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# *Visualization in Transportation*

## **INTRODUCTION**

The challenges facing today's transportation professionals are numerous and continue to rise. Increasing demands on the transportation system, combined with competing community values, urban complexity, and a growing commitment to finding solutions that are context sensitive, place extreme pressures on transportation professionals to arrive at solutions that balance so many diverse needs. Few topics stir public interest more than transportation improvements. Additionally, the public expects and even demands the opportunity to fully understand and participate in the development process of transportation improvements.

The public's growing expectation to be more involved in the decision process creates challenges that must be addressed by transportation professionals. In that regard, it is important that transportation planners, design professionals, community leaders, impacted property owners, interested citizens, and environmental resource personnel fully understand the potential impact transportation improvements have on the character of the community and the quality of the environment. This is particularly true in the "context sensitive" project development process.

Advancements in technology offer transportation planners and designers many new opportunities to improve the project through pictorial communication with the public. One such important technological advancement is the "visualization" development process, examples of which are shown in Figure 1.

Visualization provides a considerable advantage in the way transportation planners, designers, and project teams improve the project development process. Throughout this process, visualization significantly improves the range of capability that project teams have to more thoroughly test design scenarios (as shown in Figure 2), better communicate possible alternatives, and weigh potential impacts. Reliance upon traditional engineering drawings such as typical plans, profiles, and cross-sections is no longer sufficient to satisfactorily convey a clear understanding of transportation improvement alternatives and their associated impacts.

## **WHAT IS VISUALIZATION?**

Visualization is a simulated representation of proposed transportation improvements and their associated impacts on the surroundings in a manner sufficient to convey to the layperson the full extent of the improvement. An example of this is Figure 3, which shows an existing bridge and its proposed replacement at both high and low tides.

Visualization makes it possible to more clearly understand complex technical information. At a minimum, visualization should provide enough information to convey the difference between



**Figure 1. Aerial image with proposed layout and photo simulations**

proposed alternatives and existing conditions. This may include proposed design features such as number of lanes, right-of-way impacts, environmental impacts and enhancements, aesthetics, sight distance issues, median treatments, shoulder treatments, bike lanes, sidewalks, plantings, and other landscape and architectural design features.

The area immediately adjacent to the right-of-way should also be depicted in sufficient detail to articulate information on how residences or businesses will be potentially affected. This concept is illustrated in Figures 4a–c, which show the existing roadway, the properties that will be affected by the improvements, and a visualization of the area after construction is complete.

Because visualization is highly technical in nature, it also poses some unique challenges. Visualization utilizes a variety of different technologies, such as photography, photogrammetry, digital imaging, Geographic Information Systems (GIS), Computer Aided Design (CAD), and computer graphics, to create simulated views of the proposed improvements. When visualization includes the creation and use of three-dimensional modeling for animation and virtual reality purposes, the degree of complexity is considerably compounded. The level of visualization should be identified and taken into consideration during the project scoping process, which occurs in the initial stages of project planning.

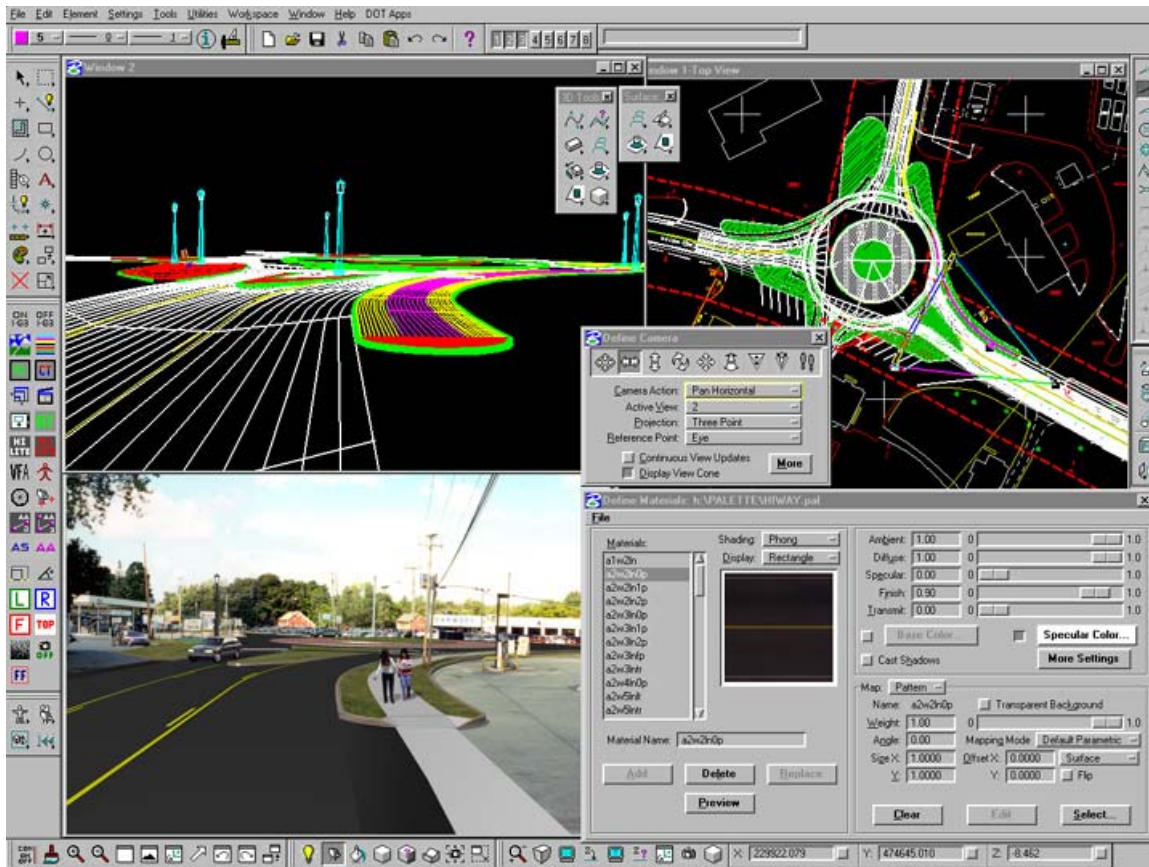


Figure 2. Screen capture of visualization software illustrating wire-frame model and rendered image

## HOW IS VISUALIZATION USED?

While the designer should always strive to provide the most current and appropriate information about a project, in many instances the information available in the early stages of project development, at the time initial visualizations are often prepared, may be incomplete or not fully developed. In these instances, the best available information should be used, but with the stated qualification that the visualizations represent preliminary project information and may be subject to change. As more detailed and definitive information becomes available, visualizations should be updated as necessary to reflect important changes. Care must be taken to always graphically portray the project with as much accuracy as possible. Images prepared with preliminary or incomplete project information should be clearly identified.



**Figure 3. Existing bridge and visualizations of proposed replacement at high and low tide**

## **TYPES OF VISUALIZATION**

There are many types of visualization products, from the simple to complex, from inexpensive to costly, and from quick to time-consuming. It should be noted, however, that “complex and costly” does not necessarily equate with improved understanding or effectiveness. Also, what is complex and costly now might become commonplace in a couple of years, as graphics technology continues to evolve rapidly.

### **Two-Dimensional**

Two-dimensional (2-D) graphics portray a spatial relationship of an object using two of its three dimensions. ‘Flat’ pictures are two-dimensional, and usually portray horizontal and vertical references. 2-D images are representative but not necessarily accurate.



**Figure 4a. Existing condition**



**Figure 4b. Right-of-way impacts identified**



**Figure 4c. Visualization of proposed improvement**

Photographs can portray the existing condition or a different location that is similar to what is being considered or proposed. Photos can be taken from the ground, from an elevated platform, or from an airplane, and can be enlarged to show detail. Examples of photographs are shown in Figures 5a, 6 (inset), 9a, and 10 (inset).

An artist's rendering is another type of two-dimensional graphic. It can consist of a free-hand drawing, painting, or computer rendering of a proposed design or facility based on an interpretation of proposed planning and design information. Each viewing location or perspective requires a separate drawing. Artist's renderings are most useful early in the conceptual development phase of design. Often in the early stages of project development, photographic quality photo-simulations may appear too polished and, as a result, give the impression that decisions have already been locked-in. This wrong impression is to be avoided if possible. Sources of ideas for an artist's rendering might be photographs, other similar built projects, or computer aided design (CAD) wireframe output.

A photo simulation (or photo composite), examples of which are shown in Figures 5b, 6, 9b, and 10, is a photo-realistic image that has been created by inserting a view of a proposed facility or treatment, which may or not be computer generated or CAD-based, into a photographic background. The product is a two-dimensional view of the facility or treatment from a single eye-point. It is not possible to generate alternative views or visual perspectives from a photo simulation or photo composite. The background imagery may be provided either from static photographs or from video.

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

### **Three-Dimensional**

'Depth' adds the third dimension, in addition to horizontal and vertical references. Three dimensional (3-D) images are both representative and accurate.

A walk-through or drive-through provides the ability to move through a virtual 3-D environment and to observe the content of that environment from a given eye-point or height above the ground. This ability may be the result of an animation sequence where the path, eye-point, and direction of gaze have all been pre-defined, or may be the result of the viewer's real-time control over those parameters.

### **Four-Dimensional**

'Time' adds the fourth dimension, in addition to horizontal, vertical, and depth. Four-dimensional (4-D) graphics are animated simulations based on 3-D modeling, and include visualizations that apply simulated motion and incorporate a wide range of dynamic imagery in a series of 3-D images that are sequentially related in space and time.



**Figure 5a. Existing two-lane roadway**



**Figure 5b. Visualization of proposed improvement**



**Figure 5c. Completed construction**

4-D technology is an innovative tool for interactive urban/transportation planning, consensus building, public education, and conflict resolution. Real-time simulation includes adaptable database management systems and an optimized desktop PC with web-enabled system configuration, all seamlessly integrated under a universal fourth dimension of time. Besides the common real-time 3-D interactive capabilities, real-time provides the ability to control the fourth dimension of time and to integrate time-based intelligence with existing information databases, such as GIS and other information technology systems.



Figure 6. Existing (inset) and proposed urban interchange improvement

4-D applications include:

- Video: the unedited recording of existing site conditions using a video camera;
- Simulated Phase Change: the process of illustrating the change that occurs from an existing base image condition to the proposed composite image condition from the same view-point and saved and played as a video sequence;
- Animation: a sequence of composite images that, when played at specific speeds, produce the illusion of motion; and
- Real Time Simulated Graphics: the ability of a computer system to generate, display, and update images in a continuous stream at the same time that data are entered, or as commands to navigate a project are given.

### **Real Time Simulation**

Real time provides the ability to control the fourth dimension of time and to integrate time-based intelligence with existing information databases, such as GIS and other information technology systems. This allows the opportunity for viewer-controlled movement and gaze.

Real time simulation, also referred to as ‘Urban Simulation,’ is the most sophisticated of all visualization applications available today (2003). This simulation provides the capability of moving about a virtual model freely, dependent on user input commands, to view, evaluate, and assess planning, design, construction, and operational characteristics of existing and potential proposed project alternatives. The ability to continuously render data on-the-fly, anywhere within the project area, makes real time simulation not only a very powerful visualization tool, but also an important simulation tool to use for analytical assessment purposes. Its performance relies on temporal database software which is substantially different from the typical CAD modeling approach, and also requires higher-end hardware capability necessary for viewing the scene in a continuous render mode.

Real time simulation offers several advantages over traditional visual photo-simulation techniques. The most significant advantage is that rendering is continuous. If a different perspective, walk-through, drive-through, or even fly-through is desired, one only must move the mouse in that direction. There is no need to re-render the scene off-line. In contrast, if a typical animation has been prepared and there is a need to change the path of movement, it is necessary to re-render the entire animation off-line. This potentially requires rendering several thousand frames, which takes a considerable amount of time and hardware resources to accomplish.

Another significant advantage that real time simulation provides is that rendered scenes are derived purely from data. No manipulation or user interpretation is made to an image which can potentially add bias to a visual photo-simulation. Another advantage is the ability for simulating ‘what if’ scenarios on-the-fly, not only to visualize but to assess complex, interactive, dynamic transportation operations within changing environments. This capability gives planners, designers, contractors, stakeholders, and project management teams the ability to test numerous options, all based purely on data input.

Conversely, if it is later decided to provide an animation or still image photo-simulation, one saves the path of movement through the desired project area sequence being displayed to prepare the animation or still image photo-simulation. Having these multiple capabilities makes real time simulation highly flexible, versatile, and more beneficial over traditional visualization methods.

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

### **WHAT DOES VISUALIZATION INVOLVE?**

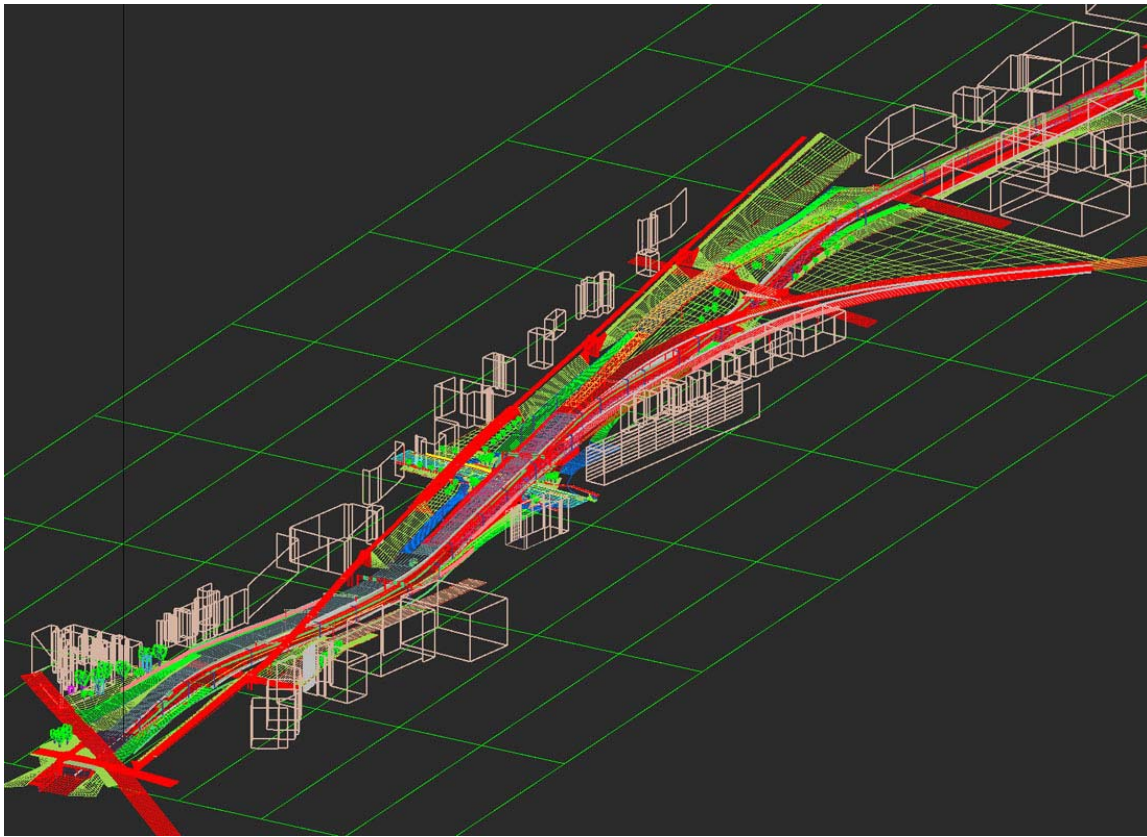
Many types of visualization exist, ranging from a simple two-dimensional (2-D) photographic or artistic rendering based on an interpretation of conceptual project ideas to a four-dimensional (4-D), fully detailed, animated, and/or real-time simulation that completely illustrates project features.

Figure 7a illustrates a wire frame model built from existing and proposed digital terrain models (DTM). DTMs contain all essential information as the basis for developing the visualization as seen in Figures 7b and 7c.

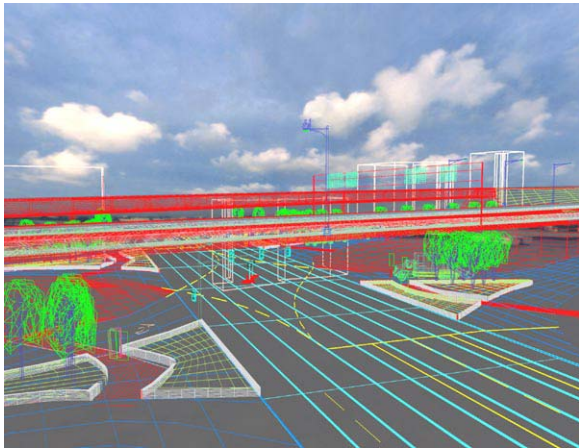
The most appropriate visualization technique should be selected based upon what stage the project is in, the needs of the project, the anticipated amount of controversy regarding potential alternatives, the cost and complexity of the project, and the need to convey understandable information to the public. Generally, the cost of the visualization should strive to be in balance with the cost of the improvement.

However, the ultimate factor for determining what type of and how much investment in visualization is warranted should be based on the value the graphic portrayal will likely provide over time when considering the magnitude of issues surrounding the proposed project. For example, when an important yet comparatively low-cost project generates significant public controversy, it may be well worth more time and expense to prepare visualizations than would otherwise be indicated by the cost of the project alone. When the cost of the visualization technique is in line with the cost of the improvement, information can be provided to the designer and public that they will find useful and necessary, yet the agency will not be criticized for spending funds unnecessarily.

If the project has the potential to include items such as planting materials that will appear different in a future condition than in the "construction" year, both existing and proposed images and/or animation should be included in the visualization. The public should be informed that the visualizations shown are a close representation of what the improvement may look like, but that it is not an actual depiction.



**Figure 7a. Wire-frame model of project area**



**Figure 7b. Close-up view of wire-frame model**



**Figure 7c. Rendering of close-up view**



**Figure 8a. Visualization of existing bridge**



**Figure 8b. Visualization of proposed bridge**

It is very important that the process used to develop the visualization is documented. This is done so that other individuals at a later time can follow the procedure and develop the same visualization if necessary. If photographs or videos are taken, the location of the images should be identified and “surveyed” in such a manner so that the exact location could be re-established and the simulation can be reproduced.

### **WHAT ARE THE BENEFITS?**

With such a wide range of capabilities and techniques possible, visualization provides the design team (i.e., transportation staff, advisory groups, community leaders, and environmental resource agencies) with a valuable resource. The design team can review the visualization to ensure that they are in consensus with the improvement as planned. This is a valuable check in determining if the proposed improvement the design team anticipated is what is being provided.

Once consensus has been reached, the information can be shared with the public to convey, in an understandable way, what the improvement alternative entails. A typical public involvement workshop is shown in Figure 11. Consensus for the project can be sought and obtained, and the proposed improvement can proceed through design to construction. Visualization can contribute to significant time savings throughout this process.

Visualizations that are accepted by project stakeholders, the public, and those living and working adjacent to the project can also be effective in conveying the design intent to potential bidders as well as to the construction contractor. These individuals often do not participate in the project development process.



Figure 9a. Existing intersection



Figure 9b. Visualization of proposed improvements



Figure 9c. Completed construction



**Figure 10. Existing (inset) and proposed interchange**

### **WHAT ARE THE CONSTRAINTS?**

Care must be taken to ensure that the visualization is a reasonable and accurate representation of what the technical documents will provide. It is important to show only those proposed features that will be built. Artistic license that illustrates or represents additional features not intended to be included in the project, merely to make the images look better, is to be avoided. This is especially true during the later stages of design development and public involvement. Not only does artistic license add bias to the proposed alternative being simulated, it can also become the basis of violating a “visual contract,” whereby what was illustrated may become necessary to be built.

### **DELIVERY METHODS**

Another important consideration when planning for and preparing a visualization is the type of medium that is most suitable to provide the desired level of communication. The format of the visualization delivery can range from simple to complex and therefore must be taken into account when identifying the visualization needs of a project. Options include printed copy,



**Figure 11. Public involvement meeting**

digital files for use in electronic slide presentations, video, compact disc (CD), simulation accessed through the Internet, or a combination of these media with or without voice narration. How visualization information is delivered or presented can ultimately contribute to the value and success of the visualization. Because different types of media have varying degrees of complexity, the choice of media can affect the delivery time, the quality, the cost, and the availability of the visualization information.

## **TRAINING**

Visualization development uses diverse processes, applications, and information. Current training for those that produce visual products is primarily obtained by on-the-job personal experience using a variety of commercially-available computer software. As use and expectation expands, it is anticipated that formal training in basic and advanced visualization will become available for engineers, planners, artists, designers, and technicians.

## SUMMARY

Visualization is an effective tool to engage and facilitate healthy, informed discussion among project team members, the public, and transportation officials. The results contribute to improved participation and collaboration, which is integral to developing context sensitive solutions that advance transportation goals while acknowledging the needs of the community. These results not only minimize environmental impact but enhance environmental quality.



Figure 12. Existing (inset) and proposed streetscape amenities

# ***Glossary of Commonly Used Terms in Visualization***

## **Aerial Photo**

An aerial photo is an image taken from an airborne platform at an appropriate altitude to resolve important details in the view.

## **Animation**

Animation is the perception of motion that is achieved by the rapid presentation (usually 30 frames or more per second) of successive stationary views. When using animation, the developer is required to define a path, or spline, through the database, as well as the eyepoint and point of gaze. There is no flexibility to alter the view without creating a new animated sequence. Animation, while effective in conveying the operational characteristics of a design, is extremely time consuming when developed on systems that do not have a real time image generation capability.

## **Artist's Rendering**

An artist's rendering is a free-hand drawing or painting of a proposed design or facility. Artist's renderings are useful early in the conceptual phase of design. An artist's rendering is not typically derived from Computer Aided Design (CAD) data. As a two-dimensional representation, it contains only that information contained in the drawing. Other viewpoints or perspectives require additional renderings.

## **Composite Image Simulation**

Composite image simulation involves merging two or more images that have the same viewing station/location, as defined by  $x$ ,  $y$ ,  $z$  coordinates and perspective parameters. Composite static images most frequently involve merging photographic or video base images for which the camera location and settings are known and/or calculated. These are then merged or overlaid with a 3-D computer image that has been generated using the real world location and settings for the virtual camera (computer camera). In this process, the background image must be taken so that the geographic location parameter, the viewpoint, the camera settings, and the actual size of some of the objects in the image are known. This is very important so that when changes are introduced (such as proposed transportation features), they can be matched to provide geometrically and dimensionally accurate images. A three-dimensional computer model is used to generate a perspective using the same coordinate camera location and camera settings as those of the original background or base image. These two images are then overlaid using control points to create the final composite image. This method provides the most visually correct, accurate, and defensible representation possible. With proficiency and care, the range of error is generally less than two percent. Several additional steps are also involved, such as material definitions and material rendering, to complete the final composite image.

## **Computer Generated Model or Image**

In contrast to two-dimensional images such as photographs, which have been digitized and stored in an electronic format, a computer generated image is one which is derived from mathematical descriptions (i.e., a model) of physical dimensions and surface attributes. As such, different visual perspectives can be generated. Computer generated images can vary from simple wire frame models with no surface texture to highly realistic, solid models with photo realistic texture maps applied.

## **Field of View**

The field of view (FOV) is the physical size of a display defined in terms of azimuth and elevation. In real time systems, the field of view generally varies inversely with the display resolution (that is, the larger the field of view, the poorer the display resolution). An example of where display resolution is important is where one is attempting to read and respond to simulated highway signing at the equivalent of real world distances.

## **Frame**

A frame is a single view as determined by observer location, eyepoint, and point of gaze. A system with real-time image generation capability can generate upwards of 30 frames per second, which is considered to be the minimum requirement for the perception of smooth motion. To create the same perception, non-real-time systems must rely upon animation for the same effect.

## **Geographic Information Systems (GIS)**

In essence, GIS is a database management system for geographically-referenced data. GIS databases are typically arranged in 'levels' where each level deals with a different type of information (e.g., demographic data, socio-economic data, land use data, etc.). All levels have a common set of coordinates. In some instances, it may be possible to 'drape' GIS 'data' over digital terrain elevation data.

## **Image Paint**

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

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

## **Operational Fidelity**

Operational fidelity describes how well a model or simulation represents (in real time or not) the essential dynamic/temporal aspects of system performance.

### **Photo-Digitized Texture**

A photo-digitized texture is created through the digitization of a photograph of a physical surface and its application (i.e., mapping) to the face of a computer generated surface.

### **Photogrammetry**

Photogrammetry involves the derivation and use of various forms of spatially defined or geographically-referenced data, generally derived from aerial photographs.

### **Photo Simulation or Photo Composite**

A photo simulation (or photo composite) is a photo-like image that has been created by inserting a view of a proposed facility or treatment (which may or not be computer generated or CAD-based) into a photographic background. The product is a two-dimensional view of the facility or treatment from a single eyepoint. It is not possible to generate alternative views and visual perspectives from a photo simulation or photo composite. The background imagery may be provided either from static photographs or from video.

### **Quick Time VR**

Quick Time VR (virtual reality) is a commercially available software capability that permits one to ‘stitch together’ individual images to collectively define a panoramic scene. The viewer is able to ‘rotate’ himself or herself 360 degrees about a point. Some capability is provided for the viewer to ‘zoom’ in or out, thus simulating movement in or out along one’s point of gaze.

### **Real Time**

‘Real time’ refers to the capability of an image generation system to compute/update the visual display at a rate where an observer perceives smooth, continuous motion. Thirty frames per second, or 30 Hz, is generally the minimum update rate for the effective perception of smooth motion. Sixty frames per second is generally required if the observer is required to effectively execute a visually mediated motor task, such as operating a vehicle.

### **Rendering**

A rendering is a process by which computer image generation software ‘draws’ an image based upon available information about the object’s physical characteristics, the relationship of the object to the observer, and the effect of lighting on the object’s appearance.

### **Resolution**

In display terms, the resolution refers to the smallest pixel (picture element) that a viewer can detect. It is sometimes expressed as “resolution per line pair,” where the measure is the smallest separation between pixels on adjacent raster lines. All other things being equal, large field of view displays have lower resolution than small field of view displays. The ability of an observer to resolve the detail in an image is also influenced by contrast and brightness.

## **Satellite Imagery**

Satellite imagery consists of images that have been recorded from a satellite, usually in low earth orbit. Imagery may be panchromatic (single color), spectral (color), or multi-spectral (including other spectrums, such as infrared or ultraviolet).

## **Spatially-Referenced Data**

Spatially-referenced data are defined, in part, by their spatial location/position. Spatial location or position becomes the basis for the management and manipulation of different data sources, such as information from GIS, CAD, a synthetic environment, photogrammetry, etc.

## **Synthetic or Virtual Environment**

A synthetic or virtual environment is a simulated three-dimensional environment defined in terms of the information contained in a visual database. Depending upon the image generation equipment being used, it may or may not be possible to ‘navigate’ (that is, drive or walk through) a synthetic environment in real time.

## **Texture**

Texture includes the visual attribute(s) of a surface’s physical characteristics, i.e., those attributes by which one infers such things as smoothness/roughness, material type and composition, color, etc.

## **Typical Section View**

A section view is a two-dimensional engineering drawing (which may be enhanced by an artist’s rendering) generally showing a cross-section of a facility or roadway, and which provides numerical measurement information about such characteristics as lane width, curb and gutter dimensions, presence or absence of sidewalks, presence or absence of a median, side slope, etc. It is ‘typical’ in that the dimensions shown are constant for the entire ‘section.’

## **Virtual Reality**

Virtual reality is a popular term generally used to refer to real-time visual simulation system capabilities that provide the viewer with a high degree of interaction. More recently, the concept of “interaction” has expanded to include both tactile and visual interaction. Virtual reality applications often employ a helmet-mounted display system which provides the viewer with an unlimited overall field of view, but usually at the expense of a rather small instantaneous field of view. The effectiveness of virtual reality is often defined in terms of how effectively the viewer can be ‘immersed’ within the virtual environment.

## **Visual Database**

A visual database is a special type of database containing spatially defined information from which visual displays of objects and their surrounding environment can be generated.

## **Visual Fidelity**

Visual fidelity is generally taken as an index of visual ‘realism,’ where realism is a joint function of scene content and overall picture quality (resolution, brightness, and contrast).

### **Walk-Through or Drive-Through**

A walk-through or drive-through provides the ability to move through a virtual three-dimensional environment and to observe the content of that environment from a given eyepoint or height above the ground. This ability may be the result of an animation sequence where the path, eyepoint, and direction of gaze have all been pre-defined, or may be the result of the viewer's real-time control over those parameters.

### **Wire-Frame Model**

A wire-frame model is a model of an object where each surface or face is defined visually by its boundaries (e.g., a typical CAD view). For the non-engineering observer, a wire frame model can be difficult to visually comprehend because the individual 'lines' that define the object's surfaces are all visible at once, making the perception of depth difficult.