from one to four on the upper right-hand corner of the cover). Also note in the upper right corner if you are submitting 4-D qualifications and what media tool you are submitting (Video, CD, or DVD).
2. **Color Is Allowed.**
3. **8½" x 11" or 11" x 17" Page Sizes**—(refer to No. 11 of SOQ Format Requirements for further details.)
4. **One (1") Margins**—(exceptions: Consultant Name/Logo and Page Headers/Footers may be within margin).
5. **Size 10 Font**—(size 10 or greater font everywhere in SOQ including graphics, unless the graphics are a duplication from another source and the source is referenced).
6. **Related Experience Chart and Project Organization Chart Are Required.** (the sample charts, Project Organization Chart, and Related Experience Charts are available on the UDOT website udot.utah.gov under "Inside UDOT > Internal Groups and Divisions > Project Development > Consultant Services > Forms" or udot.utah.gov/index.php?m=c&tid=287.)
7. **Bind SOQ on Left Side.**
8. **Tabbed Sections**—(limit information on tabs to Section Identification, Project Number, Project Description, Consultant Name/Logo, and/or un-enhanced photographs).
9. **Front and Back Cover Pages Are Allowed**—(information on cover pages is not restricted. Cover pages will not count towards the page maximum).
10. **Appendix B Is Required**—(Appendix B will not count toward the page maximum).

> *Note:* A maximum total of 100 points is available for the Visualization Statement of Qualifications **and/or** Video, CD, DVD (4-D submittals only).
>
> **A one-point penalty will be assessed by Consultant Services for each applicable violation of the above (#1 through #10) format requirements for a maximum 11-point penalty per SOQ/Video.**

11. **10-Page Maximum**—(Statement of Qualifications has a maximum page limit of 10 pages).

> *Note:* A page is defined as a single-sided 8.5" x 11" or 11" x 17" sheet that contains text, pictures, tables, graphs, charts, plan sheets, or any other graphics. There is a limit of up to three 11" x 17" sheets that may be used in conjunction with pictures, graphs, charts, plans, or any other graphics.
>
> **The Introductory Letter, Appendix B, and Cover Pages will not count toward the page maximum. Any SOQ that exceeds the 10-page maximum will not be distributed to the Selection Review Team.**

This Form Revised in May 2004
For Visualization Pool

APPENDIX B
Proposed Visualization Key Personnel to Be Used on Upcoming UDOT Projects

Name*	Firm Name	Title (Within firm and/or proposed on project)	Certification Category/Level	Utah License/ Certification No.	Other State License/ Certification No.	Education Level

*Include all key personnel who are proposed to work on UDOT project including sub-consultants. Add additional pages if needed.

The form and an example of the completed form along with further descriptions of the column headings are available on the UDOT website udot.utah.gov under "Inside UDOT > Internal Groups and Divisions > Project Development > Consultant Services > Forms" or udot.utah.gov/index.php?m=c&tid=287.

APPENDIX C
Scope of Work/Pool Objectives and Tasks

The scope of services for visualization may be advertised for a specific project, in which case the deliverables may be described in detail, or for statewide use on any project that requires an element of visualization. In the latter case, the scope of services must include all components and levels of visualization. Statements of Qualification in this case must indicate the consultant firm's capabilities and experience with visualization applications and programs. The consultant should indicate the dimensions (2-D, 3-D, 4-D) to which their firm can accommodate and submit the appropriate Statement of Qualifications and Video, CD, or DVD submittal requirements.

The Department seeks qualified consultants to perform visualization for projects on a statewide basis. Visualizations may include two-dimensional (2-D) photo-simulations such as photographic renderings based on artistic interpretation, three-dimensional (3-D) photo montage-simulations based on existing and proposed digital terrain modeling, four-dimensional (4-D) urban/animated/real-time simulations based on motion within a virtual model, or other project related information.

Deliverables may include hard copy color prints for inclusion in reports and newsletters, large format color prints of various dimensions for displaying at public information meetings, digital images for progressing design development and/or inclusion in electronic presentation slides for public information meetings, or inclusion to the Department's website on subject projects. All project videos, images, digital files, and deliverables will become the property of the Department.

End of report.

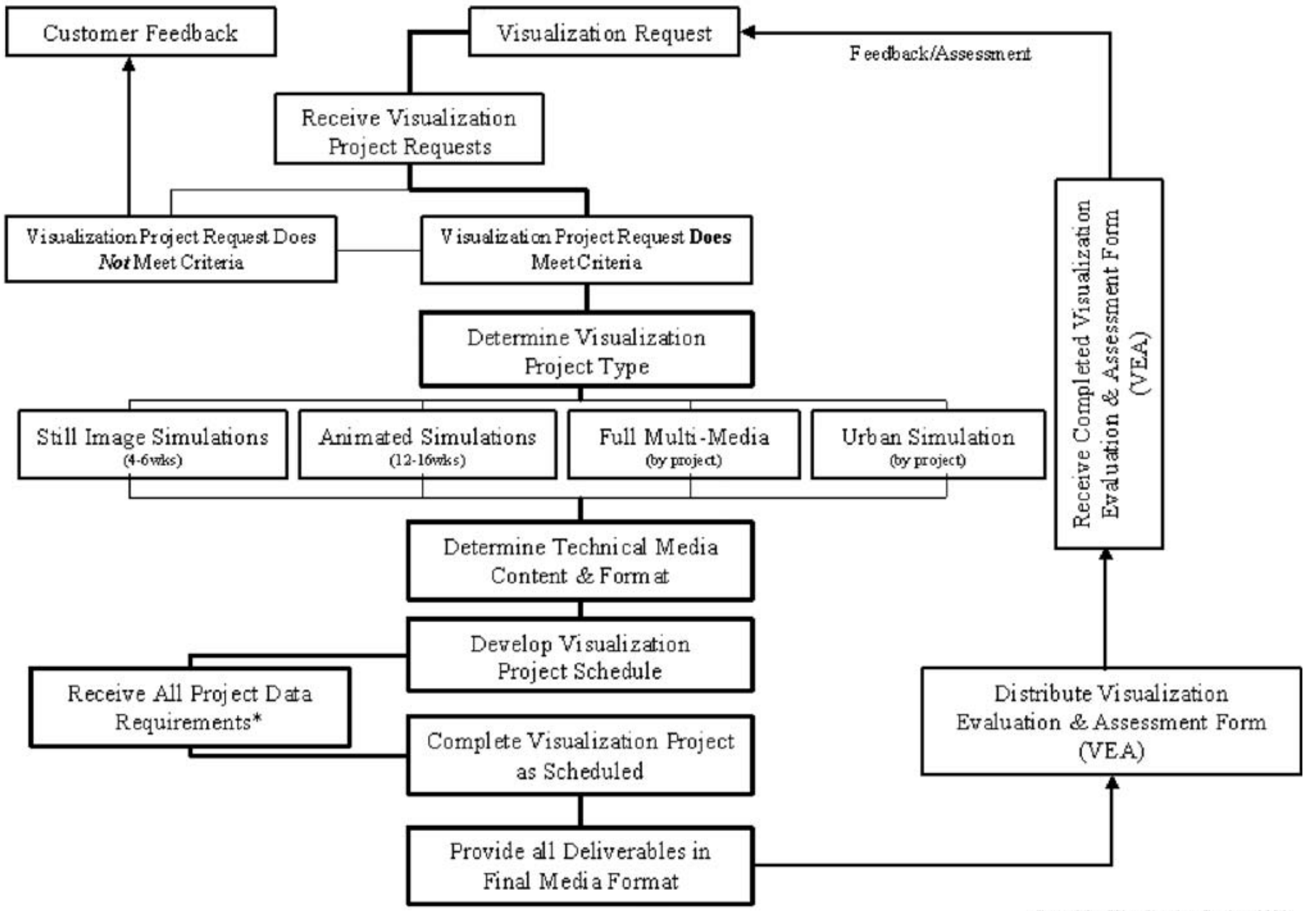
APPENDIX C

New York State Department of Transportation Visualization Project Workflow Fact Sheet

August 2002

Visualization Project Workflow

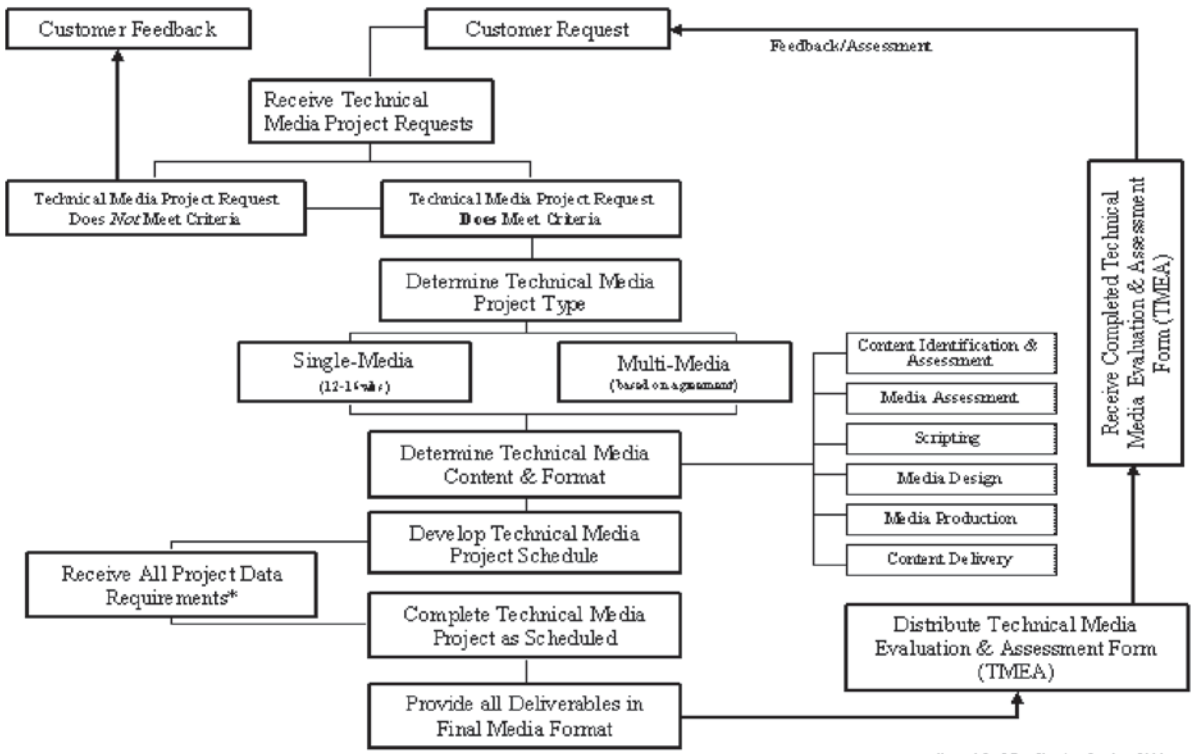
Fact Sheet



November 2000

Technical Media Interactive Scheduling Workflow

Customer Fact Sheet



1) ❑ Digital Terrain Model files -
   - ❑ Original Ground Surface Model or (Existing Ground)
   - ❑ Proposed Surface Model.

2) ❑ Photogrammetry files including 9 x 9 aerial photographs

3) ❑ Striping Plan

4) ❑ Typical Section(s) & Profiles

5) ❑ Preliminary and/or final design considerations for any aesthetic treatments

6) ❑ Conceptual or detailed planting plans

7) ❑ Pavement and curbing materials including walks.

8) ❑ Guide rail type

9) ❑ Planned or potential ROW impacts

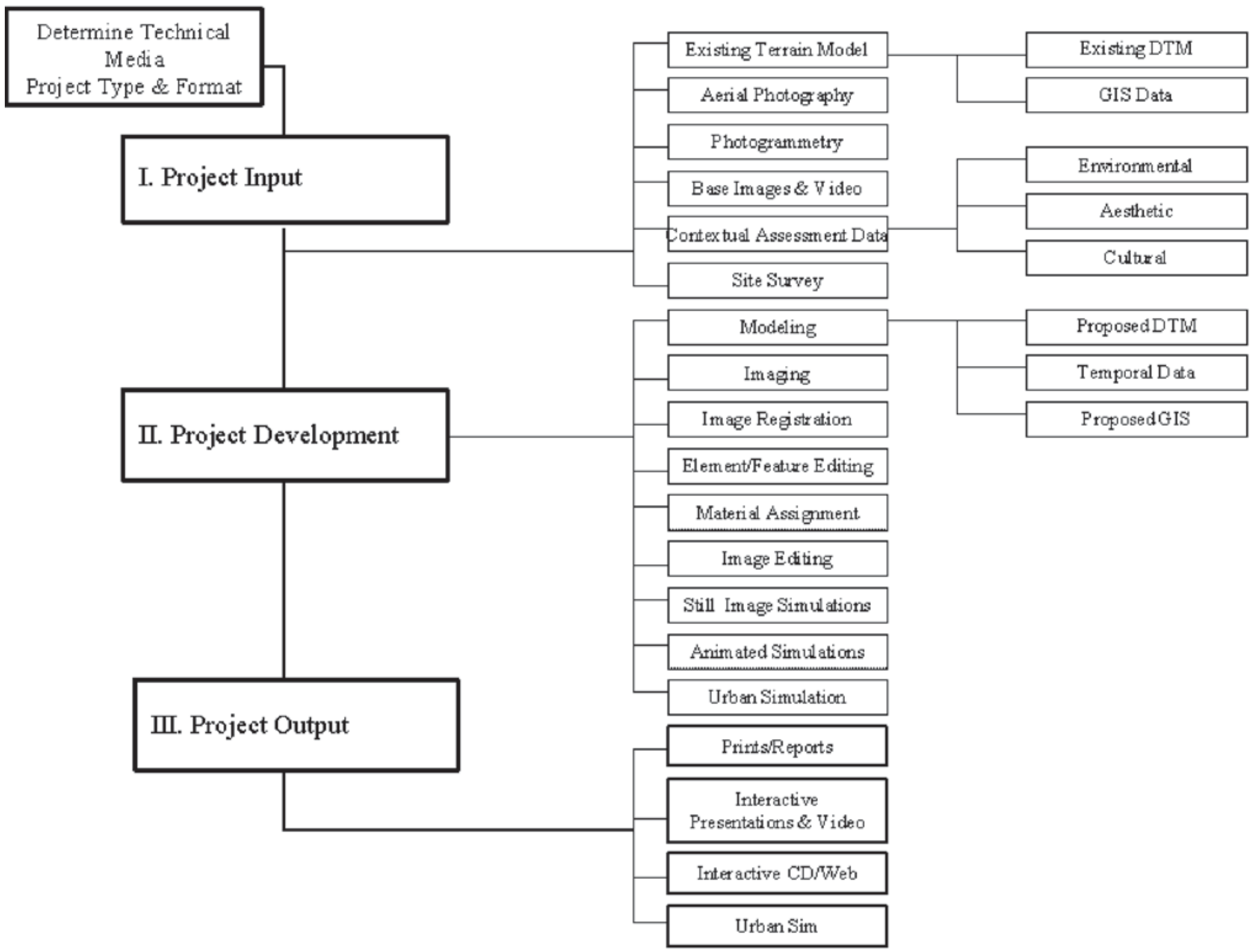
10) ❑ Planned or potential environmental impacts as applicable such as: wetlands; visual character; etc.

11) ❑ Crosswalk locations

12) ❑ Proposed utility impacts/ relocation and/or if undergrounding is an option.

13) ❑ Planned amenities

Visualization Project Development Dataflow



APPENDIX D

New York State Department of Transportation—Visualization Request Form

VISUALIZATION REQUEST FORM

Project Name:		P.I.N.	
Contact Name:		Date Needed:	
Phone Number:			

I. General Information: (Check all that apply)

		Project Type:			**Project Phase:**
		a.) Major Alignment Modification			a.) Planning (IPP or EPP)
		b.) New Construction and /or Reconstruction			b.) Phase I-IV, Preliminary Design
		c.) New Structure and / or Replacement			c.) Phase V-VI, Final Design

		d.) Structure Rehabilitation			**Construction Applications** (check as nec.)	
		e.) Other (eg. Visual Impact Assessment, Cultural Resources, etc.)			MPT:	
					Phasing:	
					Coordination:	

II. Visualization Objective: (Describe what you need and why)

III. Visualization Types Requested (Check all that apply)

	Photo-Simulation – Include Approximate Number and Size of Photo-simulations	
	Animation - Include purposes & possible durations & traffic simulation data	
	Real Time / Urban Simulation ñ Include Traffic Simulation data	
	Media - List any Multi-Media or Other Special Media Needs	

VISUALIZATION REQUIREMENTS

1. **Site Photos**, labeled sequentially (locations to be "visualized"; need minimum 50% more photos than potential sites)
   Note the following:
   - date and time of day photographs were taken
   - lens size (50mm recommended: if zoom lens, need focal length for each photo)
   - precise x, y, z location of photo by station and offset or landmark, plus height of camera
   - line of sight of photo (e.g. along curb or stripe, or towards a particular house or target)
2. **Support Photos**, to be used as supplementary data as needed (e.g. to rebuild areas behind objects being removed during construction, such as structures, trees, fences, buildings, or if needed to show high detail.
3. Proposed design **Digital Terrain Model** (as detailed as possible, and should include curb and curb cuts)
4. Existing ground **Digital Terrain Model**
5. **Photogrammetry** files, if applicable
6. **Typical Sections, Profiles**, and half size set of **General Plans** including any plantings with annotations of photo locations and directions
7. **Striping plan**, if available
8. **ASCII Job file** including details on any deviations from standards as defined by Engineering Instructions
9. **Animation or Real Time Urban Simulation**:
   - Traffic Modeling Data
   - GIS and other Modeling Related Data

I have discussed the feasibility of visualization with the appropriate people within the Regional and feel that this project is an appropriate use of their visualization capabilities. We will provide the above listed information to facilitate the production of accurate visualization products and will keep those involved in the visualization process apprised of any changes.

Signature: Project Manager - or - Planning/Design/Public Involvement/ Program or Squad Leader's (CE-II)	Signature and title	**Date:** **Visualization Sect. ID Log**

VRF 3_04

APPENDIX E

New York State Department of Transportation—Visualization Assessment Form

Visualization Assessment Form

In order to help us provide the best possible service to meet your visualization needs, the following assessment form is provided. Please take a few moments to complete the form and return it to the address indicated below. If you have any questions regarding the form please do not hesitate to contact Phil Bell of the Visualization Section either by phone at extension (518) 485-8219 or by e-mail at pbell@gw.dot.state.ny.us. Your input helps us to continuously improve our deliverables and services.

Project Name		PIN	
Contact Number		Date Provided	
Phone Number			

Project Requirements	
1. Were all of your project requirements met?	Yes ____ No ____
2. Did the project deliverables meet your expectations?	Yes ____ No ____
If you responded **no** to either question 1 or 2 above, use the space below to briefly describe how your expectations were not met and how we could improve similar needs in the future.	
3. Please rate the overall success of the project content delivered.	High___ Moderate___Low___

Media Content Design	
1. Were all of your media requirements met?	Yes ____ No ____
2. Did the media deliverables meet your expectations?	Yes ____ No ____
If you responded **no** to either question 1 or 2 above, use the space below to briefly describe how your expectations were not met and how we could improve similar needs in the future.	
3. Please rate the overall success of the media content delivered.	High___ Moderate___Low___

Please use the space provided below to add any additional comments or suggestions that you may have to help us improve our services.

Thank you for your input!

APPENDIX F

Utah Department of Transportation—Virgin River Arch Bridge Case Study

3D modeling helps UDOT verify critical design areas, secure public approval

Cost reductions yielded 15-to-1 return on technology investment

A new steel arch bridge spans 392 feet across Utah's Virgin River between Hurricane and LaVerkin. The $11 million project was designed to add a second bridge, easing traffic congestion on the existing, 384-foot steel arch bridge over the Virgin River gorge. In addition, it was to be a work of art in its own right, blending into the area's scenic surroundings.

The older bridge was built in 1937 along State Route 9, the main road to Zion National Park. Over the years, the bridge has been well-traveled, due to the hundreds of thousands of tourists that visit the park each year.

The principles that we discovered … led us to believe that the value of 3D design and visualization was not just as tools for large, very complex projects, but that it would bring us significant value on almost every project.

Bob Nash, a structural engineer for the Utah Department of Transportation (UDOT), developed the initial design for the bridge using a combination of electronic and manual methods. The design was then passed to a drafting technician, who used MicroStation and InRoads to create 2D drawings and detail sheets of the design.

Creating 3D model from 2D designs

Not long into the project, the designers realized they would need a 3D computer model of the structure to facilitate public involvement, and also to meet Context Sensitive Solutions requirements and verify constructability. Bob Peterson of UDOT's Engineering Technology Support (ETS) staff imported the 2D designs using Bentley 3D tools to create a model that was accurate to the smallest detail.

Using MicroStation, the team was able to graphically review the design at every step. The ability to render and shade each component as it was being graphically constructed helped the engineers visually inspect the structure. "Critical design areas—such as bolt spacing and drill-hole angle and location, gaps, and complex angle measurements—could not have been easily verified without MicroStation," said Greg Herrington, ETS manager for IT at UDOT.

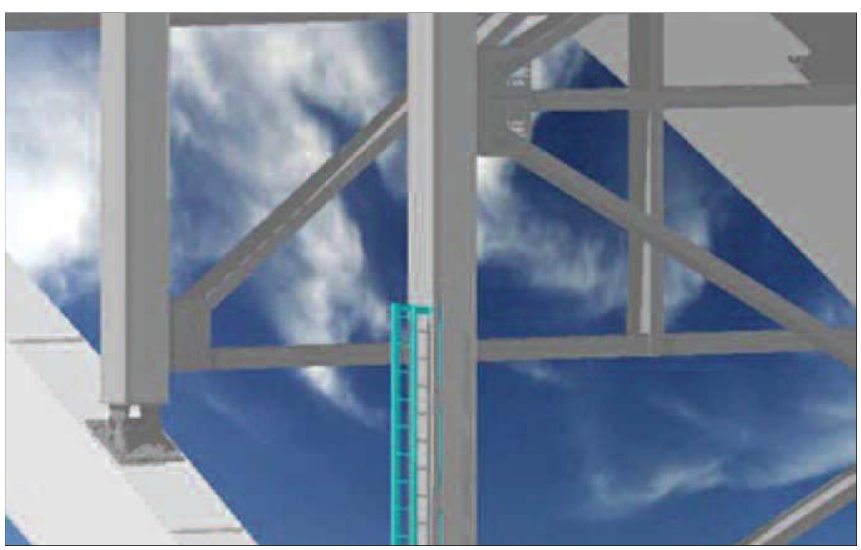
The main components of the bridge were built on two large parabolic arches, making it difficult to verify fit and angle of the crossing members, diaphragms, and joints. Using MicroStation's 3D and rendering tools, UDOT could create each structural member graphically to verify its location and fit. This helped the designers verify the clearance on a large crossbeam location as well as the gap clearance on a half-inch bolt.

The ability to render the drawing let UDOT see whether the element was located correctly, or whether there were any gaps or overlaps. With 3D and rendering tools, the agency was much more efficient at recognizing potential conflicts or design deficiencies, and could resolve them swiftly and accurately.

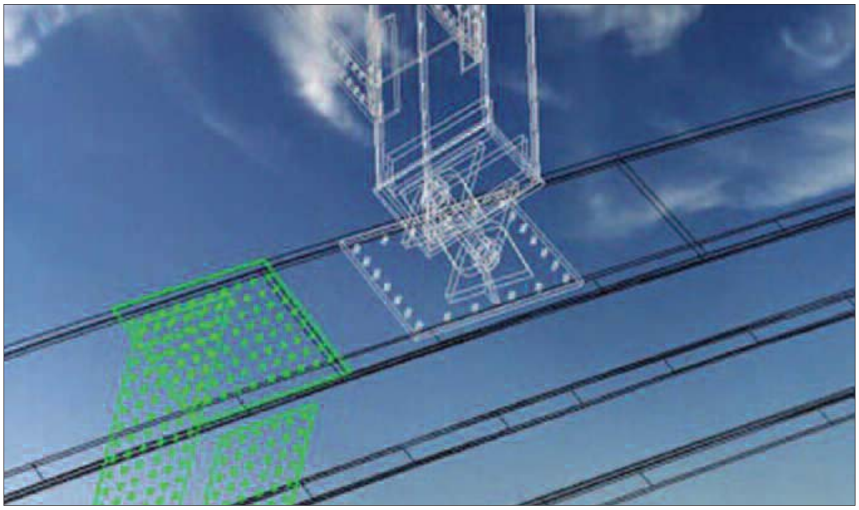
Model brought to light new design challenges

Working together, ETS and the UDOT Structures department were able to find and fix several design challenges that were not apparent in the 2D drawings and plans. With MicroStation, the team was able to meet a very tight project schedule while constantly improving the design. As a result of design issues being resolved before the release of the plans, there were no significant change orders during construction of the structure.

Herrington stated that although the learning process was initially demanding, the time and cost of modeling the structure gave



▲ The ability to render and shade each component as it was being graphically constructed helped the engineers visually inspect the structure.



▲ A wireframe view of the main arch with column and splice connection.

a return on investment of 15 to 1 based on reduced change orders and construction cost savings.

The 3D visualizations were useful externally as well, helping UDOT secure public approval and support for the project. Long before the bridge was constructed, UDOT used photo matching, fly-throughs, and animations in public hearings to showcase the designs and ask for feedback. In turn, feedback from these sessions was used to improve the design.

Applying 3D design to a wide range of projects

"The principles that we discovered during this process led us to believe that the value of 3D design and visualization was not just as tools for large, very complex projects, but that it would bring us significant value on almost every project," Herrington said.

"We have taken what we learned and are currently applying it to a project with a simple, single-span, concrete bridge," he continued. "We have designed the bridge and the roadway components completely in 3D from the start, and our ability to recognize design problems is now clear, rapid, and apparent to all."

"The added benefits of being able to try multiple aesthetic treatments in seconds, inspect utility conflicts, and drive the project reviewing sight distance, pavement marking, and signing have already proven invaluable to the design process. We intend to further measure the value of 3D visualization by defining construction sequencing, staging, and traffic control."

The success of the Arch Bridge project earned UDOT a 2004 BE Award of Excellence for civil visualization. ■

Project

Virgin River arch bridge

Organization

Utah Department of Transportation

BE Awards category

Civil visualization

Project objectives

UDOT created a 3D computer model of the structure to facilitate public involvement, meet Context Sensitive Solutions requirements, and verify constructability.

Fast facts

The time and cost of modeling the structure in 3D gave a return on investment of 15 to 1, based on reduced change orders and construction cost savings.

The 3D visualizations were useful externally as well, helping UDOT secure public approval and support for the project.

Bentley products used

MicroStation

'Applied technology in a way we'll see more of'

The Utah Department of Transportation's use of visualization … stands out to me. Not only did the team create rendered images of the final bridge for the activities involved with gaining public acceptance, but it applied the technology in the a way I think we'll see more of in the future: to identify design deficiencies prior to construction.

By reducing change orders and construction costs, this team provided real value to UDOT, not just a pretty picture.

Shanon Fauerbach, P.E., editorial director, CE News
2004 BE Awards juror

Civil market news from Bentley

David Evans and Associates joins Bentley ETS program

Oregon firm joins Enterprise Training Subscription program, for unlimited training on Bentley software products at a fixed annual fee.

>>more

APPENDIX G

Report Questionnaire

This questionnaire is to be used as part of a case study for the synthesis topic, "Visualization for Project Development." This study is being conducted on behalf of the Transportation Research Board (TRB) for the National Cooperative Highway Research Program (NCHRP) as synthesis study topic 36-04. This synthesis will use case studies to gather and present information on the current best practices and experiences with the use of visualization technologies in transportation project development.

This questionnaire will be used in preparation for an interview with your agency. It will help you to prepare for the interview that will be conducted via telephone or by appointment. Please distribute this questionnaire to as many people and departments within your organization that might be able to provide valuable insight for the technology of visualization. Multiple responses are encouraged. If you do not have a specific answer to a question, please leave it blank or provide me with an approximated answer (please note your answer is approximated). Returned questionnaires (mail or e-mail) are welcomed if respondents cannot attend the interview. You and your organization are also encouraged to submit supporting documentation, photographs, renderings, and computer animation/graphics with the questionnaire.

Dependent on the responses to questions, the interview itself should last between 45–60 minutes. Interviews will be set up well in advance, giving you and your staff sufficient time to prepare. A consensual time for the interview will be determined by both parties.

Returned questionnaires, supporting documentation, and other content should be sent to:

Charles Hixon, Director of Creative Services
Bergmann Associates
28 East Main Street
200 First Federal Plaza
Rochester, New York 14614

Additionally, you are welcomed and encouraged to contact me at:

Telephone: (585) 325-8368
Fax: (585) 325-8307
E-mail: chixon@bergmannpc.com

I appreciate your time and effort responding to this questionnaire. Please do not hesitate to telephone me at: 585-325-8368 with your questions or concerns.

Sincerely yours,

Chuck

Please return this Questionnaire by no later than May 4, 2005.

Responder Information:

Name: ____

Title: ____

Department: ____

Agency/Organization: ____

Address: ____

Telephone: ____

Fax: ____

E-mail: ____

QUESTIONNAIRE

General Questions:

Historical:

1) How long has your organization been utilizing Visualization technologies?

2) What factors led your organization to utilize Visualization?

3) How did visualization get started within your transportation agency?
    a) Who initially championed the effort?
        i) What resistance did you meet and how did you overcome it?
    b) How were you able to implement visualization services within your organization?
        i) Who were the decision makers that you had to convince?
    c) How did you determine what visualization technologies to use?
    d) What department or section did your Visualization group evolve from?
        i) CAD
        ii) Landscape Architecture
        iii) GIS
        iv) Other, please specify

4) How much of your Visualization workload is completed by consultants?
    a) If yes, has your agency set specifications/guidelines for consultants to follow?

5) Why is your department continuing to utilize Visualization technologies?

Current Capabilities:

1) Has your department developed a specific Visualization program that is recognized by your agency or organization?
   a) If yes, please describe the program.
   b) If no, is there a plan to create a formal program at your organization?

2) What is the hierarchy of your agency?
   a) What is the process to obtain funding and approvals for Visualization services within your department?
   b) How does upper management impact the decision-making process within the department/group?
   c) Is Visualization centralized or decentralized within your transportation agency?
      i) How do Visualization policy and procedures get disseminated to the regions/district offices?

3) Does your agency request visualization to be used on design projects?
   a) If yes, are there parameters to determine the use of visualization? For example, large projects versus small projects, overall budget, etc.
   b) If no, why?

4) How are you currently using Visualization technologies within your agency or organization?
   a) Active Design Projects
      i) Is Visualization integrated or utilized with other departments or groups within your organization?
         (1) If yes, please specify the department/group and the relationship.
            (a) CAD
            (b) GIS
            (c) Other, please specify:

         (2) If no, do you see a future need to establish a close relationship with other departments or groups within your transportation agency?

      ii) Is there an active effort to incorporate 3-D design into the design process?
         (1) If yes,

(a) Please specify the process to incorporate 3-D design.

(b) How is data preparation being done? (For example, putting in 3-D geo-referenced data into the department/agency's databases on an on-going basis so that it can be utilized for visualization purposes later).

(c) What design discipline areas is the technology of Visualization being used? (Select all that apply.)

(i) Public involvement

(ii) Construction sequencing

(iii) Environmental review

(iv) Planning

(v) Mitigation

(vi) Safety issues

(vii) Land use

(viii) Legal

(ix) Development

(x) Other

(d) If Visualization will become part of the design process for your agency, will the function be part of the existing design team or a separate work group?

(2) If no, are there future plans.

b) Non-Design Projects

i) Do you complete non-project-related visuals for other departments/groups within your transportation agency?

(a) If yes, please specify the relationship.

c) Research and Development

i) Is Visualization within your group or organization integrated with software and hardware vendors?

(1) If yes, please specify the vendor and the relationship.

(2) If no, do you see a future need to establish a close relationship with a hardware or software vendor?

5) Is Visualization within your group or organization integrated or coordinated with other transportation agencies?
   a) If yes, please specify the transportation agency and the relationship.
6) Is Visualization within your group or organization integrated or coordinated with other governmental agencies such as the United States Military, Homeland Security, etc.?
   a) If yes, please specify the agency and the relationship.

7) Is Visualization within your group or organization integrated with other agencies or consultants?
   a) If yes, please specify the agency/consultant and the relationship.

8) Do you or members within your agency belong to other groups or organizations that promote the use of Visualization?
   a) TRB
   b) AASHTO
   c) SIGGRAPH
   d) AEC SYSTEMS
   e) Others—please specify:

9) What Visualization applications are you using at this time?
   a) Hand renderings
   b) 2-D graphics
   c) 3-D renderings
   d) Photo-simulation
   e) 2-D and 3-D computer animation
   f) Virtual reality simulation
   g) Web development
   h) Multi-media development
   i) Video production
   j) Other

10) How is the department/group conducting research and development?
   a) What sources are being used to gather information?

b) Are you using consultants or other agencies for R&D?
   i) If yes, please specify:

11) How is your department/group sustaining visualization productivity levels?
   a) Where are the projects coming from?
      i) In-house design projects
      ii) Large projects
      iii) Others—please specify:

<u>Staffing:</u>

1) Do you have a specific Visualization staffing protocol at your agency?
   a) If yes, please list and detail job titles and descriptions.
      i) Do you have a minimal and optimal staffing configuration?
         (1) What is the ideal composition of your Visualization department?
         (2) What is the minimum that can achieve successful results?
   b) If no, is there a plan to create formal job titles and descriptions?

2) How did staffing occur within the Visualization department/group?
   a) Where did they come from?
      i) Department transfers
      ii) In-house CAD technicians
      iii) Outside hiring
      iv) Other, please specify:

3) Is there a training program for visualization technologies within your agency?
   a) If yes, what types of applications are available for training?
   b) If yes, what training sources are you utilizing?
      i) In-house training and mentoring
      ii) Conferences and seminars
      iii) Vendor specific training
      iv) Other, please specify:
   c) If no, please specify why:

4) Is there a specific budget for training?
   a) Financial
   b) Scheduling

5) Is training coordination centralized or decentralized?
   a) For either option, why?

Technical Questions:

<u>Standards:</u>

1) Does your department/group have visualization standards?
   a) If yes, please specify:
      i) Naming conventions, font type, border type, etc.
      ii) Software programs used
      iii) Hardware platforms
      iv) Protocol when starting up a project.
   b) If no, are there plans to generate standards?

2) How are the standards created?
   a) Who creates them
      i) Are standards dictated to you by others within your organization?
      ii) Are the standards centralized or decentralized?

<u>Budgetary Issues:</u>

1) What is the budgetary process for Visualization?
   a) Centralized or decentralized
   b) Who sets spending limits and how are they determined?
      i) How are you educating decision-makers that have little to no experience with Visualization?

2) When utilizing Visualization on a design project, what economic factors determine which visualization application to be used?
   a) Is there a budgetary hierarchy in place when applying visualization to design projects?

3) Does your department conduct a costs–benefit analysis when using visualization technologies?

a) If yes, please detail the analysis.
   i) Do not limit this assessment to financials, please consider productivity savings, scheduling enhancements, quality control, and the approval process, etc.
b) If yes, what results have been achieved to date?
c) If no, why not?

4) What is the Visualization groups' relationship with the agency's Information Technology (IT) department?
   a) Are there obstacles to overcome with IT?
   b) Does the IT department help with your research and development efforts?

Results of Using Visualization Questions:

1) What would you recommend to start up Visualization within a transportation agency today?

2) What visualization applications have worked best?
   a) Why did they work?
   b) What did they accomplish?

3) What visualization applications have failed?
   a) Why?
   b) What actions has your department/group taken to correct these failures?

4) What are the key lessons that your department/group learned when utilizing visualization technologies?
   i) What worked?
   ii) What did not work?

5) What has been the most successful use of visualization technologies to date?

Goal Related Questions:

1) Where do you see visualization technologies developing within your organization over the next 2–3 years?

2) Does your organization have a strategic business plan for Visualization in place for the next 2–3 years?
   a) If yes, please detail your projections.

b) If no, why not?

3) What are the short-term visualization goals of your department/group for the next 2–3 years?

   i) Software applications

   ii) Hardware

   iii) Training

   iv) Other

4) Where do you see visualization technologies developing within the next 5–10 years?

Other Comments:

1) If there are other comments and suggestions that you would like to add to this questionnaire, please insert them below.

Questionnaire Complete—Thank You!

Thank you for helping to research the synthesis on *Visualization for Project Development* by completing this questionnaire. You do not have to fill out this questionnaire. It can be used as just a guideline for the interview process. If you do complete and fill out the questionnaire, please save an electronic copy and forward it to me via e-mail, fax, or standard mailing services.

Please send the complete questionnaire to:

Charles Hixon, Director of Creative Services
Bergmann Associates
28 East Main Street
200 First Federal Plaza
Rochester, New York 14614

Additionally, you are welcomed and encouraged to contact me at:
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Please respond to this questionnaire by no later than May 4, 2005

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation