National Cooperative Highway Research Program

NCHRP Synthesis 229

Applications of 3-D and 4-D Visualization Technology in Transportation

A Synthesis of Highway Practice

Transportation Research Board
National Research Council

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Applications of 3-D and 4-D Visualization Technology in Transportation

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Topic Panel

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis describes the application of computer graphics technology to transportation practice. It will be of interest to the more traditional users such as transportation planners, facilities design and construction personnel, as well as to traffic engineers and other officials concerned with administration, public information, legal aspects, right-of-way, maintenance, operations, and safety of transportation facilities.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series

This synthesis features a series of photographs at the lower right corners of right-hand pages that the reader may flip to achieve a sense of the effectiveness of animation in visualization practice.

in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This report of the Transportation Research Board describes the use of 3-D (artist's concepts and image composites) and 4-D (animation) visualization applications in transportation agencies; however, since there are presently only limited applications, it is, in fact, a primer, providing information on the required hardware and software, as well as on costs, production time, and issues of complexity. More detailed information is provided on how data bases are assembled, various types of imagery, how the visualization image is generated, rendering and animation programs, printers and other output and postproduction activities. An extensive glossary is also included.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the research in organizing and evaluating the collected data, and to review the final synthesis report.

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 the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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APPLICATIONS OF 3-D AND 4-D VISUALIZATION TECHNOLOGY IN TRANSPORTATION

SUMMARY

Three-dimensional and four-dimensional computer technology is a branch of computer science becoming known as "visualization." Visualization applies computer graphics technology to tasks as divergent as cinematography and scientific research. Recent advances in hardware and software technology have now made visualization an attractive tool for many areas of transportation practice.

Computer graphics have been used in transportation for more than 20 years, although their use was generally of an experimental nature or for a very specific purpose that could justify the cost. However, rapid advances in desktop computing and the increased sophistication of softwares and user interfaces since 1990 have resulted in an exciting new tool with widespread application in transportation.

The study for this synthesis of practice found that throughout the transportation community, interest in 3-D and 4-D technology is very high. While a survey of state transportation agencies and transportation consultants found only limited use of 3-D media (artist's concepts and image composites) and very little use of 4-D (animation) technology, the industry is moving to adopt 4-D technology at an almost exponential rate. The reason that there has not been more widespread use of the technology can be attributed to a lack of cost-effective tools and to the time required to become proficient in producing 3-D and 4-D materials. It has only been since 1991 that computer speed, storage space, memory, and software came together in a way that began to make 3-D modeling cost-effective for applications in transportation.

The continuing development of computer-aided drafting and design (CADD) capabilities is largely responsible for the rapid growth of interest in visualization. The competition among software vendors has spurred continuing efforts to upgrade the utility of CADD systems. One of the most significant developments brought about by the intense competition has been an industrywide shift from two-dimensional to three-dimensional software architecture. It is the addition of the 3-D capability in the software structure that allows the construction of 3-D models from which a variety of traditional as well as nontraditional visualization products can be produced.

The new 3-D architecture underlying the CADD softwares developed for use in transportation suggests that the industry will convert to 3-D production procedures in the very near future. This was evident in the fact that several states indicated that they had one or more 3-D production systems in evaluation or have already made recommendations for adoptions.

The challenges posed by converting to a 3-D production system will be in the cost of upgrading the hardware platforms necessary to work with 3-D graphics and in training professional and technical personnel. Upgrading equipment and software will likely be a matter of time and budget cycles in most agencies. However, the solution to personnel training issues does not have a simple or clear-cut answer.

The focus on the implementation of CADD has generated a core of transportation industry personnel who are reasonably skilled in computer graphics. These men and women provide a valuable core of human resources from which transportation visualization capabilities are being developed. However, the primary deficiency in knowledge and skill is in the area of generating the finished product. Single frame (3-D) visualization products require a considerable amount of artistic skill to achieve acceptable results, and animated (4-D) sequences are even more demanding. Artistic skill is essential in 3-D products to maintain a good sense of perspective, appropriate use of color, shade, and shadow, etc. In addition to the basic artistic skills, animation requires that operators set the path of the virtual camera, along with selecting the materials, light conditions, light sources, camera parameters, levels of rendering, and making a variety of other technical decisions before any frames are rendered.

The output equipment, particularly for 4-D materials is also an unfamiliar world that requires special training. The most important of these is video technology, which is currently the favored output medium for 4-D products. This requires the equipment to transfer graphics from the familiar digital computer environment to the analog video environment.

Future conversion to digital technology and advances in other forms of output media will likely converge to solve some of the current problems. However, until this occurs video output will continue to be an important area of technical consideration when developing visualization capabilities.

Visualization is an exciting new tool that is rapidly becoming a part of the tool base in transportation practice. Visualization is a democratic technology that will provide an array of services to a much wider range of agency activities than previously provided with traditional two-dimensional media. Where graphic products, i.e., plans, were once associated with planning, design, and construction operations, agencies will find visualization materials with applications in administration, public information, legal, right-of-way, maintenance, and operations activities.

The speed with which visualization tools will be adopted is related to how quickly agencies adopt the 3-D modeling environment provided in the improved CADD software environments. Because the three-dimensional features of the technology are initially more difficult to use, it is reasonable to anticipate some increase in the learning curve associated with the training of operators and professional staff. However, once the system is mastered there should be no significant increase in production time. The fact is that even current two-dimensional production systems require the gathering and recording of x, y, z information. Thus, no new information is necessary in the data set, only a different and more useful data format.

Because visualization technology applied to transportation is so new, it is not possible to draw any conclusions about what products are most cost-effective, useful, or best received in various venues. However, it can be stated with some confidence that there will be a rapid increase in the use of 3-D and 4-D technology over the next few years. The focus will be on the use of the 3-D modeling tools provided in the current CADD systems that are in widespread use throughout the industry. These offer the advantages of familiarity, dimensional accuracy, and the ability to produce 3-D and 4-D products from the same data base.

CHAPTER ONE

INTRODUCTION

BACKGROUND

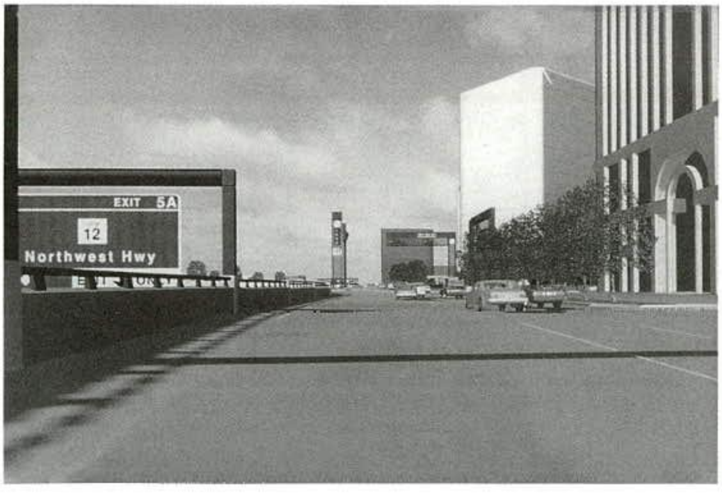
The transportation infrastructure of the United States continues to increase in extent, coverage, and complexity every decade. The increased complexity is a function of multiple transport modes and the need to ensure the highest possible level of safety to transportation users. It is anticipated that future demands on the existing transportation system will lead to even greater functional and modal differentiation in the years ahead. The complicated nature of the nation's transportation system is most apparent in cities that developed in the post-World War II era and have principally grown along, and have been shaped by, highway corridors. The newest generation of limited-access highway is an intricate network of multiple driving lanes, grade separated interchanges, and an assortment of hardware (signs, lighting, guard rails, and the like), to ensure the safety and comfort of highway users. Further diversification can be anticipated with the emerging multimodal emphasis, and a focus on shared transportation corridors.

Increased complexity is accompanied by a need for new tools in all areas of planning, design, construction, maintenance, and operation of the transportation network. This is evidenced in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) which provided for development of management systems for pavement, bridges, safety, congestion, and other elements of the transportation system. Another area where increased complexity has had a significant impact is the tool base used for spatial representation of transportation corridors. The traditional 2-dimensional tools—plans, sections, and profiles—become less and less effective in portraying the 3-dimensional world as complexity increases and it becomes more difficult to clearly visualize all of the construction details and ramifications, even for trained professionals.

External influences also continue to mount as communication with outside interests becomes more important. The growth of cities along transportation corridors, coupled with rapidly increasing urban populations, high visibility, increased public interest, and concerns about the operation, location, and appearance of the transportation network generate more intense public involvement. Because transportation networks are the primary arteries of commerce and are closely tied to the public's image of the city, changes in any part of the system impact the economic and social milieu far beyond the right-of-way of the immediate corridor. These emerging public pressures require that administrators, designers, and managers of the transportation system develop and use a much wider range of information handling and communication tools to promote better design and gain greater public understanding and acceptance.

The variety and quantity of information needed to design and operate the modern transportation system necessitate a team approach and require the use of numerous computer-based tools. As computers have become more common and more accepted, a variety of visual displays have been devised to help people quickly evaluate and assimilate information. The simplest graphic tools are charts and graphs that show the relationships between two or three different variables at the same time. An even more powerful visual device is the thematic map. A thematic map produced from a geographic information system (GIS) places multiple sets of information in 2- or 3-dimensional space and displays the relationships among the various components. However, even the map is of limited value when trying to visualize the relationships between physical objects in space. For example, a map can show a bridge and its supports in relation to other elements on the ground, but a map cannot display the height of the support bents in relation to the support beams.

The need for a more powerful graphic environment has fostered the development of a new generation of computer-based visualization tools. The computer revolution in design graphics began with the development of what have become known as computer-aided drafting and design (CADD) systems. The focus in these systems is to assist the user in presenting, evaluating, and interpreting spatially based information. The shortcoming of the first CADD systems was that they adopted the traditional 2-dimensional orthographic structure used in technical drawing. However, as CADD



systems matured, all of the major vendors have gravitated to some form of 3-dimensional structure (Figure 1).

Closely tied to the evolution of CADD technology is an allied application that is being called "visualization." Visualization is not a self-contained technology in the sense that CADD is. Visualization combines a variety of different technologies: photography, video, computer, and electronic technology to generate visual products that can realistically portray past, existing, or future conditions. It is important to understand that visualization is not limited to single kinds of applications, such as drawing perspectives of objects and places. Using visualization technology, dissimilar kinds of information can be integrated and displayed at one time to examine the relationships. For example, data on surface temperature, relative humidity, barometric pressure topography, and solar radiation can be processed by a model that generates 3-dimensional displays of cloud mass, cloud shape, and wind circulation patterns within the cloud mass. A similar application in transportation is the recreation of automobile collisions. Three-dimensional models of the vehicles are developed with appropriate structural properties, suspension, frame strength, frame shape, weight, etc. A collision is then simulated at controlled speeds and angles of impact to examine the type and rates of failure of each vehicle. This type of visualization is generally classified as "scientific visualization" because the graphic output is controlled by models that can accurately simulate the results of the interaction of specific sets of variables. Because the computer-based tools provide an accurate mathematical framework for developing graphic illustrations, this medium lends itself to a broad range of applications in transportation.

The emerging palette of visualization tools being adopted in transportation has not evolved within the industry. A majority of the current technology has spun off from developments in the motion picture industry, the military, the automotive and aero-space industries, and the medical profession. As might be expected, when computer-based tools originate from different disciplinary roots, there is a lag between the emergence of the technology and the development of refined applications tailored to the needs of a specific industry such as transportation. As noted, the techniques described earlier are more properly called scientific visualization. "Transportation visualization" is a subset of scientific visualization that applies to the unique needs and requirements of the transportation community. It combines elements of the physical world, the dynamics of vehicular motion, and the future condition of the transportation network.

A review of the literature suggests that there have been sporadic uses of computer-based visualization technology in transportation for more than 20 years (*1,2*). However, contemporary efforts to apply visualization technology to transportation can be traced back to the decade of the 1980s (*1,3–5*). This period saw the introduction of inexpensive desktop workstations, increased processing power, and improved color graphic displays coupled with image-capture technology (analog to digital conversion), and scanning. From very simple beginnings the technology has continued to improve at what seems to be an exponential rate. In today's market there is a plethora of multimedia hardware and software capable of producing visual products that were, only a few years ago, the exclusive domain of a commercial film maker's studio.

The increased availability of visualization tools to transportation interests has been accompanied by some confusion, and has raised questions about applicability, cost and cost effectiveness, potential benefits, employee education, space requirements, organizational impact, artistic freedom, as well as staff and public acceptance. These are all basic questions that must be explored before making a major institutional commitment to a new technology.

The objective of this synthesis report is to help transportation agencies and others with transportation interests explore and understand visualization technology as it relates to their particular practice. It is intended to acquaint the reader with the language of visualization, to explore its basic forms and underlying technologies, to describe its current level of use in the transportation industry, to provide examples of its application in transportation, and to discuss basic strategies for developing visualization production capabilities.

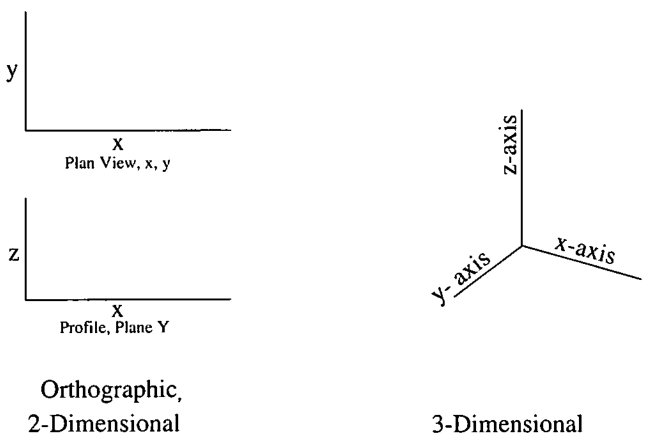


FIGURE 1 2-D and 3-D graphics.

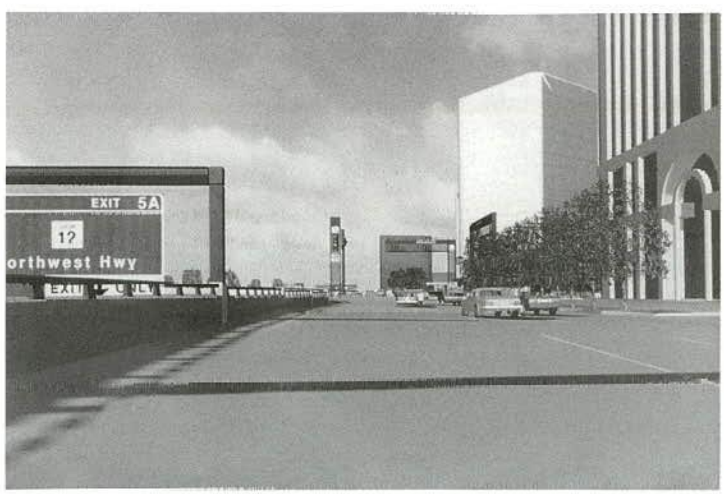
ORGANIZATION OF THE REPORT

The report is presented in five chapters. Chapter 1 is a brief introduction and overview of visualization and the structure of the report. Chapter 2 defines and describes the visualization products used in transportation practice, along with a brief discussion of the application and limitations of the various products. Chapter 3 examines current applications of visualization in transportation. The information presented is based on a review of the literature on the use of visualization in transportation, and a user survey of transportation agencies, consulting firms, and universities. Chapter 4 provides a more detailed discussion of the components—

hardware, software, and peripherals—that make up the technology base of visualization. This chapter will be of particular benefit to administrators and managers who have to make decisions about operations and acquisitions, but who may have little first-hand knowledge of the combined technologies involved in the visualization tool base. Chapter 5 is a discussion focused on a process for planning for and implementing an in-house visualization capability.

Some features added to the report have been included to enhance the reader's understanding of the field of visualization. In addition to the reference list, an annotated bibliography is provided for those who would like to have more information about a particular subject. Citations have been annotated to help readers identify publications that apply to their situations. The bibliography includes some references that have been used in preparation of the text but many of them are sources of information that go beyond the immediate scope of the report. A glossary of terms is also included as a reference for individuals just getting started in the field of computer graphics and visualization. Appendix A is a copy of the survey instrument used to gather information for this report.

The body of the synthesis is focused on the basic components of visualization technology, those components that will not change rapidly over the next few years. The lines between these levels of detail are not always well-defined. In these cases the discussion will usually focus on the basics of the technology rather than operational detail that might be associated with specific types of equipment. The goal is to provide sufficient information to allow users to evaluate proposals and equipment specifications and to ask intelligent questions.



CHAPTER TWO

VISUALIZATION TECHNOLOGIES FOR TRANSPORTATION

THE VISUALIZATION TECHNOLOGY PALETTE

Visualization embraces a variety of technologies used to produce 3-dimensional imagery. To place the discussion that follows in the appropriate context, it is important to acknowledge the component technologies and describe the graphic products that are produced. Although visualization has become a recognized term for describing the technologies and methods associated with computer-generated imagery, there is no universally recognized vocabulary used to describe the various products.

The classification of products and vocabulary used in this report has been developed to describe the current use of visualization technology in transportation. In other publications, readers may encounter different terminology. With respect to vocabulary, every effort has been made to use terms that are consistent within the industry of the component technology. For example, when discussing video technology, the vocabulary follows terms common to that technology. A glossary of terms is also provided to assist readers with the language of the industry.

3-D AND 4-D MEDIA

All visualization uses 2-dimensional media to convey an understanding of the 3-dimensional world. Some familiar 2-dimensional products are photographs, television, movies, and perspective drawings (Figure 2). Regardless of the medium, a visualization product translates to a 2-dimensional image that represents or depicts a 3-dimensional setting. The major difference between the 3-D and 4-D products is that 3-D products are static and 4-D materials simulate motion.

Static images are single frames that represent a view from a fixed point at a single instance in time. Examples of static images are photographs and perspective drawings (Figure 3). Media such as video and dynamic computer graphics that simulate motion provide greater flexibility because they can represent multiple views from a series of sequential viewpoints over a period of time.

In the course of compiling this report a number of different terms were encountered for describing visualization imagery. The context in which these terms were applied was not always clear and could be misleading. For this reason the following definitions are provided to establish the use of various terms in the context of this report.

3-D Graphics

As used here, the term "3-D graphics" will be used to describe any static 2-dimensional image that portrays a space or an object with three dimensions defined by x,y,z coordinates. "Renderings" or "artist's concepts" will be used to describe an image that is created by drawing or painting on a photograph or video frame called a "base image" to generate a near photographic image of a proposed transportation element. In the artist's concept or rendering, no mathematical model is used to ensure that the perspective parameters of the photographic base image is matched to the elements being added.

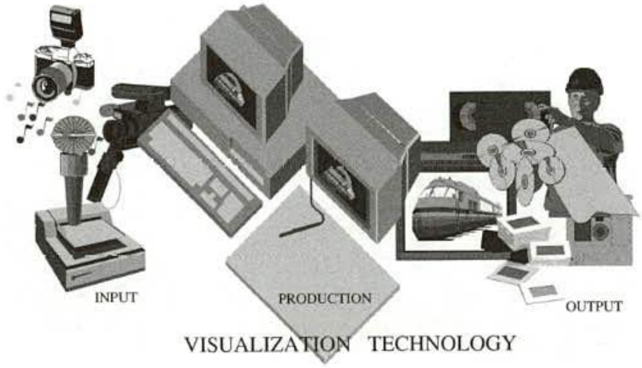


FIGURE 2 Components of visualization technology.

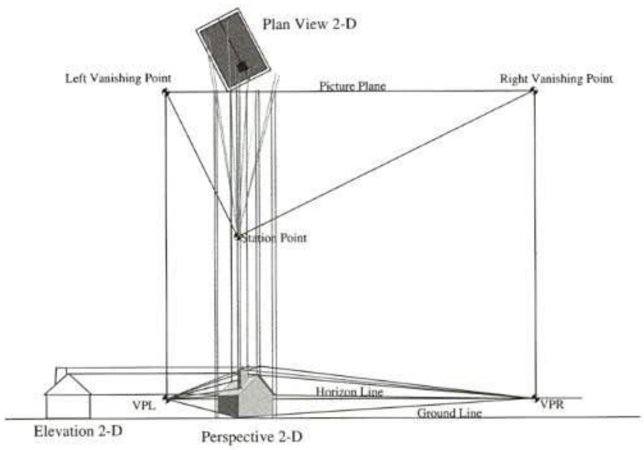


FIGURE 3 Principles of 2-point perspective.

"Composite image" or "photomontage" is used to describe products produced by merging two or more images that have the same viewing station and perspective parameters. Composites most frequently involve merging photographic or video base images for which the camera location and settings are known or are back-calculated. These are then merged or overlaid with a computer image that has been generated using the real-world location and camera settings for the virtual camera (computer camera). This method yields the most visually correct representation possible.

4-D Graphics

The terms used to describe visual products that simulate motion can be equally misleading when related to the lexicon of visualization. In the context of this report "4-D graphics" will be used to describe the full spectrum of dynamic media. Dynamic imagery is any series of 3-D images that are sequentially related in space and time. When these images are viewed at the rate of 15 to 30 frames per second (f/sec) they create the illusion of motion. At frame rates less than 15 f/sec, motion appears jerky. Frame rates above 30 f/sec are used to generate slow-motion sequences. Thus, the time reference is considered a fourth dimension. "Video" will be used to describe unedited images recorded with a video camera. "Animation" refers to dynamic media made up of synthetically generated or composite images. "Real-time graphics" or "dynamic computer graphics" refers to dynamic computer images generated in near real-time, based on the user's interaction with the computer software. The discussion that follows relates this basic vocabulary to more detailed descriptions of specific visualization products. The dialogue is divided into the two broad categories of 3-D and 4-D imagery.

3-D VISUALIZATION IMAGERY

Renderings and Artist's Concepts

Computer-based renderings and artist's concepts are created by "painting" new elements on a base image. Base images can be converted from photographic or video formats by using scanners for slides and paper photographs or "image capture boards" for video. Image capture boards are computer-based scanning devices that convert analog video signals to a digital format. Optical scanners convert slides or paper images from a continuous tone signal to a digital format.

"Paint" is a generic term used to characterize computer-based softwares that create or modify digital images. Paint softwares have an interface that provides a palette of artist's tools that range from freehand line drawing to air-brush painting and texturing. The combination of scanning and image paint technologies makes it very easy to modify base images and to create new near-photographic quality images.

In the last few years a new class of software for manipulating 2-D images has emerged. Labeled "image editing software," these products offer the traditional artist's tools associated with paint programs with added features that include color manipulation, compositing, and image processing. Image processing comprises a diverse set of tools that include sharpening and blurring, brightness and contrast, gama correction, edge sharpening, and others. Sharpening and blurring operate on color or contrast boundaries in an image. To sharpen an image, the contrast is increased and to blur, the contrast is decreased. Sharpening can highlight edges and blurring could be used to create a visual effect similar to fog. Brightness and contrast controls achieve the same effects as the same controls on a television or computer monitor. Gamma correction is a feature that enhances the detail in the lighter or shadowed areas of a picture. A common problem with images taken in bright sun is the loss of detail in deep shadow (Figure 4). The gamma correction tool can be used to enhance the detail in these deeply shadowed areas of the picture. Image editing softwares have application in all 3-D image work as well as some application in frame-by-frame editing of 4-D materials.

The levels of realism achieved with paint or image editing software depend on the quality of the base image and the skill of the artist–operator. Renderings and artist's concepts can be very convincing, and they can be very useful in communicating design concepts. However, it is important to remember that manipulated images are not based on geometrically accurate elements and the resulting image may not truly reflect the actual outcome. This is very important when images are used for public communication.

Image Composites or Image Compositing

The "composite image" usually begins with a photographic or video background image just like the rendering or artist's concept. However, in the compositing process the background image must be taken so that the geographic location parameter, the viewpoint, the camera settings, and

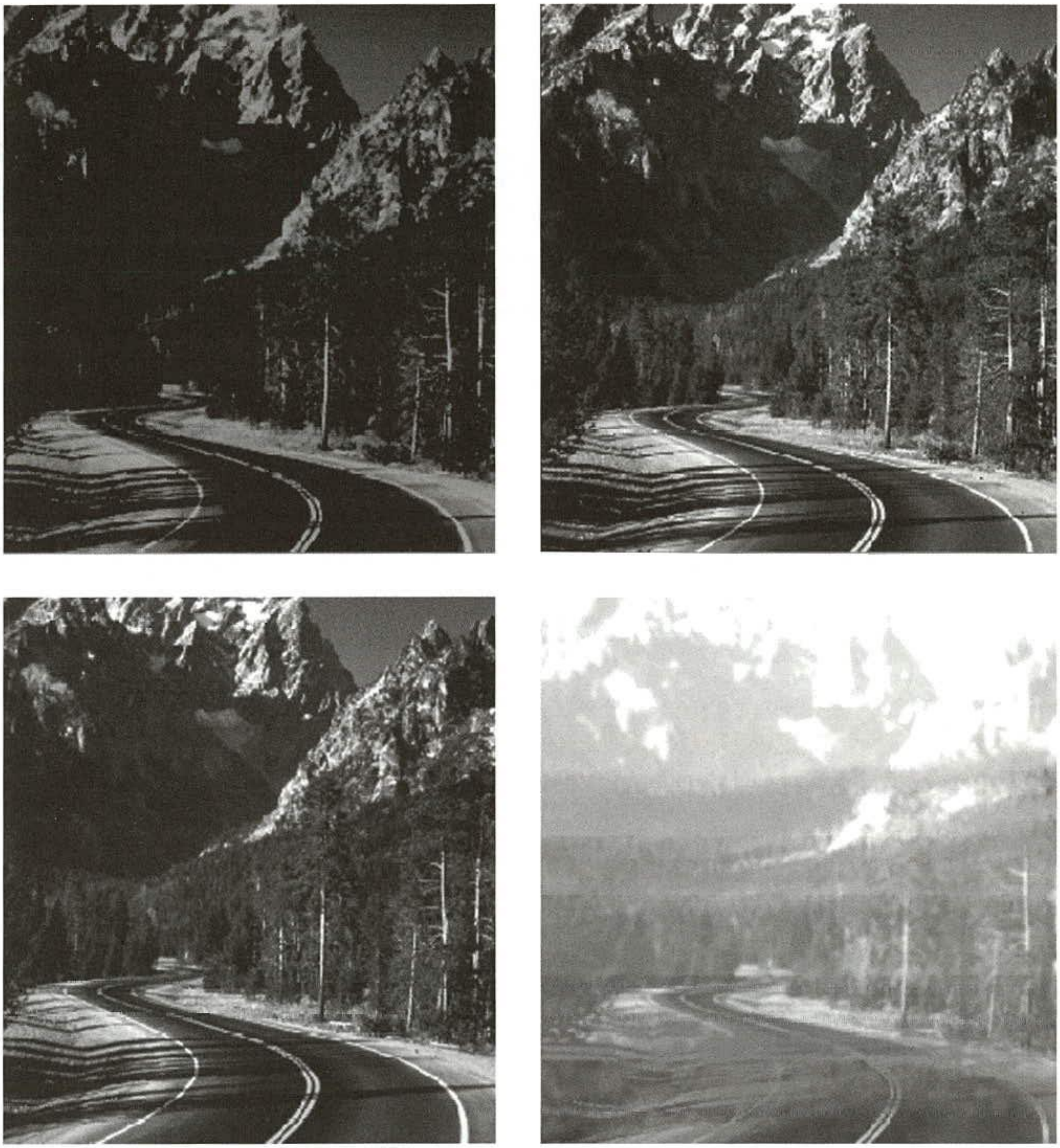


FIGURE 4 Example of effects using image editing software.

the actual size of some objects in the scene are known. This is necessary so that future views can be "matched" to provide geometrically and dimensionally correct images.

After the base image is acquired and scanned into the computer, a model is generated of the new transportation elements. These might be a bridge, the addition of new driving lanes, noise walls, landscape development, or similar elements. The 3-D computer model is then used to generate a perspective using the same camera station point and camera settings as those of the original background image. These two images are then overlaid and adjusted to create the final composite image. This method results in a more accurate representation and is generally more defensible. With care, an error margin of less than two percent should be possible. This range of error is generally accurate enough for all but the most exacting transportation applications.

Gathering base data for a composite imagery is more time intensive than for the artist's concept. On the other hand,

if several different images of a site are required, developing composite images can actually be faster. This is because the 3-D model only has to be constructed once. The same model is then used to generate the overlay for each of the selected views taken in the field. This fact, coupled with the flexibility of the approach, and the increased realism, make it the most desirable method for most transportation visualization applications. Even if an animated sequence is produced, additional still renderings can be produced quickly for added emphasis and portability.

4-D VISUALIZATION MEDIA

Video

Video combines the advantage of photographic accuracy with real-time motion. In the context of this document, the term video applies to segments of unprocessed video. Products that involve considerable postproduction work to mix edited images frame by frame or synthetically generated animation clips, or to add voice-over sound, titles, and transition effects would be considered in the category of "multimedia." Video has the advantage of being immediately accessible without further processing. Access to postproduction editing technologies can further enhance the functionality of video by allowing the addition of text and titles, joining separate video segments and doing voice-over narration or sound track additions. Software developed for multimedia purposes provides an in-house alternative to commercial postproduction houses that have traditionally provided these services.

Dynamic Image Compositing

This technology is an extension of single-image compositing described in the previous section. In its simplest form, dynamic compositing involves overlaying a synthetic image over a dynamic video sequence instead of a single frame. This technique allows motion to continue, which makes a scene more lifelike. Depending on the sophistication of the image editing software, some very realistic effects are possible. The primary disadvantage of this form of dynamic compositing is that the camera viewing point is fixed.

A more time intensive form of image compositing is frame-by-frame editing. This method requires that each frame of base be overlaid with a perspective generated specifically for that frame. This method allows the camera used to acquire the base imagery to move freely through the site to be viewed. In this method careful field records must be taken so the virtual camera of the computer can be matched to the base footage. This method is extremely demanding in terms of time and requires a high degree of sophistication in hardware, software, and technical capabilities in order to produce a product of good quality.

Animation

Animation is a set of sequential images that, when viewed at rates of 15 to 30 frames per second, create the illusion of motion. Because this imagery portrays movement through space over a period of time, it is often called 4-dimensional or 4-D graphics. The key characteristic that differentiates animation from other forms of 4-D imagery is that all frames in the animation sequence are produced synthetically from a 3-D computer model that defines all points in the graphic data set in 3-D space. That is, each point is defined in relation to an x, y, and z axis. Thus, all of the images in an animated sequence are generated from a common 3-D model seen from different points of view.

Animation has the advantage of allowing a viewer to see what it would be like to move through transportation corridors not yet built. The path of the "camera," its angle of view and direction can be changed to show any desired points of view. This is a distinct advantage over simple dynamic image compositing where the viewer is locked to a single viewpoint.

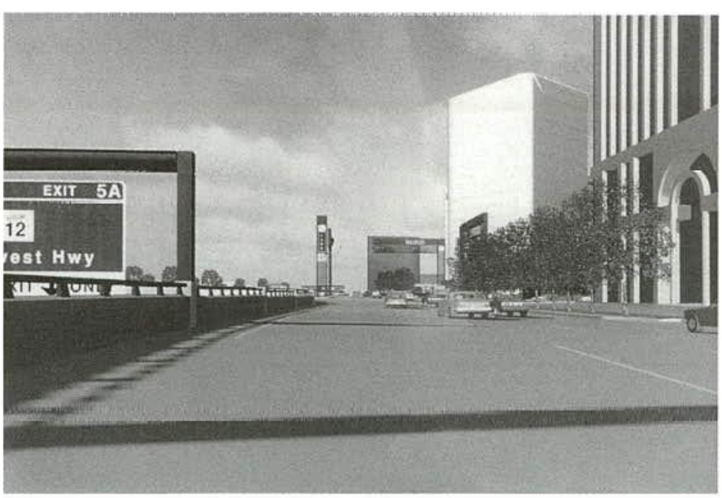
An example of animation can be achieved by flipping the lower right corner of the pages in this document.

Related Technologies

Two other technologies that are sometimes associated with visualization are stereographics and virtual reality. Both stereographics and virtual reality are often mentioned in discussions of visualization. To keep the discussion as clear as possible, definitions of these two terms are provided to place them in an appropriate context with relation to this discussion.

Stereographics

Stereographics is actually a form of graphic output. The technology uses dual images and optical devices to create the illusion of three-dimensional space. The basic components of this technology have been known for a long time. One of the most common uses of stereo imagery has been in the



area of aerial photograph interpretation and map making. The potential of stereographics as a design exploration and communication tool are in the very early stages of development. There are software systems available that allow the generation of on-screen stereographic displays that, when viewed with the appropriate glasses, cause the images to appear in three dimensions. This technology holds great promise for 3-D design. Very likely, stereographics will be one of the next steps in the evolution of visualization technology. However, with respect to the current state of visualization technology, stereographics is not in sufficiently widespread use to justify more detailed consideration in this document.

Virtual Reality

Virtual reality is a term that is frequently associated with many forms of computer graphics. However, virtual reality is more properly used to described a suite of technologies that integrate real time, full motion, or stereographic imagery with other input/output devices that control all stimuli to the user. Virtual reality generally relies on specialized devices, such as head-mounted displays and data gloves, or entire rooms to provide direct interaction with the computer generated virtual world. A key concept in virtual reality is controlling the sensory stimuli in the physical space the user currently occupies. By limiting visual, audio, and other sensory stimuli to the computer controlled, 3-D virtual world, the user can function in a manner very similar to the real world. The best example of virtual reality in common use is in high-end flight simulators used by commercial airlines, NASA, and the Department of Defense.

An example of virtual reality technology applied to transportation might begin with a virtual world that contained a model of a site where a bridge was to be constructed. The operator would then be able to select basic bridge components in real time and move them around in virtual space. The experience could be enhanced with sound or by sensing resistance of the soil to the blows of a pile driver, etc. The design process would allow designers to explore numerous options, such as physically placing bents, changing vertical and horizontal alignment properties of the driving surface, and checking for deflection and movement of other structural elements and connections in the structure.

The technologies required to produce virtual reality displays are evolving rapidly. However, there is no evidence of any emerging use of virtual reality in transportation other than in the area of flight simulation and pilot training. Because the technology is largely experimental no further discussion of virtual reality is included in this report.

CHAPTER THREE

APPLICATIONS OF VISUALIZATION TECHNOLOGY IN TRANSPORTATION

SURVEY: USE OF 3-D AND 4-D VISUALIZATION IN TRANSPORTATION

A survey was mailed to the state and provincial transportation agencies of the United States and Canada to determine the current use of visualization technology in transportation practice. A copy of the survey instrument is included in Appendix A. Responses were also sought from selected transportation consulting firms and research universities working with visualization technology in transportation.

The survey questionnaire included five sections. Section I was to determine awareness of the variety of visualization tools. Section II sought information about the audiences for which visualization products were being prepared. Section III focused on the production environment and methods for acquiring visualization products. Section IV asked for information about agency perceptions of visualization tools with respect to relative value, cost-effectiveness, and public acceptance. Section V requested general information about the responding agency's organization and size.

AWARENESS AND USE OF VISUALIZATION TECHNOLOGY

The responses to the items in Section I of the survey document are summarized in Figure 5. Of all of the basic visualization tools, video has clearly achieved the highest level of use among transportation interests. More than 65 percent of the agencies responding indicated that they were using video in some capacity. About 55 percent reported using paint/image capture or image compositing as part of their tool base. There was very little indication that dynamic compositing was being used. Animation was cited as having some use by 38 percent of the respondents and was in common use by only 10 percent. The other forms of visualization—multi-media, stereographics, and virtual reality—were cited by fewer than 10 percent of those responding.

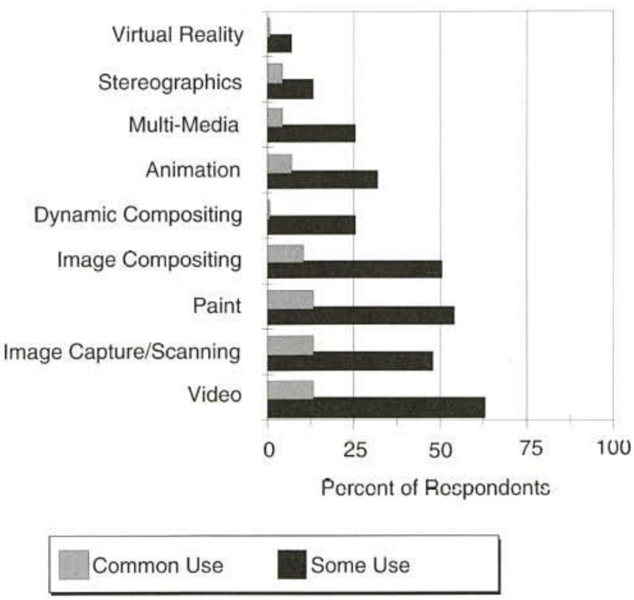
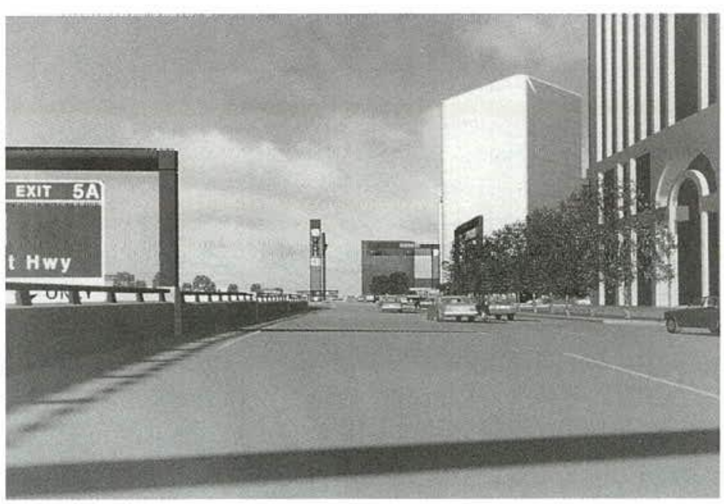


FIGURE 5 Use of 3-D and 4-D visualization.

The graph shows that 10 percent of the respondents indicated they were using virtual reality. It is believed that these cases involved a misunderstanding of virtual reality technology. Further follow-up showed that reference was being made to computer animation rather than virtual reality as defined in this report. Overall, there seemed to be a high level of awareness of visualization technologies. This was true even in the agencies that indicated little or no current use.

AUDIENCE

Because the production of visualization products involves a considerable investment in equipment, software, and training, it is important to know more about the audiences for whom the materials are being produced. Audience refers specifically to the groups of individuals for whom visualization materials are being prepared. This part of the survey focused on three different venues for visualization materials: public participation, internal review, and public information/education. The results are summarized in the graphs shown in Figures 6 through 8.



Public Participation

Public participation along with public information/education account for the majority of cases where 3-D and 4-D products are produced and used (Figure 6). As many as 65 percent of the responding agencies indicated that they have used 3-D or animated materials in public participation forums. The use of 3-D materials was generally uniform across all activities mentioned in the survey. Activities associated with soliciting public opinion and answering the questions of special interest groups topped the list for the use of animated materials.

Interagency and Intra-Agency Project Development and Review

More than 50 percent of the responding agencies were using some form of visualization as part of their interagency planning and design process (Figure 7). Most of the focus was on evaluation of alternatives, environmental conflicts, and design aesthetics. This seemed to be true for both 3-D and 4-D materials. Specific design related uses, such as evaluation of sight distance requirements or traffic control were infrequently cited. This same pattern was evidenced in intra-agency relationships.

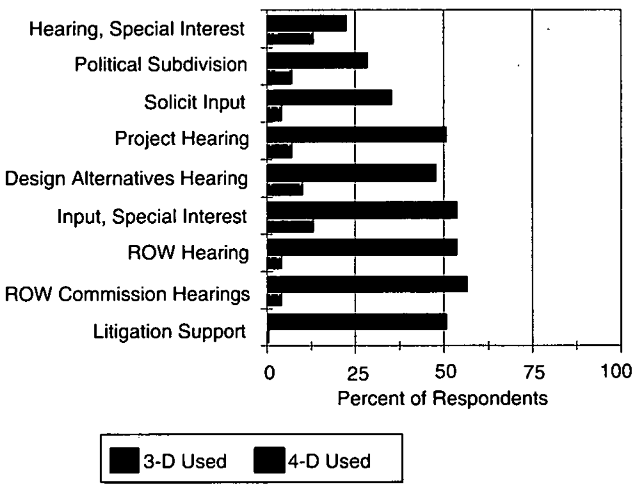


FIGURE 6 Use of visualization in public participation forums.

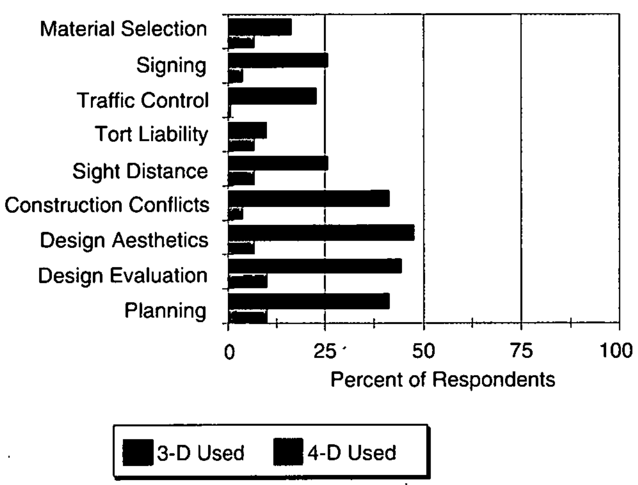


FIGURE 7 Use of visualization in intra-agency reviews.

Public Information and Education

Fewer than 25 percent of those responding indicated that they were currently using animation and other 3-D visualization products in their public relations activities (Figure 8). The organizations using visualization as part of their public information activities tended to be in the more urbanized states. The most frequently cited use of visualization materials was for notification of route closings and rerouting of traffic. Other activities included public service announcements (PSA) that paralleled the uses in public participation such as environment, planning, and aesthetics.

3-D and 4-D MEDIA PRODUCTION AND PROCUREMENT

The third survey section sought information about base materials used for producing visualization graphics, the types of hardware and software used in the production process, and whether visualization materials are produced in-house or by outside vendors. The questions were separated into sections on still imagery, 3-D media, and animated materials, 4-D media.

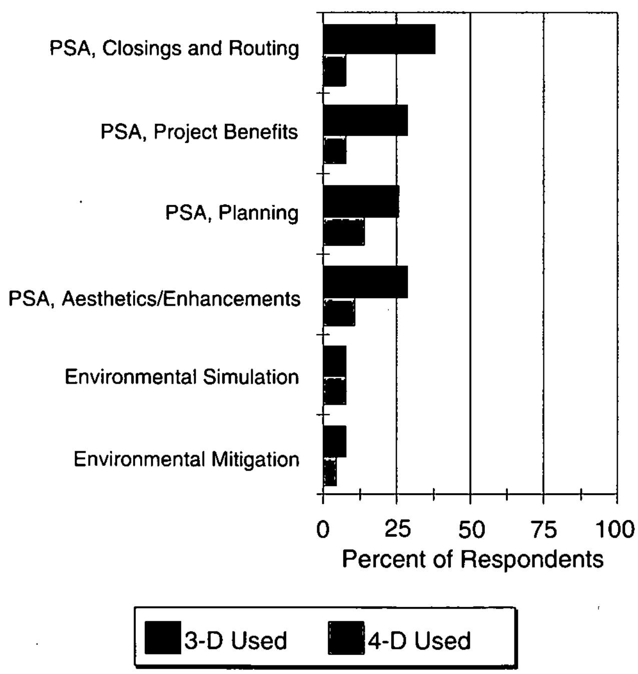


FIGURE 8 Use of visualization in public information and education.

Sources of 3-D and 4-D Base Information

CADD files and digital terrain models (DTMs) were the most common sources of base information. Seventy-one percent of the agencies using 3-D products use CADD and DTMs and 54 percent of the agencies developing 4-D products use CADD and DTMs as their primary data sources. Video was equally popular for obtaining base imagery for 3-D products. More than 50 percent of those producing visualization materials still reported using paper plans and profiles as a source of base information rather than digital files. This means that there is still a great deal of time being spent converting paper information to digital files.

Sources of 3-D and Animated (4-D) Materials

A majority of the transportation agencies using visualization generate the materials within the agency (Figure 9). In the case of 3-D imagery, 62 percent of the materials are produced in-house and 35 percent of the products were acquired through vendors. In the case of animated imagery, over 75 percent of production is being handled within the agency.

Hardware for Production of 3-D and Animation Materials

Intergraph equipment clearly dominates the production environment for both 3-D and 4-D materials in transportation. More than 60 percent of responding agencies use Intergraph hardware as their primary visualization production platform. The PC-DOS/Windows environment was second with just over 20 percent, followed by the Macintosh, at slightly over 10 percent. Other Unix platforms accounted for the other types of equipment.

Significantly, more than 93 percent of those responding were considering the purchase of equipment and software to produce visualization materials. The equipment under consideration is most often Intergraph, followed by Sun and Silicone Graphics workstations. PC-DOS/Windows was the third choice followed by the Macintosh at less than 5 percent.

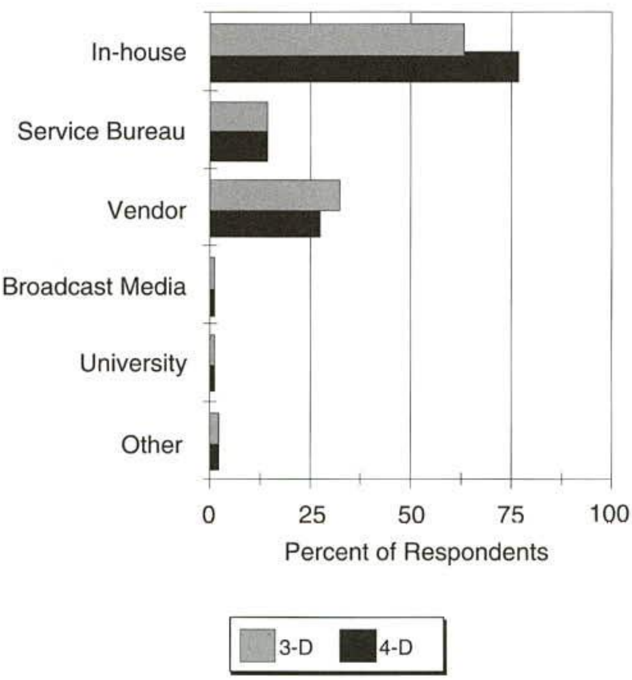


FIGURE 9 Source of 3-D and 4-D products.

Output Media for 3-D

Slides, photographs, and video were the most frequently used media for the output of 3-D products (Figure 10). There was also a very widespread use of computer slide show capabilities; more than 50 percent of those responding indicated some use of computer slide shows. Interestingly, a few respondents indicated the use of laser disk and several others indicated that they were using photo CDs as a primary output medium. This was not anticipated because laser disks with read/write capabilities are expensive and usually used

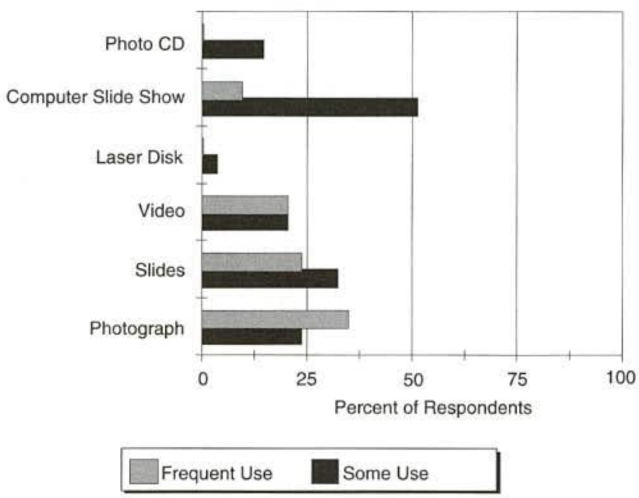
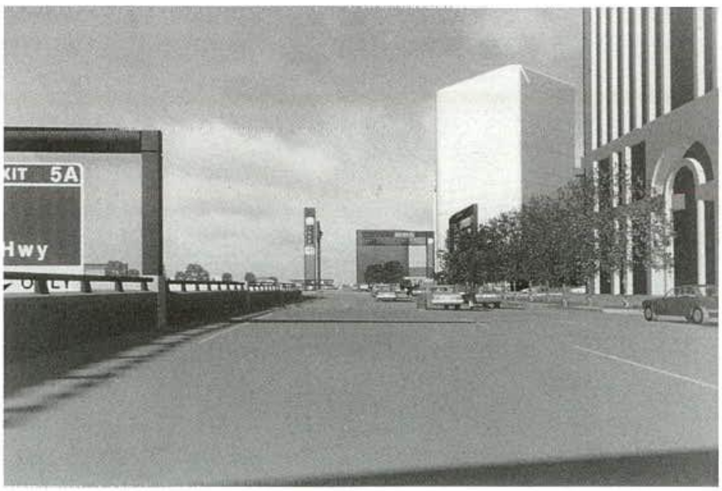


FIGURE 10 Output media for 3-D products.



as editing devices. So-called "WORM" media, meaning write once/read many, include both laser disks and photo CDs. These types of media are usually used as archiving techniques rather than distribution media. Categories not included in the survey that have numerous citations for output of 3-D materials were pen plotters and various types of printers. This was an oversight in the survey and this technology will probably continue to be a valid output format for 3-D materials in the near future.

Output Media for 4-D

Computer slide shows and video dominated the responses for 4-D output (Figure 11). These were followed closely by slides and photographs. The large percentage of respondents citing slides and photographs as output media for 4-D materials suggests that there is still some confusion about the difference in 3-D and 4-D materials. Slides and photographs are by definition 3-dimensional media, whereas video and computers can be used for 4-D display.

There was also some indication that compact disks and laser disks were being used. These are appropriate media for 4-D output. However, it was not clear from the responses if these were the primary distribution media or editing and archiving methods.

Applications for Visualization Products

Issues related to environment seem to top the list of areas where 3-D and 4-D materials are being used. Aesthetic factors, as might be expected, are also very high on the list (Figure 12). Bridge design dominates the technical areas where visualization materials are being used in transportation. Other technical categories include: traffic simulation, sight distance, lighting issues, and accident reconstruction.

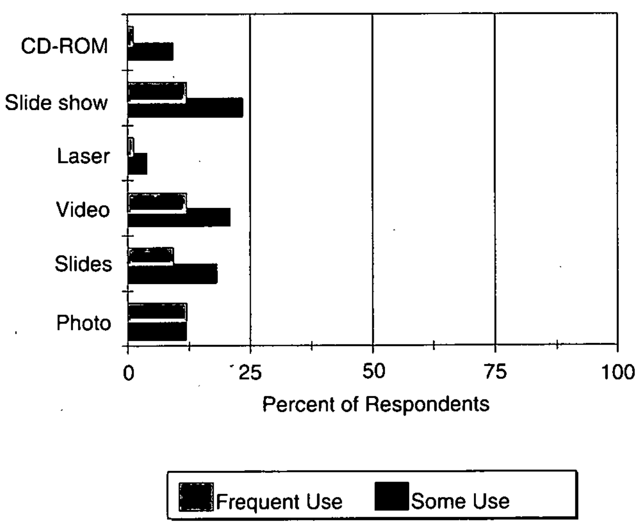


FIGURE 11 Output media for 4-D products.

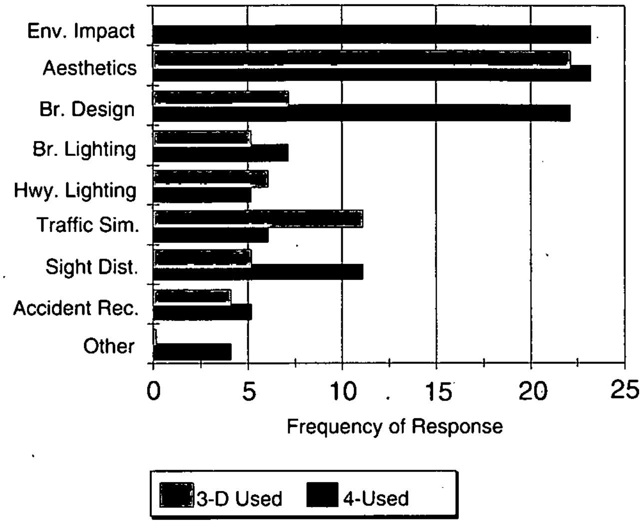


FIGURE 12 Application area for visualization products.

In almost every category, 4-D dominated as the primary tool. The only exceptions were in the areas of highway lighting and traffic simulation. It seemed unusual that a dynamic medium would not have been used for traffic simulation. However, this could be related to the use of "plan view simulations," which may not have been considered as 4-D displays.

Image Acquisition and Video Formats for 3-D and 4-D

Scanners are the dominant hardware used for image capture associated with 3-D production. Very few agencies indicated the use of video image capture cards as a primary input device for 3-D work. Because 4-D work typically does not use base images, it was not surprising that little use of scanners or video was reported in this regard.

In cases where video was used, the VHS format seemed to be the most popular. This was followed by M-2, Betacam, and finally the Hi-8 format.

IMAGE QUALITY AND REALISM

This section sought to determine perceptions about the relative importance of image realism and other measures of image quality, such as resolution and color palette. Answers to the questions require subjective judgments, but it was believed that this would be helpful in understanding the focus of current visualization practice. The results of this section are summarized in Figure 13. Please note that the original survey allowed a scale of four choices: *not important, important, very important, and extremely important.* Figure 13 combines the "important" responses into a single item letting the "not important" category stand alone.

From the responses received it appears that ease of generating alternatives and being able to construct mathematically

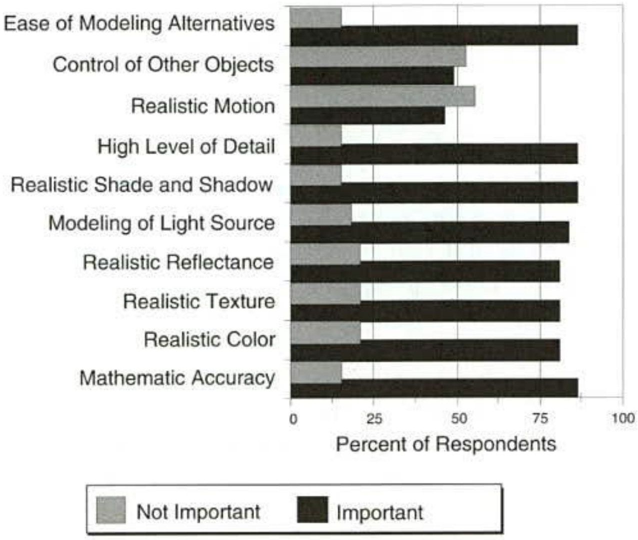


FIGURE 13 Importance of realism and ease of operation.

accurate representations of projects are perceived as the most important criteria. These were closely followed by the capability to render with a high level of detail. Where detail was concerned, realistic shade and shadow ranked the highest, followed by realistic color, reflectance, and texture. The functions perceived to be the least important were the ability to create realistic motion and to control the motion of other objects.

BASELINE DATA

Baseline data were collected in order to classify the responses. Surveys were sent to all 50 state transportation agencies in the United States and to the provinces of Canada. One Canadian province and 29 states returned the survey, a 58 percent response rate. In addition to the state agencies, several universities and transportation consulting firms were contacted. Responses were received from two consulting firms and five universities. This yielded a final total of 36 usable responses. A majority of the responses from states came from data management, CADD, or landscape architecture services divisions within the various agencies. The responses from universities came from architecture and landscape architecture departments. Consulting firms that responded were all engineering practices.

Because the responses represent a range of size, geographic region, and use of technology, the results of the survey provide a reasonable overview of the current use of visualization in transportation.

INTERVIEWS

To supplement the survey and clarify some of the questions it raised, followup interviews were done with several units that have been using visualization technology in transportation. The interviews were most useful in developing a better understanding of overall perceptions of the technology and how it is being used.

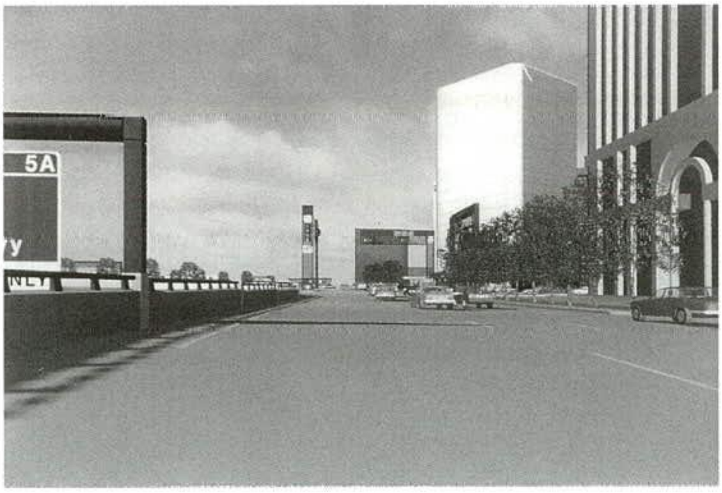
New York Department of Transportation

The New York Department of Transportation (NYSDOT) has been using transportation visualization in selected projects for the past several years. Currently, the production facilities are centralized so that the various technologies can be evaluated and techniques developed. The long-range plan, however, is for each district to have its own equipment and staff. In this way, the technology will be closer to the end user and more responsive to the district's needs.

The decision to develop and use visualization technology was driven by the need to increase public participation in the design process. Difficulties resulting from the use of traditional engineering drawings have led to miscommunication in the past, with subsequent misunderstandings between the department and the public it serves. The emphasis, however, is not on persuasion, but on communication. By using visual techniques that rely more on realistic presentations than symbolic representations, the department believes that public meetings will provide both more useful feedback on the design and improved public relations.

During one recent project, an informal survey was conducted to measure the results. An important urban corridor, approximately 4 miles long, contained many significant pedestrian hazards, including several school zones. A sequence of 10 "before and after" images was selected as the presentation format. Using InRoads software, the corridor improvements were modeled and rendered through Modelview. Adobe Photostyler was used to composite the images and for final retouching. Plan sheets were displayed alongside the visual images. Results of the survey, while unscientific, were very encouraging with most of the responses indicating a high to extremely high approval rating for the visual images over the plan sheets.

Currently, a typical project requires 4 to 5 weeks lead time, which includes 3 to 4 weeks of intense production time.



NYSDOT has chosen to develop its visualization capabilities in-house rather than use outside providers. This decision was based primarily on two factors. First, most of the necessary hardware and software were already available, and second, the agency's cost analysis indicated a significant cost savings could be achieved over the standard commercial rates. Hardware used for the visualization products includes an Intergraph 6050 workstation, an HP flatbed scanner for color input, and an HP 650 plotter and a thermal printer for output. Software including Microstation, Modelview, and Inroads are available for the workstation. Aldus Photostyler and Pixar's Renderman are used in a PC environment for photo retouching and rendering respectively. Fortunately, an individual was available in-house whose 8 years of 3-D modeling experience provided the core skills required. Shortly, two additional team members will be added to provide staff training as the visualization efforts become decentralized.

NYSDOT is beginning to use computer animation for certain projects instead of still images and hopes to move toward the use of integrated 3-D data bases instead of the traditional 2-D form. Animation is viewed as a better technique for displaying the impact of transportation modifications. It was noted, however, that significantly more training is required, for which the agency expects to use vendors or outside consultants.

Minnesota Department of Transportation

The Minnesota Department of Transportation (MnDOT) began using visualization products in the 1980s. Early in the development, graphic artists were used to produce renderings of high-visibility projects or complex projects where a high degree of misunderstanding was possible. These renderings were used for public meetings and by project managers to study such things as road alignments and visual analysis. With the development of the electronic technology, the artist's concept has been supplanted by the digital version. Referred to as "photo simulation," about one-half of the state's districts use this technology for major projects.

Over time, an approach has been developed that has proven useful for most of MnDOT's work. The project is first analyzed to identify those parts with substantial complexity or a high degree of significance. Views are selected—either aerial, low elevation or ground level—that best portray the condition. The background images are photographed from these locations and converted into digital form using a Nikon film or flatbed scanner attached to a Macintosh Quadra 950. Depending on the project, from 4 hours to a week may be spent on each image. For the quicker images, artist's concepts are still used, but when appropriate, a 3-D model is developed and used as a guideline for the artist's rendition. Microstation and Modelview are used for the modeling. Adobe Photoshop provides for artist's concepts, retouching, and image compositing. Final output is produced with either a film recorder or a dye sublimation printer from a commercial graphics production facility. While most of the visualization products are produced in-house, outside consultants are also used.

Most of these visualization products are actually accomplished before and during preliminary design phase. Photo simulation is used for environmental studies, conceptual design, and identifying the scope of work, as well as the development of design alternatives. Following the preliminary design phase, photo simulation is again used for the final design. Because of the time and expense required, animation is not being considered until after the final design phase when the project details have been established.

MnDOT has found it valuable to use a team concept in its visualization process. Typically, a graphic artist and a landscape architect work together to develop visualization products. The use of photo simulation has several advantages. A higher level of realism can be achieved than with the traditional methods. In addition, the computer allows alternatives to be generated faster, which results in more cost-effective products being developed. The use of photo simulation for both public meetings and as a design aide has met with a high degree of public acceptance with no apparent downside.

Texas Department of Transportation, District 12, Houston

The Houston District of the Texas Department of Transportation (TxDOT) has used 3-D visualization for several years and a politically sensitive project in the Houston Galleria area in 1991 provided the impetus to begin exploring the use of 3-D modeling, digital compositing, and animation. Several types of products were produced over the next 3 years in support of the planning and public participation phases of the project. This was quickly followed by successes on other sensitive projects.

With the enthusiastic support of the District Engineer, staff has increased along with equipment and general capabilities. The Design Visualization Section of Information Systems has been responsible for 10 major projects in the last 4 years and several minor ones. While previous efforts have been directed toward public communication, aesthetics, design investigations, and right-of-way litigation, visualization for construction sequencing, tort litigation, and public affairs announcements are anticipated in the near future.

For a typical project, the process is well defined. Starting with RDS information (the American Association of State Highway and Transportation Officials (AASHTO's) earlier Roadway Design System) and any available geometric files, InRoads is used to generate the road surfaces. Stripes, crash cushions, and other highway elements are generated in a conventional manner using Microstation. Physical elements outside the right-of-way, including structures, topography, and landscape, are also created in Microstation. Views are usually generated at this point as a "check set." Because much of their work is developed for Advanced Planning,

design engineers are routinely contacted to view the check set so that they may evaluate the design at the earliest possible stage.

Following the modeling phase, these Microstation files are imported into Modelview where the process is completed. If single views are to be produced, a photographic background image from the desired viewing location is displayed so that the virtual camera's parameters can be accurately matched with the background view. If animation is to be produced, key frames are created, which in turn, are used to generate a camera path. Texture mapping is used wherever possible, especially for buildings and vegetation. A flatbed scanner is used to scan these texture maps into DP/Studio or Adobe Photoshop. After sizing and retouching, they are attached to surfaces directly in Modelview. Rendering of the final Phong-shaded sequence is accomplished at a resolution of 1024 × 964. Single frames are rescaled to a resolution of 512 × 482 to remove unwanted visual artifacts from the images, a technique called anti-aliasing.

Currently, the animation sequence is stored on read/write optical storage media and sent to TxDOT's Information Systems Division in Austin where a single frame animation controller is used to put the sequence onto SVHS video tape. Soon to arrive is an Intergraph Video Engine that will allow control of the entire production sequence to be accomplished in-house.

In deciding on the use of digital compositing or animation for a given project, both the available time for producing the visualization products and the purpose for which the visualization is intended are considered. If only single views are required, only visible components of the highway and only minimal elements outside the right-of-way need be modeled, which speeds the process. Additionally, errors are much easier to correct as image retouching can frequently be used instead of correcting the model geometry and re-rendering. Animation is frequently the technique of choice because the continuous sequence of views is less biased and is closer to the driver's actual experience. Particularly for design development, animation is much preferred as a tool for identifying design problems.

The Design Visualization Section of Information Systems employs a system manager and two technical staff full time. One of these individuals has extensive experience in highway design, and the other has a background in art and communication. This diversity in background is very beneficial because of the different skills required to produce visualization pieces. The training of the team has been accomplished either through specific Intergraph software courses or through in-house training.

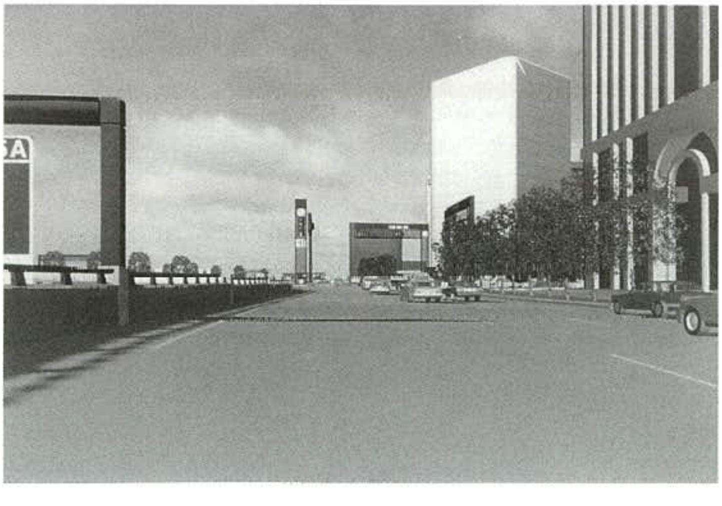
The equipment within the Information Systems Section includes 3 CLIX Intergraph 68080 workstations configured with 96 MB of memory and a 1 GB disk drive. In addition, 7 GB of external disk storage is available and a 1 GB optical drive is used for backups and permanent archiving of images. A 66-MHZ 486 PC with 32 MB of memory is used for running PC-based software including Photoshop, CorelDraw, and PageMaker. A network links the PC and Unix workstations. Input/output (I/O) devices include a 24-bit, 4-color dye sublimation printer, an 8 ½ × 11 in. thermoprinter, a 24-bit flatbed scanner, and LaserGraphics slidemaker. Access to other devices, such as a Xerox 5770 color copier, and 36-in. color plotters are also available. For rendering purposes, access to four additional CLIX servers at night and on weekends doubles the effective rendering capability. Over a weekend, 60 seconds of high-detail animation can be produced on these machines.

With more than $400,000 invested to date, the addition of the Video Engine and 2 Panasonic DS850 SVHS tape decks will permit the entire production to be accomplished in-house. While the use of outside post production houses has been investigated, they have been cost prohibitive. On the other hand, service bureaus offering I/O services for single photographic images have proved to be a good option when the volume of work is small.

LITERATURE REVIEW

It would be difficult to pinpoint the beginning use of computer-based visualization technology in transportation. The transportation industry embraced computer technology very early. However, visualization has depended on the evolution and development of computer graphics, which is a relatively recent technological development. Beginning in the late 1960s and into the decade of the 1970s, computer graphic systems evolved slowly and there is little evidence in the early literature of any concentration on transportation applications specifically. Computer equipment was still quite large and cumbersome, software was limited, there was very little available in the way of graphic displays and there were only crude devices available for graphic output. However, even during this period the electronics, automotive, and aerospace industries were beginning to develop the basic computer graphic technology. The research was usually associated with the major defense contractors. It was this early work that led directly to the development of modern CADD systems.

There is a considerable body of literature on the specialized subject of computer graphics that documents the early



period of computer graphics development right through the present day. The two primary sources of information are the Association for Computing Machinery (ACM) and the Institute of Electrical and Electronic Engineers (IEEE). The ACM is organized into special interest groups, one of which is the Special Interest Group on Computer Graphics (SIGRAPH) which holds annual meetings and publishes refereed proceedings. SIGRAPH tends to focus on the art and science of visual technology. The IEEE publishes a regular journal, *IEEE Computer Graphics and Applications*, which tends to focus more in the area of scientific visualization. While these sources contain a wealth of information about the mechanics and application of computer graphics, they offer little in the way of direct application to transportation.

The real genesis of computer graphics applications in transportation as noted, evolved from early automated drafting systems. This early technology became known as Computer-Aided Drafting and Computer-Aided Mapping (CAD/CAM) (*3*). Then, in the late 1970s, with the development of the microprocessor and the advent of the stand-alone workstation and more sophisticated color displays, computer graphics began to mature rapidly. From about 1984 through 1990 CAD began to be adopted by the transportation industry at large (*1, 3–5*). As the evolution continued between 1985 and 1988 developers began adding data management modules and links to the basic CAD/CAM softwares and the modern day CADD systems began to emerge.

From the late 1980s to the mid 1990s, the focus in the transportation literature on computer graphics has tended to continuing the evolution of CADD systems (*6*). A periodical index search using CADD and Transportation as the key words shows 148 different entries and they all fall between 1987 and 1994. Using Computer Simulation and Transportation led to some 487 citations. Further examination of these articles and papers revealed that the early focus in transportation graphics applications was on the underlying processes with little attention given to the graphic output. In most all cases, the final product of a modeling effort such as traffic simulation, was a 2-dimensional display. No articles were found in the leading journals from 1985 through 1990 that related specifically to transportation visualization. However, there were 3-D/4-D visualization efforts being undertaken in other disciplines that related to transportation and transportation facilities. Barsam and Simutis's work on terrain visualization (*7*), Orland's work with people's perceptions of street trees (*8,9*) and Sipes' early work with the U.S. Forest Service (*10*) all had tangential impact on the emergence of visualization use in transportation. From about 1989 to date there has been a marked escalation in the use of visualization technology particularly with respect to projects that are being built in very sensitive, usually urban areas. Two of the earliest projects to integrate 4-D computer visualization technology in the development process are the Boston Artery/Tunnel Project (*11*) and the North Central Expressway project in Dallas (*12*).

From these earliest experiments it became clear that visualization, particularly realistic 3-D and 4-D materials, had a place in examining design proposals whether in-house or to the public. The broad range of application within the transportation industry can quickly be seen by the diversity of venues exemplified by Cordes in architecture (*13*), Huber et al., in driving simulation (*14*), Krieger in tort liability (*15*), Pihlak in realism and resolution (*16*). However, there was no evidence that the industry used or was broadly embracing the technology as part of its tool base.

This led to a joint TxDOT-HPR project (*17*) that sought to evaluate the development of visualization technology for transportation. While the study was limited to the state of Texas, it covered a variety of administrative units including: the state headquarters, major urban districts and some small rural districts across the state. This report made several important observations with respect to the evolution of transportation visualization.

First it was noted that the technology with respect to hardware and software was not yet completely developed for use in transportation. Second, the report identifies a broad range of potential clients for the technology. More specifically, it was noted that 3-D and 4-D products had applications in practically every operating unit of a transportation agency while traditional 2-D media had only limited audiences. Third, there was an attempt to understand the relative benefit to be derived by adopting visualization as a tool within an agency. A case is made but the conclusions are not particularly definitive.

The most important observation of this particular study was that the biggest obstacle to the adoption of visualization technology in transportation was the current commitment to a 2-dimensional production environment. This simple fact essentially means that the data must be reprocessed or reconstructed before 3-D viewpoints (perspectives) can be constructed (*18*). The significance of this single limiting factor will be explained in much greater detail later in this report.

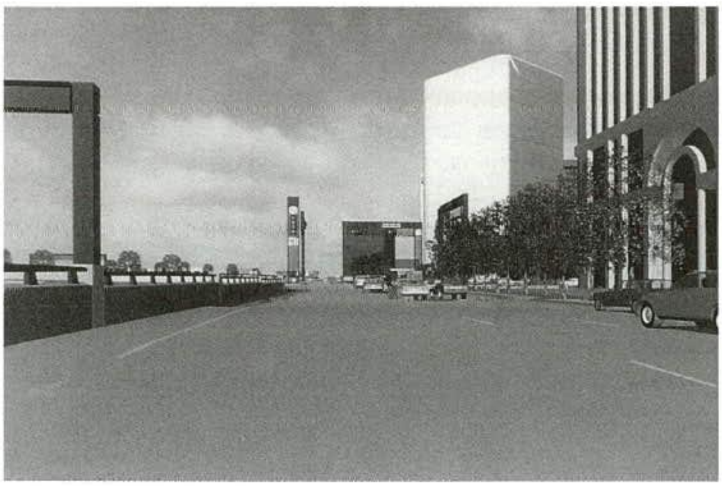
Since 1991 there has been at least one entire session of the Transportation Research Board's Annual Meeting devoted to the subject of applications of visualization technology in transportation (*19*). Unfortunately, a majority of these presentations have not been formally published. Some of the unpublished presentations have been cited in the reference list along with key contacts.

These presentations are the beginning of what should be a growing literature on visualization in transportation and they clearly demonstrate the breadth of application that lies ahead. In the area of technical design and geometry we can expect to see extensions of the work begun by Sanchez (*20*) and Rathbone (*21*). In the area of construction, which is not traditionally an area associated with graphic applications, visualization technology has been used by Jackson and Schintzel (*22*) to animate and examine complex construction processes. Information developed by Landphair and Larsen in their study of visualization in TxDOT (*17*) illustrates the dramatic increase in the types of output that can be achieved by adopting a true 3-D production environment (Figure 14).

Cartography	Advance Planning	Right-of-Way	Design	Construction	Maintenance and Operations
• Digital Terrain Models • Traditional Topographic Maps	• Animated Sequences • Still Renderings • Wire Frame Perspectives • Traditional Design Schematics, (2-Dimensional Plan/Profile Sheets) • Aerial Photograph Overlays	• 3-D Images To & From Sites • Still Renderings • Wire Frame Perspectives • Traditional Design Schematics, (2-Dimensional Plan/Profile Sheets) • Aerial Photograph Overlays • Traditional ROW Maps • Integrated Illustrative Plans	• 3-D Images To & From Sites • Still Renderings • Wire Frame Perspectives • Traditional Design Schematics, (2-Dimensional Plan/Profile Sheets) • Aerial Photograph Overlays • Aerial Photograph Overlays • 3-D Alignment Studies Animated Sequences (Drive-Throughs) • Construction Sequencing Studies	• 3-D Images To & From Sites • Construction Sequencing Studies • Wire Frame Perspectives • Traditional Design Schematics, (2-Dimensional Plan/Profile Sheets) • Alignment Data Sheets • Detailed Schematic Plans • Animated Sequences (Drive-Throughs)	• Still Renderings Wire Frame • Perspectives Traditional Design Schematics, (2-Dimensional Plan/Profile Sheets) • Construction Sequencing Studies • Animated Sequences (Drive-Throughs)
• Traditional Topographic Maps	• Traditional Design Schematics, (2-Dimensional Plan/Profile Sheets)	• Traditional Design Schematics, (2-Dimensional Plan/Profile Sheets) • Traditional ROW Maps • Aerial Photograph Overlays	• Traditional Design Schematics, (2-Dimensional Plan/Profile Sheets) • Alignment Data Sheets • Detailed And Schematic Plans • Aerial Photograph Overlays	• Traditional Design Schematics, (2-Dimensional Plan/Profile Sheets) • Alignment Data Sheets • Detailed And Schematic Plans • Aerial Photograph Overlays	• Traditional Design Schematics, (2-Dimensional Plan/Profile Sheets) • Alignment Data Sheets • Detailed And Schematic Plans • Aerial Photograph Overlays

FIGURE 14 Products available from 3-D data base compared with a 2-D data base.

The basic technology of visualization continues to evolve. Sophisticated 3-D modeling and rendering tools are already being included as a part of all CADD environments. As these tools become fully utilized, visualization will evolve as rapidly as CADD systems did in the late 1980s. Researchers looking to the future believe the next generation of the technology will see transportation design take place in a fully interactive visual environment. Within a very few years it is being hypothesized that designers will work in three dimensions and in real time. As the design process proceeds the designer will receive visual and numeric feedback that will help optimize all design decisions (*23,18*).



Some general conclusions can be made from the information gathered in the survey and literature review. However,

the most significant observation is the fact that visualization in transportation is coming but has not yet arrived, a fact that has impacted the organization and content of this report. In completing this part of the work, it became clear that the technology of visualization is only beginning to emerge as a viable tool that applies to almost all areas of transportation practice. So while the beginnings of a tool base exist, it cannot be said that this technology has matured to the degree that one can characterize the state of the practice in a traditional sense of the expression.

The Infrastructure for Visualization

The results of the survey indicate that the transportation industry in both the public and private sectors has adopted a computer-based drafting and design environment. Some of the larger states have had long-term experience with these systems while some of the smaller, less populous states, have only recently moved to adopt computer-based systems (*4,24*). This means that a majority of the states have basic platforms in place that can be used to explore and begin to produce some types of visualization imagery. The difference between public agencies and private firms appears to be in the level of sophistication of the tool base and the demand for creating visualization materials. Because of the complexity of 3-dimensional modeling softwares and the lag in developing intuitive graphical interfaces, the labor and equipment costs for developing visualization materials has been prohibitive. Particularly for 4-D materials, the cost could only be justified in the most extreme cases. However, recent improvements in software, hardware, and user interfaces have made the technology more and more cost-effective.

As the hardware and software continue to improve, the visualization components built into the software will improve as well. These improvements have resulted in much greater accessibility to the technology and are rapidly increasing the use of visualization. This is very much in evidence by the fact that more than 90 percent of the respondents to the survey indicated that they were currently considering acquisition of hardware and software specifically for visualization applications.

The major factor in the growth of interest in this technology is the improvement in 3-D modeling environments that are embedded in the new CADD software packages. It seems reasonable to infer that as software continues to improve, offering more intuitive user interfaces, the three-dimensional working environment will gradually replace the traditional two-dimensional methods. As this important transition occurs, there will be more and more use of visualization in planning, design, and communication.

Still Imagery or Animation?

All but one of the responding agencies that use visualization materials began their efforts with some form of ''image paint'' or ''image compositing.'' Most of the work used an image capture board or scanner to convert video imagery to digital formats. These images were then modified to create before-and-after scenes like those shown in Figures 15 and 16.

The example from Minnesota is an artist's concept using paint, the Wyoming example is an image composite where a 3-D model was constructed and overlaid on the base image. The third frame of the Wyoming example is a photograph taken after the project was constructed to illustrate the high level of accuracy that can be achieved with the composite imagery.

What was most surprising was that, while almost every agency surveyed and contacted indicated a great deal of interest and enthusiasm, almost none of them had actually produced any animation products in-house. Of the respondents to the survey, only Texas had actually produced and used animation as part of a project development process. The other agencies that had used animated materials—usually as part of a major consulting project or commissioned as part of a litigation proceeding—had acquired them from outside sources.

On the other hand, 20 of the survey respondents indicated that they currently had some form of 4-D production effort underway. These ranged from pilot modeling efforts as part of a software evaluation program to full-scale production of an animated product. This particular finding reinforces the notion that visualization will become a part of the transportation tool vocabulary over the next few years. It also underscores the need for some basic information about the considerations that enter into the development of a visualization production unit, with respect to hardware, software, training, cost, and various options.

In the private and education sectors there was a much broader and more diverse use of visualization technology. Examples of applications range from examination of conflicts between current AASHTO sight distance standards for vertical and horizontal alignment (*21*) to the visualization of complex construction phasing (*22*) and the interactive study of the Personal Rapid Transit corridor locations (*23*).

The apparent lack of visualization use in state agencies is probably related more to the evolution of the tools rather than any lack of knowledge or desire to use visualization tools. Like any service provider, transportation agencies must focus on their primary mission. In consequence they seem slow to adopt new tools until the applications have been developed to a point of proven cost-effectiveness.

It is always difficult to predict outcomes and directions a technology might take. However, on the question of still imagery versus animation it would appear that animation is the overwhelming preference for transportation applications. This seems to be related to two very important considerations. First, a transportation system by its very nature deals with movement. Because it is a dynamic system it stands to reason that designers will opt for tools that allow them to deal with a dynamic world of space and time. Second is the issue of defensibility. The three-dimensional modeling

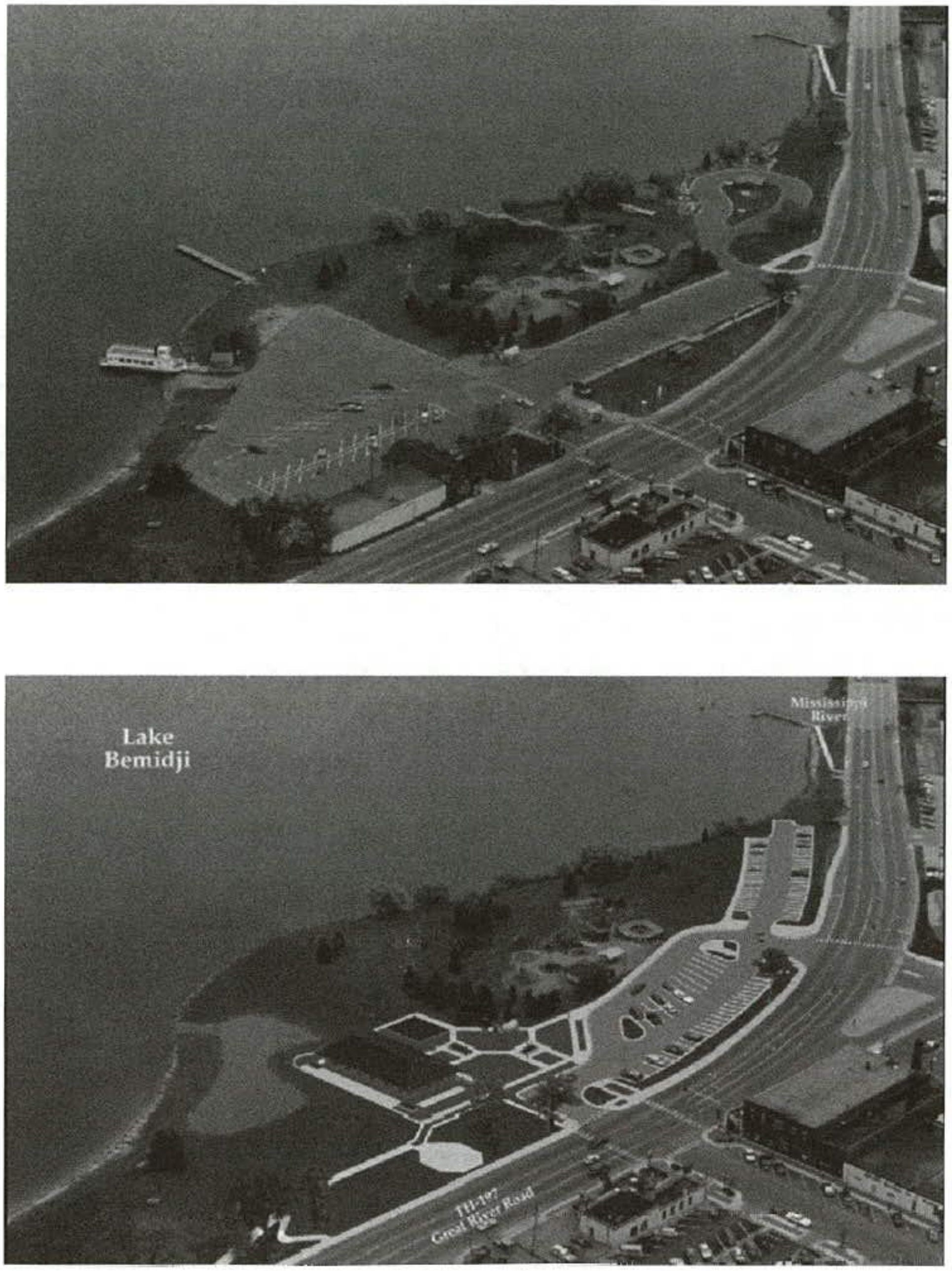
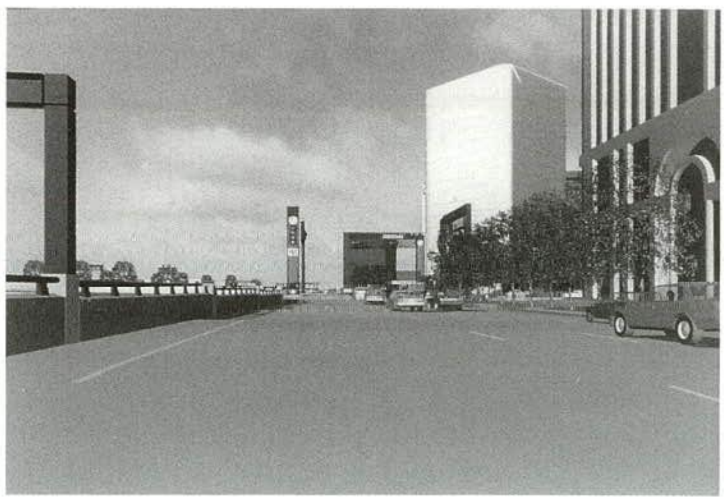


FIGURE 15 Artist's concept showing before and after a project. (Photo courtesy of MnDOT)

environment coupled with the technology to produce mathematically correct animated sequences offers the highest level of visual and mathematical accuracy. This feature is very important when dealing with the general public and those audiences with a special interest in a project.



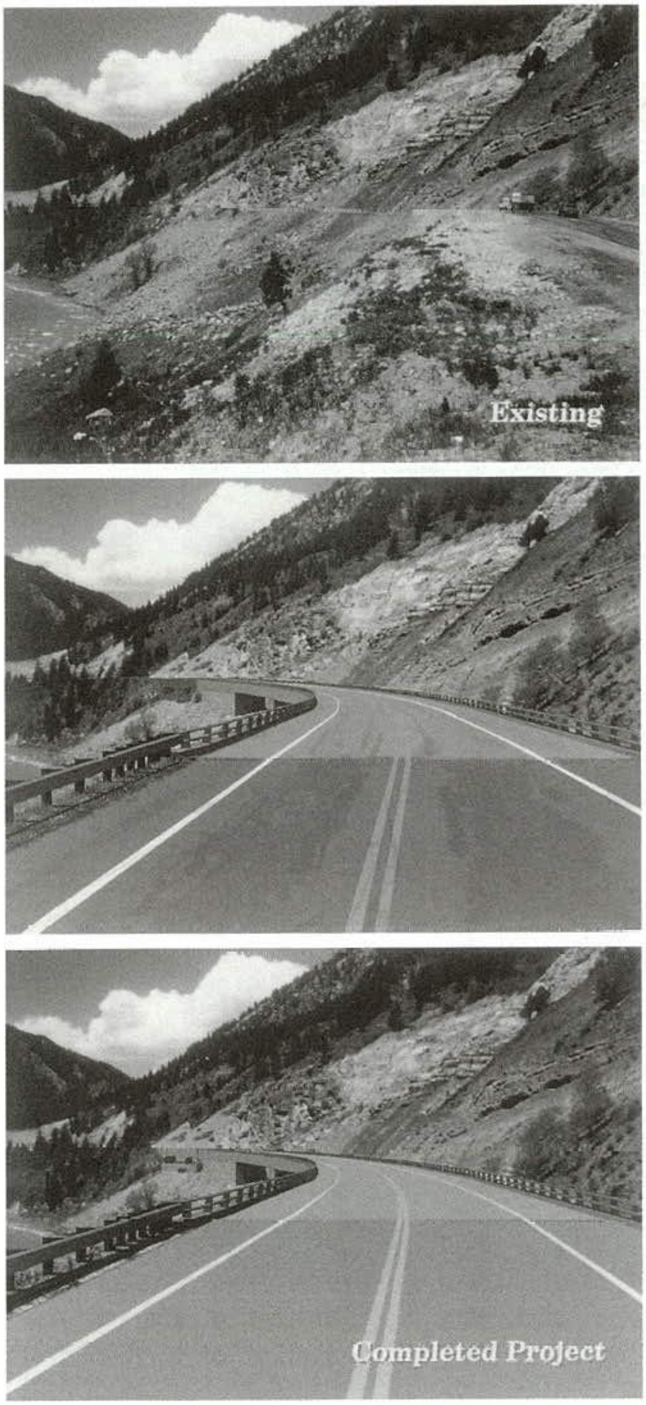


FIGURE 16 Image composite showing before, proposed, and after construction views. (Photos courtesy of the Wyoming DOT)

Visualization Technology in Transportation is Becoming More Common

A synthesis report is an attempt to consolidate the knowledge of practice in order to describe the state of the art in a particular field of endeavor. What has been discovered in the research phase of this particular document is that visualization, with respect to current transportation practice, has not yet evolved to a degree that will allow a meaningful characterization of its application. Quite simply, most all of the applications identified in the preparation of this document can best be characterized as pioneering efforts.

Although visualization technology could not be described in terms of meaningful case studies and a significant base of reference literature, the level of interest encountered at every turn suggested there was a need to bring together some basic information that could be used to direct those who will have to make decisions about adopting and implementing this new tool. To the casual observer visualization generally appears to be nothing more than a fancy CADD system. However, this is a pitfall that many neophytes to the world of visualization quickly learn is not the case.

The difficulties encountered when moving into the visualization world revolve around the vocabulary of the three key components: computer graphics technology, analog video technology, and graphic software architectures. Because even the very basic technology of computers, computer graphics components, and the software systems are so new there is a lack of any standardization in the use of vocabulary. Throughout the preparation of this document there have been numerous cases of conflicts with the application of terms. Some of this is related to the difference in terminology usage between disciplines and in other instances the terms have simply been misused. This confusion in language is quite typical of any cutting-edge technology.

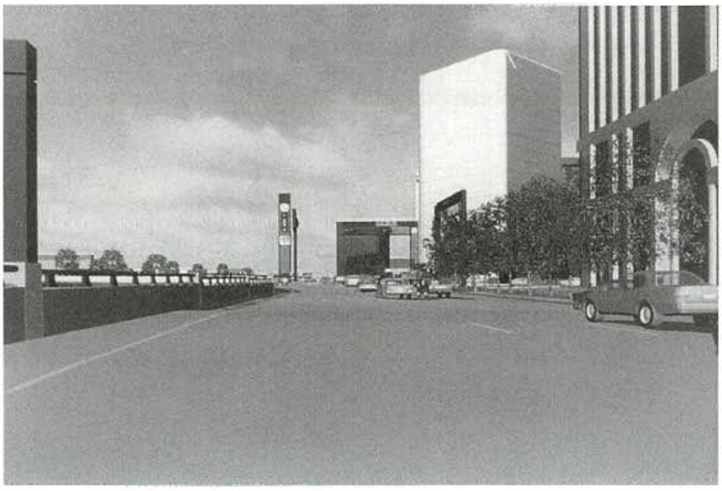
Computer graphic technology is also one of those grey areas where the visualization novice often gets trapped. Some of this is related to an understanding of the basic electronics technology and a knowledge of what will be important when it comes time to produce a final product. CADD workstations have had color capabilities for quite some time. However, all color is not equal and it does make a difference when it is necessary to produce photo-realistic imagery. As most newcomers to the visualization world quickly learn, what you see is not always what you get.

Most transportation applications are moving in the direction of animation products, which usually involves the use of analog video technology at one or more points in the process. This interface can be the source of many problems and frustrations for beginning visualization developers. In the simplest terms, analog signals are not compatible with digital signals and must be converted before they can be used in a particular environment. The technology necessary to accomplish the digital-analog/analog-digital conversions is generally expensive and it does not always work as billed.

Finally, there are the problems of software architecture that generally revolve around issues of scale, topologic structure of the data, and limitations on data base size. Not all visualization systems work in a precisely dimensioned environment. That is, the system works only with proportional or virtual units but there is no way to easily translate a virtual unit to an appropriate unit of measure.

Because graphics environments may be either two- or three-dimensional they will pose limitations on the utility of the modeling environment as noted earlier. In addition, the structure of most programs has been developed to depict objects and not the containing space. This poses some real problems because transportation corridors are spaces, voids, rather than solid objects or surfaces. These architecture problems often lead to data storage problems related to size, which can also result in loss of speed and efficiency.

These are categories of concern that will be common to any unit considering the development of a visualization capability. Consequently, this report focuses on developing an understanding of, and providing the information necessary to deal effectively with, these basic issues.



CHAPTER FOUR

THE INFRASTRUCTURE FOR VISUALIZATION

INTRODUCTION

Transportation agencies with well-developed CADD operations have a basic hardware and software framework around which they can begin developing a visualization capability. For a majority of transportation agencies and their consultants, Intergraph's Microstation has virtually become the industry standard. This comprehensive CADD software has evolved to include a 3-dimensional modeling environment, which is fundamental to developing most visualization imagery. Similarly, the computer platforms used for CADD operations provide an entry level capability suited to the production of simple visualization materials.

What will be lacking in most cases are the trained personnel and some specialized hardware and software components necessary to extend the existing CADD capabilities into a complete visualization production environment. Some specific examples of these components include:

- specialized software and hardware for digitizing and manipulating images,
- specialized software and hardware for output of visualization materials such as photographs and video tape, and
- personnel with knowledge and skill to use and effectively manage the system.

The need for a knowledgeable professional staff cannot be overemphasized. In practically every case reviewed in the course of this study and in previous work, one of the key impediments to effective use of visualization technology was the professional staff's lack of knowledge about the capabilities and potentials of existing "in-house" technology. In many cases it appeared that professional staff relied on technicians who frequently lacked the broadbased knowledge to properly assist the professional staff.

The purpose of this chapter is to provide administrators and professional staff with information about what additional equipment and software is necessary to develop various visualization materials. It provides a framework that will help professional staff understand what can be reasonably expected from the various components of hardware and software used to produce visualization materials. Issues of time, common mistakes or misunderstandings, skill and expertise of technicians, cost-effectiveness and pitfalls will be cited. As appropriate, specific examples of software and hardware will be given.

THE VISUALIZATION TOOL BASE

Visualization materials used in transportation practice are generated in a three-step process regardless of the type or complexity of the product. The three steps are:

- image acquisition and input
- visualization production
- visualization output.

Each of these steps requires careful planning and the appropriate equipment in order to achieve good results. Figure 17 illustrates the three steps and some of the equipment used in each part of the process.

Acquisition and Input of Base Images

The need to produce visualization materials is usually generated by a desire to show how additional project elements or new proposals will impact a site. Thus, the first step is to acquire imagery and data about the site in its existing condition. For renderings or artist's concepts this only requires taking video or photographs of the site. If a composite image is to be produced, it is also necessary to gather topographic and camera information so that a matching 3-D model can be generated. If the final product is to be an animated sequence, a digital terrain model will have to be developed. Depending on the level of detail planned

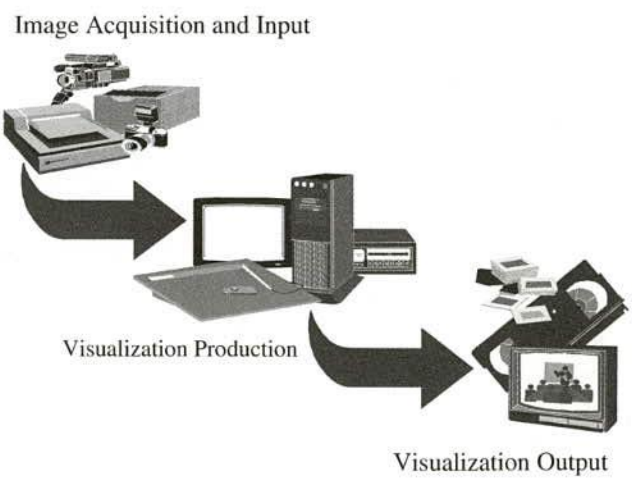


FIGURE 17 Production of visualization materials.

for the final material, photographs or video may need to be taken along the entire corridor. This information will be used in the rendering process to provide texture maps which are applied to the 3-D model to generate more realistic images of the site features.

The equipment required in the first step of the process includes:

- video cameras
- film cameras
- flatbed or film scanner and/or an image capture board
- digitizers.

A high-quality video camera can be used to transfer imagery directly into the computer by way of the image capture card, which is a digitizing device that converts an analog video signal to a digital format. Film imagery must be processed and then transferred to the computer with a scanner. Methods for entering other kinds of information about the site include:

- manually typing alpha numeric data
- digitizing tablet
- direct field logging
- electronic data collection.

Visualization Production

Once all base information has been converted to a digital format it is manipulated in the computer environment to produce a new image. This requires a variety of computer peripheral devices and software tools. Modification of photographic images or video frames requires access to a paint/image editing program. Composite images require the use of a 3-D modeling package and rendering software. Three-dimensional modeling capabilities are available in Microstation, and some limited rendering capabilities are built into the program. However, for purposes of flexibility it is desirable to have access to a full-feature rendering package such as Intergraph's Modelview, or Pixar's version of Renderman. Where animated sequences are concerned, a full-feature rendering and animation package is needed. Modelview and Autodesk's 3-D Studio® are the two rendering and animation programs mentioned in the survey. As of this writing these programs do not have all the features found in the high-end products used for commercial broadcast and cinematography, but Autodesk and Intergraph have strong commitments to these products and continue to upgrade them with each release.

The basic hardware necessary to produce visualization products is essentially the same as that used to support CADD operations. The major hardware differences are considerations of the graphics environment, monitors, memory and data storage capacity. Each of these will be considered in more detail later in this chapter.

Visualization Output and Postproduction

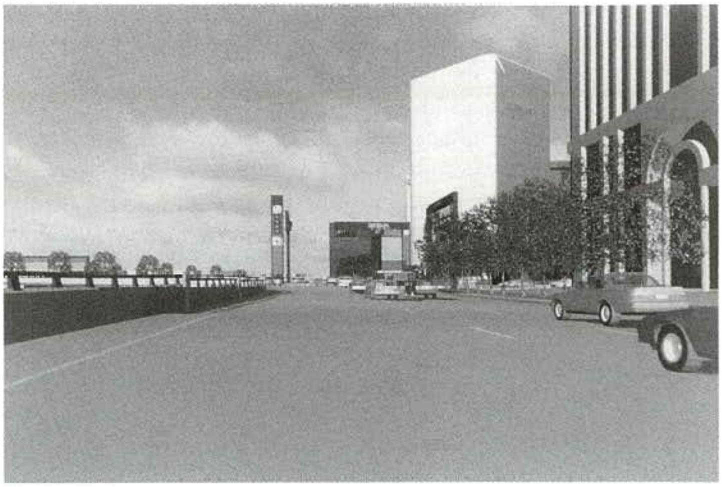
The final visualization product may remain in the computer environment in the form of a computer slide show or multi-media presentation. These types of presentations can be very effective if the audience is small and can be conveniently placed in front of the computer. Computer projectors and powerful notebook computers will likely make this a very attractive option in near future but, for the time being, videotape, slides, and photographs are the most feasible options. Compact disks (CDs), and Photo CDs are also showing a great deal of promise as means for the mass distribution of visual products. The primary drawback is the same as for the computer-based presentation—a computer is required to run and view the presentation.

The equipment and software necessary to output visualization imagery includes:

- printers and plotters
- film recorders
- video cassette recorders
- software and hardware devices that control video output
- software for text generation and special effects.

COMPONENT TECHNOLOGIES FOR VISUALIZATION

A completed visualization image, video, slide show, or multi-media presentation depends on the integration and use of multiple technologies: analog video, film, digital devices, a variety of peripheral devices, and appropriate software. The technologies that most influence current visualization practice are analog video and digital computing. With the advent of digital television the distinction between the two technologies will disappear and many of the current problems with conversions and differences between media will be gone. However, until a national digital television standard has been adopted, production must use both technologies. For this reason it is important to understand the differences in the technologies and how the basic components, such as video cameras and monitors, work.



Analog Video

Analog video displays a picture by continuously varying the luminance (relative brightness), and shade (a grey scale from black to white) along a line. In the broadcast industry this stream of data is referred to as a scan line. When several lines of information are displayed together they form a picture. Current video technology dates back to 1940 and the formation of the National Television System Committee (NTSC). The committee was formed to establish a standard for monochrome television broadcasting. At that time, state-of-the-art technology had achieved 525 lines of resolution per frame at a scan rate of 60 frames per second. This was adopted as what has become known as the NTSC broadcast standard and is in use today. In the late 1940s the committee was asked to develop a similar standard for color television. By this time the popularity of television entertainment was so widespread the committee felt it was essential that the new color standard be compatible with the existing black and white broadcast system. To achieve this goal and not affect the monochrome signal, a subcarrier was added to the monochrome signal to carry the color information. The subcarrier is responsible for the color component, or chromacity, which is overlaid on the luminance signal and broadcast simultaneously. The video monitor decodes this information and generates a display made up of 486 lines of vertical resolution.

While the standard has proved to be an adequate compromise, unavoidable errors are induced in the encoding process that cannot be reversed in the decoding process. Because this error is cumulative across each encoding and decoding cycle, analog video images quickly loose their sharpness and color each time they are copied. This generation loss leads to some basic problems that will be discussed further in association with video cameras and video editing.

Color Digital Computer Displays

When the cathode ray tube (CRT) was first used to display computer-generated graphics it was accomplished using vectors, which are lines generated from x,y coordinate pairs. Most all early computer displays were vector systems. They could display graphic primitives with zero, one, and two dimensions. That is, they displayed images in combinations of three basic graphic primitives: points, zero-dimensional; lines, one-dimensional; polygons, two-dimensional. These primitives could be quickly generated by an internal vector processor and refreshed 30 times each second. The major drawback to the vector system was that it could not display more than four colors and it could not fill polygons with a solid color.

The availability of lower cost memory modules removed earlier cost constraints and led to the rapid development of raster graphic displays, which depend on the use of *frame buffers*. Frame buffers are essentially high-speed memory that generate the color information to be displayed by each picture element (pixel), of the digital raster display. A frame buffer actually stores a red, blue, and green (rgb) value for each addressable pixel, which must be updated 30 times each second. Even a very low resolution of $300 \times 400 \times 24$ requires 1,160,000 bytes of information to be addressed 30 times each second.

The CRT of a computer display operates on the same principal as that of a television monitor. However, the digital frame buffer is not compatible with the component color video signal. For this reason, digital displays use digital-to-analog converters (DAC) to convert the signals to voltages that drive each of the rgb guns.

Most current video graphics adapters (VGA) are capable of 24-bit color (Figure 18). So-called 24-bit color uses three buffers of 8 planes. Each plane represents two possible conditions of a particular color or 2^8 possibilities, which is 256 colors. Thus, each buffer represents 256 different colors of red, green, or blue. Because there are 256 possible colors for each of the primary colors, this represents 256^3 colors possible on the display or about 16.7 million colors. A 24-bit color system is essential for 3-D and 4-D visualization so that an accurate duplication of the image can be seen prior to final output.

If real-time computer graphics are to be achieved, a double buffered system should be considered as a minimal system. In a double buffered system, the second or ''back buffer'' is used to record the next image while the initial image is being displayed on the screen. The front and rear buffers are simply swapped during the vertical scanning process so that the motion seems smooth and seamless. If only a single buffer is used the redrawing process will be visible and causes the image to appear jerky.

Display Resolution

Picture resolution is the greatest difference between video and digital displays. This is sometimes confusing as it is

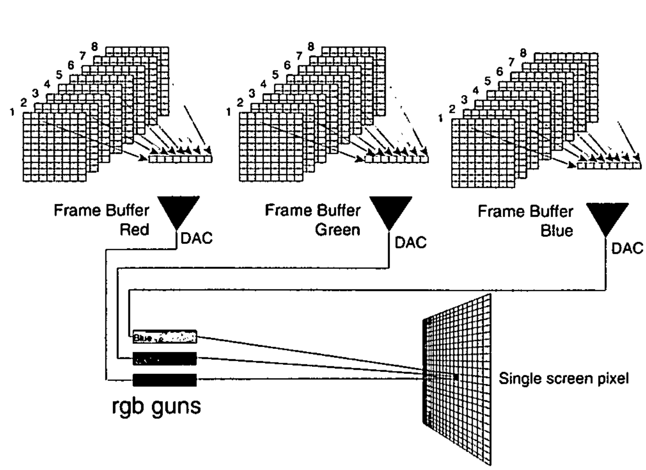


FIGURE 18 24-bit color buffer.

not always clear which resolution is most important to the image quality.

In a raster display, resolution refers to the number of addressable picture elements or pixels. The actual resolution of a display is related to the size of the frame buffer which represents a two-dimensional array of color values. While variation exists between operating environments, some of the more common resolutions are: 640 × 480, 800 × 600, and 1024 × 768; while most Unix workstations use 1280 × 1024 as the standard. The higher the resolution of the graphics display the greater the memory required to drive the graphics display. With the cost of memory decreasing there is a corresponding increase in the availability of displays of higher resolution.

The resolution of an analog display refers to the ability to record detail rather than the number of addressable pixels. An analog image is not represented as discrete values, but as a continually fluctuating signal (line), thus; resolution has a wholly different meaning. The pickup sensor moves over the recording medium from left to right and from top to bottom of the image in a series of horizontal scan lines. The detail that is recorded on each line is a function of the pickup head in the camera and the available band width necessary to carry the signal. This band width is set at one megahertz (MHZ) for every 80 lines of horizontal resolution. The total band width for the NTSC signal is 4.5 MHZ, thus 4.5 × 80 gives a theoretical horizontal resolution of 360 lines. Vertical resolution is dependent on the number of scan lines per frame. The NTSC standard is 525 lines. However, 40 lines of resolution are required for vertical blanking, which is the time required for the beam to retrace from the lower right corner of a frame to the upper left corner of a frame. This leaves a total of 485 lines of vertical resolution. At first this would seem to be a much lower resolution than current VGA displays. However, this is misleading because a video line is actually made up of a black and white component. This essentially doubles the lines of resolution to 720 × 485. When clean component signals are displayed at this resolution the images are clear and sharp. Another factor that impacts apparent resolution is the fact that an image is only displayed for one-thirtieth of a second. These sequential images are fused in the brain so that the lack of detail is not perceived in a video image.

For a more detailed discussion of color and resolution see Larsen, Terry R. *Integration of Video and Computer Generated Imagery in Transportation Visualization*, 1995, Transportation Research Board, 3-D Transportation Visualization and Simulation Symposium and Workshop, Houston, Texas.

HARDWARE FOR VISUALIZATION

The hardware necessary for the production of visualization products is discussed in this section. The content is intended to be sufficiently detailed to afford a good understanding of the important operating features of each component, while avoiding specific references to technologies that could be quickly outdated. The discussion is divided into the three phases of visualization production: image acquisition, input, output production, and postproduction, outlined earlier in this section.

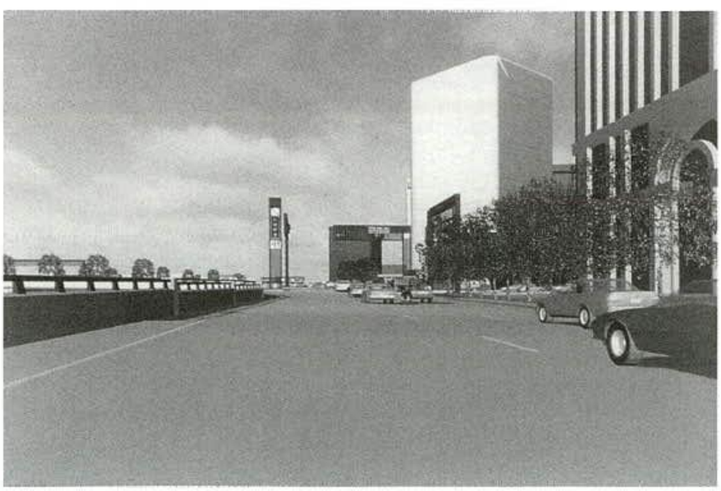
Hardware for Image/Data Acquisition and Input

The basic tool used for recording base imagery is the camera. Film cameras are portable and inexpensive and photographs provide sharp images with good color qualities. The disadvantage is that they are single-frame still images that must be converted to machine readable form with some type of scanning device. Considerable care must be given when acquiring the base imagery as a slight change in position may make the difference between a useable image and another site visit. Video cameras have become very popular in recent times because they are portable and have the advantage of recording motion. While multiple images are a definite plus, the generational loss of sharpness limits the usefulness of this technology. A variety of video camera technologies is available and many of the less expensive video cameras are not well suited to visualization work.

35mm Film Cameras

The 35mm camera is the most common and versatile camera available for general photography. These cameras are standardized, relatively inexpensive, and most film can be processed quickly. The pictures are of good color and picture clarity. Because of the popularity of the 35mm format there is a variety of accessories such as lenses, filters, and flash attachments that make it a very useful tool.

The primary limitation of 35mm photography is the small negative. If it becomes necessary to enlarge a 35mm image, the picture can become grainy and begin to lose color, quality, and sharpness. Large negative film cameras such as the 102 mm × 127 mm or 229 mm × 229 mm (4 in. × 5 in. or 9 in. × 9 in.) are used for studio photography or for



aerial photography. The large negative ensures a sharper image when the picture is enlarged.

A high quality 35mm, single lens reflex (SLR) camera and matched lens will be satisfactory for most general photographic work. The advantage of the SLR is that the user is looking directly through the lens of the camera. This provides a more accurate view of the scene than is possible with a camera that uses a view finder. If a camera and lens package is being considered there are several very good 35mm SLR bodies that offer fully automatic film loading, automatic film advance, auto focus, and auto flash. Any of these bodies fitted with a high-quality single focal length lens of 45 mm to 50 mm will serve most of the photographic needs. One of the best choices is a perspective control lens. By optically compensating, vertical elements remain vertically aligned with the edges of the frame. Where still images are concerned, these "2-point perspectives" are more visually appealing.

Video Cameras

The popularity of video cameras in the consumer market has resulted in the availability of a wide range of video cameras. While these cameras have reasonable picture quality when played back directly from the recorded cassette, consumer market video cameras are not well suited to the production needs of visualization. The major drawback of the video medium is the marginal resolution available, even in the original image. When the original image is regenerated for the purpose of copying or editing, the quality continues to degrade. The amount of degradation is substantial past the second generation for most consumer market cameras. Figure 19 illustrates the problem of video image degradation compared to that of a digital display.

This is a problem that cannot be overcome; every time a video tape is copied the image will loose color quality, sharpness, and resolution regardless of the camera format. High-quality component format cameras will allow as many as eight generations before there is noticeable loss in quality. This quality also comes at a considerable increase in price.

Moderately priced video cameras use a single sensor chip to record the video signal to tape (Figure 20). This is a composite signal. More expensive cameras divide the signal into components and use three sensor chips. The information recorded with a single chip is less precise because the sensor must interpret and record both luminance (relative lightness or darkness) and color information. Multi-chip cameras split the signal into luminescence and color elements (Figure 20). The actual separation of signal components differs between the camera formats but the principles remain the same. It is often difficult to scan pictures from a single-chip camera into the computer as single frames because the signal cannot always be isolated and held steady long enough to perform the scan operation.

Because of the image degradation problem with video, it is essential that strong consideration be given to the purchase of a component signal camera. An industrial or broadcast quality video camera will give the best results.

Digital Video

Digital video is available and it does not have the image degradation problems of analog video standard. While this is a desirable advantage, digital video would probably not be a good investment for most transportation agencies. At this writing, the cameras and production equipment are much more expensive than conventional analog video formats and there is no widespread infrastructure for showing digital television. This, coupled with the fact that there is not yet an

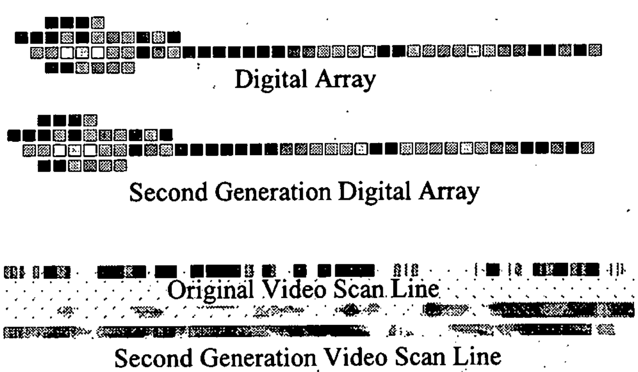


FIGURE 19 Example of the reproduction of digital and NTSC analog signal.

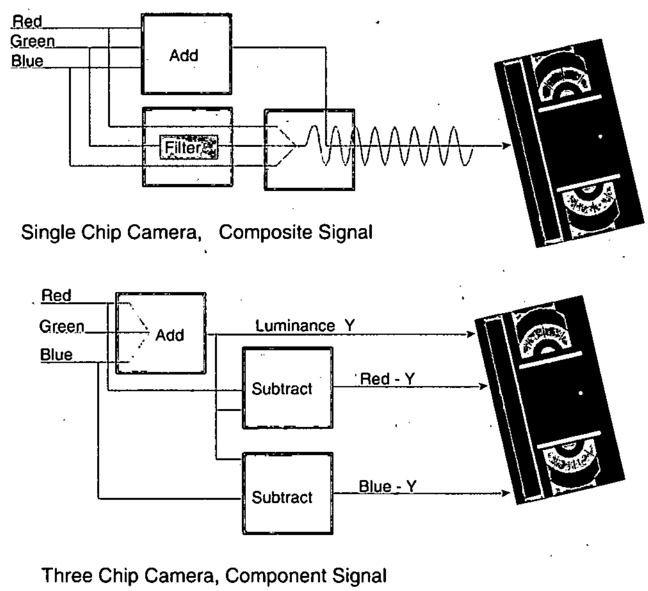


FIGURE 20 Comparison of composite and component video signals of video cameras.

adopted digital video standard, restricts its use to specialized closed circuit video applications.

Video Formats

Video cameras are available in three video tape formats: VHS and S-VHS, 8-mm, and Sony Betacam. The VHS and S-VHS are the most familiar and widely used video tape formats. The 8-mm tape is a small tape cartridge that is very popular in the home video market. Betacam is a proprietary Sony format that has become the default standard of the broadcast industry. There are also some remnants of the three-quarter inch video tape format that was the industrial video production standard for many years. The three-quarter inch format is being rapidly replaced because of its cost and the rapid improvements in the quality of the S-VHS and 8-mm formats.

The existing infrastructure in video replay is dominated by the VHS and S-VHS format. There are several cameras available that use standard VHS cartridges and have three-chip recording engines. This will usually provide sufficient image quality to allow two or three generations from the original recording without unacceptable loss of picture quality. The Panasonic M-2 system is the upper end of the industrial camera line.

DIGITIZING TABLETS, SCANNERS, AND CARDS

Converting an image or information from a plan profile sheet to machine readable form requires a digitizing device. This covers a wide array of equipment that includes digitizing tablets, image capture boards, and scanners.

Digitizing Tablets

Entering precise planimetric information into the computer is usually done with a digitizing tablet. For most applications a digitizer should be large enough to handle full-size working sheets, which for most transportation agencies included up to the ''E'' size sheet.

When selecting a digitizer, look for the attributes of resolution and accuracy, cursor type, and software drivers. Advances in technology have generally resolved problems of tablet resolution. Almost all tablet manufacturers now offer a basic resolution of .0025 mm (.001 in.) with an accuracy of .0003 mm (.01 in.). Factory calibration for accuracies of .0001 mm (.005 in.) or less are available from most of the major manufacturers. Three-dimensional digitizing technology that allows concurrent input of x, y, and z information is also available. However, these have very limited value to most transportation applications.

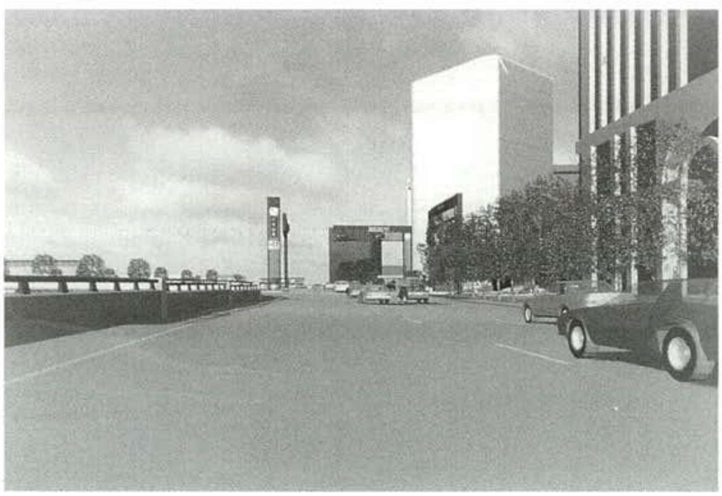
Most digitizers offer three pointing instrument options: one- or two-button stylus, a four-button cursor, and a 16-button cursor. For visualization, the stylus and 16-button cursor are the most useful options. The stylus is most natural for point-by-point entry of two-dimensional information while the 16-button cursor can be very useful for entering x, y, z information from two-dimensional drawings. Another use for the digitizer is as an interface to paint or image editing software. Some of these packages can take advantage of a pressure-sensitive stylus that provides a much more natural interface than the mouse.

Scanners

Scanners are a very important part of the front-end visualization capability. These machines basically digitize hard copy graphics and text to machine readable (digital) information. For visualization applications, two types of scanners should be considered: slide scanners and flatbed color scanners.

Slide scanners are capable of digitizing 35mm slides and other film formats. This particular technology has been expensive until very recently. However, it is now possible to purchase a good quality slide scanner for under $1,000. These machines will scan images at sufficient resolution and color depth for practically all general transportation applications. When selecting a slide scanner, resolution is a primary concern. If the purpose of scanning is to acquire base images for image paint or image compositing techniques, a resolution of 2000 DPI should be considered minimum. Lower resolution will fail to hold textural details in objects like signs and other highly detailed areas, and will probably not be satisfactory for most situations.

Flatbed color scanners are used to digitize paper-based images and text. Full-feature color scanners with 215 mm × 355 mm (8.5 in. × 14 in.) beds are available for less than $500. These machines offer a full range of options that will provide color depth and picture resolution sufficient to most transportation applications. Most of the less expensive color scanners use a three-pass scan process to pick up the rgb components. In some of the newer models this can be accomplished in a single pass. Because scanning generally ties up the computer terminal while these operations are being performed, single-pass scanning may be a feature to



consider. The single-pass feature will have to be balanced against the initial cost, which is currently two to three times higher than three-pass technology.

Scanners with large beds are available. However, the increase in size is substantially more expensive when compared to the class of equipment just described. In most cases investments in larger bed scanners is difficult to justify because most distribution and video media are not capable of displaying the higher resolution or color values that would be recorded. While there will be some marginal increase in video image sharpness, film is the only finished medium that can justify the higher level of resolution and color.

The choice between slide and flatbed scanners is generally based on the type of input document. Slides offer superior color clarity compared with fidelity and print films. On the other hand, flatbed scanners are more versatile and some of the newer models are much faster than slide scanners.

Image Capture/Image Processing Boards

Image processing boards are computer-based digitizing devices used to convert analog video signals into digital formats. This capability is essential if video cameras are to be used as a primary input device. Image processing cards have a wide range of prices and capabilities. The primary factors that should be considered in selecting an appropriate image capture/image processing card are picture resolution, color, processing speed, and compatibility with the operating system environment. Cards capable of 1024 × 768 pixels of resolution with 24-bit color are reasonably priced and provide images of sufficient quality for most applications. The other area of importance is the compatibility of the board with the computer platform and the operating system. Some boards are only supported in PC-DOS, Windows, Apple Macintosh and/or Unix environments. Issues of compatibility should be checked carefully and if possible tested on site before a purchase is made. Some applications may require expensive software interfaces to achieve working compatibility. When a software interface is required to make a piece compatible with a particular platform, some features of the hardware may be lost. It is also a good idea to ensure that the vendor has a continuing commitment to support the hardware and software.

PRODUCTION HARDWARE: COMPUTER PLATFORMS

The computer platform is at the heart of the visualization production process. As noted in the introduction, most agencies are already committed to a CADD environment for the production of contract documents. This existing commitment provides a core for the development of a variety of visualization capabilities with appropriate additions and modifications. In this section, considerations related directly to the computer platform will be discussed. The survey indicated that most agencies are operating Intergraph software in a Unix environment, so the discussion will focus on this environment. Where appropriate, mention will be made of Macintosh, PC-DOS, and Windows environments.

Graphics Displays

When selecting a graphics monitor for visualization production, a balance is sought between color definition, spatial image resolution, and cost. Common video graphics adaptor displays include 640 × 480 pixels (307,200 pixels), 800 × 600 (480,000 pixels), 1024 × 768 (786,432 pixels), and 1280 × 1024 (1,310,720 pixels). At each level of increased resolution the image can be displayed with greater detail. Other advantages of higher resolution are that more of an image or multiple views of an image can be displayed at one time, which limits the need for zooming and panning and more space is available for menus and other working tools.

Color definition is the number or shades of color that can be displayed on the screen. The original VGA standard was 16 colors, (4-bit color). Current mid-range graphics adapters are usually capable of generating up to 16.7 million colors (24-bit color). There are color graphics adapters that go up to 64 bits of color but these are for generating graphic displays in multiple planes and are not really necessary for most general applications. A full-color graphics card used with a high-resolution monitor can display an acceptable range of refinement in color depth and resolution. Highlights, subtle changes in light, shade, and shadow can be seen, giving excellent levels of realism in the computer's screen image. There are some drawbacks. First, the greater the color definition and spatial resolution of the picture, the larger the file size. For example, file sizes for uncompressed images of 1024 × 768 resolution and 24 bits of color will require 2.4 MB of space for each frame.

It is important to remember that film is really the only medium that is capable of displaying the level of detail in a 24-bit color image. So, while the detailed color information can be generated in the computer, it is the output display that determines how much of the detail can actually be seen.

For general transportation visualization needs, a graphics card that will produce a resolution of 1280 × 1024 pixels at 24 bits of color depth (16.7 million colors) is sufficient. This level of color produces the full range of visible light colors that the average human being is capable of seeing. For this reason it often called "true color." A card with true color capability should be sufficient for most general applications. There are numerous cards available that operate in this level of resolution and color for a variety of workstations. Depending on the hardware platform, the cards are reasonably priced.

An additional feature to look for in a graphics card is the processing capability. Most cards in the mid to upper price ranges provide "on-card" graphics processors and random access memory (RAM). This feature takes the graphics pro-

cessing load off of the main computer processing unit (CPU) and speeds up the overall performance of the platform. A graphics card with a good graphics processor and around 4 MB of local RAM will usually result in significant time savings when processing graphics files.

Beyond the basic characteristics of color and processing, the application software must be taken into account. If the primary application is for image editing, boards that accelerate raster displays are preferred. If the application is aimed at real-time display graphics, select a board that has high throughput for 3-D vector processing.

Two primary criteria are recommended when trying to balance matters of cost with respect to the graphics display. First, consider the probable life of the technology being purchased in terms of rate of technological change. Current technological life is approximately 2 to 3 years for most graphics hardware. After that period of time it will probably be necessary to upgrade to a different graphics processor. Second, consider the capabilities of the display technology for which the visualization products will be produced. If the final product is to be current NTSC CCIR601 video standard, the maximum possible resolution is only 720 x 486. This will change as the technology moves to digital, high-definition television (HDTV). This change will very likely occur in the next few generations of graphics technology.

Data Storage Capacity

Production of visualization products is a data intensive process. Most graphics files, scanned color pictures, composite images, and rendered 3-D frames will be measured in megabytes. Large, uncompressed, 3-D models of transportation corridors will likely be measured in gigabytes. For this reason it is very important to be sure that the primary production platform(s) for visualization work will have sufficient storage capacity. Depending on the number of projects that might be in production at any one time, a disk capacity of two to four gigabytes should be considered for each active project. For example, 30 seconds of full-color video imagery at the CCIR601 standard of 30 f/sec requires 657 MB of space. A high-capacity back-up system should also be part of the storage scheme. One of the most useful is the 8 mm tape format, which stores up to 10 gigabytes of information in compressed format on an 8 mm tape.

Processing Power

Processor speed and RAM availability are also important when developing the visualization platform. Memory and processor speed are of the greatest importance if animation is going to be part of the overall visualization capability. Allowing for the complexity of the images to be processed in an animation, rendering time per frame can run from less than a minute to more than an hour, depending on the processing power available. If a single machine is going to be built to accomplish rendering tasks it would be advisable to explore a platform with multiple processing units. Several manufacturers offer multiple processors. This is like having two or more CPUs in a single machine sharing the processing load. If there are several workstations in an existing production unit, an alternative would be to consider a network software that would allow processor sharing. These applications essentially monitor the network for idle or under-utilized processors and distribute the computing load across an entire network. This can be a very efficient solution to increasing the graphics computing power for visualization operations. Most major vendors offer network sharing software.

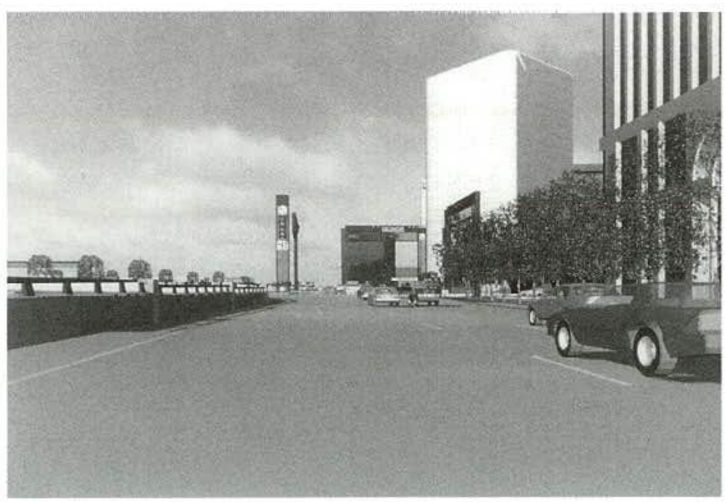
Of all the considerations, memory is probably the most important. All image processing and rendering tasks are memory intensive and throughput is frequently proportional to available memory. In general, consider purchasing as much memory as the processor will support or to the limit of the budget, whichever comes first. It is recommended that 64 MB be available for small projects and 128 MB or more for large projects that require animation.

OUTPUT HARDWARE

Postproduction hardware includes the peripherals necessary to transfer the visualization images and animation sequences from the computer environment to an appropriate distribution medium. The most common distribution media are prints/plots, 35mm slides, video tape, and compact disks (CDs). Each form of output requires a different set of peripherals that can often represent a monetary investment equal to the computer hardware and software required to capture and produce the imagery.

Real-Time Editing Devices

If an animated sequence is being produced for mass distribution, it is usually recorded on video tape. This requires close communication between the drive and the computer so that each image in a sequence is matched exactly to the



previous image on the tape. The basic problem is that a computer cannot generate and display complex images at a full 30 f/sec. This requires some means of controlling the tape so that each image is recorded in exactly the right position on the tape, or the completed sequence must be generated and stored in a way that allows direct recording (Figure 21).

With current software and hardware, the need for separate equipment to control the output operation has been virtually eliminated. However, the ability to preview a completed sequence with all postproduction text and effects prior to recording it on tape requires some type of real-time editing device. The most reasonably priced devices for performing this work currently are read-write laser disks, which allow the operator to assemble a sequence of rendered images, review them, add any postproduction features, such as text or special effects, and then record the entire sequence to video tape in real time.

Three other options exist for putting animated sequences onto video tape. The traditional animation recorder controls the video tape recorder (VTR) so that each successive frame is put on the tape with no space or overlap. These machines are relatively inexpensive but they place an extremely high work load on the recorder. Because images are recorded frame by frame, the VTR must be re-queued each time an image is written to tape. The queuing process is slow and the recording process is very time intensive.

The second option is a scan converter that reprocesses the rgb signal received by the computer monitor into an analog signal that can be recorded by a VTR. With this system a powerful CPU and a large amount of memory are required to store successive images in memory and ''flip'' through them at 30 f/sec. For example, a 20-second sequence may require up to 512 MB of memory (RAM).

The third option is the use of data compression prior to storing frames. Accessory boards are available that write and manage JPEG and MPEG compression and decompression software. JPEG and MPEG are acronyms for Joint Photographic Experts Group and Motion Picture Experts Group, respectively. Compression boards allow direct recording to a VTR through an image capture board. It is important to remember that most compression results in a loss of information. The greater the compression, the greater the loss of information. If the distribution medium is to be video tape, some loss of image detail may not be noticeable.

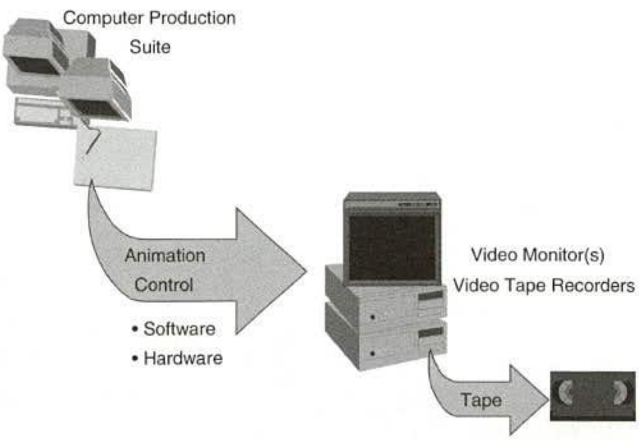


FIGURE 21 Output of animation from digital to video environment.

Video Recorders

Video recorders for transcribing animation sequences and dubbing them to distribution tape are one of the most important visualization hardware components. The quality and capabilities of the VTR ultimately control the quality of the final presentation. While the computer may be working at very high picture resolution and 16.7 million colors, the viewer will only see what the video recorder is capable of transferring to tape. In general, consumer market video cassette recorders and players do not have the capability necessary to record high-quality master images. This means that when the sequence is moved to the final distribution medium images will begin to appear soft or fuzzy.

For general purpose video production, the most popular option would be the mid-range industrial S-VHS recorders/players. Like all technology, constant change and improvement make any discussion beyond basic features quickly dated. The important features that should be included in video recorders are:

- time base correction
- frame-by-frame advance control
- date and time reference stamp
- edit control.

Writable CDs

Writable CD technology is just emerging as another form of output. The CD has already become a preferred medium for the distribution of software and other kinds of data, but inexpensive equipment for writing to the compact disk has only recently been made available. Several companies now offer peripherals for writing to compact disks at very reasonable prices. That is, they compare favorably to the commercial grade VTRs. The current disadvantage of the writable CD is the lack of a developed infrastructure for viewing and showing visualization materials written to CDs. At this point it essentially requires that the material be viewed on a computer with CD capabilities, which limits the audience. To serve a large audience there must be access to a computer tethered to a digital video projector. The technology in this area is improving and the problem of portability is already being addressed. The power of portable notebook computers continues to increase and they are now available with CD drives. Compact digital video projectors are also becoming available and at

increasingly attractive prices. With an almost certain conversion to digital television in the next few years, the writable CD will become an increasingly popular alternative to video tape.

COLOR PRINTERS AND PLOTTERS

One option for the output of composite images, artist's concepts, and still clips from animated sequences are color printers and plotters. These devices have the advantage of one-step processing from computer to finished product. In the case of color plotters, there is also the ability to control image size. Many of the new color plotters can produce full "E" size images on plain paper.

The different technologies being used to produce color prints and plots include ink jet and dye sublimation. The primary differences in the various technologies are image resolution and color quality, initial cost, and cost per copy.

Ink Printers and Plotters

Ink jet printers and plotters are currently the most popular and inexpensive of the color printers and plotters. They will print on plain paper but there may be some blurring of edges if the paper is very porous. Some improvement in image quality can be achieved if a clay-coated medium is used. The resolution and color quality is somewhat limited when compared to other kinds of color printers with resolutions of about 300 dots per inch. Color quality is also limited by the quality of the ink in the cartridges. However, these disadvantages are offset by reasonable cost and rapidly improving technology.

Dye Sublimation Printers

Sublimation is the phenomenon observed when a substance transitions from a solid to a gaseous state without becoming a liquid. The most familiar example of sublimation is dry ice. At room temperature, compressed carbon dioxide changes quickly from a solid to a gas. This is essentially the process that is used in the dye sublimation printer. A dye is heated until it changes to a gas and this is fused to another surface.

The dyes used in dye sublimation printers are polymer materials that gassify at around 400° F. In a gaseous state, the polymer materials will react with other polymer based materials. As they cool, they form a permanently fused bond with the base material. Because the color is applied to the output medium as a gas, it produces almost continuous gradations in tone and color, which result in near photographic image quality.

Thermal Waxing Printers

Thermal waxing printers use a tape or ribbon to hold the color material. The mechanism for effecting the actual transfer of color differs among machines, but the basic principle is the same: the ribbon is heated, the color material is detached and transferred to the target medium. The charm of the color waxing printer is that this method produces a high-gloss image with good gradation in the color image. Because of the glossy surface and vividness that can be achieved in the color dyes, the image resembles a photograph.

Color Laser Printers

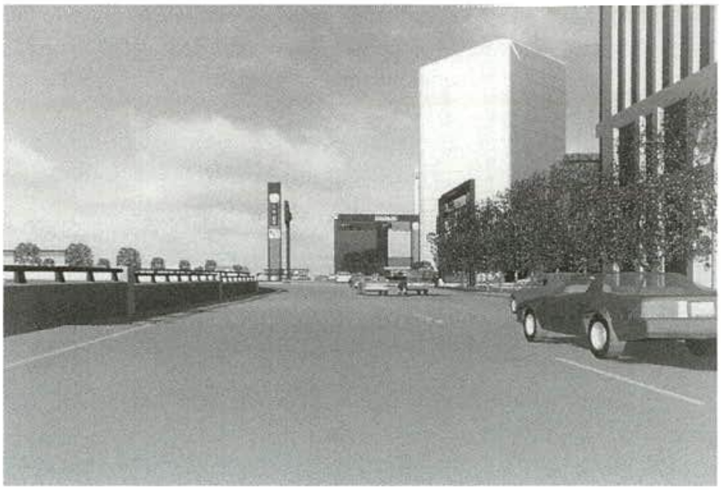
Color laser printers have been available for some time but they have been at the upper end of available technology in cost. Very recently, the price of color laser printers has begun to decline to a point where it is a competitive color output device. In the top-of-the-line machines, the color quality and picture resolution are nearly as good as the dye sublimation printers. Its advantages are that it prints on plain paper rather than a more costly special medium.

Film Recorders

Film recorders are used to transfer computer-generated images to photographic film. They are essentially a camera body attached to a small, high-quality, flat screen computer monitor with a very high picture resolution. The computer image is generated on the monitor and the camera body exposes the film, which is then processed.

Most all film recorders use digital signals. That is, they send the image directly to the recorder's monitor screen in digital format rather than converting the signal to an analog video signal. This provides very good color and picture resolution, depending on the quality of the film recorder's display capabilities.

Many film recorders are fitted with 35mm, 60 mm ($2^1/_4$ in.) square, and 102 mm × 127 mm (4 in. × 5 in.) camera backs and they will support a variety of film types and



speeds. For text and basic graphics, film recorders at the low end of the price range will provide good results. However, when considerations of time and complex imagery, multiple objects, or large variations in light and color are involved, consideration of a better quality camera may be warranted. Higher quality will come at a significant increase in price. In the case of a film recorder, it may be advisable to contact a service bureau in the local area to provide appropriate services when high-resolution work is required. This approach can limit the initial investment until internal needs can be better established.

SOFTWARE FOR VISUALIZATION

The software necessary to generate visualization products is best explained in relation to the three phases of visualization product development. As in the previous section, software will be discussed in relation to image/data acquisition and input, image processing, postproduction, and output. Where software is concerned the variety of choices is even greater than the available hardware.

Software for Image/Data Acquisition and Input

Aerial Photogrammetry and Mapping

The relationship of mapping operations and data may not be immediately associated with visualization capabilities. However, most transportation projects are impacted by the physical location of transportation corridors in space and these must be faithfully reproduced. Thus the construction of an artist's concept plan or a 3-D model usually requires a topographic map. Illustrative plans can generally use nonrectified photography, i.e., aerial photos that have not been adjusted for scale and to remove lens distortion. However, when the information is used to construct a 3-D base for an image composite or animation sequence it is necessary to have rectified imagery that can be converted into reliable x, y, z coordinate data.

Most of the conversion of aerial survey data in the past has been accomplished using manual stereoptical interpretation methods. More recently, data are processed by computer-based systems that merge stereoptical interpretation and the computer is used as a computational and plotting device. What is significant about these systems is that they record information in a true 3-D (x, y, z) environment. The term applied to these 3-D data files is digital terrain model (DTM). Information captured as a DTM can be moved directly into most 3-D modeling environments and displayed as triangulated irregular networks (TIN's), plans, sections, or elevations. Models of other structures can then be constructed on this 3-D base.

The problem encountered in most transportation agencies is that the 3-D data set is not maintained through the planning and design parts of the project development process. By continuing to use the two-dimensional methods in planning and design, much of the value of this initial data set is lost.

Image Acquisition

Regardless of the camera used to record an image, a software interface is required to move the imagery from the capture board or scanner to the computer. Most image capture boards have proprietary drivers and software that come with the board. Devices such as scanners may have drivers, called plug-in modules, that operate within other graphics software packages. For example, in the DOS/Windows environment most graphics packages and scanners use a "TWAIN" compliant driver. This means that the device complies with industry standards for scanning devices operated in this environment. Thus, any software that supports a TWAIN compliant driver can control the scanning device. All of the major graphics softwares and the top word processing programs can directly access scanning devices that use TWAIN compliant drivers.

The features that should be considered in scanner drivers include:

- pre-scan/preview options
- image processing features that allow the operator to adjust the scan settings for characteristics such as contrast, brightness, shadow contrast, etc.
- color adjustments
- edge interpolation adjustments, (smoothing and sharpening).

These features allow an image to be scanned into the computer environment ready for manipulation with minimum additional modification.

Visualization Production Software

Paint/Image Editing Programs

Paint/image editing programs vary in their features and operational interface and, as might be expected, the greater the flexibility the more difficult mastering the program is likely to be. When selecting a program for use in transportation applications it is important to be aware that these programs require an operator skilled in operating both software and hardware and who has considerable artistic ability in order to achieve good results. Most of the paint programs, which will be discussed in more detail later, do not have the sophisticated capabilities necessary to construct perspectives and control surface texture variation, shade and shadow, light source, and other variables found in the rendering softwares. These variables must be carefully controlled by the operator if acceptable results are to be achieved.

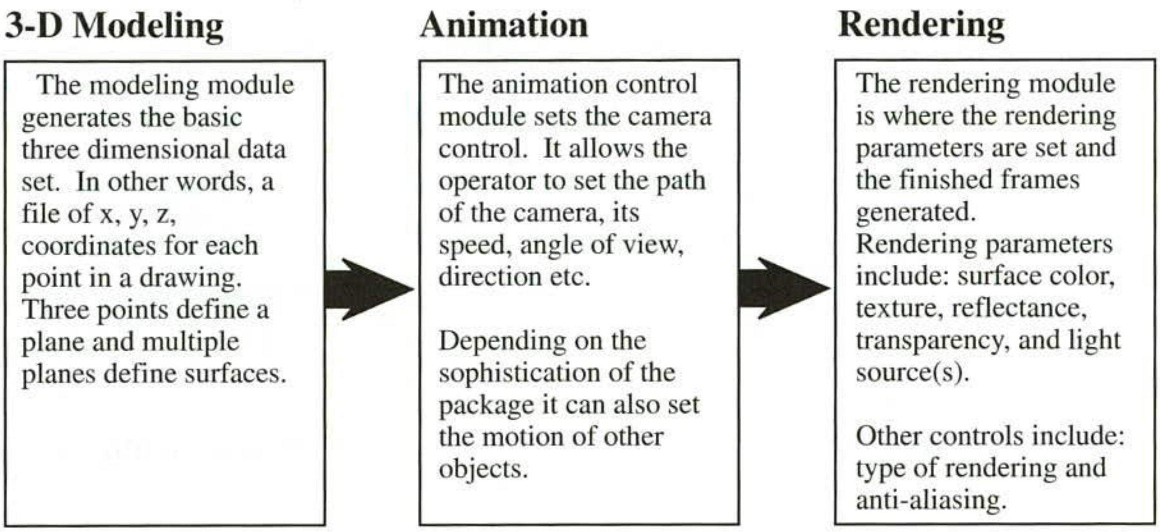


FIGURE 22 Modular components of 4-D software.

Modeling Animation and Rendering Software

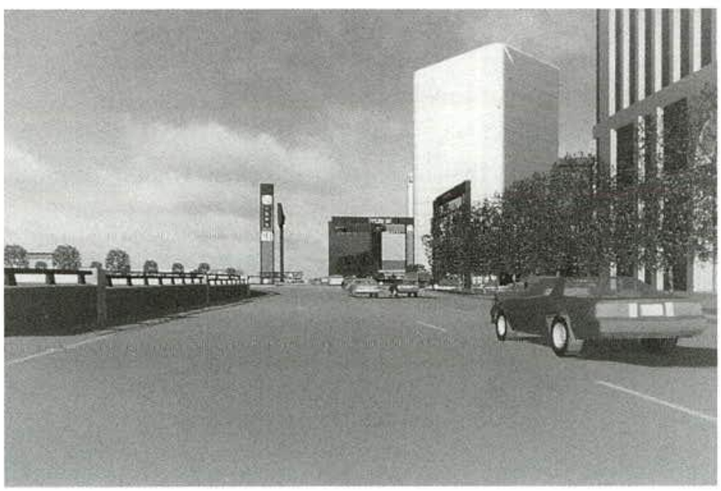
Software used to produce animated products can be separated into three basic modules: modeling, animation, and rendering as shown in Figure 22.

Modeling and Rendering Features

The differences between the modeling, animation, and rendering modules, as shown in Figure 22, are not as clear-cut as they used to be. In the last few years all of the major CADD programs have incorporated 3-D modeling environments along with some fairly sophisticated rendering capabilities. What really differentiates the various software products is the level of sophistication in the fine points of the software. The high-end animation software packages, used to generate animated movies, combine the modeling, animation, and rendering control modules in a single package. The results that can be achieved with these softwares are impressive, but there are some distinct disadvantages that make them unsuited to visualization applications in transportation. The primary disadvantage is that the modeling environment does not provide a set of true-scale modeling tools similar to those available in CADD software. That is, the software architecture does not deal with the x, y, z, information in relation to a real-world coordinate system. This makes it somewhat difficult to use when precision is needed and it is almost impossible to manage if it is necessary to import and export information. Recognizing this shortcoming, several of the high end systems now support the transfer of data through data exchange formats such as .DXF.

Based on the survey, Microstation is the most widely used CADD software for transportation applications. Although it is primarily used as a 2-D CADD environment, it offers very good 3-D modeling capabilities with some reasonably high-level rendering capabilities. Other production softwares gaining widespread popularity are InRoads and GEOPAK. Both of these products are tool base extensions to Microstation that enhance and facilitate the use of its 3-D capabilities. For agencies and offices moving into a 3-D production environment, InRoads and GEOPAK seem to be the products of choice. Their popularity is generally attributed to a generous palette of tools that allows an operator to build 3-D forms quickly by extruding, adding, and subtracting volumes and forms. These can then be translated into traditional plan-profile sets, single rendered perspectives, or animated sequences, which can be viewed on screen using a ''flip file'' routine.

The difference between the full-feature CADD systems and high-end modeling and rendering softwares is the level of sophistication available to the operator. What is meant by the level of sophistication is most easily illustrated by comparing differences in rendering capabilities. Several different types of rendering techniques are available and each type represents a successively higher level of detail and sophistication. Microstation offers seven levels of rendering: wire mesh, hidden line display, filled hidden line, constant



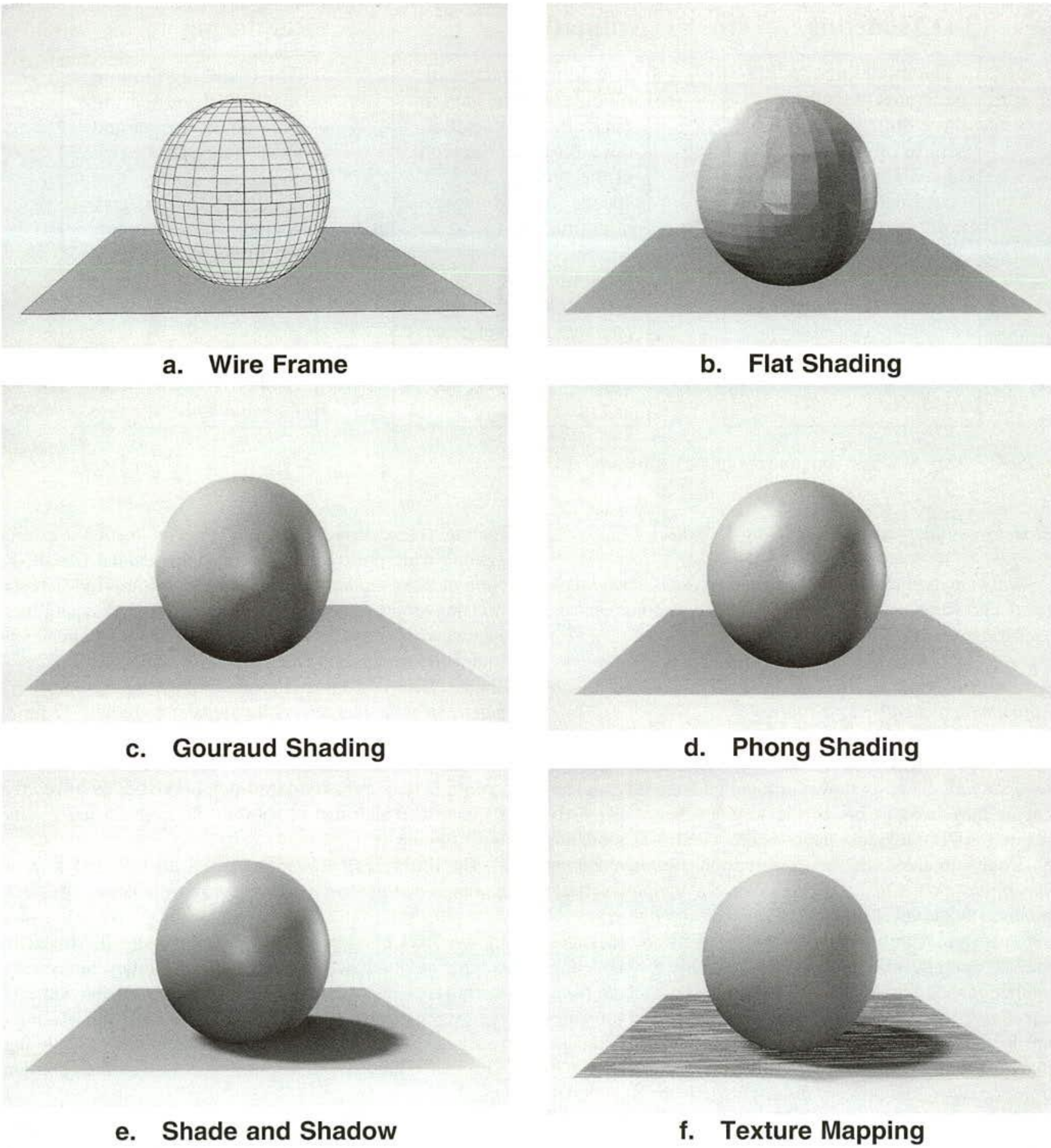


FIGURE 23 Comparison of different levels of rendering.

shading, smooth shading, (Gouraud shading) and Phong shading. The simplest method of rendering is the wire mesh. All elements of the image are transparent and the edges of masses are delineated by lines and a polygon mesh is used to delineate curved surfaces. Hidden line rendering establishes a station point and view direction so that polygons can be shown as opaque elements that conceal elements that lie behind. Filled hidden line rendering shows elements as solid polygons of specified colors that conceal elements that lie behind them. Constant shading displays each surface as one or more polygons filled with a solid color. Smooth shading displays a surface as one or more polygons but the shading smooths the edges between the polygons. Phong shading is the most realistic, it smooths all edges and varies the colored surface by computing the color for each pixel in the image. Six different levels of rendering are illustrated in Figure 23. If

several sequential frames are rendered along a specified path and viewed at 30 f/sec, the illusion of motion is created.

Depending on the type of rendering, each image in a sequence may range in size from as little as a few hundred kilobytes to several megabytes. An image rendered for video resolution requires 750 KB and an image rendered for slide film resolution (4096 × 2762) will be approximately 33 MB. When images reach this size, storage of the rendered frames can become difficult to manage with respect to disk space.

Software for Image Compression

When selecting a modeling and rendering package careful consideration should be given to a product that provides file compression features. Compressed files increase the number of images that can be stored on the disk and in active memory. When images are stored in active memory it provides real-time display capability or on-screen animation. Onscreen viewing capability is very helpful when making preparations to output an animation to the final medium. However, there are some aspects of compression that should be considered.

There are two types of compression that are popularly called ''Lossless'' and ''Lossy.'' ''Lossless'' compression reduces the size of the file by coding so that no information is lost at compression ratios of 2:1 to 3:1. The disadvantage of this type of compression is that the image must be ''decoded'' in order to write the display to the screen. This is a time and memory consuming process.

''Lossy'' compression physically reduces the size of the file. The process of reducing file size is done by reducing the amount of color information in the file. Once this conversion is complete the information is permanently lost. With this method, compression rates of 10:1 to as high as 60:1 are possible. At a rate of 60:1 there will be some visible reduction in picture quality. The most popular lossy format is JPEG (Joint Photographic Experts Group) compression. This is the most common technology used to provide onscreen playback of rendered sequences.

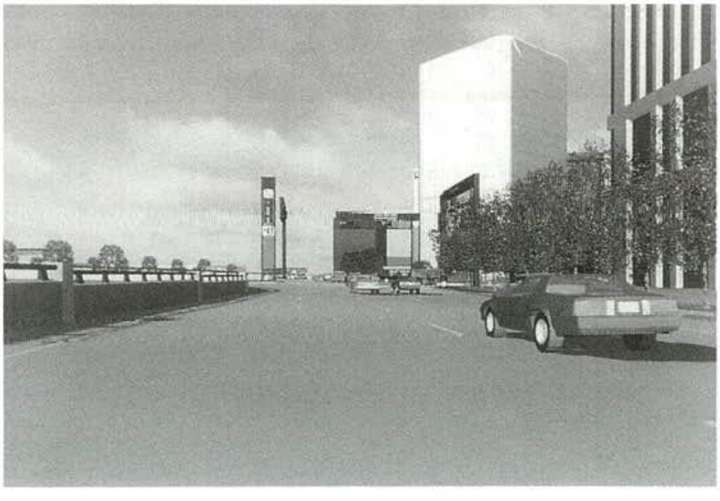
Output and Postproduction Software

Output or postproduction operations involve moving rendered images from the computer to a final medium for distribution. At this time the most popular medium is video tape. However, CD technology is rapidly becoming more common and affordable. The current drawbacks to the use of CDs as an output medium are the cost of the CD writing equipment and the lack of a well developed playback infrastructure. Irrespective of the target medium, postproduction concerns and methods will remain much the same.

The software products used in the postproduction process generally include character generators, transition effects, and sound. Character generators are used to overlay text or other icon figures on the video tape imagery. The most common uses are for titles and credits but they are also handy for adding notes and labels to graphics as instructional and informational aids.

Transition effect softwares are used to provide smooth changes between video segments. Transitions include effects such as fading an image from full brightness to black and bringing a new segment up to full brightness, called ''fades.'' Another kind of transition blacks out the current image in segments, for example blacking an image out in a series of continuously wider parallel lines creates the effect of venetian blinds being closed. These transitions are called ''wipes.'' Another effect gaining great popularity is called ''morphing.'' An example of morphing is changing a speedy sports coupe to a running tiger in one smooth continuous motion.

Postproduction software varies in its variety and level of sophistication. Many of the animation control software packages include some postproduction capabilities that probably are sufficient for most general applications. If video is going to be an integral part of an agency's visualization activities, some postproduction capabilities should be considered.



CHAPTER FIVE

VISUALIZATION PRODUCTION

INTRODUCTION

Chapter 4 presented the basic tools used for generating visualization products. This chapter discusses how the various pieces of equipment are orchestrated to produce a visualization product. The discussion is directed to administrators and professional staff who may find themselves charged with the task of developing a visualization production capability.

Figure 24 illustrates the steps required to produce the three most common visualization products used in transportation: the artist's concept, the composite image, and the animation sequence. The processes for producing these types of imagery are described, along with some examples of common tools used to accomplish each task. As appropriate, reference is made to the relevant output media.

SELECTING VISUALIZATION PRODUCTS

The key considerations in selecting the type of visualization to be used are: cost, time, audience, and project complexity.

Cost

Cost is a consideration in any selection process. In the case of visualization materials, cost is often evaluated as a percentage of the overall development and construction cost of the project, the probable need for visualization materials, and the period over which there will be a need for visualization materials. Relating visualization costs to the construction budget can provide a quick overview of project expenditures, but experience suggests that it is not a very reliable measure of cost-effectiveness. More often the cost of visualization materials has to be viewed in relation to the sensitivity and complexity of the project. In other words, the costs will have to be judged against the potential costs that result from project delay, negotiations, litigation, and other delays associated with public education.

A third criterion that is easily overlooked is the long-term value of the visualization materials. This is particularly true when considering the cost of developing a 3-D model of a project corridor. The TxDOT study (*17*) noted that many different units within a transportation agency could and would use visualization materials generated from a 3-D data set if it were available. The problem was that the cost of developing the 3-D model was difficult to justify in relation to any single need. This suggests broader application of visualization materials where a 3-D model is available.

In terms of labor and materials the artist's concept is usually the least expensive of all visualization products because it involves only three steps: base image acquisition, concept creation, and output. The "composite image," still or dynamic, represents the middle ground of cost with the animated sequence usually representing the most expensive product. Within each of these techniques, different levels of detail effect the cost of the final product considerably. For this reason it is seldom prudent to make a final decision based purely on generalized notions of cost. For example, an animation rendered with only hidden line removal and viewed only as an on-screen computer display could easily cost less than two or three artist's concept sketches of the same area. The question is which product will be most effective in meeting the needs of the audience.

Finally, while it is generally true that a 3-D model will cost more than a single-image presentation, one should not lose sight of the fact that once a 3-dimensional model is developed an almost infinite number of still views and animations can be generated at a very nominal cost increment for each product. For this reason, and the fact that the data set has value long after the construction process is complete, the 3-D model should not be rejected out of hand simply on the basis of cost.

Production Time

The time required to produce a particular product must be taken into account when selecting a visualization product. In general, artist's concepts can be produced in the least amount of time, while the realistically rendered animation represents the highest time requirement. Time will, of course, vary with the complexity of the project, availability of base materials and the level of detail needed in the final visualization product. For example, a wire frame drive-through of a relatively simple corridor can probably be generated in the same amount of time as that required to do a fairly detailed artist's concept. In either case it is important to select a visualization type that fits the time available.

Another factor that will significantly impact the production time of a visualization product is the agency's CADD/Graphics production environment. If the primary production environment is 2-D, using a system such as RDS or IGrds,

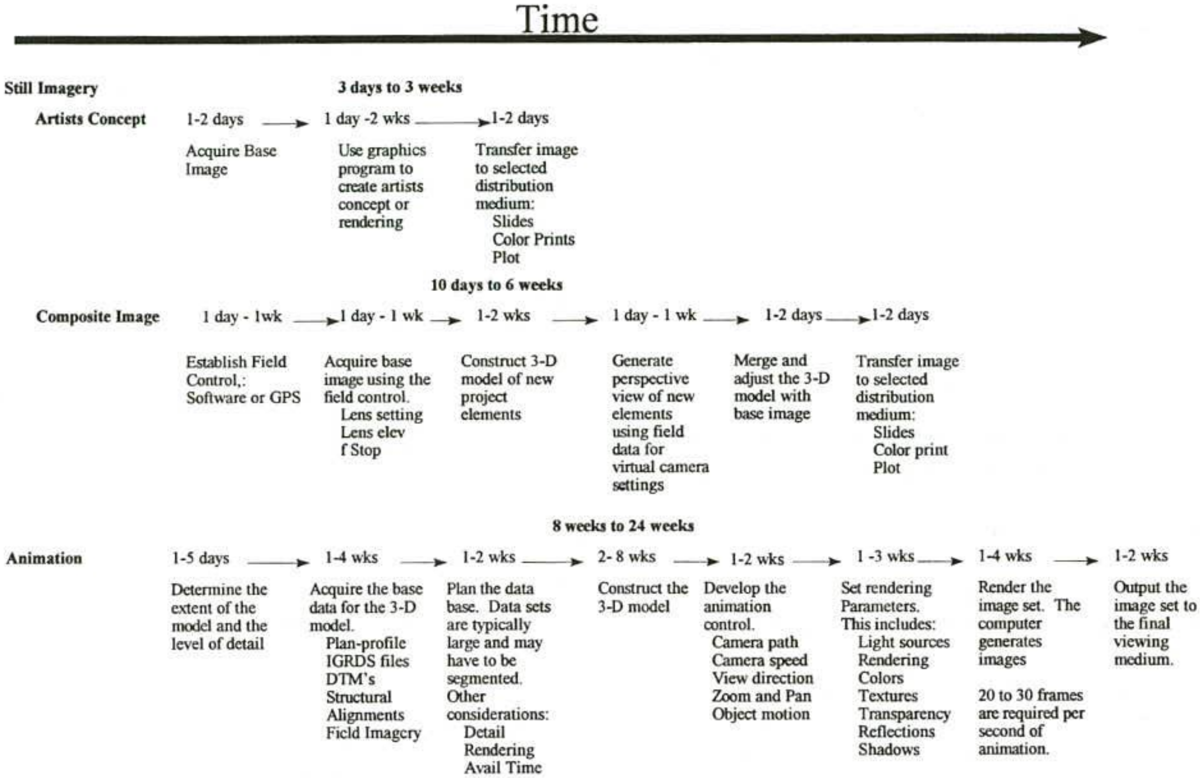


FIGURE 24 Steps in the production of three visualization products.

it is necessary to add or extract the z dimension in order to generate perspectives. This task represents a considerable time commitment. On the other hand, if the agency uses a 3-D production environment such as that afforded by InRoads or GEOPAK, it is a straightforward matter to generate perspective images at any time from any viewpoint in the model space. Because the life of the data set continues long after construction of the project is complete, it is there to support activities related to litigation, maintenance scheduling, and public information.

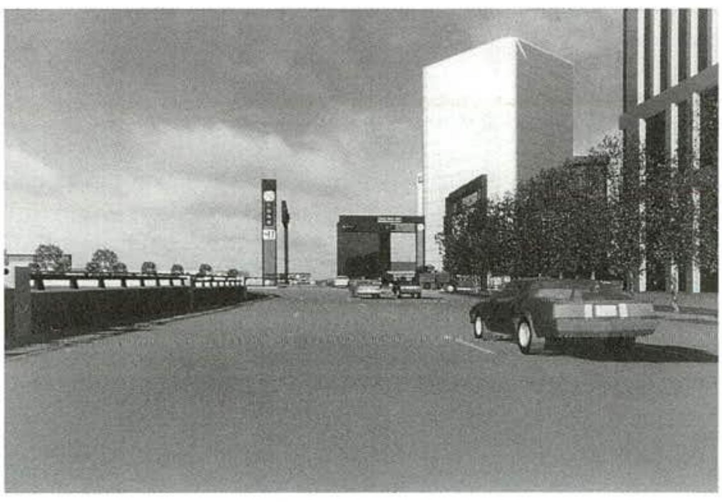
Figure 24 illustrates the production steps for the three most popular types of visualization products. Each step in the process has a range of time that should be anticipated for the task, depending on the size and complexity of the task. One of the most time-consuming parts of the process can be acquiring design information in sufficient detail to generate a representative visualization product.

Developing 3-D models of the type required for animation and image compositing can vary markedly and will be impacted by the skill of the operator, the software environment, machine speed, quality of design information, and the complexity of the structure to be modeled. A simple at-grade intersection, for example, will require substantially less modeling time than a grade-separated interchange with multiple direct connects.

For animated products, the time is even more difficult to estimate. Not only do the size and complexity of the 3-D model have to be taken into account, but the complexity of the rendering as well. If fairly complex rendering and effects are to be included in a final animated product, several test runs may have to be completed before the final rendering parameters, motion control, materials palette, and lighting scheme are set. Rendering time may then be measured in weeks, depending on the computing capacity available.

To the extent possible, these differences in time have been recognized in the discussion.

The process of designing a transportation corridor and its related structures requires the generation and use of all three dimensions. In the past, manual and even computer-based graphics systems worked with this information in two separate, two-dimensional planes: the plan and the profile. CADD technology has now evolved to the extent that engi-



neers have an effective set of true 3-D design tools. These new systems will slowly change the current 2-D production process to a true 3-D environment. As this occurs, the time required to develop 3-D imagery and animation will be markedly reduced, which will almost surely lead to a wider use of 3-D and 4-D products.

Audience

The intended audience should be carefully considered when selecting and planning visualization materials. Many audiences do not understand or respond well to two-dimensional drawings like plans and profiles, sections, and elevations. In the case of very complex projects, even trained professionals will have difficulty understanding two-dimensional materials without sufficient time to study the drawings.

Audience impact is also related to the level of detail that will be used in the imagery. Design professionals have very little problem understanding wire frame or quick-shaded representations of project elements, and for most situations the wire frame provides sufficient detail for in-house review and design exploration. On the other hand, the general public tends to evaluate imagery based on their contact with commercial television. Images that do not come up to that level of detail and quality are often described as "cartoonish" and therefore viewed with some degree of suspicion.

There is little in the transportation research literature that suggests what types of visualization products will be most effective for a given audience or what level of detail may be required to achieve the greatest level of understanding. However, information from agencies and consulting firms with substantial commitments to visualization technology provide some insight as to its use.

A majority of the public transportation agencies identified as generating and using visualization products began with computer generated artist's concepts. For the most part these efforts were in association with demonstrating design outcomes for sensitive environmental conditions or were used to facilitate the public participation process. While several states indicated some experience with these media the states providing follow-up information for this report were: New York, New Jersey, Minnesota, Texas, and Wyoming. What may be more significant is that all of the agencies that reported the use of still imagery also indicated that they were working with, or in the initial stages of exploring the use of 4-D as a next step in their visualization production.

The Texas Department of Transportation was the only survey respondent that reported any extensive use of 4-D visualization within the department. It seemed that the most concentrated use of 4-D technology at this time was in research universities and private sector transportation consultants (*11,23,25*). In the cases identified, animation was used for facilitating the public participation process, right-of-way litigation, evaluation of complex structures, and the review and visualization of complex construction processes. There is also reason to believe that states other than those that responded to the survey have had some experience with 4-D media. However, it appears that the use of the materials is consistent with those that were identified.

Project Complexity

The relative complexity of a project should always enter into the selection of a visualization product. This is particularly true where relationships exist between site elements, property, buildings, narrow rights-of-way, and where project elements are going to be visually complex. The best example of a complicated structure is a three-level, grade-separated highway interchange. The visual confusion generated by the number of bents, ramps, signs, lights, and grade transitions makes it difficult for even the trained professional to understand, and almost impossible for the untrained eye. When a project is this complex, careful consideration should be given to developing a 3-D computer model to avoid any misjudgment in scale or alignment. It may also be desirable to use higher and higher levels of rendering to make it easy to distinguish various structural elements and to add a sufficient sense of visual depth so the image can be easily and accurately interpreted.

Several major architectural and engineering consulting firms have made a strong commitment to 3-D modeling and animation as part of their production process (*11,22*). By working in a 3-D environment, errors can be avoided in dimensional clearances and locations that are all too frequently encountered when only 2-D design techniques are used. A direct benefit of using 3-D modeling technology as an integral part of the planning and design process is that animation sequences can be generated for a variety of presentations, which provides better overall communication.

ASSEMBLING BASE DATA FOR VISUALIZATION PRODUCTION

The production of a visualization image or animated sequence requires the collection and assembly of a variety of information. Some of the information is readily available as part of the normal project planning and design process, while other information must be carefully planned and collected for a specific project. This section discusses the kinds of information needed for producing different types of visualizations and suggests some of the better methods for acquiring the information. The broad base of technology—computers, scanners, image capture devices, film cameras, and video cameras—available to gather base information was presented in the previous chapter. The focus here is on applications of the components rather than the idiosyncrasies of the various component technologies.

Topographic and Alignment Data

Most transportation agencies have maps that show corridor topography and corridor (center line) alignment. This information is most often displayed as rectified aerial photographs, right-of-way maps, topographic maps, and plan-profile sheets. Depending on the stage of project development, the information needed to prepare a 3-D image or animated sequence can range from very sketchy and preliminary to very detailed. Where only sketchy information is available, model construction time and accuracy must be given very careful consideration. There are cases where disagreements between early project visualization and completed projects have resulted in public dispute and litigation. (*12,17*)

Digital base information is by far the most useful in developing computer-based graphic products. Digital terrain models (DTM) are very useful for developing the ground plane model of a transportation corridor. CADD files are invaluable for establishing the new 3-D construction parameters. True 3-D files are clearly of greater value than two-dimensional files. If no 3-D files have been developed, software aids are available that allow operators to "loft" a 2-dimensional drawing into a 3-D file if vertical alignment information is available.

The availability of base information must be carefully considered when planning the development of the final product. Commitment to an animation sequence, for example, would be very costly if it meant building a 3-D model from very limited digital information and the results may be of very limited use. Always keep in mind that the tools allow development of very convincing illustrations but a 3-D model built with assumed information is of questionable value because it will not necessarily reflect a real or practical solution and this can have negative results.

Base Imagery

Artist's concepts and image composites require a base image to achieve the highest level of realism. Images for artist's concepts need only follow good photographic techniques. Image compositing, on the other hand, requires field control.

Field Control for Base Images

Computer programs use the analogy of a camera to generate perspective images. That is, they establish a viewing station, a focal length, and lens aperture to determine what is in the field of view. The camera height is selected to establish the horizon line from which the perspective will be constructed. Depending on the sophistication of the software's camera algorithm, lens distortion will be calculated and the final image adjusted. Figure 25 is an example of a computer perspective adjusted for camera lens distortion.

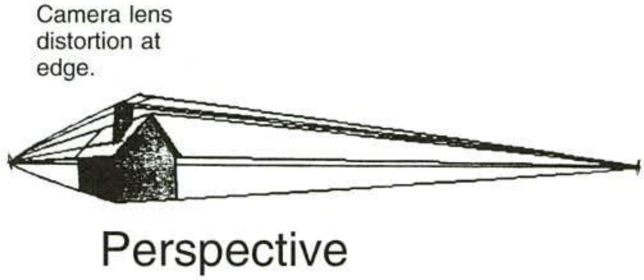


FIGURE 25 Perspective adjusted to simulate lens distortion.

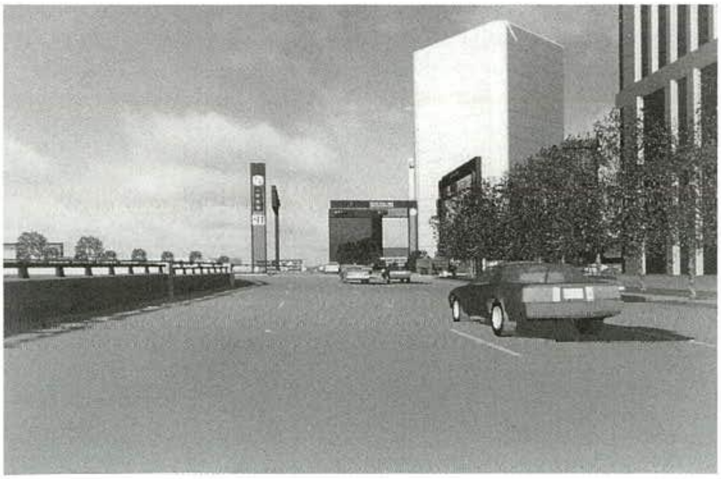
The objective in developing a composite image is to match the physical camera to the computer's virtual camera location and camera settings as closely as possible. Then, when the two images are brought together during the compositing process, the images' perspective and shading will match closely.

To achieve the closest possible match it is necessary to locate the station point of the camera in the field. The most convenient way to do this is with a global positioning system (GPS) receiver. This gives the basic x, y, z, information of the station point and the remaining parameters can be easily recorded. The time required to use a GPS receiver will vary depending on the receiver and the number of satellites that can be acquired.

If good topographic information is available, station points can be selected before going to the field, or measurements can be taken from known points in the field which can be located on maps in the office. Other than the x, y, z, information of the station point, it is necessary to record the camera's line of view (azimuth, bearing), and record the camera's focal length and f-stop (aperture).

For the best results, the camera used for taking base images should be calibrated in a studio condition prior to using it in the field. Factory calibration markings on the lenses are frequently inaccurate. This is difficult with video cameras because they use variable focal length lenses (zoom lenses), which have a wide variability in lens performance.

Software methods can also be used to generate this information but they still require that field measurements be



taken. The software methods backcalculate the field camera settings based on actual dimensions provided by the operator. Using this method the photographic base image is digitized. Then several known points, usually five or more, are identified in the photograph along with the actual field dimensions. Important reference points might be the corner locations of existing buildings and the lengths of the walls, bridge bent locations and heights, or other physical objects such as retaining walls, poles, and signs. When physical features are not available, large cones can be used. The best references are always objects that have clear sharp edges and where the horizontal and vertical dimensions are known precisely.

Photographic Base Images

Using photographs as base images offers the advantage of very fine-grain picture texture, depending on the film grade, quality, and negative size. For most cases a medium- to low-speed 35mm film, (ISO 64, 100, 200), will provide the best results. The disadvantages of using film include: limiting the views to a few selected station points and the need to have film processed and then converted to a machine readable form with a scanner.

Video Images

Video images have the advantage of multiple frames that can be reviewed to select the most advantageous or instructive view. The camera operator can pan an area, zoom in and out, and adjust the viewing point to provide a wide variety of choices for the base image. The video tape can be viewed in real time and the best view(s) selected. Unlike film, video does not have to be processed.

On the other hand, video does have some serious disadvantages. Like film, it must be digitized by an image capture scanning device to convert the analog signal to a digital file. Because of the data loss during the conversion of the analog video signal, the resolution of video imagery is limited to the maximum video resolution, which is approximately 720 × 486. This is considerably lower than the available digital resolutions. The best image capture boards scan video at the full NTSC standard 760 × 486 resolution; other boards are available with resolutions of 720 × 486 or 512 × 486.

Digital Cameras

Digital cameras have been available in the commercial and consumer markets for some time. These are still-image cameras that record images directly in a digital format on an 89 mm (3.5 in.) floppy disk. At this writing, the state of digital camera technology is not developed sufficiently to make them cost-effective tools for general use. Their disadvantages are cost and portability. Cameras capable of recording high-quality images are still very expensive. Secondly, most of the current cameras require that they be tethered to a computer to receive and record the digital signal. However, this technology is maturing rapidly and it will likely replace the use of film cameras for computer-based graphics applications in the very near future.

Material and Texture Libraries

Another important form of base imagery is the materials and textures library. The generation of photo realistic images requires collecting other kinds of imagery that can be used in the final visualization product. This includes things such as brick and concrete finishes, wall systems, plant material, and building elevations or any other special materials or surfaces that might be unique to the project.

Most of the full-feature paint programs have tools that allow the operator to import images or portions of images, from any machine readable file into the final image. Elements such as trees and plants can be captured, scaled, and placed in a new image. If this is done from high-quality base imagery the results can be very impressive. Another tool is called texture mapping. Through texture mapping, a feature such as the texture of a wall or even the elevation of a building, can be associated with a plane or surface in the image. The surface can then be scaled and adjusted to match the perspective of the final image.

To take full advantage of these program features, it is usually desirable to photograph or video a wide variety of materials and keep them in a library for use in developing visualization products. Once a particular effect is created it can be saved and used in other images. One major consideration in developing these libraries should be light conditions. Try to plan photographing and video sessions when the sun is near its zenith. This limits shadows and allows the images to be moved into a wider range of light conditions.

Material and texture libraries are being produced commercially and are available on compact disks. However, they are of necessity general in scope and may not reflect regional conditions well. Another problem is that some of the pictures are captured from video and the image quality is often poor due to the video to analog conversion. A good quality materials library would be handy as a foundation if it fits regional light conditions and reflects appropriate materials. The library can then be expanded to meet organizational needs.

GENERATING THE VISUALIZATION IMAGE

Visualization images are generated by paint/image editing programs or 3-D modeling and rendering programs. These represent completely different classes of programs in terms of organization, structure, and operation. They also require much different levels of skill to achieve the desired results.

Paint/Image Editing Programs

Paint programs are a collection of computer-based tools and procedures intuitively arranged and patterned to mimic the traditional tools and methods of the artist or "painter." Numerous programs are available that offer a variety of options and degrees of sophistication. Simple paint programs produce images by assigning a grey scale value or a color to each pixel or raster of the drawing area. In general the programs are arranged with a set of drawing tools, painting tools, a color palette, special effects palette, editing filters, and a suite of input and output options. The drawing tools are like a pencil or a pen. They are used to draw lines, arcs, circles and other geometric forms, as well as text. The painting tools simulate the effects that could be achieved with a paint brush, a pen, or an air-brush. Controls are provided in the paint tools panel to adjust the width of brush or spray pattern, the color concentration or relative transparency, and the edge effect. The color palette allows control of the colors up to the maximum potential of the graphics environment of the computer and the monitor display.

Special tools and filters allow the operator to capture all or parts of images, manipulate them, and insert them into a new image. The more complete programs include a variety of transition effects that can be used when assembling video taped or computer-based presentation. They also allow images to be developed in a series of layers, which faciltates developing complex images that involve transparent or translucent surfaces. Using layers, objects behind can be shown in the appropriate relationship.

The input and output tools link the paint program to the peripheral devices. On the input side, the program will include the scanner or image capture controls. The output side controls the drivers for printers, plotters, and film recorders.

The distinguishing difference between a simple paint program and image editing software are the features for image processing allowing full-image manipulation. This includes features such as blurring, sharpening, color correction, changing from one color palette to another, and image compositing using alpha channels or mattes and layers.

Paint/image editing programs are the primary tools for merging composite imagery. To generate a composite image, a single frame is rendered in the modeling package and then imported into the paint environment. In most cases it is not desirable to render the model to any high level of detail because the light conditions usually cannot be specified accurately enough to achieve the desired level of realism. For this reason, the 3-D image is usually brought in as a constant or smooth-shaded object and the shadows and surface tones are adjusted to blend with the light conditions of the base image.

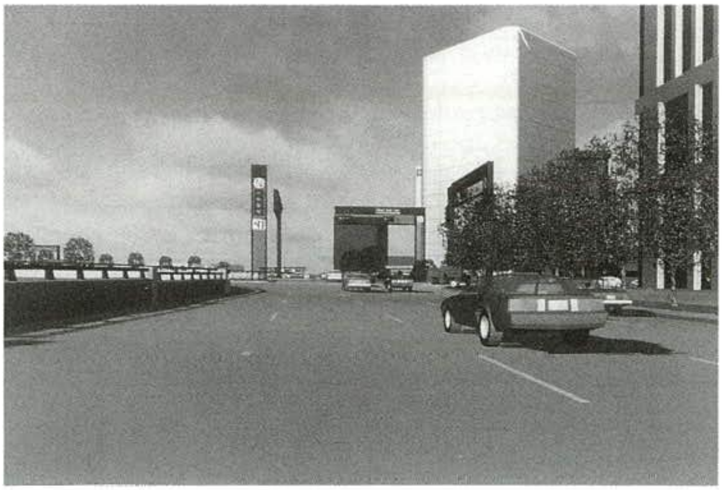
A good paint/image editing program is capable of generating images of near photographic quality and realism. However, the results obtained from paint/image editing programs are most dependent on the artistic ability of the operator and not the sophistication of the software. Artistic ability is essential because there are no tools to automatically control the perspective, color, light effects, and other considerations that are important to achieving a good representation. Even the best programs cannot compensate for the lack of an artistic eye.

3-Dimensional Modeling Programs

Software for 3-D modeling tends to be complex in its structure and tool vocabulary and require considerable time to master. Based on survey data, the most popular 3-D modeling packages for transportation are Microstation, InRoads, GEOPAK, and AutoCAD. Most transportation agencies have or are evaluating one or more of these programs. It was also noted that most agencies do not have widespread use of the 3-D capabilities of these programs.

3-D modeling programs use vector coordinates, x, y, z or x, y with z attributes, to define graphic primitives, lines, arcs, circles, and polygons. Perspective algorithms are used in the display routines to generate the foreshortening effects of visual perspective. The differences among 3-D modeling programs are functions of the sophistication of the drawing tools, the user interface, and the structure of data set. Some of the older CADD structures deal with data as x, y coordinates with a z attribute. This structure is not truly three-dimensional because z information is carried as a data attribute of an x,y point. The net effect is an increase in the processing time required to build the model and the time required to generate perspective images. In a true 3-D environment, coordinates are carried in a true x, y, z matrix. This permits near real-time viewing and interaction with the model because the topology (relation between the data points) is maintained regardless of the viewing point.

The pallet of modeling tools available in the user interface is also variable among the available software environments. As the interest in 3-D tools has increased in the transportation industry, the software industry has responded with numerous improvements tailored specifically for transportation applications. Tools that allow direct entry of alignment information are very useful. Likewise, the ability to extrude forms along and around all three axes simultaneously, markedly



increases the utility of modeling programs and makes 3-D a more cost-effective option as the primary production environment.

RENDERING AND ANIMATION PROGRAMS

Rendering capabilities are provided at various levels of sophistication in most CADD programs and in the popular modeling packages. However, if there is a need for a reasonably high level of realism in the finished product, it will be necessary to use a more sophisticated rendering package. The most popular renderers as identified by the survey were Modelview and Renderman. The modules in these packages have a very similar look and accomplish very similar tasks. The primary differences are in the algorithms used to accomplish the rendering tasks.

When a 3-D model is moved from the modeler to the rendering package it goes through three additional steps prior to generation of the final image. These are: setting up the virtual camera and camera path for animations, assigning color and surface qualities, and establishing light sources.

Setting the Camera Station or Path

In the first step, the camera station point and view port are set. If an animated sequence is to be produced, a more involved process of establishing a camera path must be specified and the motion of other objects choreographed if that capability is available. Most programs allow the camera path to be specified by picking points on a schematic plan and then establishing the angle and direction of view. These are the so called "key frames." By establishing the key frames in the sequence, the computer can interpolate the intervening frames, camera parameters, and object motion. The new user interfaces simplify this process. The remaining settings, such as camera height and lens, are simply point-and-click operations.

Setting Colors, Materials, and Surface Qualities

The second step involves assigning colors, materials, and surface qualities to all objects in the model. Depending on the complexity of the model and the variety of textures, materials, and colors, this can be a very time-consuming process. The materials module of the software will usually display a simple sphere to which the operator assigns different values for material, color, texture, reflectance, transparency, and highlights. Once the desired effect is achieved those qualities are assigned to a selected surface in the model. This process is repeated until all surfaces in the model have been defined. Texture mapping or bump mapping is an advanced feature of the surface qualities module of the software. Texture mapping routines essentially start with a raster image of a particular material or object and then the perspective of the image is adjusted to match the surface to which it is applied. For example, the elevation of a building can be taken with a camera and digitized into the computer. Then this image is assigned to the surface of the appropriate building in the 3-D model. Once this is done the computer will adjust the perspective of the texture-mapped building front to fit the perspective properties of any selected view point. This results in very realistic images but it also increases rendering time.

Setting Light Source(s)

The third step in preparing to render an image involves setting the light sources. A single light source can be set to depict bright sunshine, or multiple sources can be established to illustrate the conditions that might occur on a cloudy day or at dusk. Lights can be located at fixed points, as would be the case with street lamps, or they may be assigned to moving objects such as lighted vehicles.

Rendering Considerations

Once the camera, materials, and light conditions have been set, the image can be rendered. There are two important considerations during the rendering phase: rendering time and disk space.

Rendering Time

Assuming an animation sequence of one minute at 30 f/sec, 1,800 rendered frames will be required. Assuming an average rendering time of 15 minutes per frame for simple smooth shading, 450 hours of CPU time would be required. If the sequence is rendered at a resolution of 720 × 486, the full set of images will consume about 1.4 gigabytes of uncompressed disk space. If the images are more complex and rendered at a higher level of detail, the size and time required for rendering each frame will increase significantly. One hour or more rendering time per frame is not unusual depending on the power of the processor available. Given these factors, it is important to carefully consider the trade-offs between rendering speed, file size, and image realism.

Figure 26 lists some representative processing times for various levels of rendering detail. These are times for rendering on a Sun Sparkstation 10 with a 50 MHZ processor and 112 MB of RAM. Each increase in realism requires additional resources. Changing from flat to Gouraud to Phong shadings extracts little penalty in CPU time. Shadows, texture mapping, and surface materials definitions are more demanding. Figures 27 through 30 illustrate the relationship between computing time and the level of visual realism.

Rendering Technique	Time in Minutes	Difference in Minutes	Percent Difference
Gouraud Shading	38	-	-
Phong Shading	48	10	26
Phong Shading with Shadows	54	16	42
Phong Shading with Shadows and Texture Maps	90	52	137

FIGURE 26

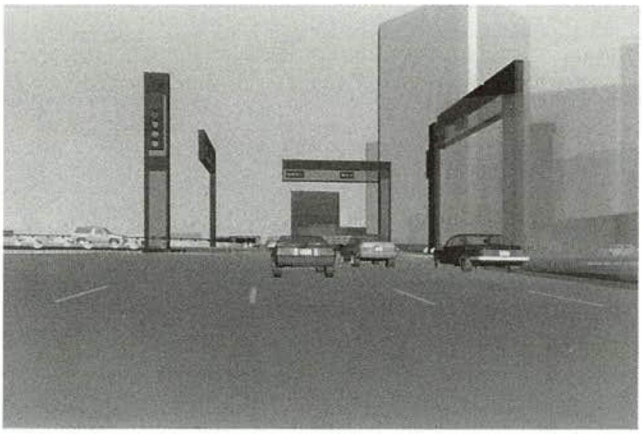


FIGURE 27 Frame rendered with flat shading.

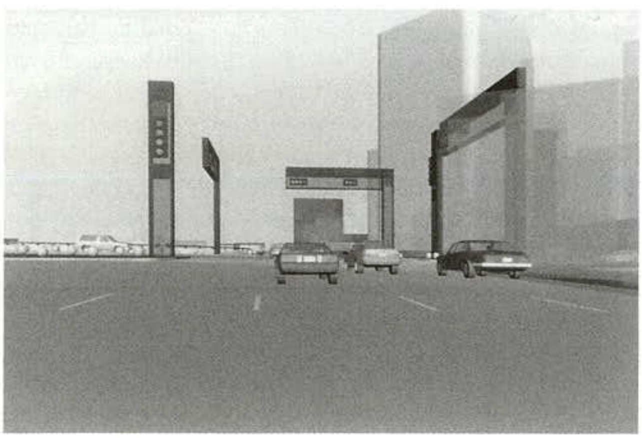


FIGURE 28 Image rendered with Gouraud shading.

Disk Storage Space

The issue of disk space is more difficult with fewer options. Texture mapping takes not only computing time but also consumes disk space as well. Almost 200 MB of disk space is consumed by the texture maps for the graphic data base for the frames in Figures 27 through 30. Compression is an option but only if some loss of image quality is acceptable.

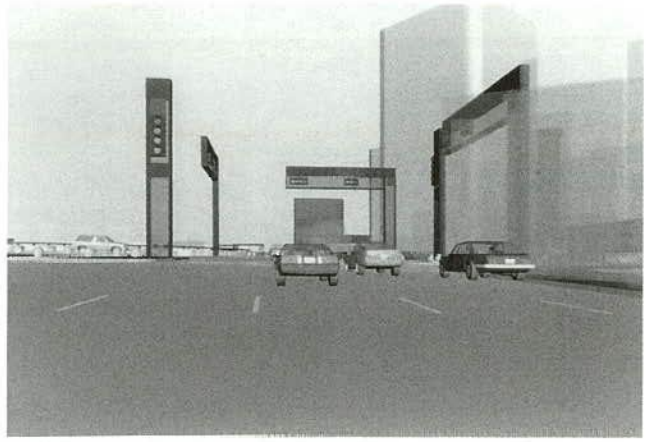


FIGURE 29 Image rendered with Phong shading.

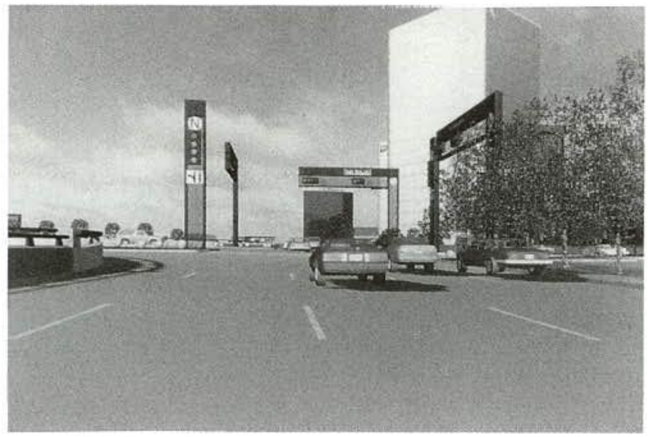


FIGURE 30 Image rendered with Phong shading, shadows, and texture maps.

Figure 31 shows a compression ratio of 10:1. Figure 32 is the same image with a compression ratio of 100:1.

The reproduced images do not reflect the true extent of image degradation because artifacts or errors are introduced in the animated sequence due to the color compression of each frame. In other words, compression involves an interpolation between pixel color values and this interpolation will not exactly match each adjacent image. Thus, images viewed

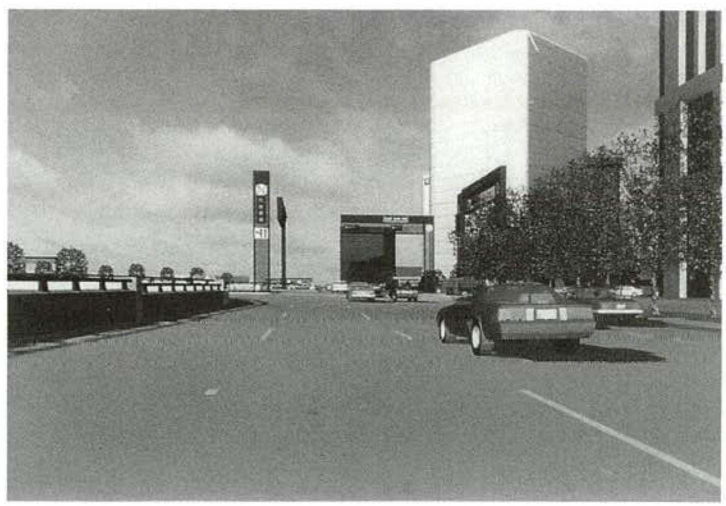


FIGURE 31 Image stored at 10:1 compression.

FIGURE 32 Image stored with 100:1 compression.

in an animated sequence tend to produce a flickering or blinking effect. A better alternative when camera motion is relatively modest is to render every other or every third frame at the desired level of quality and only render every frame during high periods of camera motion. Another alternative procedure is to render background elements with every second or third frame and render foreground elements with every frame. Properly planned and executed, both rendering time and disk space can be significantly reduced with virtually no loss of visual quality.

OUTPUT AND POSTPRODUCTION

Output and postproduction is the process of generating the product that will be used for exhibition. This part of the process uses a variety of hardware and software related to the specific output medium. In the case of still imagery, artist's concepts and composite images, the target medium will usually be color prints, color plots, or film. Final production of animated sequences will usually be output to video tape. Once the master video tape is produced it can be dubbed to different video formats or written to a compact disk.

In this section the processes of producing final output will be explored. This part of the production process affects the character and quality of the final product and should be carefully considered. The printers, plotters, and film recorders used to produce still imagery will directly impact the resolution of the final image, its color quality, sharpness and overall appeal. The video equipment used to produce a master tape will similarly impact the quality of animated materials. If low resolution or poorly matched and adjusted equipment is used in the postproduction process, the quality of the output will be poor regardless of the image quality generated in the computing environment.

Good quality postproduction requires careful planning and sufficient time. This is particularly true when it is necessary to produce a variety of media or to compile before and after presentations. Time must also be allowed if text and titles are to be added to slides and video and to prepare scripts and do voiceover recording for stand-alone narrated pieces.

Output and Postproduction of Still Imagery

Still images are produced by printers, plotters, or film recorders. These images can also be recorded to disk and viewed or projected as a computer slide show. Because computer slide shows do not currently have a great deal of portability, the discussion is weighted in favor of the mass distribution media.

Color Printers and Plotters

When fairly large images, A-size or larger, are needed color printers and plotters offer reasonable quality hardcopy output at reasonable cost. At present there is a confusing variety of printer and plotter technologies being marketed. Each technology produces an image by a different process and the images vary in quality. They also represent an equally wide range of cost. While each of the available technologies may have some application, the most prominent color printers and plotters are: color laser printers and ink jet printer/plotters. Where very high image quality is the concern, dye sublimation printers offer the best quality.

Color Laser Printers

Color lasers are being offered by a number of the printer manufacturers. These relatively new printers have 300 to 600 dpi resolution and most of them produce images up to 279 mm × 432 mm (11 in. × 17 in.). The sharpness of the images is consistent with the quality black and white laser images and they print on plain paper. The cost of color laser printers and color supplies is still quite high when compared with ink jet printer technologies. However, the sharpness and color quality of the color laser printer is better than the current ink jet printers. Thus, cost must be weighed against the type and quality of images required.

Ink Jet Printers and Plotters

As a rule, ink jet technology is satisfactory for very simple types of illustrations and applications that require only basic color rendering. In cases where there is a high level of color contrast and variation in the image to be recorded, ink jet technology often will not produce satisfactory results.

Ink jet technology has become quite common in the form of color printers with a maximum of a B-size sheet. Because the ink application head moves over the surface of the print medium, it has been possible to translate this same technology into a traditional plotter format for making large color plots. These new plotters appear to offer numerous advantages over older pen plotter technologies.

The newest generation of ink jet technology has the ability to print and plot in color and black and white on the same sheet and at resolutions of 300 dpi. While the 300 dpi resolution has been a limiting factor, improvements in software and media are rapidly improving on this limitation. The price of ink jet technology is very attractive, offering good quality color and near laser text printing in a package that costs considerably less than a laser printer. In the plotter format, ink jet technology is still more expensive than conventional pen plotters. However, there are dividends in terms of plotting speed and color control. For example, in order to shade an area with a solid color, pin plotters must use tight hatch patterns. This process requires a great deal of time and there is little flexibility in the shade or quality of the color.

Film Recorders

Film in the form of slides or color positive prints is still the highest quality form of graphic output and probably the most portable of all output options. Slides are an excellent format for exhibiting still images for large audiences and projection equipment is usually readily available. Color prints are equally portable, require no projection equipment, and can be very effective for communicating with small groups.

There are several different film recorders available at considerable differences in price. The price differential between film recorders has primarily been a function of screen quality, ability to record to a variety of film media, and the speed of image generation. Cameras in the low-end price range have screens that do not produce as sharp an image as the higher priced options. They are also limited with respect to the available camera backs that can be used. The less expensive recorders may only accept 35mm and Polaroid camera backs, while the more expensive models will accept 102 mm × 127 mm (4 in. × 5 in.) and larger film formats. Output speed is a function of both the camera and the film recorder. The more expensive recorders provide features that accelerate the output speed by generating the red, green, and blue bands simultaneously.

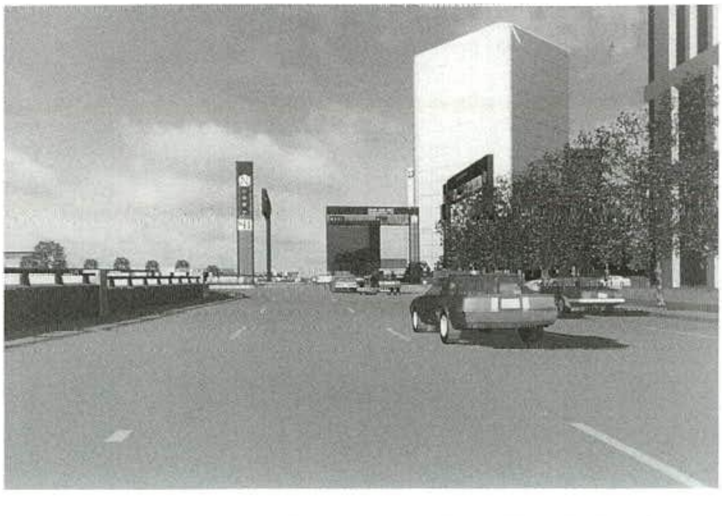
Film recorders like other forms of technology are developing and improving rapidly. Several of the low-cost cameras are now producing very good quality imagery for general applications.

The aspect ratio of the final film medium is an important consideration when using a film recorder. Thirty-five mm slides have an aspect ratio (width to height) of 0.67 and the computer screen has a ratio of 0.75. This means that the image must be cropped or compressed into the 35mm film format. This can lead to unwanted distortion of the image or loss of important detail near the edges of the image. The 102 mm × 127 mm (4 in. × 5 in.) format has a 0.8 aspect ratio which presents similar problems even though the negative is larger. Many of the better paint and presentation programs have built-in tools that help the operator with this problem by formatting the image to the proper aspect ratio during preparation.

Film size and type are also important considerations with respect to the final product. If slides are the final format, 35mm film is the logical choice. However, if color prints are the final product, a larger negative will give much better clarity and grain when the image is enlarged. Film type and speed are also important factors. Slower films, ISO 64, 100 and 200, will have less grain than faster films. Color is also a consideration. Some films tend to record certain parts of the visual light spectrum more faithfully than others, usually the mid-range frequencies, blues and greens. The higher frequency violets and purple and lower frequency red colors require a more sensitive film and specialized processing for the best results. As a general rule, color intensity will be lost as the image is enlarged.

Output and Postproduction of Animations

The most cost-effective means of outputting animated sequences currently is video tape. Other options include film (motion pictures) and compact disks. Considerations of cost and limited playback infrastructure simply make the latter options ineffective for application in most transportation venues. For this reason this discussion concentrates on output to video tape.



The process of transferring animated sequences to video tape involves working across the boundaries of digital and analog environments and there is a variety of hardware and software tools available to bridge the two worlds. This often leads to some confusion when trying to describe the process because there are numerous paths that can be taken to the final product. Figure 33 illustrates four different processes for moving an animated sequence from the digital environment to analog video tape. The shaded background represents operations that take place in the digital environment in each process and the white background represents the analog world.

The video postproduction process shown in Figure 33 begins with recording the imagery to a sequential access video tape, which provides frame-by-frame reference. This tape is then edited and compiled onto a master video tape used to make copies.

The digital postproduction process is the one that is probably the most useful for transportation applications because it can use existing computer platforms. It works by storing the animation sequence frames in the random access memory of the computer. This usually requires that the images be compressed so they can be viewed in real time. Once the images are moved to memory they can be manipulated with specialized editing and sequencing software packages to add text and transitions, and to handle the time-sequencing coordination necessary to record the images to tape.

The advantage of the digital postproduction process is that the editing, compositing, and coordinating is accomplished in the digital environment. This means that there is no degradation of image quality as there would be if this were done entirely in the analog video environment. The only image quality penalty will come from the image compression where color information will be lost.

The video disk system illustrated utilizes random access read-write video disk technology. This is a very useful system that allows random interaction with the animation frames for editing and compositing. However, the cost of the video disk is generally prohibitive for all but the most sophisticated operations. The mixed system uses both video tape and computer-based editing tools in the postproduction process. This is common where a lot of video footage may need to be added as part of a final video presentation. The primary difference between the mixed system and the digital postproduction process is the addition of the tape editor controls. These are controls that record read and write time codes on the video tape and permit random access and control of the video tape equipment. This used to require a separate piece of hardware, but many of the packaged video editing systems now have software interfaces that accomplish the same control and edit functions.

CONCLUSION

The technology associated with the visualization production and postproduction processes just described is evolving at a very rapid pace. New products in the form of add-on

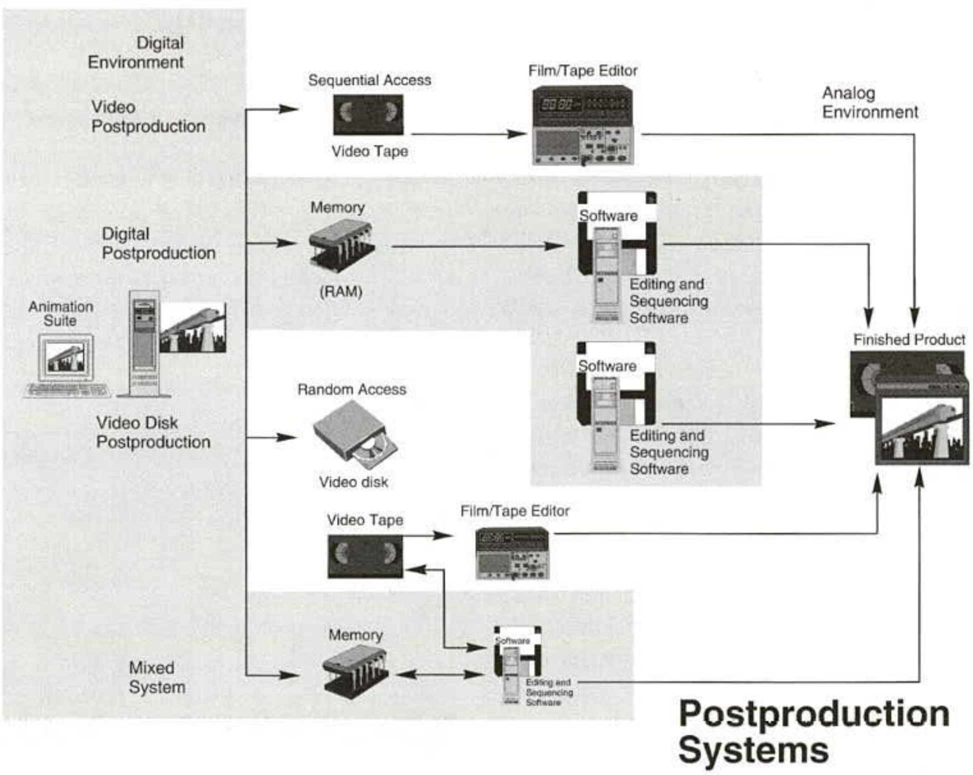


FIGURE 33 Postproduction process and editing environments.

boards and specialized software are being announced at a pace that would quickly outstrip any further discussion here. Likewise, the technology rumor mill as well as vendor claims and promises all combine to complicate the process of making well-informed decisions.

The most important emerging technology is digital HDTV. This technology, once a national standard is adopted, will solve many of the problems that are currently encountered in working between the digital and analog worlds. Likewise, the combination of computer portability, compact disks, and video projection technology have the potential to replace both film slides and video tape as the primary exhibit and mass distribution media.

Experience with the development of computer-based drafting systems provides most transportation agencies a very good foundation on which to extend their capabilities into 3-D modeling and rendering. There should be a fairly high degree of comfort with vector graphic systems but there will probably be a lag in developing an experience base with combining vector and raster graphics systems.

The biggest step will be in developing the visualization output and postproduction capabilities. Postproduction is as specialized as the process of generating the 3-D models and animation frames. Thus, agencies that are just beginning to develop visualization capabilities should be sure that this part of the process is not overlooked. Output and postproduction is a vital step in producing a usable visualization product. The production process is currently complicated by the need to merge two different technologies. Because analog video is much less familiar than the digital computing environment, the need for careful evaluation of the output and postproduction cannot be overstressed. Individuals responsible for selecting visualization system components should spend as much time evaluating the postproduction side of the system as is spent on the production side.

CHAPTER SIX

PLANNING PROCESS FOR THE DEVELOPMENT OF VISUALIZATION PRODUCTION CAPABILITIES IN TRANSPORTATION AGENCIES

INTRODUCTION

No single process can fully recognize the differences in the mission, organization, and needs of an individual agency. However, when approaching a new venture that involves a considerable investment in time and capital, information on the planning process can be useful. This chapter sets forth some basic steps to follow as an agency considers the development of its visualization capabilities, discusses some of the basic decisions that must be made, and identifies some pitfalls to avoid.

It is important to understand that the field of visualization is closely tied to a rapidly evolving set of technologies that includes computing and video. As we have seen in earlier discussions, these technologies interact at numerous points in the production process and the boundaries between them are not always clear. This means that any effort to link the planning process to the technology would be quickly dated. This chapter, then, focuses on issues related to identification and definition of an agency's needs for visualization capabilities and the options that exist for obtaining appropriate products and services. References to specific equipment or technology will be made only as examples to clarify the discussion.

MISSION ASSESSMENT

Long-Term Mission of Transportation Agencies

A consensus exists among transportation professionals that the long-term mission of transportation agencies is changing. This is the result of two dramatic influences: the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, and completion of the Interstate Highway System.

The ISTEA has mandated several new components to transportation development and operation of the country's transportation infrastructure that are having a profound impact on public transportation agencies, particularly in the area of planning and programming projects. The mandate to focus the planning process in the metropolitan planning organizations (MPO's) has led to a much greater involvement of the public in the planning process. The involvement of MPOs is clearly an effort to make the transportation planning process more responsive to the needs of communities and at the same time it has placed significant demands on the communication resources and capabilities of public transportation agencies nationwide. Implementation of these new provisions has created an immediate need for better visual products to communicate the complexity and impacts of contemporary multimodal transportation improvements.

The completion of the Interstate system has refocused the mission of public transportation agencies from the development of new corridors to "rebuilding" the infrastructure within existing corridors. This often means redesign of an existing corridor to accommodate additional transportation modes. This change in focus is proving to be every bit as difficult and challenging as the process of building transportation routes through virgin territory. Where once there were large, single parcels of undeveloped land, corridors are now confined by developed land and with multiple business and or residential interests involved. This phenomenon, combined with the demands of ISTEA, continues to escalate the need for improved communication capabilities.

Not all transportation agencies are impacted in the same way by the national shift in mission. Each agency will have to assess its own position and determine how the changes in the overall environment of practice will affect their own needs for better visualization and communication capabilities.

Audiences

There is significant potential for variation in the audiences with which an agency will have to work. State departments of transportation tend to have significantly larger and more complex audiences than do other transportation authorities, such as toll roads or port authorities. Not all units within a transportation agency will have contact with special interest groups but each agency needs to identify all potential consumers of visualization materials related to their particular mission. Because of the nontechnical appearance of 3-D and 4-D materials, the list of potential consumers will be much broader than for traditional engineering drawings. This is a very simple point but one that should not be overlooked in the planning process. It must be remembered that technical documents, while essential to the construction process are not easily understood without appropriate knowledge and training. Likewise, because these drawings have been the primary graphic tools by which the business of transportation planning, design, construction, maintenance, and operations traditionally have been conducted, it is easy to forget that 3-D and 4-D materials are more easily understood and have much broader application

Visualization Tool	Wet-lands	Arch/ Anthro Res	Visual Res	Established Neighbor-hoods	Habitat Conflict	Access Limitation	Visibility Conflicts	Const Conflict	Historic Res
	Classic Types of Conflict								
Video	❽	❽	❽	❽	❽	❽	❽	❽	❽
Image Paint/ Image Composite	⑧	❽	❽	❽	⑧	⑧	❽	⑧	❽
Dynamic Composite		⑧	❽	❽		❽	❽	⑧	⑧
Animation	⑧	⑧	❽	❽	⑧	❽	❽	❽	⑧
Multi-Media	❽	❽	❽	❽	❽	❽	⑧	❽	❽

⑧ **Some Use**
❽ **Common Use**

FIGURE 34 Visualization products related to typical communication needs.

and utility. For these reasons, 3-D and 4-D capabilities considerably widen the potential audience.

One new audience where there is a distinct need for developing good communication is the MPO. Where state transportation agencies are concerned, the MPO represents a major constituency where good communication is absolutely essential if operations are to proceed in a timely fashion.

Dominant Types of Project Work

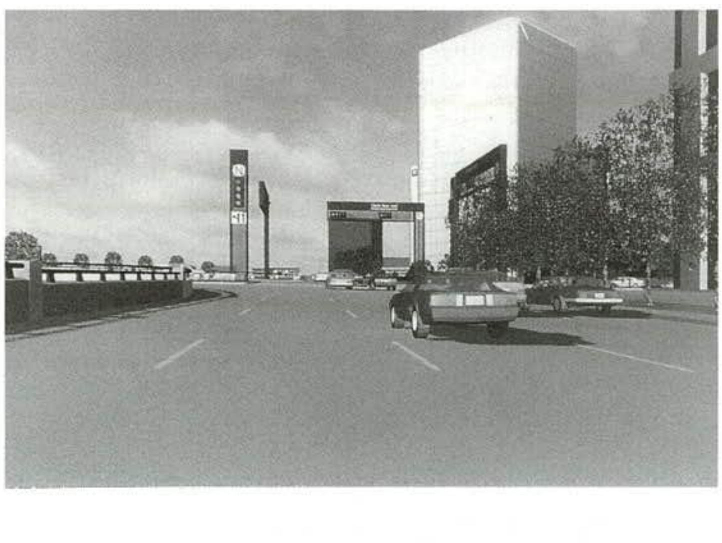
The future needs for visualization materials will depend somewhat on an agency's dominant types of project work. During the review be particularly alert for project work that will require significant public participation related to the physical appearance or operational properties of a design solution. Any work that has these qualities is a candidate for some form of visualization support.

Almost all services within an urban context will require permitting and public participation. Improvements in rural jurisdictions should also be screened carefully for potential environmental or cultural conflicts. In cases of environmental or cultural concern, there is often a need to visualize processes and sequences that may prove more important than producing images of the finished product. Figure 34 is a matrix showing some of the classic conflicts, linked to visualization materials that could be useful in studying alternatives and resolving conflicts.

INTERNAL ASSESSMENT

Organization of Computing and Information Services

The current organization of computing and information services should be carefully considered. While visualization technology is a significant tool that should be considered for any transportation agency, it is only one of the computer-based tools that will form an important part of the overall transportation computing environment of the future. While the scope of this report does not allow any detailed consideration of other technologies, Figure 35 illustrates some of the more common computer-based tools being adopted in the transportation industry. The Executive Information System (EIS) is being developed as a "Capstone" application to furnish information and provide assistance in top-level decision making. Global positioning system (GPS) technology is a satellite navigation system being adopted as a means of providing location controls on the vast right-of-way networks of transportation systems being managed by an agency. GPS technology is being linked to automated drafting and design systems, which in turn are linked to the geographic information system (GIS-T). The "T" has been used in the transportation literature to indicate applications developed to meet specific transportation needs. GIS-T is a sophisticated technology that links computer graphic display



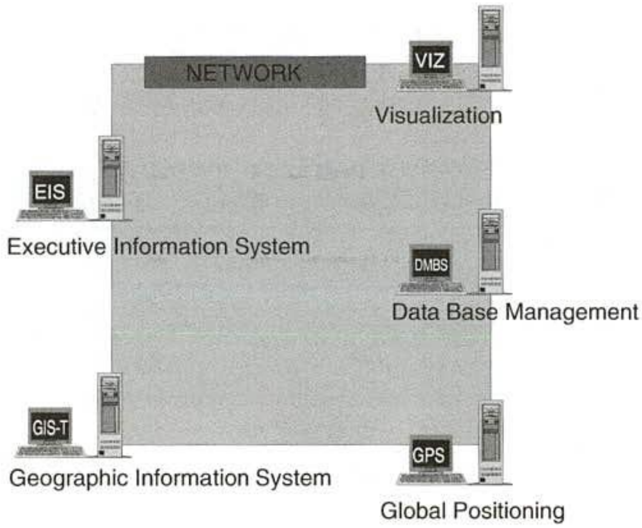


FIGURE 35 Related technologies in transportation computing.

systems with data base management systems (DBMS). The data base management capability of an agency while linked to the GIS and CADD systems is also the mechanism that links and operates the EIS and other internal recordkeeping systems that generally include accounting, project management, and budgeting.

The organization and relationships within these various system components are going to be different for each agency because of differences in size, mission, administrative structure, operational mission, and personnel. When planning any individual part of the system it is absolutely vital that impacts on, and relationships with other parts of the computing environment of the agency not be overlooked.

Existing Infrastructure for Developing Visualization Capabilities

The administrative location of basic resources (hardware, software, and personnel) and the impact this organization may have on the provision of visualization services is also important to consider when assessing the computing infrastructure. In some organizations, CADD services are separated from the planning and design functions of the agency. At first glance the equipment and software resources of a CADD services unit will be appear to be a very logical place to develop the agency's visualization production capabilities. However, if the CADD services unit is primarily responsible for production of contract documents for construction, it may not have the appropriate mission orientation or experience needed to cut across the wide range of clients that will use the visualization capabilities. On the other hand, the CADD services unit may have a broad service bureau mission already providing a variety of graphic arts services to the agency which would make it a very logical choice. The key consideration, when assessing the administrative organization in relation to the development of visualization needs, is that visualization products have application across a much wider scope of transportation activities than the more traditional graphic materials. Thus, the client base may include every administrative unit in the organization.

Potential Applications

In earlier work on the applications of visualization technology in transportation, several areas of activity common to transportation organizations were identified as having need for some type of visualization products. (*17*) In this context, Figure 36 illustrates the difference between traditional graphic tools and visualization products and materials that can be produced from a 3-D computer model.

Administration

Administration needs included materials that could be used to illustrate long-range plans, and to justify and illustrate budget requests for projects. Most of the examples cited indicated that the products would be used for communications with funding and policy-making bodies to which the agency is responsible.

Planning and Programming

This particular function has one of the broadest needs for visualization products because of the different constituencies they contact in the normal discharge of their duties. In general, the planners must deal with the full range of potential audiences, including administration; permitting agencies; federal, state, and local political jurisdictions; special interests; neighborhood groups; and individual property owners. These various audiences generate needs for all types of visualization materials from simple video and photographs to sophisticated multi-media presentations.

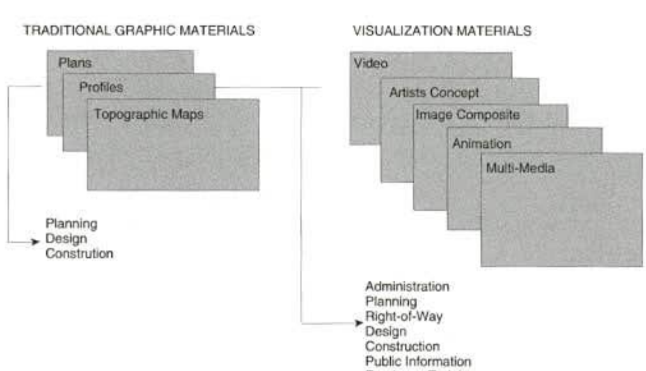


FIGURE 36 Scope of visualization application in transportation.

Right-of-Way

Personnel charged with the acquisition of right-of-way have relied on traditional aerial photographs, plats, and surveys as the primary graphic tools of the trade. However, as the sophistication of the highway system has increased and the need for greater capacity in urban areas has increased, the problems of acquiring additional right-of-way have grown in complexity. Questions of fair market value and damages to remaining property are increasingly contested in special commission hearings and in civil suits. Issues such as obstruction of visibility, loss of access, noise encroachment, inability to continue a business on remaining property, and loss of view are quite common. Answering these questions or countering the claims of plaintiff's attorneys requires graphic materials that communicate accurately and clearly.

Design

Design personnel are increasingly called on to answer public queries as the design process proceeds. In many organizations, this is a recent phenomenon which, again, seems to be a function of the increasing complexity of the transportation net and the variety of issues that an agency is required to address. In particular, issues related to visual constructs—color, texture, landscape development, lighting, signing, and environmental requirements—demand continuous communication and review during the design process. These activities increasingly require the generation of high-quality visualization materials in order to communicate design intent effectively.

Construction

The need for visualization materials and capabilities in construction is not as apparent as with other areas of activity within a transportation agency. However, there are some very important areas of operation were visualization technology is proving a very important tool. The primary uses identified in this area are construction sequencing and construction traffic routing and control. Complex construction projects involving large structures that must be integrated with existing structures while at the same time maintaining traffic flow are increasingly difficult to visualize and schedule. Using 3-D models to show the various stages of the construction process is very helpful in planning and scheduling operations. A second issue that parallels construction is the issue of safely maintaining traffic flow during construction. While most construction sites may appear to be chaos with barrels, signs, blinking lights, barriers, and the like, these measures must be carefully planned and designed. Once again, the 3-D model provides a very useful tool for developing and optimizing this important part of the construction process.

Public Information

Persons within transportation agencies responsible for public information and education have needs for visualization materials that are almost as broad as those associated with planning. In small agencies these two functions may, in fact, be combined. The reason for separating them in this discussion is that many public information functions go well beyond the activities normally associated with planning and programming. Needs for visualization materials have been identified in association with activities such as media announcements of public hearings, closings, construction sequencing, news letters to property owners affected by construction, and display maps of construction sites. These are all activities associated with public information offices. In each case, the availability of clear graphic materials, particularly 3-D imagery, can increase the impact of the communications.

Employee Training and Staffing

Employees not necessarily involved in the front-line operations of an agency still need a basic understanding of the system and its mission if they are to communicate effectively in their daily duties. Training officers are well aware that more graphic training materials usually result in more effective training. The development of the visualization capability within an agency can contribute substantially to the employee training mission.

Maintenance

Maintenance activities associated with reconstruction of lanes, renovation or refinishing of structures, or performing roadside maintenance tasks are up against many of the same problems that face the planning and design personnel of the agency. The availability of 3-D models has been cited by maintenance personnel as a valuable resource for planning and communicating maintenance operations, such as major resurfacing or lane-leveling projects that require lane clos-

ings. These concerns parallel the traffic control and routing described under construction.

Personnel

The availability of knowledgeable personnel is clearly an important component of planning for the adoption of a new tool. In most transportation agencies, there is a centralized computer services or automation unit that maintains and operates the budgeting, accounting, and record-keeping apparatus of the agency. However, these personnel are seldom the individuals who have the skills and knowledge to operate and maintain computer-based graphic systems. More often than not, people skilled in graphic design are associated with the CADD services unit or a special services unit within the agency.

When evaluating current human resources there are two areas of job responsibility that should be considered carefully—technical and professional. In doing so, it will not always be clear where to look within the organization to find experienced or qualified personnel. This assertion is based on the experience of followup responses to the survey conducted for this report. Most of the surveys were returned from the CADD services or the automation units of agencies. Subsequent followup revealed that many of the personnel involved in visualization efforts were associated with professional staff located in environmental or special design sections of the agency.

When evaluating existing personnel for initiation of visualization production capabilities, it is vital that the professional staff not be overlooked. They must have a thorough understanding of the software systems, input and output peripherals, production time requirements and, most importantly, what type of product is most appropriate for the task at hand. In the case of technical personnel issues of efficiency, knowledge of the software and hardware, and artistic ability are very important.

Experience suggests that the most overlooked criterion is the knowledge of the professional staff. (*17,18*) Professional staff often shy away from the technology side of the production environment. This often leaves very important decisions to technical staff who may not have qualifications or responsibility for making them. When this occurs, it usually results in very inefficient use of the media. Professional staff do not need to be qualified operators of the equipment or software systems. However, they must know the system capabilities, what types of products can be produced, what time frames are reasonable for production of accurate, high-quality products, and they must be able to make decisions or provide advice other to professional staff about what products are appropriate for a given audience or situation.

IDENTIFICATION OF NEEDS AND DEFICIENCIES

Organizational Needs

When establishing the organizational needs, it is essential that the long-term structure of the agency's computing environment be taken into account. At the uppermost level of organization, consideration must be given to the adoption of a centralized or decentralized computing services model. There is no evidence, from the survey, that the administrative organization model has any impact on visualization capabilities. The critical consideration has more to do with the operational computing environment of the agency.

The model that appears to be emerging in transportation practice is a network format that links subunits or local area networks (LANs) to a primary net that provides access to the rest of the world (Figure 37).

Visualization is a very democratic technology. That is, it has value to many more operational units within an agency than the traditional graphic products such as plans, profiles, and aerial photographs. From an efficiency point of view, visualization capabilities should be administratively located to provide the best possible service to the audiences and operational units identified in the previous section. The goal being to provide the greatest possible access to all units in the agency.

Infrastructure Needs

For most agencies, a basic hardware and software base will already be in place. However, the capacity of that existing structure will not likely support any meaningful visualization production effort. But, the existing infrastructure serves as a beginning point and will provide a strong internal knowledge base on which the future capability can be built. When making decisions about the infrastructural needs, issues of color displays, monitor resolutions, and size must be considered. However, the two most significant factors that should drive the needs identification process in this area are data storage capacity and processor capacity.

Data Storage Capacity

Visualization graphics production is data intensive. Single scanned color images are commonly measured in megabytes

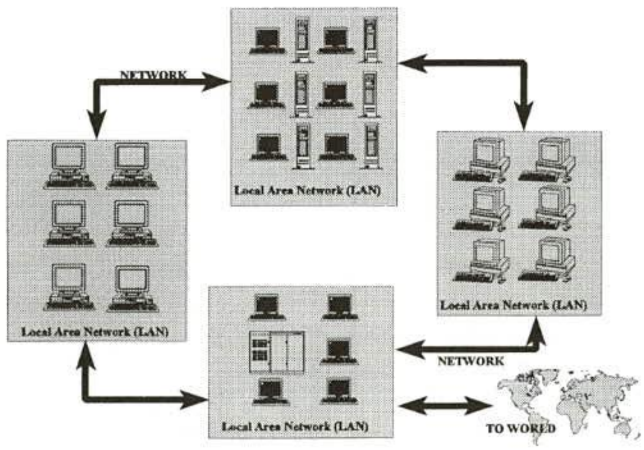


FIGURE 37 Typical computer resources network for transportation.

and 3-D models are most often measured in gigabytes of data. For this reason, the disk capacity of the primary production platforms is critical so that reasonable segments of a model can be active during a work session. This capability needs to be supported by a good backup storage system. There is a variety of technologies available for this function—tapes, optical drives, read/write CD, removable disk, and others. The best systems for visualization are those that can record at least one gigabyte of data on a single storage module.

Processing Capability

The other key consideration with respect to the production platforms is random access memory (RAM). Working with 3-D models places much greater demands on the central processing unit of the production platform. It is simply a function of the number of calculations that must be made each time a display is changed or modified. The more of the model that can be held in the active memory of the production platform the less time will be spent reading back and forth to the hard disk. With respect to how much memory is enough, one thing that most all graphics terminal operators agree on is that there is no such thing as too much memory.

Peripheral Devices

Another component of the infrastructure assessment is the need for peripheral devices. These needs will be based on the products that are identified for in-house production. In many cases front-end equipment, such as cameras, scanners, and the like will be available. In most cases, the output side of the process will require most of the attention. This is particularly true if animation and video are to be a significant part of the visualization product base.

As discussed in earlier chapters there is a significant difference in handling video output and writing it to tape. Likewise, the cost of acquiring and bringing this part of the production process on line is significant. As equipment needs are reviewed the most important consideration is that choices are made that work well with the production platforms selected. The communication problems between the digital and analog environments simply cannot be over stressed. Unfortunately, there are no easy answers or rules of thumb that can be recommended with respect to making decisions in this area. The best advice is to ask lots of questions, visit operations using the equipment or processes being considered and wherever possible get on-site demonstrations using your equipment.

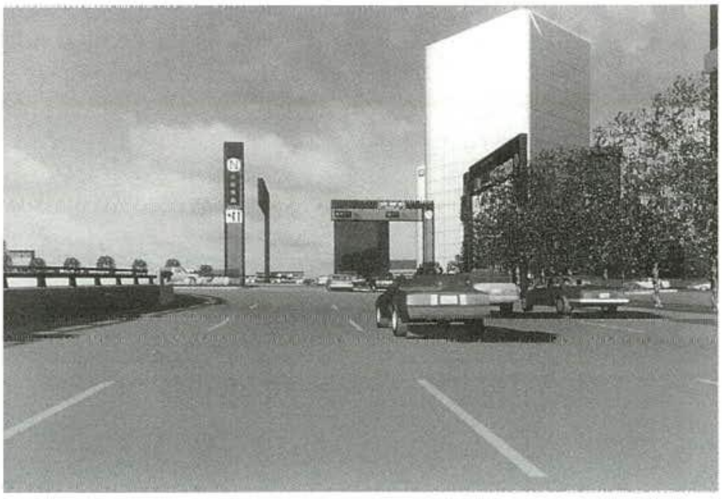
Software

Software needs must also be established. CADD systems continue to improve, adding more visualization capabilities to the basic products. This trend is likely to continue, which suggests that jumping to a totally different software environment should be evaluated carefully. The issue of the greatest importance is related to the project production process. That is, whether the production tools are used in 2-D or 3-D mode.

All plan production systems produce 3-D information. That is, controls are set for the horizontal alignment, x, y coordinates, and vertical alignment, the z dimension. The distinction is in the way these dimensions are handled in the computer data model (Figure 38). In a 2-D format, the x, y coordinates of points lie in an established two-dimensional drawing plane, usually defined as a plane projection of the earth's surface. The z dimension is carried as an attribute of the x, y point. When this data format is used as the primary production process, only two-dimensional output can be produced from the data set. To draw a plan, the x, y coordinate pairs are used. To draw a section or profile, the x coordinate is taken as a horizontal distance, the y coordinate establishes the plane, and z the positive or negative distance from the plane. In the 3-D format, the x, y, z, coordinates are maintained as points in three-dimensional space. That is as the location of the viewer (station point) is moved in relation to the model, the topological relationship between the x, y, z point coordinates is maintained. This characteristic of the 3-D model is what allows perspectives to be generated along with standard plans and profiles.

Obstacles to adopting the 3-D format usually hinge on the investment in existing production software systems, time and cost commitment to bringing a different production environment on line, and cost commitment to personnel training and re-training.

There is also a general belief that using a 3-D system is more time consuming than the conventional 2-D CADD systems. However, continuing development of the software tools and user interfaces have improved to the point where this issue is questionable. Everyone contacted in the followup agreed that there is a significantly longer learning curve for 3-D modeling environments. On the other hand, those who have transitioned from 2-D environment to 3-D production environments seem to believe strongly that it is just as fast as the old 2-dimensional systems, and that the advantages far outweigh the costs of implementation.



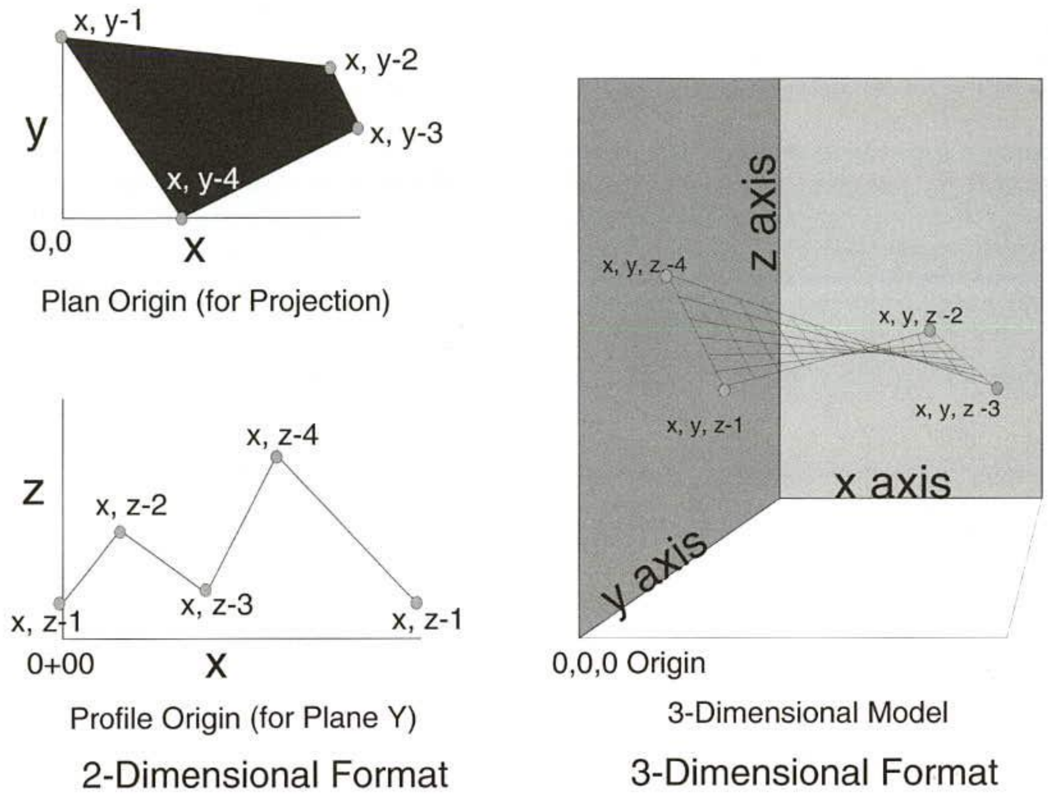


FIGURE 38 2-D format compared with 3-D format.

Personnel Needs

The primary issues of personnel are annual time requirements for the production of visualization in terms of person years available and the kinds of expertise necessary to develop visualization materials. In the cases reviewed for this publication, visualization sections grew from communication needs of a professional staff member, supported by a willing, knowledgeable technical staff. As other staff became aware of the capability and had experience with the use of visualization materials, demand increased and visualization became a recognized area of endeavor. This may be a very desirable model because it allows the effort to mold itself to the organization over a period of time.

From a technical staff point of view, proficient CADD technicians can usually master the software production, input, and output procedures associated with visualization production. The one element likely to be missing in the technical and professional staff is the necessary design experience and expertise.

Creative design ability should not be overlooked in evaluating visualization personnel. Great amounts of time and effort can be spent preparing technically correct materials and generating still images or animated sequences. However, if the wrong views are selected, if the presentation is poorly formatted, or if the light and materials rendering is unappealing, the final product may not accomplish its task.

PRIORITIES AND PHASING PLAN

It is suggested that the development of visualization capabilities in an agency be divided into two phases: input and production and output-postproduction. Following this path through the production process results in a logical division of hardware, peripherals, software, and technical and professional knowledge. It is also suggested that the development process include a well-defined product goal as the focus of the development effort. Projects that provide a good pilot experience include: a complex interchange slated for construction or redevelopment, a widening project through an established neighborhood or other environmentally sensitive area, or a redevelopment project in a designated historic district. All of these projects will require exploration of alternatives, permit hearings, public input, internal and external review. Each of these project types includes elements of sufficient complexity to identify the production problems unique to the individual agency.

When selecting a pilot project a conservative approach is suggested. Try not to select a project where demand for output will in any way place unreasonable time demands on the project design, production, and construction sequence. Be very conservative with production time estimates when working with visualization in the early stages of learning; be assured that ''Murphy's Law'' applies.

Phase One: Initial Development Plan

Initial development of visualization capabilities should focus on the input process and construction of 3-D models. The indications are that a majority of transportation agencies will opt for visualization products that are spatially accurate, that is image composites and animated sequences. For this reason, construction of the 3-D computer model and the associated input, compositing, and rendering tasks, become the core of the focus in this phase.

Throughout this part of the process, focus should be on the adequacy of existing platforms to produce imagery in a cost-effective manner, developing procedures for file management and backup, and conventions for drawing files, data storage, and other functions. All this information is required to flesh out the needs identified in the early part of the process. On completion of this phase, it will be possible to make informed decisions about specific needs such as software, disk storage space, backup, and the preferred modeling environment. Some specific recommendations are made later in the implementation section.

Phase Two: The Postproduction and Output Development Plan

Phase two requires a careful study of the available output technology. Very few decisions can or should be made about the output side of the visualization system until the front end production process is thoroughly understood. The reason for this recommendation involves the transitional nature of video technology and the problems of compatibility between the computing environment and many output peripherals. Postproduction hardware and software is a small market area and lacks the level of standardization and compatibility that characterizes the current computer industry. If the computer production environment is not thoroughly understood, it is very easy to become trapped in compatibility problems.

In addition, the area of video technology is changing so rapidly that all acquisition decisions must be evaluated carefully. Purchasing equipment before the agency is ready to go into production on a regular basis will not likely be cost-effective.

IMPLEMENTATION OF VISUALIZATION TECHNOLOGY

This section provides an outline strategy for bringing visualization technology on-line in an agency. The focus of this discussion is on state transportation agencies, but there should be something of value for almost any transportation related practice. The discussion in this section draws heavily on the experience of researchers and from information gathered in the survey and in followup conversations with agency personnel involved in visualization efforts.

Turn-key solutions are often very attractive options when considering a new technology for an agency. However, experience and observation suggest that trying to develop a visualization capability by a turn-key method is not advisable. There are several reasons for this conclusion related to the kinds of software tools available, the on-line hardware and software in the industry, the personnel requirements and the pace of technological change.

While software is constantly being improved, there is still a significant gap between the needs of transportation practice and the current capabilities of the software. The existing hardware inventory in many agencies is also somewhat limiting. In many cases agencies are still tied to outdated proprietary systems that, for financial and budgetary reasons, must be phased out of use over a reasonable time. Similar problems exist with the input and output peripherals. These considerations together with the availability of knowledgeable, appropriately trained professional and technical staff combine to suggest that development of the visualization capability should be staged in-house and closely keyed to development of the overall computing environment of the agency. This does not mean that consultants and vendors should not be a part of the process. Rather, the consultants and vendors should be used as an integral part of the development effort under the direction of agency personnel.

Implementation: 3-D Modeling and Rendering

It is suggested that visualization development be accomplished by a minimum of a two-person team. The team should include one professional and one technical staff member. The professional staff member should focus on the issues of budgeting, internal and external audience, relationships between visualization and the production process, cost-effectiveness, product planning, and product needs. The technical staff should focus on system operation, procedures for modeling, file management, input procedures, data transfer, and all other issues related directly to the actual production of products. The team should also be responsible for educating each other. The professional needs to understand system capabilities and what are reasonable production estimates with respect to time. The technical staff needs to understand the use of the products being produced, matters of budget and

fiscal planning, project production, and other administrative issues that impact the production environment. This will ensure a better transfer of the technology throughout the organization as it evolves.

Begin with the software and computer platforms that are already available. This is suggested because in the transportation industry a majority of the agencies use Intergraph Microstation as the primary graphics environment. Focus on the available 3-D modeling capabilities in Microstation and the additional effort required to work in the 3-D environment, as opposed to the normal production process.

After the team is familiar with the model-building process in Microstation, other modeling environments such as Intergraph's InRoads program should be evaluated carefully. The InRoads system provides a suite of tools and a 3-D modeling environment tailored specifically for highway transportation. Some of these products offer compatibility with other applications such as AASHTO's IGrds system, Bridge Analysis and Rating System (BARS), the Bridge Design System (BDS), and the Survey Data Management System (SDMS). The AASHTO IGrds system is a Microstation overlay that is structured as a 2-D production environment but it allows full access to all the 3-D modeling features of Microstation. *For more information about AASHTOWare™, software packages for transportation, contact the project director, 444 N. Capitol Street, N.W., Suite 249, Washington, D.C., 20001.*

Initial development should continue through the production of finished rendered products, still synthetic frames, and composited graphic images. In the early stages of development, photographs and a flatbed scanner are suggested as the primary means of raster graphic input. Later, consideration can be given to video digitizing and image capture equipment.

Experiment with a variety of rendering techniques and several levels of rendering detail. Particular note should be made of the time requirements for rendering at various levels of detail. Once this part of the work is complete, experiment with on-screen viewing of still-image sequences, animation sequences, and composite raster images using the built-in features of "Slide Show," "Display>Movie" and "Display>Image" in Microstation. These are the preliminary tools that will be used to plan animated sequence output and postproduction.

The objective of this phase is for the development team to learn the basic tools and become familiar with working in a 3-D environment. The team will also gain experience with setting up perspective/camera parameters, generating and rendering images, and the time required to produce images at various levels of detail. Figure 39 is the time sheet used by the Texas Transportation Institute Visualization Laboratory to track time on visualization production projects.

This part of the process will more firmly establish the actual needs for expanded memory, more processor speed and processor sharing capabilities, disk storage space and backup, and software tool preferences.

Implementation: Postproduction and Output

The current trend in output and postproduction hardware/software is the digital process illustrated in Figure 33, chapter 5. Using image file compression routines, usually JPEG, image sequences can be stored in active memory, reviewed, edited, and then written to video tape. This technology is still relatively new but cost and recent improvements in the software suggest that this is a most promising approach, certainly with respect to issues of cost.

The team focus in this part of the planning process should be compatibility. The limited market in multi-media and video production has not achieved the level of compatibility so common to the digital computing environment. The rapid development of the technology, the lack of a large consumer market, and the complexity of the digital-to-analog interface all contribute to the difficulties of developing this part of the system.

In this phase, the "turn-key" option is probably the best option with respect to hardware, software, and peripherals. Working with an established vendor with experience in the technology is probably the best insurance that the output suite will work with other parts of the system. The fact that video technology is in a transitional period cannot be overstressed. Where possible, keep the production process in the digital environment. This will be the best insurance against premature obsolescence. Large investments, particularly in analog video equipment must be carefully evaluated in relation to the amortization period of the investment. In the current world of video and computing, 2 years is a very long time.

CONCLUSIONS

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

There are numerous examples of visualization technology being applied as design aids and communication devices, but there has been little information gathered with respect to how cost-effective these devices are over more conventional methods. For example, some major engineering consultants are using 4-D products to review complicated structures and machines as a means of identifying conflicts between components. Others have used the technology to optimize construction sequences. Each of these uses implies a savings of time and money that could be substantial. However, no

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, review procedures and processes that could offer significant savings in the design, permitting, and construction process.

Acceptance and Appropriate Levels of Detail

A second question that currently has no answer in the literature has to do with public acceptance of computer generated graphic materials and what threshold of detail is required to communicate effectively with various audiences. In discussions with professionals who have used visualization materials there is almost always a concern expressed about the public's suspicion of computer-generated imagery. However, the basis of this suspicion is not well understood. In certain cases it is thought to relate to the "cartoonish" nature of some of the synthetically generated graphics. In these instances it is thought that the level of detail, shade and shadow, material color, texture, and other features is not sufficiently realistic to generate a high level of confidence. On the other hand, agencies are concerned that if very realistic images are generated, there may be negative repercussions if changes in the project become necessary during final design and construction. Because the cost, in terms of planning, production, and final output, of a visualization product increases rapidly with the level of detail, 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

The use of expert systems or rules-based design systems will be the next step in the evolution of transportation project development. These systems will essentially be composed of modules that evaluate design decisions or options from a catalog of adopted rules. For example, rules-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 component of the feedback loop in these systems will be 3-D visualization. The value of 3-D visual feedback was clearly illustrated in Sanchez's study of conflicts between vertical and horizontal alignment standards for safe stopping sight distances on interchange ramps (*20*). 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.

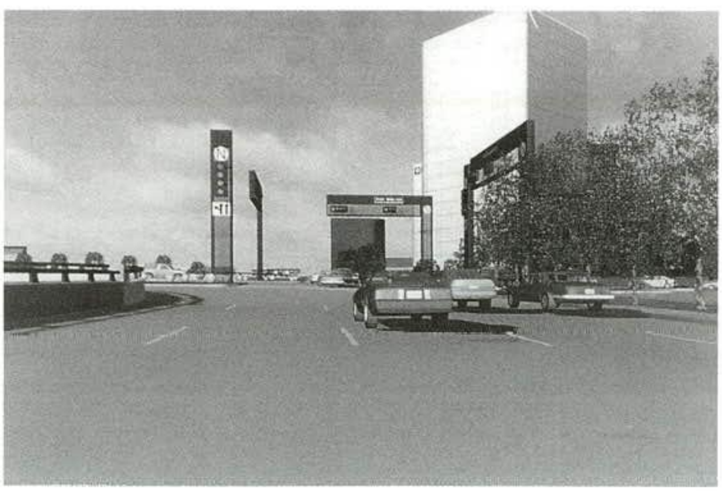
TRANSPORTATION APPLICATIONS

The results of the survey and rapid development of visualization tools related specifically to transportation applications strongly support the conclusion that computer based 3-D and 4-D visualization technology has a prominent place in transportation practice. With few exceptions, transportation agencies in the United States and Canada are in the process of reviewing, evaluating, or implementing some sort of 3-D visualization modeling capability.

The overwhelming focus is on 3-D modeling systems as opposed to 2-D systems, based on image capture, paint, and image editing technology. This appears to be related to the need for dimensional accuracy and the ability to produce still as well as animated materials from the same data set. Likewise, the need to be sure that all visual products are as accurate and faithful to completed conditions as technologically possible makes the 3-D modeling systems preferred for transportation applications.

While there is widespread awareness of 3-D modeling technology and a great deal of consensus about its value to the transportation industry, examples of actual application are very limited. Most of the experience within public transportation agencies has been with paint and image editing in the form of artist's concepts or composite images. The use of 3-D modeling to produce animated, 4-D materials has until very recently been limited to research universities and transportation consultants with strong commitments to technology applications. However, it appears that by the end of the decade, 3-D systems will probably be the rule rather than the exception.

The single most important factor that will influence the speed of adoption will be the conversion from a 2-D CADD environment to a true 3-D environment. The 3-D modeling environment has many advantages related to the traditional engineering design process in addition to the visualization capabilities that have been the focus of this discussion.



VISUALIZATION TIME SHEET

PROJECT ID.________________________________

NAME ________________________________

REMARKS:

TASK CODE	MON	TUE	WED	THR	FRI
MODELING					
100- DATA INPUT- BASELINE					
101- DATA INPUT - SECTIONS					
102 - ROADWAY PROGRAM					
103- VERIFY AND CORRECT					
104- CLEANUP					
105 - BREAKUP (GRID)					
106 - CREATE .RIB FILES					
107 - TRAINING					
108 - PROCEDURE DEVEL					
109 - PROJECT MGMT					
110 - CORRECTIONS					
111 - FILE MANAGEMENT					
NON-ROADWAY MODELING					
200 - BUILDING BASE PLAN					
201 - ROADWAY BASE PLAN					
202 - PARKING AND DRIVES					
203- Median/Curb EXTRUSION					
204 - ENTRANCE DETAILS					
205 - TOPOGRAPHY					
206 - VEGETATION					
207 - DETAILS EG. SIGNS					
208 - BUILDING EXTRUSION					
209 - TRAINING					
210 - BREAKING GRID					
211 - CREATE .RIB FILES					
212 - PROCEDURE DEVEL.					
213 - PROJECT MGMT					
214 - FILE MANAGEMENT					

TASK CODE	MON	TUE	WED	THR	FRI
ANIMATION & RENDERING					
300- RENDERING SETUP					
301 - FILE MANAGEMENT					
302 - CREATE MOTION TRK.					
303 - ERROR CORRECTION					
304 - PROCEDURE DEVEL.					
305 - PROJECT MGMT.					
306 - TRAINING					
307 - TOTAL MACHINE TIME					
VIDEO SERVICES					
400 - CLIENT MEETING					
401 - PROPOSAL DEVEL.					
402 - STORY BOARDING					
403 - VIDEO TAPING					
404 - PRE PRODUCTION					
405- VIDEO COMPOSITING					
406- POSTPRODUCTION					
407 - DISTRIBUTION					
408 - PROJECT MGMT.					
409 - TRAINING					
410 - OTHER________					
411 - FILE MANAGEMENT					
ADMINISTRATION					
500 - PROPOSAL DEVEL.					
501 - REPORT GENERATION					
502 - STAFF MEETINGS					
503 - SUPERVISION					
504 - WORK REPORT					
505 - CLIENT MEETINGS					
506- OTHER ________					

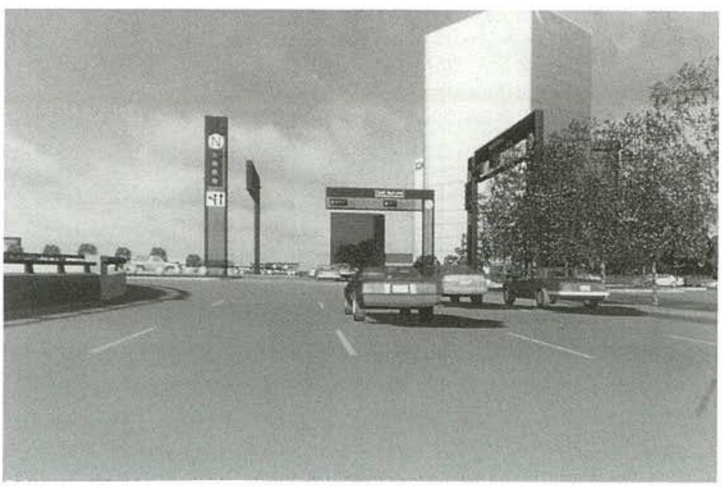
FIGURE 39 Timesheet used by Texas Transportation Institute for tracking visualization tasks.

The 3-D revolution is not dependent on the transportation industry it—has already taken place in the CADD software industry. Microstation, which was the clear leader in all of the transportation agencies contacted, has been a 3-D system for more than 5 years. Programs such as GEOPAK, InRoads, and Modelview are simply extensions that take advantage of the 3-D capabilities of Microstation and provide interface enhancements and extensions to the basic software. Because the basic CADD environment has become three-dimensional and there continues to be rapid improvement in the tool base and the software interfaces, there is every reason to believe that the conversion to a true 3-D modeling environment is simply a matter of time.

Emerging technologies that will continue to impact the application of visualization in transportation in the near future are computer portability, compact disk (CD) technology, digital projection equipment, digital photography, and digital video. Computers are becoming more and more portable. Disk storage space, memory, and processor speed are escalating at an exponential rate and costs are coming down. CD drives are becoming as common as floppy disk drives and read/write technology is available at more and more reasonable costs. Digital projection equipment is also becoming more compact and reasonable in price. When considered together the portable computer, the CD and the digital projector offer an attractive alternative to video tape and slides as mass distribution media for pictures, animation, and other multi-media materials. As digital photography becomes more practical and less expensive it will allow direct image capture and input to the computer environment by passing the scanner and image capture process. Finally, as digital video emerges in the consumer market, problems with the interface between analog video and digital graphics will be come a thing of the past.

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 than currently available technology. However, these are existing technologies and they promise numerous advantages in terms of portability, compatibility, and image quality.

What is certain is that these technologies do represent the 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 an agency must stay abreast of developments in these emerging systems.



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Transportation Visualization

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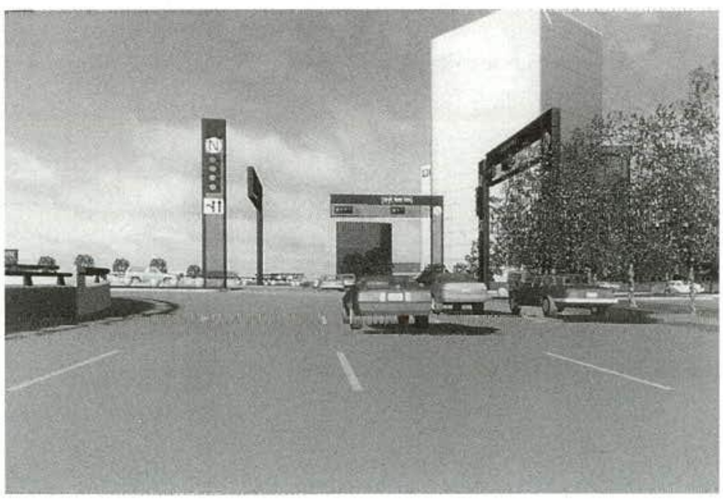
Describes the Princeton Intelligent Transit Visualization System (PITVS), an interactive, three-dimensional design and analysis tool. Using a graphical user interface, the software permits construction of the transit network, creation of station demand characteristics, and generation of simulated operations.

Kubota, Y., and H. Kubota. "Effectiveness of the LANDSCAD System for the Citizen-Participation Process in Traffic-Environmental Improvements in Residential Areas." *Environment & Planning* B 21 (January 1994): 109-120.

Presents a case study of the effectiveness of using of LANDSCAD to assist residents in a suburban neighborhood of Tokyo in their efforts to develop a traffic calming plan for their neighborhood.

Landphair, Harlow C. and Terry R. Larsen. *Evaluation and Development of Visualization Technology for Highway Transportation.* Washington, D. C.: Texas Department of Transportation in cooperation with the Federal Highway Administration, 1993. FHWA/TX-92/1284.



Computer and video visualization technologies offer an effective means of presenting complex proposed projects to the public. The objectives of this study were to evaluate current graphic capabilities and their transportability as base material for visualization applications; to develop the most cost-effective means to meet state and district visualization needs; and to develop a pilot visualization application and make recommendations for future development.

Larsen, Terry R. and Harlow C. Landphair. ''Defining Visualization Technology for Highway Design in this Decade and Beyond.'' In *Proceedings, TAC Annual Conference,* v. 1. Ottawa: Transportation Association of Canada, 1994, C69-C89.

Describes the various types of visualization technology and major concerns for their use.

McLellen, B. ''Seeing is Believing: Harnessing the Power of Virtual Reality Imaging.'' *Civil Engineering News* 7 (January 1995): 30-32.

Discusses the benefits of virtual reality imaging in reducing approval times, and planning costs.

Prevedouros, Panos, Dave Brauer, and Randolph J. Sykes. ''Development of Interactive Visualization Tool for Effective Presentation of Traffic Impacts to Nonexperts.'' In *Transportation Research Record 1463: Travel Behavior Analysis, Telecommuting, and Public Participation.* Washington, D. C.: Transportation Research Board, 1994, 35-44.

Discusses interactive visualization of traffic impacts (IVTI) as a powerful tool for planning efforts and the approval process in transportation infrastructure proposals. Users see photorealistic images.

Sanchez, Eddie. ''Three-dimensional Analysis of Sight Distance on Interchange Connectors,'' In *Transportation Research Record 1445: Cross Section and Alignment Design Issues.* Washington, D.C.: Transportation Research Board, National Research Council, 1994, 101-108.

Documents the use of three dimensional modeling as an aid in the design of ramps and connectors. Sight distances were the major consideration. The study showed that current 2-D practices are not as safe as generally considered to be true. Identifies the major advantage of designing in four dimensions.

Sipes, James L., and Richard F. Ostergaard. ''Use of Computer Animation Technology for the Development of Interpretive Facilities on the San Juan Skyway.'' In *Transportation Research Record 1419: Roadside Safety Features and Landscape and Environmental Design.* Washington, D.C.: Transportation Research Board, National Research Council, 1993, 119-126.

Discusses the development and use of computer animation in a study of the San Juan Skyway in Colorado's San Juan National Forest and many of the benefits realized through this approach.

Sullivan, Richard D. ''Highway Design in 3-D.'' *Civil Engineering* 62 (June 1992): 68-70.

Discusses customizing a commercial roadway design package. Data files from two-dimensional construction documents can be downloaded into three-dimensional models. Advantages include time savings and the ability to catch mistakes early in the process.

Tarricone, Paul. ''Let's Go to the Videotape.'' *Civil Engineering* 64 (June 1994): 42-45.

Describes several projects, such as the Denver metro area rail system, in which computer animation and video technology were combined to help citizens visualize the impact of high profile projects and to generate public support.

Yedlin, M. and R. Goldblatt. ''3 Dimensional Animation of Simulated Traffic Operations.'' In *Traffic Technology International* '94, ed. T. Robinson. Westcott, U.K: U.K. & International Press, 1994, 112-4.

By combining TRAF-NETSIM (a traffic simulation model) with a 3-D animation package, visual simulations of an urban street network are possible. Described are the features and advantages of this technique for the design and operations of the transportation system.

Computer Graphics and Animation

Anand, Vera B. *Computer Graphics and Geometric Modeling for Engineers.* New York: Wiley, 1993

Written as a textbook for engineering design, it covers the basic principles and techniques from the perspective of engineering applications.

Hall, Roy. *Illumination and Color in Computer Generated Imagery.* New York: Springer-Verlag, 1989.

While much of this book discusses the illumination basics for ray tracing and radiosity rendering methods, it also contains a valuable section on colorimetry as it applies to the description of materials, color spaces, color monitor calibration and considerations for video output. The material begins at a basic level but assumes that the reader has considerable background in computer graphics.

Haralick, Robert M. and Linda G. Shapiro. *Computer and Robot Vision*, v. 2. Reading, Mass: Addison-Wesley Pub., c1993.

Provides a thorough introduction to the issues of obtaining 3-D information from 2-D images.

Longuet-Higgins, H.C. ''A Computer Algorithm for Reconstructing a Scene from Two Projections.'' *Nature* 293 (10 September 1981): 133-135.

Describes a simple algorithm for computing the 3-D structure of a scene from a correlated pair of perspective projections. Strong math background recommended.

Mitchell, William J., and Malcolm McCullough. *Digital Design Media: A Handbook for Architects and Design Professionals.* New York: Van Nostrand Reinhold, 1991.
Although written for the architectural profession, this provides a good introduction to the vocabulary and technology of 3-D modeling and visualization.

On the Cutting Edge of Technology. Carmel, In: SAMS Publishing, 1993.
Good introduction to the digital revolution in computer technology. Topics include virtual reality, fractal geometry and multimedia.

Porter, Thomas, and Tom Duff. ''Compositing Digital Images.'' *Computer Graphics* 18 (July 1984): 253-259.
Frequently, we composite images with little thought because commercial software hides all the details from the user. This classic paper describes the range of possibilities for combining images as developed at Pixar.

Sheppard, S. R. J. *Visual Simulation: A User's Guide for Architects, Engineers and Planners.* New York: Van Nostrand Reinhold, c1989.
Excellent reference on 2-D photo simulation. Includes useful information about the process. Much of the discussion is applicable to 4-D techniques.

Tsai, Roger Y. ''Versatile Camera Calibration Technique for High-Accuracy 3D Machine Vision Metrology Using Off-the-Shelf TV Cameras and Lenses.'' *IEEE Journal of Robotics and Automation* RA-3 (August 1987): 323-344.
Provides a good introduction to the general subjects of camera tracking and motion tracking. The discussion of previous techniques is useful for anyone not familiar with this subject.

Wilhelms, Jane. ''Using Dynamic Analysis for Realistic Animation of Articulated Bodies.'' *IEEE Computer Graphics and Applications* 7 (June 1987): 12-27. Providing a more in-depth discussion of dynamic motion, this article also contains a good list of references on the topic.

Video and Video Production

Blinn, James F. ''NTSC: Nice Technology, Super Color.'' *IEEE Computer Graphics and Applications* 13,(March 1993): 17-23.
A succinct technical discussion of NTSC (the color television encoding scheme) color theory from the viewpoint of the computer graphics user.

Conrac Corp., Conrac Division. *Raster Graphics Handbook*, 2nd ed. New York: Van Nostrand Reinhold, 1985.
Although written about CRT display technology, this book contains much information on video signals, color theory, and computer graphics in general.

Inglis, Andrew F. *Video Engineering.* New York: McGraw-Hill, c1993.
Discusses the fundamental issues of video technology. Includes several chapters on NTSC color and image quality issues.

Jouannet, J.P., M. Robert, and J.J. Davaine. ''Automatic Positioning of Cameras in Urban Environment for Visualization of Traffic Anomalies.'' In *Vision in Vehicles III,* ed. A. G. Gale. New York: North Holland, 1991, 239-246.

Luther, Arch C. *Digital Video in the PC Environment*, 2nd ed. New York: Intertext Publications, McGraw-Hill, c1991.
Focuses on digital video, which is the basis for multimedia applications. Includes information about interface between analog video and digital computer technologies.

Mattison, Phillip E. *Practical Digital Video Programming with Examples in C.* New York: John Wiley, 1994.
Explains and describes the video-computer interface. Provides excellent background information on the technologies.

GLOSSARY

2-D—Described by dimensions of width and height, but not depth. A 2-D data point exists on a flat surface represented as an (x,y) data value. Images are almost always 2-D, even in animated sequences.

3-D—Having dimensions of width, height and depth. A 3-D data point is represented as an (x,y,z) tuplet. 3-D space represents the world in which we live and the synthetic model space used for animation sequences.

4-D—Containing the spatial dimensions of a 3-D representation with the additional element of time which describes the parameter of movement through 3-D space. Real-time interactive graphics and computer animation are examples of 4-D space.

aliasing—A term applied to a variety of undesirable visual artifacts that appear in computer-generated images. These artifacts are the result of under-sampling in the spatial or temporal domains. Aliasing is much more noticeable in animation because the eye is very sensitive to rapid changes in the visual field.

alpha channel—A separate layer associated with a two-dimensional image that specifies the opacity of each pixel. Alpha channels are important for the description of mattes used in the compositing or overlaying of 2-D images.

ambient light—Light that bounces randomly throughout the environment. In rendering, ambient light affects only the brightness of the scene. It neither shades surfaces nor produces shadows.

analog—Continuously varying signals or data. Video signals are analog which explains the difficulty with the integration with computer graphics, which are digital by nature.

analog to digital conversion (A/D)—Process of converting an analog signal into a digital bit stream. Analog to digital conversion requires two steps: sampling and quantizing. Some information is always lost in this conversion.

animation—A sequence of images, that when rapidly displayed, produces the illusion of motion.

anti-aliasing—The removal of unwanted visual artifacts, normally referred to as ''jaggies'' from lines and/or edges of planes in a 2-D image.

artifact—In a 2-D image, an undesirable pixel color which is not representative of the color of the real or synthetic object represented at that pixel's location.

aspect ratio—The ratio of an image's width to it's height. Different media have different aspect ratios. The aspect ratio of video is 1.33; that of a 35mm camera is 1.5. When mixing formats in a presentation, decisions must always be made about cropping or scaling one format to fit another.

attribute—Description of a single characteristic of an object.

bit—A binary digit. The smallest unit of information in a computer; either a 0 or 1.

bump mapping—A rendering technique in which the shading of a surface is produced by small random variations in the normal to the surface at that point. The result is a texturing of the surface with a rough or irregular appearance.

byte—8 bits of information. 256 (2^8) unique values can be stored in a byte of information. In a full color image, 3 bytes of storage are required for the red, green, and blue values.

CCIR—Abbreviation for Consultative Committee, International Radio.

CD-ROM—Compact Disc Read-Only Memory. A popular medium for images and audio.

chrominance—Color information. In NTSC composite video, the color information is recorded as a subcarrier on top of the luminance.

channel—A single component of an image. The red, green, and blue values of an image each comprise a separate channel.

component video—A video signal that describes a color image as separate color channels. Examples are R,G,B; Y,I,Q or Y,U,V.

composite video—A video signal that contains all of the color information in one channel. Examples are NTSC and PAL.

compositing—The combining or overlaying of two or more images to produce a new image. All or part of the images may be used through the use of mattes.

compression—A digital process that encodes digital information in less than the required number of bits. Examples of digital compression include JPEG and MPEG techniques.

cropping—Deleting or removing part of an image. Cropping is an alternative to nonuniformly scaling an image to preserve the aspect ratio of the original image.

cyberspace—The ''space'' created with a virtual reality system. Access to cyberspace requires the use of special I/o devices to minimize the sensory information of the user's environment.

depth cuing—A display technique in which the darkness of a line is associated with its distance from the view plane. This effect makes lines farther from the viewer appear to fade away.

digital—Data consisting of discrete steps or values as opposed to continuous, analogue values.

digitize; digitizing—The conversion of analog information, such as sound or motion, into discrete steps or units that can be represented in digital form. The process of scanning an analog image is such a conversion.

display—A device on which an image can be viewed. Typical display devices are monitors and laser printers.

double buffering—The process of using two 24-bit frame buffers to display images in real-time. The advantage to double buffering is that while the front buffer is being displayed, the back buffer can be filled with the next image. Double buffering speeds up real-time graphics and gives the appearance of much smoother motion.

edge—The line formed when two geometric surfaces meet or when a geometric surface ends.

eye point—A point in world coordinate space that represents the location of the virtual camera.

field—One of the two parts into which a display frame is divided in an interlaced display system.

field of view—The angle at the viewpoint which determines the portion of the scene actually displayed.

film recorder—Specialized output device containing a high-quality monitor and camera. An RGB image is displayed a channel at a time, which is then recorded on film.

flat shading—A rendering technique in which all the points on a surface are given the same color. Flat shading provides for fast image generation at the expense of visual quality. This is the quickest color rendering method.

fractal—A class of geometrical objects that are frequently used in the modeling of natural objects. Fractals can be used to simulate topography, vegetation, and clouds.

frame—A single image in an animation or video sequence. Frames are frequently divided into two interlaced fields which correspond to NTSC standards.

frame buffer—Memory array in which color information is stored prior to display on a color monitor. The more 'bit planes' a frame buffer contains, the more unique colors that can be displayed simultaneously.

generation—One recording and playback process. With VHS, a quality loss can be seen with three generations but even with the highest broadcast quality equipment, some information is still lost.

geometric modeling—The process of defining physical objects as a set of simple primitives.

genlock—The process of synchronizing video signals. Genlock is required for frame level accuracy in video editing.

Gouraud shading—A common rendering technique in which the color of a surface is determined based on the interpolation of the colors of the surface vertices. Gouraud shading produces smooth color gradations over a surface.

head mounted display—A helmet-like viewing device that contains small monitors and is used in virtual reality systems.

hidden line removal—The removal of lines or portions of lines that are obscured by objects closer to the viewer.

hidden surface removal—The removal of surfaces or portions of surfaces during the rendering process that are obscured by objects closer to the viewer.

image—A two-dimensional array of pixels containing color information about a scene.

image paint—See photosimulation.

I/O—An abbreviation for input/output commonly used to describe a general class of devices used to transfer data to or from a computer.

jaggies—A type of aliasing in which a line or an edge of a polygon which is not orthogonal to the axes of an image appears as a series of 'stair steps.'

JPEG—Acronym for the Joint Photographic Experts Group; JPEG is a lossy compression scheme that permits variable compression ratios from 2 to 100. JPEG compression is widely used because it only requires knowledge about the single frame being compressed and because the algorithm is easily coded into hardware.

keyframe—A starting, ending, or extreme position in a motion sequence.

line of sight—The vector which indicates the direction of view in three dimensions.

luminance—In an image, the brightness or gray scale representation.

matte (channel)—A 2-dimensional array of pixels that specifies areas of an image that can be composited with other images.

mesh—see triangulated mesh.

modeling—The process of geometric modeling. Modeling is a necessary prerequisite before computer animation.

MPEG—Motion Picture Experts Group. MPEG is a compression algorithm that achieves high compression rates based on the continuity of one frame to the next in a video sequence. Generally, higher image quality is available than JPEG, but the compression cannot be accomplished in real time.

multimedia—The presentation of information on a computer that incorporates video images, sound, text, animation and/or other computer-generated images.

multi-tasking—In computer systems, a technique that permits several processes to appear to run simultaneously on a single CPU by switching between these separate tasks several times a second.

normal—A 3-dimensional vector that denotes the perpendicular to a plane, surface or vertex. The normal is frequently used for lighting calculations and hidden surface removal.

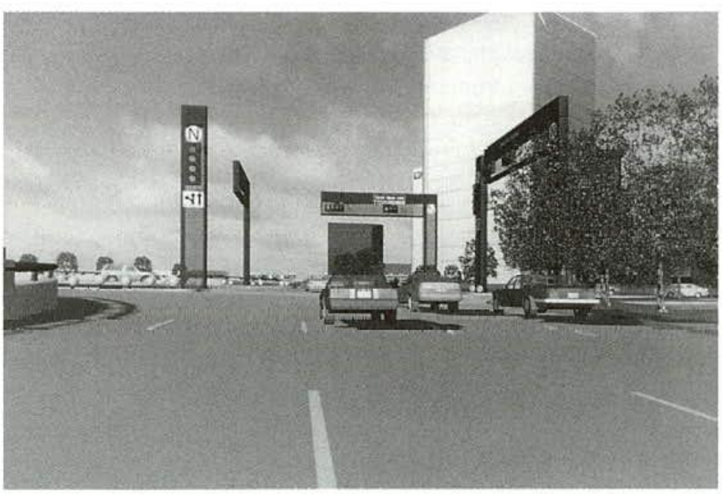
NTSC—Acronym for the National Television Systems Committee, which developed the standards for color television.

nurb—An abbreviation for non-uniform rational b-spline used for specifying curved lines and surfaces.

object—Surfaces grouped together and treated as a single entity.

opacity—The property of a surface that absorbs light, causing the object to appear solid.

perspective—The projection of a 3-dimensional scene onto a 2-dimensional plane so that objects that are closer to the



viewer appear larger than similar objects which are more distant from the viewer.

Phong shading—A rendering technique in which surfaces are shaded based on the direction of the surface normal. Phong shading is the most realistic looking method of shading as it is capable of producing surface highlights that flat or Gouraud shading cannot replicate.

photomontage—The overlaying of two or more photographic images or parts of images, to simulate altered conditions from the existing site.

photo retouching—The manual altering of a photographic image through the use of dyes or paint.

photosimulation—The altering of an image, either by compositing or retouching to simulate physical conditions that do not currently exist.

pixel—The smallest addressable screen location on a display device or picture element.

pixel value—The attributes associated with a single pixel. Typically, this value is composed of several channels, such as red, green, blue, and alpha.

polygon—Primitive in which all the vertices line in a single plane. The vertices are connected with nonintersecting line segments.

primitive object—An object composed of a single geometric surface.

quantizing—The process of converting an analog value into a digital value having a limited number of bits. This results in a reduction of the continuous analog signal level to a discrete number of levels represented by 2 to the nth power where n is the number of bits.

radiosity—A rendering technique that specifies the shading of a surface based on the distribution of light in the scene.

random access—The ability to access information in any order. Computer memory is random access while video tape is sequential, the opposite of random access.

raster—A single row of pixels in an image.

ray tracing—A rendering technique that traces the geometric path of light rays as they are reflected in the computer model.

realistic image synthesis—A term used to describe the various rendering techniques that attempt to depict objects with photographic realism.

real-time—The ability of a computer system to generate or display images quickly enough so that the illusion of the event occurring in actual time is created.

reflection—Surface attribute of a material that affects the way in which light 'bounces' off the surface.

refraction—A material's surface attribute that specifies the amount of light allowed to pass through the material.

rendering—The process of generating a synthetic image of a scene given a description of the objects in the scene, lights, and camera position.

resolution—In video technology, the ability to reproduce fine detail. In computer graphics technology, the size of an image in pixels.

RGB—An abbreviation for the red, green, blue color model. Computer displays use RGB while video technology does not.

RGBA—An abbreviation for specifying color in the RGB color model with the addition of an alpha channel.

sampling—The process of reading the value(s) of a continuous signal at regular intervals.

saturation—The amount of color intensity. A value of zero represents white (no color), while the maximum saturation is the most intense color possible.

scale—A change in size of an object. The change could be in the x, y, or z axes, singularly or in any combination.

scan line—A single horizontal raster line in a video frame. There are 512 scan lines per frame, 486 of which are visible.

scanning—The process of converting a continuous toned (analog) image to a digital signal as a series of scan lines.

shading—The process of changing the color of a surface based on its orientation in relationship to the light sources in the scene.

simulation—See visual simulation

solid modeling—The use of 3-D primitives that have not only size and shape attributes, but volumetric as well. Solid modeling uses the concept of set operations (union, intersection, subtraction) to create very complex shapes.

spline—A mathematical description of a curve, based on the specified control points. There are several types of spline curves, including Bezier, cubic, beta, Catmull-Rom and hermite. Each type of spline has a corresponding type of surface.

supersampling—An antialiasing technique that samples the scene several times for each pixel.

surface—A set of connected points in 3-dimensional space that has a defined mathematical description.

TBC—Time base corrector. Equipment that corrects for analog artifacts resulting from the non-uniform motion of the tape over the reading head.

texture—The attribute of a surface that affects the local color or appearance.

texture mapping—The process of applying 2-dimensional images onto 3-dimensional surfaces during the rendering process. Frequently, scanned photographs are used which adds greatly to the realism in the scene.

TIN—An abbreviation for triangulated irregular network, which defines a 3-dimensional surface as a series of connected triangles.

transformation—A change in position, size, or orientation of an object.

translation—A specific type of transformation in which the position of an object changes.

transparency—The attribute of a surface that permits light to pass through it. Transparency is the opposite of opacity.

vertex—A point where two or more edges meet. In three dimensions, a vertex is specified in x,y,z coordinates.

video—The recording of photographic information on magnetic tape or disk, typically at 30 frames per second. Typically, a CCD (charge-coupled device) is used to transfer images to electronic impulses, which are coded into two interlaced fields per frame.

video overlay—The use of a sequence of video images as a background on which a foreground image can be composited. The advantage to this technique is its realism and cost-effectiveness.

viewshed—The areas of land surface visible from a given viewpoint.

virtual camera—The synthetic camera which identifies the position, viewing direction, and viewing angles in a computer-generated view.

virtual reality—A computer-based technology that permits the user to interact with 'virtual objects' by projecting the user into the created, virtual world, through the use of head-mounted displays and data gloves as I/o devices.

virtual world—Created 3-dimensional environments that exist within a computer and within which the user can directly manipulate objects.

visual simulation—One, or a related sequence of, visual images depicting a proposed project or future environmental conditions in the context of the project's actual location.

wireframe—The representation of a 3-D model that depicts visible polygons as edges.

APPENDIX A

Survey Questionnaire

SURVEY

Applications of 3D and 4D Visual Modeling for Transportation Systems
NCHRP Project No. 20-5 Topic 25-01

The use of 3D (still perspective) and 4D (animated) visualization technology is evolving as an important tool to transportation agencies nationally. Unlike engineering or technical drawings the perspective or "Artist's Concept" view of a transportation facility, corridor, or situation does no require a trained eye to interpret or understand. For this reason its value cuts across a much wider section of agency functions and activities. This questionnaire is intended to help the Transportation Research Board clearly identify the existing trends in usage nationally and prepare a synthesis publication that will help the industry understand the applications, equipment and software requirements, uses, advantages, and limitations of the technology.

To accomplish this task your input is earnestly solicited. TRB, and the committee asks your cooperation by completing the following survey and returning it as soon as possible. Questions should be answered with the response most appropriate to your situation. Comments on special cases or items you may feel have been overlooked are earnestly solicited. If necessary use a separate sheet and appended it to the questionnaire.

Please return the completed surveys to:

Mr. Terry R. Larsen
Texas Transportation Institute
Texas A&M University
College Station, TX 77843-3137

SECTION I: Current Awareness and Use of the Technology

3D and 4D involves the combination of a variety of technologies to perform the input, processing and output of visual products. This section is intended to determine the relative awareness of the technologies.

Definitions:

3D Media: *3D refers to any static/still 2-dimensional products used to visualize 3-dimensional spaces or objects.*

4D Media: *4D refers to any animated, synthetically generated 2-dimensional products used to visualize 3-dimensional spaces or objects over time.*

Please rank each of the following based on your Agency's/Unit's familiarity and use of the various technologies described. Please use the following scale:

No use	Some Use	Widespread Use
0	1	2

__ 1. Video, use of television/video media to communicate information about sites, projects, project proposals or operations.

__ 2. Image capture, use of digitizing devices to capture still scenes which can then be modified to suggest a proposed condition.

__ 3. Paint, use of computer based "art" programs to generate synthetic images or "Artists Concepts" of facilities, conditions or events.

__ 4. Image compositing, the merging of photographic images with mathematically correct computer generated images such that the new images that are visually and mathematically correct.

__ 5. Computer Animation, use of totally synthetic computer generated images to simulate motion and portray a situation, event or facility.

__ 6. Multi-media, use of composited media including photography, video, animation, sound and graphic effects.

__ 7. Stereographics, use of dual image media to generate the illusion of three dimensional space.

__ 8. Virtual reality, use of multiple media such as stereographics in combination with lighting sound and other effects to create an illusion of reality.

SECTION II: Audience

The following questions are concerned with the audience or forum where 3D and 4D products are used. Please rate each of the following audiences in relation to your agency's/unit's usage. Please use the following scale

Never use 3D or 4D Graphics	3D Graphics are used	4D Graphics are used	3D & 4D Graphics are used
0	1	2	3

__ 1. Presentations of project proposals to special interest groups, neighborhoods, environmental interests, special authorities, utilities, etc.

__ 2. Presentations of project alternatives to city or county governments, councils, commissions, boards.

__ 3. Presentations to solicit inputs from city or county government units.

__ 4. Presentations of projects to public hearings and open forums.

__ 5. Presentation of alternatives to public hearings and open forums.

__ 6. Solicitation of input from public bodies, citizen forums and public interest groups.

__ 7. Presentation of projects to property owners during right-of-way acquisition process.

__ 8. Presentation of cases to special commissions on right-of-way acquisitions

__ 9. Presentation for litigation support.

__10. Internal planning assessment of project alternatives, eg. corridor location, visual impact, structural alternatives, etc.

__11. Internal design evaluation of alternatives.

__12. Internal design evaluation of aesthetic alternatives.

__13. Design review of construction conflicts or alignments, such as bridge bents to support column alignments.

__14. Design review of sight distance conflicts and requirements

__15. Tort liability support.

__16. Exploration of construction traffic control plans and sequencing.

__17. Evaluation of signing and traffic control plans.

__18. Evaluation of material selection for color, reflectance, shade, etc.

__19. Public service announcements on closing and routing

__20. Public service announcements on project benefits.

__21. Public information on project planning.

__22. Public information on aesthetics and enhancements.

__23. Please note any other uses in your agency that may not appear here.

____

SECTION III: Media Production and Procurement

This section is included to gather information about how 3D and 4D products are acquired or produced by your agency. If you do not use any 3D or 4D technologies please go on to the next Section.

3D Media	4D Media			
		1.	What is the primary source of the numeric base data used to generate 3D and 4D products.	
____	____		a.	Paper plan profile sheets
____	____		b.	Digital CADD files
____	____		c.	Digital terrain models (DTM)
____	____		d.	Photographs
____	____		e.	Video
____	____		f.	Other (please specify) ____________________
		2.	3D and 4D products used your agency/unit are:	
____	____		a.	Acquired from private vendors
____	____		b.	Produced by a central service bureau of the agency
____	____		c.	Produced by staff housed within the immediate administrative unit.
____	____		d.	Acquired through association with a college or university
____	____		e.	Acquired from broadcast media
____	____		f.	Other (please specify) ____________________

3D Media	4D Media	3.	In-house 3D and 4D products are produced using:
______	______	a.	No 3D or 4D products are produced in-house
______	______	b.	Macintosh based software (please list program if known) ______.
______	______	c.	IBM-PC based software (please list program if known) ______.
______	______	d.	Intergraph based software (please list program if known) ______.
______	______	e.	Unix based software (please list program if known) ______.
______	______	f.	Other: ______.

4. Are there products and or equipment being considered for the purpose of producing in-house 3D and 4D products. Please indicate product if known.

3D Media	4D Media		
______	______	a.	Macintosh based software. ______.
______	______	b.	IBM-PC based software . ______.
______	______	c.	Intergraph based software. ______.
______	______	d.	Unix based software. ______.
______	______	e.	Commodore Amiga based software. ______.
______	______	f.	Other: ______.

5. 3D and 4D products are output to which of the following media? Please use the following scale.

Never use	Use Occasionally	Use Frequently
0	1	2

3D Media	4D Media	
______	______	a. Photographs (prints)
______	______	b. Slides
______	______	c. Video tape
______	______	d. Laser disk
______	______	e. Computer display (slide show)
______	______	f. CD ROM
		g. Other (please specify): ______

3D Media	4D Media	6. Which of the following describes the subject matter of the 3D and 4D products that have been produced by your agency/unit. Please check all that apply.
______	______	a. Highway corridor aesthetics
______	______	b. Environmental impact concerns other than visual
______	______	c. Bridge design/location
______	______	d. Bridge lighting
______	______	e. Corridor lighting
______	______	f. Traffic simulation
______	______	g. Sight line, sight distance, geometrics, signs
______	______	h. accident reconstruction
______	______	i. Other (please specify): ______

7. What is the primary source of background imagery used to produce 3D and 4D visualization products?

3D Media	4D Media	
______	______	a. Image capture from video camera, Panisonic M2 or Sony Betacam
______	______	b. Image capture from video camera, VHS/SVHS
______	______	c. Image capture from video tape, High8/Super 8 (8mm)
______	______	d. Scanned photographs, slide or flatbed scanners
______	______	e. Freehand sketches
______	______	f. Other (please specify): ______.

Section IV: Image Quality and Realism

This section is included to determine the perceived importance of image quality and image realism in visualization products. Please answer each of the following in accordance with the following scale:

Not Important	Somewhat Important	Very Important	Extremely Important
0	1	2	3

3D Media	4D Media	
		1. For 3D and 4D products rank the relative importance of each of the following.
______	______	a. Mathematic and Geometric accuracy of the base model
______	______	b. Realistic color rendition of surfaces
______	______	c. Realistic reproduction of the textural quality of the surfaces
______	______	d. Ability to simulate the reflective quality of the surfaces
______	______	e. Ability to model multiple light sources accurately
______	______	f. Realistic surface shading and shadows
______	______	g. Including high levels of detail eg. signs, poles, guard rails, cars, etc.
______	______	h. Realistic motion control of viewer
______	______	i. Realistic control of the motion of other objects in scenes eg. cars and people.

Section V: Base Line Data

This section is to gather information about your agency for the purposes of segregating and better understanding the responses to the previous sections.

1. What is the full title of your Agency and immediate subdivision: ______________________

2. What other groups within your agency use 3D and 4D visualization products? ______________

3. How many employees are in your division/section/department/bureau,etc. ______________

4. How many employees are in your Agency ______________________

5. Is your immediate unit responsible for generating graphic materials ie. plans, images, video tapes, etc.

6. What is the primary function of your immediate organizational group eg. "CADD Operations", Design, Public Affairs, etc.

8. What is/are the primary computing platforms within the agency? eg. HP Apollo, Intergraph, Sun, PC-DOS, etc.

9. How is computing distributed within the agency? eg. Centralized, Administered by Division, Centralized Data Management with Separate CADD support group, etc.

10. How are computer operators and technicians trained? In-house, by vendors, in local educational programs in community colleges and universities, etc.

11. Do you have still images, video tape, laser discS or other media displaying your visualization products that might be included in a future video synthesis statement?

Thank you very much for your participation ! Please provide your address, phone number, FAX number and Network address we will provide you with a copy of the survey results when they are compiled.

Name: ______________________

Title: ______________________

Address: ______________________

____

____

Phone: ______________________

FAX: ______________________

Network Address: ______________________

THE TRANSPORTATION RESEARCH BOARD is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. It evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 400 committees, task forces, and panels composed of more than 4,000 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encouraging education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is interim president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences, by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce Alberts and Dr. William A. Wulf are chairman and interim vice chairman, respectively, of the National Research Council.

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National Research Council
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ADDRESS CORRECTION REQUESTED

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