
**3D VISUALIZATION OF HIGHWAY CORRIDORS:
THE I-77/81 CASE STUDY NEAR WYTHEVILLE, VA.**

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(ABSTRACT)

The application of Visualization and Simulation technologies to intuitively depict, analyze and execute transportation projects is gaining momentum, as advances in 3-Dimension (3D) Geographic Information Systems (GIS) technologies are rapidly progressing and there is an increased need for public acceptance of transportation projects.

This thesis presents a visualization process framework that is applicable to highway corridor visualization, and the I-77/81 Relocation Study Visualization project is discussed along the lines of the visualization framework that has been developed. The changes in the roadway alignment and associated traffic volume and pattern changes will affect the town of Wytheville, both in terms of economy and community development. The goal of the project is to present these visualizations at public participation meetings. Visualizations that have been developed in 2D, 3D, 4D, and virtual reality, will be discussed along with their developmental life cycles and issues affecting their quality.

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Always yours...

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1. Introduction

The purpose of developing 3-dimensional (3D) visualization for transportation planning projects is for all involved parties to more easily and intuitively understand the project impacts on the community and the environment. Design alternatives can be viewed and evaluated and changes can be made before construction takes place. With the advent of 3D, 4-dimensional (4D), virtual reality, 3D simulation and visualization tools, facilities and systems do not have to be installed or built to determine their impact. They can be thoroughly visualized, reviewed, tested, and improved at much earlier conceptual stages, before millions of dollars are spent, even on design (Dewar et al., 2000). The application of visualization technologies in transportation engineering is being driven by the increased need for public acceptance.

In the context of public participation meetings, 3D visualization assumes a role of communication facilitator and has proven to be very useful in conveying information regarding the design and impacts of proposed engineering projects. Traditional methods such as topographic maps and design plans that are overlaid on orthorectified imagery are not as intuitive as 3D visualization to the public, and the animations and movies produced are in most cases self-explanatory.

1.1. Thesis Objectives

The ability to visualize spatial data has led to increased research in transportation engineering for combining the strengths of Geographical Information Systems (GIS) and 3D visualization. Transportation visualization has progressed from using paper maps to 3D and 4D using scalable computing environments, enabling visualization and simulation outputs to depict “what-if” scenarios.

However, the process of developing visualization products depends on several factors, including: 1) The final goal of the visualization, 2) Available data sources, 3) Visualization tools, and 4) Time and budget constraints. Many visualization projects also involve custom software development and are used in specific scenarios.

On close observation, many projects use different datasets, visualization tools and have variable project requirements, however, there is generally a common methodology that is applicable to the majority of the projects involving highway corridor visualizations. This thesis is an attempt to extract that common methodology by analyzing the historical and current trends of visualization technology as applicable to transportation engineering, and to apply this methodology to a 3D visualization project entitled “The Interstate-77/81 Relocation Project” near Wytheville, VA sponsored by the Virginia Department of Transportation (VDOT).

The specific objectives of the thesis are to:

1. Outline a common visualization workflow process as applicable to highway corridor visualization from the best practices encountered.
2. Present the I-77/81 3D-visualization project as a case study that has incorporated many types of geospatial data layers and various kinds of commercial software packages.

In addition to extracting a common methodology for corridor visualization, this thesis will attempt to provide the reader with a brief history of visualization and also the present trends as evidenced from literature review. Visualizations have been divided into four main categories, and will be discussed in subsequent chapters. A software evaluation matrix has been developed for evaluation-comparison of different commercial software products that are used in corridor visualization. Based on the experiences with the project described in this thesis, a description of main features of the software used has also been presented. A Visual Basic application has been developed to recommend software solutions for available data. The features and its description is given in Appendix E.

2. Literature Review

2.1. History

The history of computer visualization can be traced back to the 1970s and the early 1980s with the introduction and development of computer graphics based Computer Aided Design and Drafting (CADD) systems. These systems provided 2D visualizations of construction plans and other forms of “data” using paper maps. Computer visualization in the transportation industry only started to happen after 1984, when CADD systems were adopted by the transportation industry.

Landphair and Larsen (1996) have outlined a general perspective on the historical milestones in visualization technology applicable to transportation industry. The early technology was known as Computer Aided Design/Computer Aided Mapping (CAD/CAM) and the late 1970s saw a rapid development of stand-alone workstations and color display monitors. Data management modules were added to the traditional CAD/CAM systems during the later parts of the 1980s. According to Landphair and Larsen, the earliest transportation projects to integrate the 4D visualization technology are the Boston Artery/Tunnel project and the North Central Expressway project in Dallas.

Current visualization technology has spun off from developments in the motion picture industry, the military, the automotive and the aerospace industries. This can be best corroborated by observing that the high-end immersive visualizations that were being used for flight simulations and other defense related simulations, can be now reproduced to a fairly accurate level of sophistication using desktop workstations. This is demonstrated by the work of Bayyari et al. (1996), in the field of enabling virtual reality for urban simulation and driving simulation on desktops. In addition, the efforts by the UCLA’s Urban Simulator project (Jepson et al., 1995) are noteworthy in drawing from technologies that were previously in the domain of military flight simulation and virtual reality.

In a survey conducted around 1995-96, Landphair and Larsen (1996) sent out survey questionnaires to state and provincial transportation agencies to determine the current usage of visualization technology in transportation practice. The following observations are the main focus with regard to this thesis. Regarding awareness and use of visualization, Video technology appeared to be the most popular (65%) with Paint (55%) and Image compositing (50%) also gathering high response rates from the agencies. The surprising aspect is that the survey revealed that more than 65% of the agencies have used some form of 3D or animated visualization materials in public participation forums. The activities associated with soliciting public opinion and answering the concerns of special interest groups topped the list for use of visualization materials. More than 50% of the agencies reported using some form of visualization as part of their interagency planning and design process. Evaluation of alternatives, environmental conflicts and design issues seem to be the top activities in the interagency use of visualization technology. Bridge Design (22%) and traffic simulation (12%) appear to be the specialty areas using visualization technology the most.

2.2. Types of Visualizations

A review of the literature GIS, 3D Visualization, Traffic Simulation, Virtual Reality and various other related topics has made clear that all the visualizations that are being done today can be classified into 4 main categories:

- 1. Still Visualizations (2D and 3D).**
- 2. Animated Visualizations (3D and 4D).**
- 3. Simulated Visualizations.**
- 4. Immersive Visualizations.**

Each of the above topics will be reviewed separately in different sections. An attempt has been made through this literature review to analyze and exhibit to the reader, some of the visualization work being done in the transportation industry.

2.2.1. Still Visualizations (2D and 3D)

Still visualizations are static models that can be either in 2D or 3D. These do not incorporate the temporal factor in their display.

In the survey (Landphair and Larsen, 1996) that was described above, most of the agencies have reported that their visualization efforts have started with some kind of paint or image compositing. Photosimulation is used to depict the changes in the before and after scenarios. This typically would involve using photo-editing software to "touch up" the photographs to present an artist's perspective of completed projects. The effectiveness of this photosimulation depends on the skill of the artist, and also on information provided to him by the agency. Apart from the photosimulation, another category of 2D visualizations is the product of 2D GIS analyses. The FAU/FIU Joint Center for Environmental and Urban Problems' (York et al., 1999) published a report in 1999 on the creation of a Visualization Tool Based on Best Practices. This tool called Visualization of Land Uses and Transportation Interactions (VOLUTI) allows information about transportation systems and their effect on land uses to be analyzed and presented to the public and the elected officials in a visual way. There are twenty-three themes that include data layers like lifestyle data, transportation systems, and public facilities. Additional menus that were added include a land use menu, and environment menu, a socio economic menu, a transport facility menu, and the accessibility menu.

The New York Department of Transportation (NYDOT) has been using transportation visualization for selected projects for the past several years (Landphair and Larsen, 1996). By using visualization technology in public forums, the NYDOT believes that the public meetings will provide more useful feedback and improved public relations. An example of the kind of visualization work that is being done is a recent project, which involved an important urban corridor approximately 4 miles long, containing 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 using ModelView. Adobe Photostyler was

used for final image compositing and touching. NYDOT is beginning to use 3D computer animation and is planning to migrate to the 3D database format.

The Minnesota Department of Transportation (MnDOT) has also used photosimulation products in the 1980s (Landphair and Larsen, 1996). The main software packages that were used were Microstation and Modelview along with Adobe Photoshop. Typically a graphics artist and a landscape architect work to develop visualizations.

Most of the 3D Visualization efforts that are covered in this literature review have a 2D component or a still visualization component, which forms a part of the overall 3D visualization capability.

2.2.2. Animated Visualizations.

Animated Visualizations (which are in the 3D and 4D realm) probably form the majority of the visualizations in use in today's transportation industry. These include both 3D and 4D visualizations, and are the most intuitive to understand. At present, the visualization efforts of the agencies are by and large independent and involve a lot of custom application development.

Dewar et al. (2000) have expounded on the importance of 3D and 4D visualizations. In their words, the advent of 3D and 4D visualization, facilities, and systems can be tested at the conceptual stages before a lot of money and efforts are employed to build them. The development of 3D visualization technologies makes it possible for transportation professionals to develop, better illustrate, and understand transportation systems, environments and plans.

3D visualization for transportation is an integral part of the Geographical Information Systems for Transportation (GIS-T) paradigm. With new regulations fostering a multi disciplinary approach to transportation, GIS has positioned itself as the ultimate technology integrator (Thill, 2000). Specifically for the transportation industry, issues

like legacy data management system, data interoperability, real-time GIS-T, large datasets, and distributed computing translate into challenges for the visualization process.

The VirtualGIS system (Koller et al., 1995) that was developed at Georgia Institute of Technology in conjunction with the Information Processing Branch, Army Processing Laboratory, is highly integrated and efficient real time 3D Geographic Information System. Both Windows based and Virtual Reality versions have been implemented. This system facilitates fast handling of huge files of data like textures, etc. Some of the main uses of the Virtual GIS system as projected by the authors, are in the fields of hydrosystems, town planning, police and emergency management, and military simulation. Terrain is represented by shaded polygons over a uniform rectangular grid of elevation points. The features include roads, buildings, trees, and other cultural features. Other data objects might also contain animation associated with them. Complete navigation is possible in the virtual world with the six degrees of freedom free flight capability. A visual interface to query any object within the view is also present. There are 3 types of rendering possible in this system, which are wireframe, single color Gouraud shading and phototexture rendering of polygons. Some of the special effects that are possible are haze and its color, and the position of the virtual sun. Large complex databases require special data structures. The database structure that was adopted is the quadtree database structure, which facilitates culling outside the field of view and also level of detail (LOD) management. A dataset for the National Training Center at Fort Irwin, California, was prepared and tested and the feedback gathered is being used to refine the system. The researchers hope to develop distributed, parallel computing applications to increase efficiency and power of the system, and improve the implementation of paging algorithms and incorporation of the temporal factor of data.

Suter and Nuesch (1995) of the Remote Sensing Laboratories of University of Zurich presented a strategy to generate 3D databases for real-time visualization and simulation. Results from a visualization application developed using IRIS Performer Toolkit are discussed with respect to issues concerning textures, memory and LOD. The objective of the study is to describe a visualization application with increased realism, efficient

database generation and to reduce memory overhead. The data that was used include Thematic Mapper (TM) image data and elevation data, traffic network data and buildings. Raster to vector conversions were done followed by LOD generation with 3 LODs generated at polygon cutoff areas at 0, 625 and 62,500 square meters depicting the classified land cover classes. Terrain modeling was done using the Triangulated Irregular Network (TIN) method from Digital Elevation Models (DEMs) at 10m, 25m, 100m intervals that correspond to the 3 LODs. Buffer zones around the roads were created and were overlaid as polygons over the landuse polygon theme. Each floor was assumed to be at 3m heights, and the areal dimensions derived from the statistical data about the buildings collected from The Swiss Federal Statistical Office. They then integrated elevation and landuse data. Partitioning was employed to facilitate efficient database generation involving LOD management, efficient paging and culling. Tiles built with respect to location-specific and object type-specific considerations. A sample visual simulation application was done using IRIS Performer Toolkit from Silicon Graphics, which is efficient as a database generation platform for real time visualizations. The database was developed as a tree hierarchy. Texture mapping was done depending on LODs; either geo-specific or geo-typical textures were applied. Geo-typical textures provided almost a factor of 70 in reducing the number of polygons generated. Database models of the cities of Lucerne and Stansstad were developed and visualized for geo-specific and geo-typical textures.

The Urban Simulator project (Jepson et al., 1995) has been developed at UCLA as a methodology, which integrates GIS and CAD with visual simulation to facilitate modeling, display, and evaluation of alternate proposed alternatives. It has been heavily drawn from technologies developed for military flight simulation and virtual reality. The Urban Simulator system combines relatively simple 3D CAD models with aerial photographs and street level video to create a realistic model of an urban neighborhood that includes traffic signs, graffiti and road details. The interface and the simulation software runs on a Silicon Graphics Onyx workstation with Reality Engine graphics hardware allowing extensive use of real time texture mapping. The simulation software was developed using Silicon Graphics IRIS Performer application development

environment. The simulation interface includes fly/drive controls so that the user can travel anywhere in the model. The user can "pick" any object in the model to be edited, also the user can pick any object for GIS querying and analyses. The simulation component does not include an interface for basic geometry creation; instead Multigen (A 3D database modeler) is used to do the creation. The aerial photographs are aligned to the California State Plane Coordinate System (SPCS). The footprint files were available in the form of AutoCAD Drawing Exchange Format (DXF) files or are derived from the aerial photos. These are then extruded on the surface to visualize buildings. The photorealism comes from the mapping of real world textures onto these vertical extrusions. The physical database is partitioned into tiles to facilitate faster processing. The potential applications for such a system can range from architectural context studies to medium and large-scale urban design and planning. Transportation infrastructure projects can also be evaluated using this system. The Urban Simulator project has been successfully used for neighborhood level community-based planning and communications tool to aid in redevelopment of the Pico Union area of Los Angeles, which was damaged badly in the 1992 riots and the 1994 Northridge earthquakes. This was also used for modeling the Wilshire and Vermont subway transit system for the LA Metropolitan Transportation Authority. Actual experiences of using this system on real life situations continue to validate the development of the system. The system has proven to be an extremely valuable tool for exploring potential urban design solutions.

The Houston District of the Texas Department of Transportation (TxDOT) has used 3D visualizations for several years now (Landphair and Larsen, 1996), and the most noteworthy example is a politically sensitive project in the Houston Galleria area in 1991. This gave the necessary impetus to develop ideas in 3D modeling, digital compositing and animation. The software that is used includes Microstation, Modelview, and Adobe Photoshop. The hardware setup consisted of CLIX Intergraph 68080 workstations, scanners, Video engine and 2 Panasonic DS580 SVHS tape decks. TxDOT now reports an extensive use of 4D visualization within the department.

Camiciottoli et al. (1998) and others have worked with issues regarding the joint use of multiple presentation modes, such as 3D graphics, color windowing, and text in permitting visualization of multiple dimensions of the information space. Visualizing data in the framework described above facilitates effective presentation of complex data, and allows the establishment of consistent interpretation metaphors. These metaphors help users intuitively grasp information semantics. They presented a prototype system that combines 3D navigation and filtering techniques in visualizing information associated with electricity transportation networks. The 3D Visualization is accomplished by superimposing a 2D raster map Digital Terrain Model (DTM), and subsequently additional nodes and links pertaining to power lines and power stations are overlaid after suitably georeferencing them. This makes up the geographic portion of the visualization system. The attribute information is visualized on information terrains using objects like poles, which depict different classes of information and are extruded from the information terrain. Additional flags represent additional dimensions to the information. The system provides the capability of data querying and subsequent visualization on these information terrains and context switching between the abstract information visualization and real world geographic visualization.

Federal Highway Administration (FHWA) has coupled with a Florida Department of Transportation (FDOT) Project Development and Environmental (PD&E) Study that addressed improvements to North and South Boulevard in Key West, by applying 3D/4D visualization processes and products to a proposed transportation investment (Landphair and Larsen, 1996). Some of other examples of a similar kind include the study conducted by the Texas Transportation Institute (TTI), *Evaluation and Development of Visualization Technology for Highway Transportation (0-1284)*. This study focused at how 3D technology could be useful for the Texas Department of Transportation (TxDOT) to communicate project impacts and character to the general public and special interest groups.

Wang and Li (1998, 1999) have worked on developing a Multimedia Based Highway Information System (MMHIS). This was developed using the API of OpenGL using the

DEMs from USGS. MMHIS employs a 3D map, which can be queried for a location and by using suitable menu items; the video and photologged records pertaining to that position can be pulled up from the database. The user interface for 3D visualization was designed by implementing three OpenGL C++ wrapper classes. Also, a picking algorithm was designed for positional (Lat, long) querying on the 3D map. Zooming and panning functionalities have also been implemented. The 3D files that were used were USGS 1-degree DEMS at 3 x 3-arc-second data spacing. Other datasets included 2D scanned surface paper maps, 2D coordinate maps, 2D zoom surface maps, 2D zoom coordinate maps and 2D raster map information file. The 3D visualization methods and their implementations were done using OpenGL, which is a hardware and platform independent software library for 3D graphics visualization. The terrain map initialization is done using a model transformation. The view angle adjustments are done using View transformations. Modelview transformations are used to enable the user to change maps and to view at different angles. When the angle of view is perpendicular to the surface, the 2D map is rendered. Whenever the user changes the angle of the view, a 2D surface map is draped over the 3D map and the resulting view gives a 3D effect. MMHIS allows the use to “pick” a location on the 3D map to display its attribute information.

An interesting example of corridor visualization is the project on 4D Drive-Through Visualization (Consolazio, 1998) for I-280. During 1998, the New Jersey Department of Transportation (NJDOT) aimed conducted a 4D visualization study whose main objective was to produce a simulated 4D Drive-Through of a portion of the highway (I-280 through Newark, NJ) for which proposed signing for the Performing Arts Center, Penn Station and other traffic generators in the City of Newark had to be reviewed. The existing roadway alignment was reproduced in 3D, in addition to an exit ramp connecting I-280 to Route 21 in Newark, NJ. Simulated 4D drive throughs were used by NJDOT Traffic Engineering reviewers and the public task force to view from a driver’s perspective along the road. The 3D model of the study area also included 3D models of the buildings, roadway shoulders, signs, intersecting bridge structures and other objects of visual significance based on GPS data and video log information. This was used to identify potential problems regarding excessive density of traffic signage and inadequate safe

sighting distances. The 3D geometric models were built from available construction plans. Once these were done, simulated 4D visualizations were performed using the developed wireframe models from the viewpoint of the driver at various times along a simulated journey, and a series of “movie” frames produced after rendering each of the models. To produce the final movie, all these frames were combined and compressed to form seamless animations or “digital” movies that can be played back at the correct speeds to recreate driving speeds. The author believes that the modeling and the visualization processes that were developed during the course of this project demonstrates that 3D modeling and 4D visualization can be effectively used for design purposes and for public presentations.

Mielke’s (1999) work on Enterprise Simulation is noteworthy to demonstrate the strides of visualization and simulation as decision support systems. An Enterprise Simulation is a simulation, which is constructed with a top-down view of a business enterprise, and intended as a decision support tool for decision-makers. The Virginia Modeling, Analysis and Simulation Center (VMASC), a consortium of industry, universities and government led by Old Dominion University, was established during summer 1997 to promote commercial use of Enterprise Simulation. The VMASC has identified potential uses of Enterprise Simulation, and various examples have been taken from the works of VMASC that include transportation, urban operations, supply chain management. Enterprise Simulation is always done at the entity level. Entities interact with a synthetic representation of the real-world environment and each other according to a set of rules and actions. The representative Enterprise Simulations that have been described in his work are:

1. Transportation: VMASC is currently developing a transportation enterprise simulation for the Busch Gardens Theme Park located in Williamsburg, VA. The simulation monitors important performance measures including traffic arrival profiles, traffic mix profiles, traffic backup locations and conditions, lot fill status and statistics, customer time to reach toll plaza, and customer time to park as a function of source and destination.

2. Urban Operations: It is advantageous to construct an enterprise computer representation or visualization of complex or detailed situations. Enterprise visualization can assist in developing a conceptual understanding because complexity and detail are more easily captured in a visual rendering of an object or process. Enterprise visualization is a useful tool to support collaboration because it can achieve a greater uniformity of perception and interpretation among individuals. VMASC recently developed a web-deliverable 3D interactive enterprise visualization tool for the city of Portsmouth, VA. This tool is being used for marketing a planned commerce park. The tool has been constructed using Virtual Reality Modeling Language (VRML). VRML is an interpreted language written in UTF or ASCII format, which supports runtime object creation, identification and management. The terrain model is obtained from a GIS and converted into a VRML file. The interface makes it easy to create and edit object with pick and move commands.

There are two main problems before widespread Enterprise Simulation will become a reality. The first is that the task of promoting the use of Enterprise Simulation is still a huge marketing challenge. The second is that the costs involved in developing enterprise simulations have to be reduced significantly.

An example of using 3D visualization as a tool to aid in base map production and facility planning is the work done by Dunham and El-Swaify (1998) in developing a GIS based facility management system for the Public Works Center of Yokosuka US Naval Base in Japan. The main component of the project was to use GPS technology to update the existing base map. 3D-GIS modeling was done to select the optimum location for a GPS base station, selecting benchmark locations to fix the base station location and evaluating survey accuracy for GPS rovers. ArcView 3D analyst was used to perform this analysis. The overall goals of the project included linking spatial features to tabular Naval Facilities databases and also distribute base information throughout the command using Internet mapping technologies. The ArcView 3-D Analyst was used to create a model of the terrain and buildings, which allowed for perspective viewing from any of the potential sites. The wastewater network was also converted to 3-D features to support modeling of underground facilities. Viewshed analysis was performed for each prospective site. Also,

two viewsheds were created for each building: a satellite visibility viewshed based on a 10% angle above the horizon; and communication obstacle viewshed based on total visibility.

An excellent example of interactive visualization of urban environments is the work by Fletcher et al. (2000). The Arlington County Department of Public works GIS Mapping Center and a private company IT Spatial, LLC has developed a real-time 3D visualization capability that is derived from, and totally integrated with the County's GIS infrastructure. This project involved the development of tools and processes that will provide the county with the capability to visualize, in both 2D and 3D, selected areas of interests. It involved the production of real-time urban 3D databases and also the development of a real-time 3D viewer with the ability to interactively query and display associated GIS information in ArcView. The real-time 3D database that was developed is a 3D photo-realistic database encompassing a fifteen-block area of Rosslyn, Virginia, spanning from the Key Bridge to the Iwo Jima memorial. This includes an accurate representation of the terrain contour with detailed representations of streets, pathways, buildings, vegetation and culture. Imagery and phototextures were used to get a real-world consistency. A constrained triangulation algorithm was used to generate the terrain mesh. After the generation of the terrain skin, buildings and other models produced in Multigen Creator software were added to the terrain database. Modeling and detailed texturing was performed next and the final results were stored in the industry standard OpenFlight format for 3D databases. The interactive 3D viewer that was developed works as an extension to ArcView 3.2. The software architecture is an object-oriented design consisting of three main components including ArcView GIS, a consolidated user interface, and the visualization application. Multigen-Paradigm's Vega was used as the 3D rendering engine.

Bailey et al. (2001) from the University of Kentucky's Kentucky Transportation Center have worked on investigating the utility and performance of three visualization modes, namely 2D, 3D and Virtual Reality (VR) on public participation for a case study in Central Kentucky. Visualization scenarios were designed and engineered according to the

principle of elemental decomposition. The research team investigated the efficiency and performance of visualization methods by using a combination of iterative focus group public involvement and an electronic scoring system to solicit rapid feedback. The preferred 3D visualization mode was then employed to gauge public opinion for specific highway design elements. Some of the key project findings are that 3D visualization is preferred to Virtual Reality and 2D modes when certain conditions prevail: the scenario to be modeled is rural, with many non-geometric shapes and a limited choice of highway design options is offered. Preference for visualization is dependent on previous experience of the user with that kind of visualization. Education of the various capabilities and features of the visualization technology is preferred before the viewing. Composite scenarios appear more appropriate, since they form a more realistic resource for planners and engineers. Also, benefit/cost information is appreciated by participants and affects their preference for the visualization mode.

The City and County of Honolulu (CCH) began redesigning the Honolulu intersection of Kapiolani Boulevard and Kalakaua Avenue called the “Waikiki Gateway Park”, which is basically the gateway to all of Hawaii (Boll, 2001). To get the needed funding and approval, CCH needed a visualization tool that would let people see and understand the plans without having to read plans and blueprints. RAPIDsite software was used to create the visualization of the proposed Waikiki Gateway Park, which was created by Evans and Sutherland by using a variety of GIS data. The project was a huge success and as a result, the CCH is considering a “Virtual Permitting” program that would use visualization technology to evaluate all proposed developments in Honolulu. In addition, the CCH has built a model of the entire Waikiki area and considers doing the same in future for other projects.

2.2.3. Simulated Visualizations

These visualizations are often developed to depict the results of simulation models. At present, these are still in the 2D realm, but are mostly animated.

Lieberman (1991) described the processes and techniques for combining the strengths of Geographical Information Systems, Microscopic Simulation and Computer Animation. His work describes how a traffic simulation model with graphical animation capability can be combined with a GIS to answer questions concerning transportation activity. The proposed uses of the software that he developed are to access and manage information flow between the simulation model and a GIS, display animated movement of traffic flow after simulation of a traffic model, export the information generated by the simulation model to a GIS database and querying for information suitable for any engineering needs. An example of such a query could be to identify all the links on the display that exhibit a certain amount of delay per vehicle, etc. This custom application software was interfaced with a propriety package called TransCAD that integrates the functionality with a wide variety of transportation tools. This simulation model that was developed is HCM/Cinema, which provides a Graphical User Interface (GUI) for data entry, computes Intersection capacity, performs a simulation of traffic operations, and presents an animation of traffic flow. The data required for this software works with TIGER and DLGs from USGS. TransCAD translates these files into topologically complete GIS datasets. Display is achieved by both HCM/Cinema displays as well as animation displays. The former uses both tabular and graphical format. The latter presents an overhead trajectory of simulated vehicle movement.

Another noteworthy model is a result of the work of Prevedouras et al. (1994) that visualizes the results of traffic engineering model simulations is the Interactive Visualization of Traffic Impacts (IVTI) tool. This tool has been developed at the University of Hawaii at Manoa with inputs from Pacific International Center for High Technology Research and the Statewide Transportation Planning Office of the Hawaii Department of Transportation. The objective for the development of IVTI is for public participation meeting displays and for presentation of traffic impacts to nonexperts. The main goal is to produce a turnkey hardware and software solution for the Hawaii DOT for presentation to the public. The system is driven by the results of TRANSYT-7F (T7F), traffic simulation program. The system (combines audio and digital files with the results VTI) from the T7F to produce a visual simulation that is easily understood by the general

public. The ITVI system can be used as an interactive component or a stand-alone kiosk application. The IVTI system allows for image capture, overlay, traffic results (parsed from T7F), Visualizer and final presentation. The hardware is set up of NuBus based Macintosh (such as IICI) with 8Mb of RAM and 200 MB of hard disk memory, Audio and Video cards, two monitors and external video devices to capture animation, stereo speakers and LCD units. The IVTI has two modes of operation. In the presentation mode, the presentation template is developed. In the Simulation mode, the simulations and visualizations are developed. Visualizations are one with respect to individual cars or groups based on the extent of the viewing area. The IVTI was used for a case study of Dillingham Boulevard, focused on short-term alternatives for alleviation of congestion for the morning commute from West Honolulu to the Central Business District. The arterial analysis was performed with T7F and included 10 signalized intersections. Based on the results from the model, HOV and contra-flow options were selected as the best solution, and the results were displayed as graphic animations using the ITVI system. Overall, ITVI has achieved the goal of effectively communicating the impacts of traffic to nonexperts. HDOT plans to use ITVI to make presentation or all future highway projects. The total estimated cost to develop the system was about \$250,000. Future work includes being able to take results from other traffic simulation software, trip distribution and other facilities from GIS-T software.

Goulias et al. (1995) and others from the Pennsylvania Transportation Institute of Pennsylvania State University have worked on integrating GIS systems and traffic simulation models. The GIS-based model and traffic simulation models (in this case NETSIM and TRANSYT 7F) are interfaced with software in C language that converts regional information into local traffic information for detailed impact assessment. This interfacing was done to create better quantitative models for congestion management and access control by considering local and regional traffic impacts together. The GIS technology enables users to create highly detailed highway networks that can be used in regional forecasting models and also in smaller traffic simulation models. This system can be used to forecast future changes in traffic networks and also changes in existing traffic caused by developments. A case study was performed to test the efficacy of the

concept and the resulting model. The case study area is in part of the Peach Street Corridor located in Erie County, PA. The section of the Peach Street corridor (SR 0019) under study extended from 54th Street/Zimmerly Street on the north to I-90 on the south. The results obtained from the model reported regional effects and also detailed traffic impacts.

The City of Portland, Oregon Office of Transportation (PDOT) has developed a GIS user interface (Throckmorton, 1999) that serves as both a “front-end” and a “back-end” to the Integration software (Traffic Simulation Software). The interface is called Integration Traffic Simulation Shell (ITSS) and is programmed in MapInfo’s MapBasic application development language and runs on the MapInfo Professional desktop GIS. The ITSS provides the Integration user with three main functionalities, which are network creation and maintenance, reduced data overhead, and analysis and display of results. ITSS provides the tools for creating and editing networks, creating the text file required by Integration, and analyzing and reporting the text file output produced during the Integration simulation. Integration performs the actual simulation, providing the visual output via the computer monitor and text output to files. These files contain various statistics and level-of-service measurements. The city of Portland has used the ITSS system with the Integration model to prepare a number of transportation projects, most notably the yearlong closure of a key network bridge connecting Portland’s downtown with its Central Eastside Industrial Area. The network that was developed for this project contains 1,329 links, 155 traffic signals and 4328 origin-destination pairs. The development of such a large network for the Integration software without the use of a system like ITSS would have been prohibitively expensive. The PDOT, with the cooperation of Kittelson Associates, created an add-on module that successfully imports TranPlan datasets into ITSS. ITSS was also used in conjunction with Portland’s EMME/2 travel demand model to create Integration Origin/Destination tables from EMME/2 traversal matrices.

The “City Simulator Feasibility study” (Niittymäki et al., 1999) was conducted from 1997-1998 with funding from ministry of trade and industry in Finland. Turku in Finland

and Shenyang in China are the cities selected for application of this model. The partners for this venture including Finnish Meteorological Institute (FMI), Helsinki Institute of Technology, University of Kuopio, Environmental Protection Bureau of Shenyang. The feasibility study was applied to the above two cities and the feedback was collected to develop and refine the system, and also to demonstrate the practical application of the system. The “City Simulator Study” was to analyze the possibilities of developing a tool to model the traffic and environmental impacts and visualize them in a single environment. The emissions and noise from the ever increasing traffic cross the cities in the world is a cause for concern, and tools that can quantify and visualize these effects are very useful in achieving an environmentally sustainable strategic and operative policy decisions. The main objectives of work that were accomplished are:

1. Integrated Modeling System: Model contains micro and macroscopic traffic simulation tools, emission and atmospheric dispersion models, a population exposure model, noise dispersion models and visualizations of the results of these models.
2. Traffic Modeling: HUTSIM in conjunction with HUTEMCA (emission dispersion modeling software) is used.
3. Atmospheric dispersion and meteorological modeling: The Urban Dispersion Model (UDM-FMI) that includes a multiple Gaussian Plume model and a meteorological preprocessor has been used. Also the Air Pollution Information System (API) is used.
4. CITYSIM-Noise Model: Based on the acoustical theory suitable for computer modeling, essentially the incorporation of frequency-based algorithms.
5. Visualization: Interactive use for graphics is very essential for the development of the system. The development of the 3D graphics enables the user to look at the site from different perspectives.

Redmill et al. (1999) from the Center for Intelligent Transportation Systems of The Ohio State University have implemented a road and vehicle simulation software package suitable for evaluating the interactions between multiple autonomous vehicles in automated highway and intelligent transportation system studies. The interface provides the user for specifying the roadway layout including both highways and surface roads, and multiple classes of vehicle and controller models that can be multiply instantiated to

create a world of interacting individual agents. The simulator also provides a graphical viewer output for the visualization of the results, data storage for post simulation analysis, and some user interaction.

Shadewald's (2000) work in GIS based model interfacing, which involves incorporating existing software and new techniques into a streamlined package that connects the modeling software and GIS package, will allow planners to spend less time computing and more time assessing needs. The interface that was developed in the Center for Transportation Research and Education, Iowa State University, provides analytical tools to assist the user in validation and assessment of a traffic model that is executed in a GIS environment. Through the incorporation of Visual Basic and Avenue scripting, the GIS interface assists the transfer of data between TranPlan and ArcView. Data for the Traffic Analysis Zones (TAZs) will include files of node data, link data, production/attraction data external stations data, friction file, and turn penalty/prohibitor data. A set of tools to visualize the loaded network data is made available which include validation plots, calibration plots, shortest path implementation, and turning movement display among other tools. As computation time becomes shorter and professionals' time becomes greater, the need to automate processes becomes more apparent. The above-described GIS package does the kind of automation and visualizes the results intuitively.

2.2.4. Immersive Visualizations

Immersive visualizations are based on the virtual reality technology, where the user can walk into the model and interact with the elements in real time and 3D space. It gives a high degree of immersive feeling to the user.

Virtual GIS (Koller et al., 1995) is a highly integrated and efficient real time 3D Geographic Information System and both Windows based and Virtual Reality versions have been implemented. Some of the main uses of this Virtual GIS are in the fields of hydrosystems, town planning, police and emergency management, and military simulation. The virtual reality version has a truly immersive capability with the user

using HMDs (Head Mounted Devices) to navigate in the 3D world. This system is being developed at Georgia Institute of Technology in conjunction with the Army Processing Laboratory. The Virtual GIS is implemented using the Simple Virtual Environment (SVE), a library based on the Silicon Graphics GL graphics library. The immersive virtual reality version of the system has a 3D-mouse controller (translating into a 2D cursor inside the HMD) and 6 degree-of-freedom trackers attached to both the HMD and the 3D-mouse. The 3D mouse translates into a 2D interface inside the HMD, and the user can select using the pop-up menus just like the menus in a 2D desktop application.

Breen and Scott (1995) describe Visualization Technology (VT) as a technology that can place a user in a synthetic environment enabling the user to interact with the environment just as in real world. The authors believe that VT can greatly reduce the costs involved in training T&D personnel. The authors provide an overview of the virtual reality technology and give existing applications' examples of virtual reality technology. They define Virtual Reality as a technology, which can provide a realistic model of the world, enabling the user to interact with the environment through the means of HMDs (Head Mounted Displays), CRTs, data gloves, and 3D mice. In 1993, the MITRE Corporation had developed a full-scale softcopy emulator of the Hard Panel at Boston Edison Company's Mystic #6 power plant. The instruments on the control panel operate through the touch-screen method. This was developed to support the training of power plant personnel. Seattle urban designers use a virtual environment of the waterfront to design their structures. Potential users can see the future scenarios through a 3D, 3-screen virtual entertainment theater complete with sound effects. Researchers from Purdue University have developed a virtual system that lets the executives of a company walk through the 3D models of their companies' operations. MITRE also developed a Virtual Model shop, which allow users to create full-scale replicas of man-made buildings. The source data is obtained from blueprints and CAD models with textures coming from videos, photographs etc. Interactive behavior such as opening and closing doors is also possible.

Bayyari et al. (1996) from the University of Valencia in Spain have described the data structures necessary to provide real time simulations and visualization components to

those simulations involving complex virtual environments and scenarios. They have based their strategies on work performed on a driving simulator research project SIRCA (Simulador Reactivo de Conduccion de Automoviles) developed at LISITT (Laboratorio Integrado de Sistemas Inteligentes y Tecnologias de la informacion en Trafico) to study the development of small and medium sized subject-oriented simulators using Virtual Reality. The authors propose the use of three main concepts for the data structures and modeling procedures necessary to represent the different static and dynamic objects in a viz-sim environment. Correlation of different layers in the database corresponding to abstract depiction of features in the virtual environment, connection network in the database dealing with the topology of the features in the database and Hierarchical organization of the database pertaining to the object representation as tree geometry. From this work, it can be inferred that Virtual Reality devices would offer a convenient solution for driving simulation, which are both inexpensive and that which maintains a high degree of immersion feeling.

2.3 Summary

In conclusion, a review of the literature suggests that visualization technology is being actively used in the transportation industry. The most common types being used are 2D, 3D and 4D. The high cost of developing immersive visualizations makes it prohibitive to develop these in a routine manner. It appears that 3D simulated visualizations are not being done as yet. A large number of visualization efforts are found to be custom developed for use in specific situations. Also, there seems to be a lack of a formal methodology that can be used as a reference across all transportation visualization projects.

The strength of a transportation visualization product will lie in combining the strengths of GIS, traffic simulation and realistic visualization. This should form the future focus of interest in the transportation industry.

3. The Visualization Framework

In any visualization project, there is a core framework of processes that are essential in achieving the project objectives. These processes usually involve activities that range from gathering end-user requirements to the actual delivery of output to the clients.

3.1. Types of Visualizations

Before elaborating on the process framework, it is necessary to understand the various types of visualizations applicable to the transportation industry. On close observation, it is found that most of the visualizations fall into one of the four categories that have been outlined below:

3.1.1. Still Visualizations

Visualizations that do not depict any motion or involve the dimension of time, and can be either in 2-D or 3-D. Still visualizations include image renderings in 2-D or static display of 3D models. Examples include image composites, photo imaging, artist concept renderings, building models, static 3D corridor models.

3.1.2. Animated Visualizations

Visualizations that are usually in 3-D, with the element of time included depicting motion. Animated visualizations are usually a sequence of images (3D model scenes) that are seamlessly integrated to mimic real world movement in space. Due to this, they are sometimes called 4D visualizations, with “time” being the fourth dimension. Examples include fly-throughs and drive-throughs.

3.1.3. Simulated Visualizations

Visualizations that depict the output of a traffic simulation model either in 2D, 3D or 4D can be grouped under simulated visualizations. However, at present all simulation packages are in the 2D realm and there is a lack of simulated visualization production suites in the 3D realm.

3.1.4. Immersive Visualizations

Visualizations in which, the user can “walk-in” and interact with the model virtually in real-time and 3D space. Examples include the Computer Aided Virtual Environment (CAVE¹), Virtual Reality Modeling Language (VRML) models on the World Wide Web.

The different types of visualizations have been illustrated in the following figure:

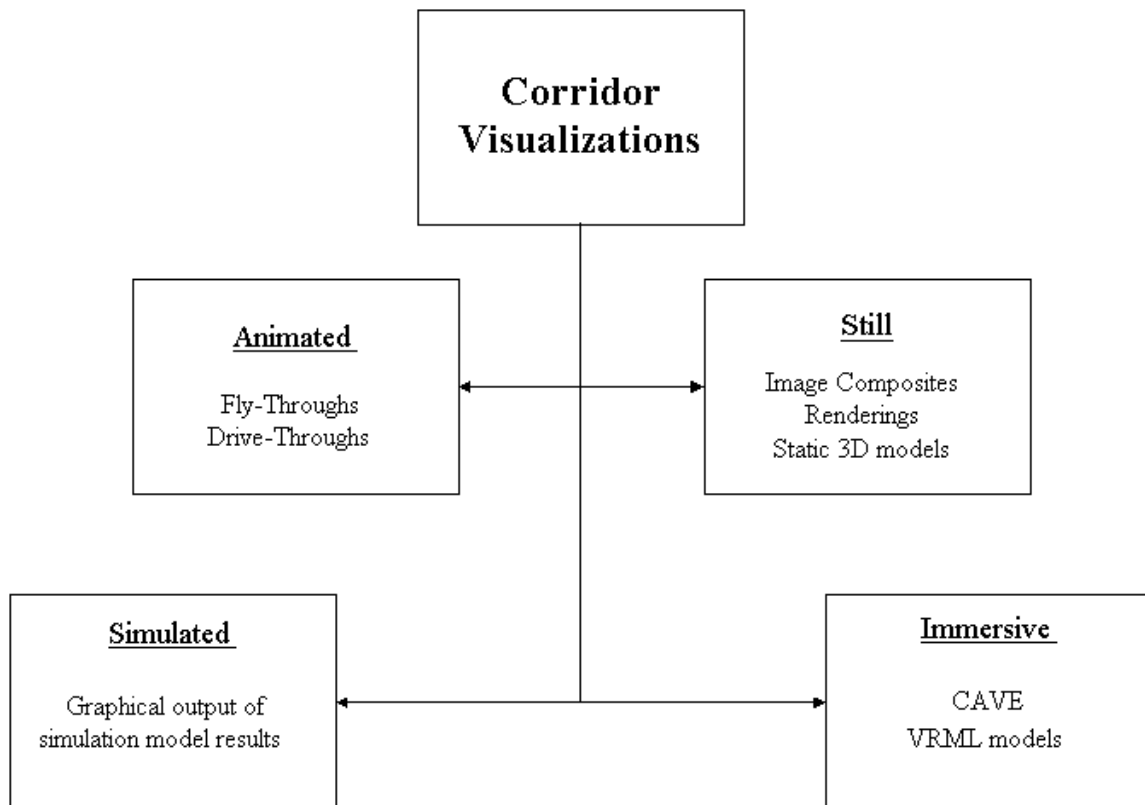


Figure 3.1: Types of Visualizations

¹ Trademark of the Electronic Visualization Laboratory of the University of Illinois.

3.2. The process framework

In any project, there is a core framework of processes that have to be performed in order to produce visualizations. The components that make up such a framework have been identified as below:

- **Objectives/End-User requirements of the project.**
- **Data and its sources.**
- **Data Manipulation/Processing Procedures.**
- **Results or Visualization products.**
- **Software Issues**

The framework is shown in Figure 3.2.

The quality of output of each of above core processes is affected by a number of internal techniques, and these are governed by a number of constraining factors such as:

- **Types of data available:** The available data govern what can be produced from a particular process, and the quality of that production.
- **State of this data:** If data is available, then the file format and the accuracy of the data will again govern the outcome of any process.
- **Software and tools available:** In each process, availability of particular software packages will impact the outcome.
- **Time and Budget constraints:** The amount of detail that is accorded to a particular process will have an impact on the overall budget and vice-versa. This would directly depend on the amount of time allotted for that procedure.
- **Personnel skill:** Expertise has a great influence on the output of any procedure.
- **Final “aim” of the visualization project:** The amount of importance given to a particular process is dependent on what types of visualizations are being done, the intended audience and goal of the project. This will translate into creation of new processes and/or editing regular processes.

The framework has been graphically conceptualized in Figure 3.2:

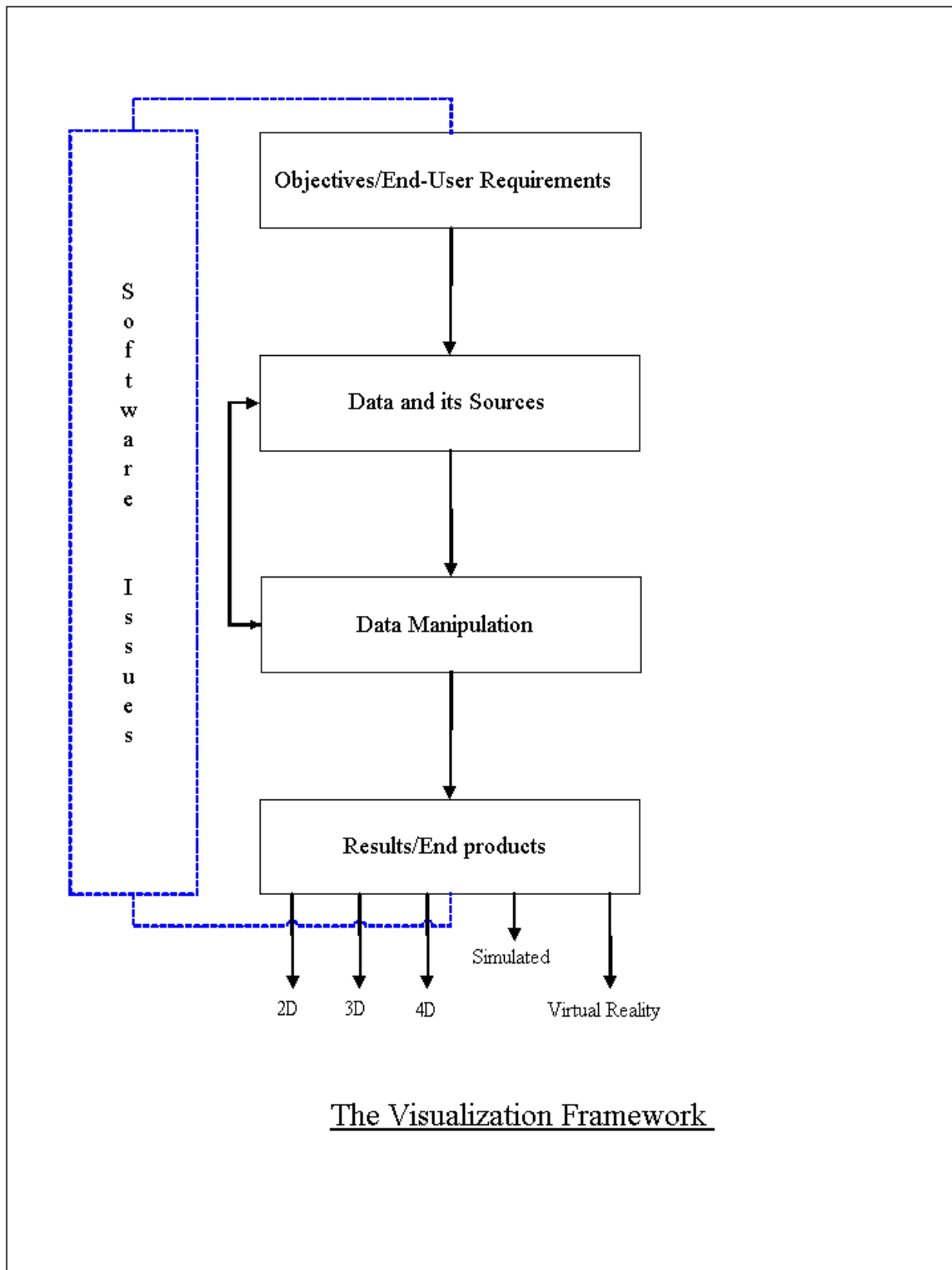


Figure 3.2: The Visualization Process Framework

Each of the above components will be discussed in detail below.

3.2.1. Objectives/End-User Requirements of the Project

The success of every visualization project depends to a major extent on correctly understanding the end-user requirements of the project. An important consideration is the time allotted for completing the project. The key issues that have to be considered when starting a visualization project are given as follows:

- **Types of Visualizations:** The main requirement that has to be noted is the type of visualization products that are expected from the project. As discussed earlier, visualizations can fall into any one of the categories: namely Still, Animated, Simulated or Immersive. Knowing exactly what kind(s) of visualization that the end-user requires will govern all subsequent efforts.
- **Audience sophistication:** The level of knowledge of the intended audience will govern the extent of detail and/or information that is to be supplied along with the visualizations. For example, visualizations for a public meeting would have a different perspective from those for a technically oriented audience like design review teams.
- **Display platforms:** The end products will depend on the platform that will be available for display. This will also govern development efforts and is a critical factor.

3.2.2. Data and its Sources

The data that is made available for the project forms a very critical aspect. The final quality of the visualizations in terms of realism and concurrency depends on the quality of the data. Some of the key issues include:

- **Data Accuracy:** Since visualizations depict existing scenarios and simulated scenarios, the accuracy of the data layers that are used becomes paramount because accurate data

will result in accurate depictions. Inaccurate datasets will introduce an element of error in the results.

- **Spatial Resolution:** The required spatial resolution of the datasets will depend on the clients' requirements. However, an optimum solution has to be reached with respect to high-resolution datasets versus disk space considerations. Availability of high-resolution data will result in very realistic visualizations, for example in urban areas, but this may not be useful when visualizing large areas, as this will put a considerable stress on the hardware resources.
- **Coordinate Systems and Map Projections:** It is rare that all data layers that are used in the project are available in a single ready-to-use coordinate system. Usually, the data layers are in different coordinate systems and in different map projections. This requires converting the coordinate systems and projections into one suitable format so as to have consistency and ease of use of the data. Sufficient care should be taken to ensure that spatial errors do not creep into the data sets as a result of coordinate system/projection transformations.
- **File formats:** Usually different kinds of data will be in different formats, and sometimes the same kind of data can also be in different data formats. This happens due to the following reasons:
 1. Agencies that produce data have their own specifications,
 2. Software packages that use and create new data have their own propriety data formats.
 3. Presence of legacy data systems.
 4. Data format standards usually evolve depending on the particular industry in consideration.

Visualization production often involves using data with varied properties, and therefore an understanding of the data formats is often necessary in order to ensure quality.

- **Sources:** Since data comes from a variety of different sources, it is important to take note of the metadata, the currency of the data, and if required the future availability of incremental data.

3.2.3. Data Manipulation/Processing procedures

This part of the visualization process forms the bulk of the development. Data manipulation, in this context, refers to all processes that are employed to convert the original data to the final products.

Highway corridor visualization primarily comprises of visualizing the terrain, roads and other cultural features like buildings and other landmarks in the study areas and giving a viewing perspective. In these projects, there are certain common data manipulation activities that have to be performed irrespective of the data that is available, the software used or the final visualizations that are expected from the project. These manipulation procedures include:

- **Data transformations:** This data preparation step primarily includes file format conversions and coordinate transformations to make the data sets consistent. Either custom written computer programs or commercially available software can accomplish file format conversions. However, commercially available software can save a lot of time.
- **Terrain:** The most common type of terrain data model is a Digital Elevation Models (DEM). The selection of the DEM type is dependent on the available data, resolution specifications, software limitations and knowledge of DEM formats. The common DEMs formats are the United States Geological Survey (USGS) 30 meter DEMs, which are freely available for download from the USGS website, and their coverage includes most of the United States of America. Other terrain formats that are commonly used are Triangulated Irregular Networks (TINs), NIMA Digital Terrain Elevation Data (DTED) datasets, and other types of grid formats.

- **Land Cover:** The display of land cover like forested areas or agriculture lands on the terrain will improve the realism of the visualizations. The land cover types are usually rendered using textures.

- **Roads:** Once the terrain is generated, roads have to be included on the terrain. These roads could be both existing alignments and proposed alternative alignments. Roads can be overlaid on the terrain, or in some advanced terrain generation software, the terrain is “stitched” around the roads to give a very realistic representation. The roads brought into the models can be in different file formats depending on the visualization requirement and the software in use. The common formats include shapefiles, coverages, Digital Feature Analysis Data (DFAD), Vector Product Format (VPF), and Microstation GEOPAK files.

- **Cultural Features:** The other important cultural features that add realism to the landscape are the buildings, landmark structures, water areas, and green areas. These have to be imported into the model or the database, suitably extruded to realistic heights and correctly placed with respect to their geographic location. Textures are then applied to these features to give realism to the model.

- **Texturing:** Texturing is the most important part in producing the realism in the visualizations. This aspect also introduces a lot of disk memory issues as they take up a large amount of disk space. The more detailed the textures are, the more disk space they occupy. The textures that are used in 3D visualizations can be divided into 2 main categories:
 1. ***Location specific textures:*** These textures represent the nature of the study area that is being visualized. Location specific textures typically will include aerial imagery or satellite imagery of the study area.
 2. ***Generic textures:*** These textures capture the essence of the study area or the models, but need not necessarily be the exact texture as found in real-life. Generic

textures typically will include building facades, lawns and green areas, deserts, mountains etc.

3.2.4. Results/Visualization products

The final step after creating the visualization model is the decision phase for output specifications, which would depend on the original client requirements. The typical outputs of visualization projects are still renderings, animated walk-throughs, drive-throughs, fly-throughs; fly-throughs with customizable flight paths, walk-in interactive models, user specified simulated run-throughs etc. The types of output will be determined by the display platforms for the visualization.

For efficient conveying of information, pertinent project information should accompany the visualizations, along with a general technological perspective about the visualization technology, so that the audiences can better appreciate what can be realistically shown.

3.2.5. Software Issues

In most cases, the software available, expertise of people who operate that software and most importantly, the generic industry focus of the particular software will limit the quality of the corridor visualizations. Industry focus in this context is defined as the parent industry that the software was developed to service.

Figure 3.3 illustrates the different industries that affect the technology applicable to corridor visualization. Software suites from each of the industries have been highlighted.

It should be noted here that the each software package that is mentioned above has been built to address specific problems. For example, the GIS software like the ESRI products have excellent GIS capability, whereas the CAD software packages aid in engineering design. The gaming software packages are capable of scenario generation; the 3D modeling software packages have excellent architectural model creation and life-like rendering capability. The traffic simulation packages are capable of traffic simulation.

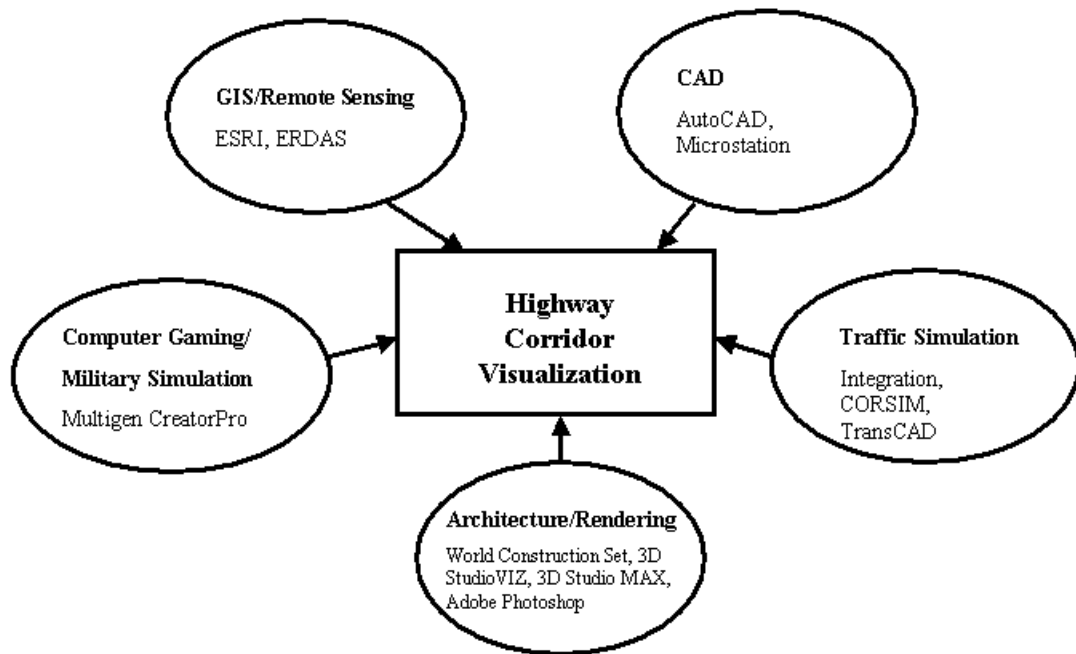


Figure 3.3: Multi-pronged Approach to Highway Corridor Visualization

However no single software is capable of meeting every requirement associated with highway corridor visualization. This requires a unique solution that must be addressed by incorporating perspectives from GIS, engineering, simulation, rendering, and model creation.

4. Manuscript

4.1. The “need” for Visualization

The purpose of developing 3-dimensional (3D) visualizations for transportation planning projects is for all involved parties to more easily and intuitively understand the project impacts on the community and the environment. Design alternatives can be viewed and evaluated, and changes can be made before construction takes place. With the advent of 3D, 4-dimensional (4D), virtual reality, 3D simulation, and visualization tools, facilities and systems do not have to be installed or built to determine their impact. They can be thoroughly visualized, reviewed, tested, and improved at much earlier conceptual stages, before millions of dollars are spent, even on design (Dewar et al., 2000). The application of visualization technologies in transportation projects is being driven by the increased need for public acceptance.

In the context of public participation meetings, 3D visualization assumes a role of communication facilitator and has proven to be very useful in conveying information regarding the design and impacts of proposed engineering projects. Traditional methods such as topographic maps and design plans that are overlaid on orthorectified imagery are not as intuitive as 3D visualization to the public, and the animations and movies produced are in most cases self-explanatory.

4.2. Objectives

Visualization has progressed from using paper maps to 3D and 4D techniques using sophisticated scalable computing environments, enabling visualization and simulation outputs to truly depict “what-if” scenarios.

However, the process of developing visualization products depends on several factors including 1) The final goal of the visualization, 2) Available data sources, 3) Visualization tools, and 4) Time and budget constraints. Many visualization projects also

involve custom software development for use in a specific visualization scenario. On close observation, there is generally a common methodology that is applicable to the majority of these projects involving highway corridor visualizations. This paper is an attempt to extract that common methodology by analyzing the history and present trends of visualization technology as applicable to transportation engineering, and to apply this methodology to a 3D visualization project entitled “The Interstate-77/81 Relocation Project” near Wytheville, VA sponsored by the Virginia Department of Transportation (VDOT).

The specific objectives of the paper thesis are:

- Outline a common visualization workflow process as applicable to highway corridor visualization from the best practices encountered.
- Present the I-77/81 3D-visualization project as a case study that has incorporated many types of geospatial data layers and various kinds of commercial software packages.

4.3. Literature Review

There has been growing interest in applying visualization technology for transportation purposes in recent years. This section presents some relevant work that is being done by state transportation agencies, university research initiatives and other organizations.

One recent project (Landphair and Larsen, 1996) of the New York Department of Transportation (NYDOT) involved an important urban corridor approximately 4 miles long, containing 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 using ModelView. Adobe Photostyler was used for final image compositing and touching. An interesting example of corridor visualization is the project on 4D Drive-Through Visualization (Consolazio, 1998) for I-280. During 1998, the New Jersey Department of Transportation (NJDOT) conducted a 4D visualization study whose main objective was

to produce a simulated 4D Drive-Through of a portion of the highway (I-280 through Newark, NJ) for which proposed signing for the Performing Arts Center, Penn Station and other traffic generators in the City of Newark had to be reviewed. The existing roadway alignment was reproduced in 3D, in addition to an exit ramp connecting I-280 to Route 21 in Newark, NJ. Simulated 4D drive throughs were used by NJDOT Traffic Engineering reviewers and the public task force to view from a driver's perspective along the road.

The VirtualGIS system (Koller et al., 1995) that was developed at Georgia Institute of Technology in conjunction with the Information Processing Branch of the Army Processing Laboratory is highly integrated and efficient real time 3D Geographic Information System. Both Windows based and Virtual Reality versions have been implemented. Some of the main uses of this Virtual GIS as projected by the authors are in the fields of hydrosystems, town planning, police and emergency management, and military simulation. Complete navigation is possible in the virtual world with the six degrees of freedom free flight capability and a visual interface to query any object within the view. Suter and Nuesch (1995) of the Remote Sensing Laboratories of University of Zurich presented a strategy to generate 3D databases for real-time visualization and simulation and had developed visualization models of the cities of Lucerne and Stansstad using IRIS Performer Toolkit. They presented their results pertaining to textures, memory and Level of Detail (LOD), like for example, disk memory was reduced by a factor of 70 when using their methodology. The Urban Simulator project (Jepson et al., 1995) that has been developed at the University of California at Los Angeles (UCLA) integrates GIS and Computer Aided Design (CAD) with visual simulation to facilitate modeling, display, and evaluation of proposed alternatives. It has been heavily drawn from technologies developed for military flight simulation and virtual reality. Virginia Modeling, Analysis and Simulation Center (VMASC) is currently developing a transportation enterprise simulation (Mielke, 1999) for the Busch Gardens Theme Park located in Williamsburg, VA. The simulation monitors important performance measures including traffic arrival profiles, traffic mix profiles, traffic backup locations and

conditions, lot fill status and statistics, customer time to reach toll plaza, and customer time to park as a function of source and destination.

An excellent example of the kind of work that this paper is being written about is the work by Fletcher et al. (2000) on interactive visualization of urban environments. The Arlington County Department of Public works GIS Mapping Center and IT Spatial has developed a real-time 3D visualization capability that is derived from, and totally integrated with the County's GIS infrastructure. The City and County of Honolulu (CCH) began redesigning the Honolulu intersection of Kapiolanu Boulevard and Kalakaua Avenue called the "Waikiki Gateway Park", which is the gateway to all of Hawaii (Boll, 2001). To get the needed funding and approval, CCH needed a visualization tool that would let people see and understand the plans without having to read plans and blueprints. RAPIDsite software was used to create the visualization of the proposed Waikiki Gateway Park and the project being a great success, the CCH is considering a "Virtual Permitting" program that would use visualization technology to evaluate all proposed developments in Honolulu.

Bailey et al. (2001) from the University of Kentucky's Kentucky Transportation Center have worked on investigating the utility and performance of three visualization modes, termed 2D, 3D and Virtual Reality (VR) on public participation for a case study in Central Kentucky. Some of the key project findings are that 3D visualization is preferred to VR and 2D modes when certain conditions prevail: the scenario to be modeled is rural, with many non-geometric shapes and a limited choice of highway design options is offered. Also, Benefit/Cost information is appreciated by participants and affects their preference for the visualization mode.

4.4. Types of Visualizations

Highway corridor simulations can be divided into four main categories. They are:

- **Still Visualizations**

These visualizations can be either in the 2-D or 3-D. Still visualizations include image renderings in the 2-D format or static display of 3D models. Examples include image composites, photo touch-ups, artist renderings, building models, static 3D corridor models.

- **Animated Visualizations**

Visualizations in 3D format with the element of time included in them. Animated visualizations are usually a sequence of images (3D model scenes) that are seamlessly integrated to mimic motion. Examples of animated visualizations include flu-throughs and drive-throughs.

- **Simulated Visualizations**

Visualizations that depict the output of a traffic simulation model either in 2D, 3D or 4D can be grouped under simulated visualizations. However, at present all the simulation packages are in the 2D realm.

- **Immersive Visualizations**

Visualizations in which, the user can “walk-in” and interact with the model virtually in real-time and 3D space. Examples include the Computer Aided Virtual Environment (CAVE).

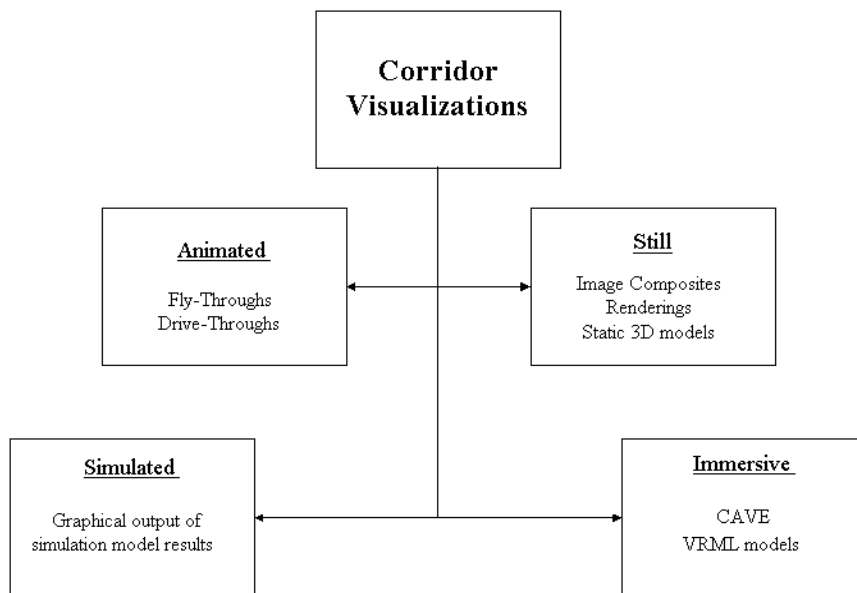


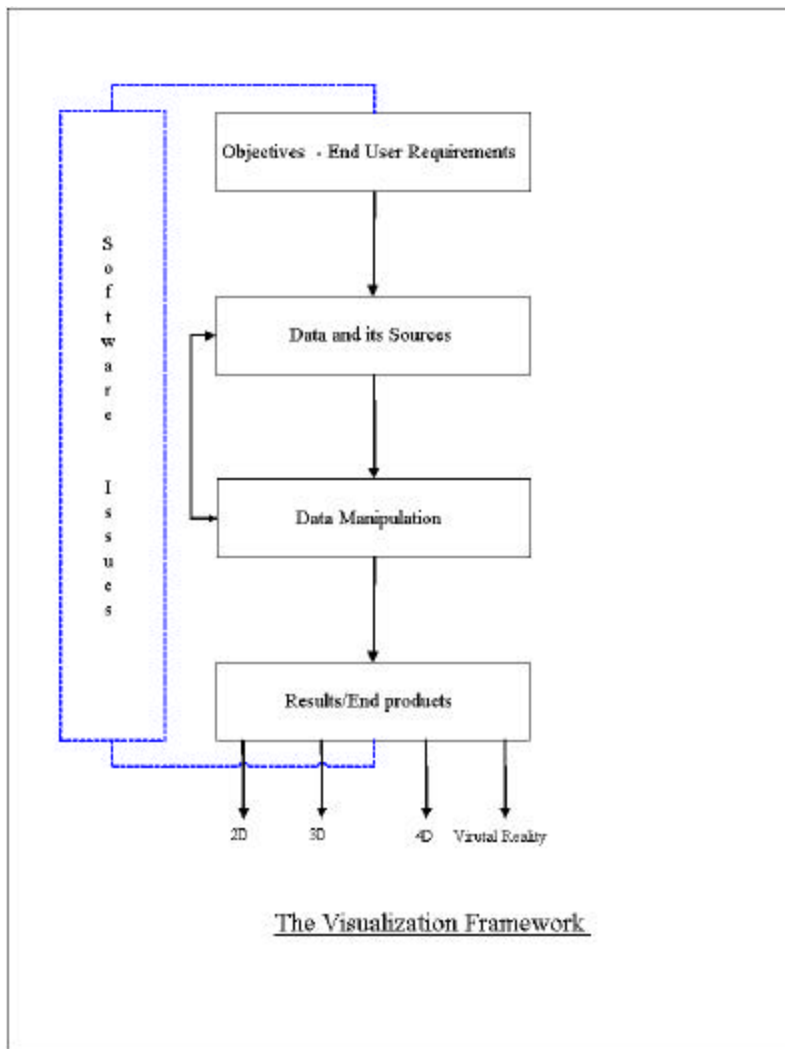
Figure 4.1: Types of Visualization

4.5. The Visualization Framework

In any project, there is a core framework of processes that have to be performed in order to produce visualizations. The components that make up such a framework have been identified as below:

- **Objectives/End-User requirements of the project.**
- **Data and its sources.**
- **Data Manipulation/Processing Procedures.**
- **Results or Visualization products.**
- **Software Issues**

Figure 4.2: The Visualization Process Framework.



The quality of output of each of above core processes is affected by a number of internal techniques, and these are governed by factors given below:

- Types and state of data available.
- Software and tools available.
- Time and Budget constraints
- Personnel skill-sets
- Final “aim” of the visualization project.

Each of the components that comprise the framework will be discussed in detail below.

4.5.1. Objectives/End-User Requirements

The success of every visualization project depends to a major extent on understanding the end-user requirements of the project. The key issues are given below:

Types of Visualizations

The main requirement that has to be noted is the type of visualization products that are needed. As discussed earlier, visualizations can fall into any one of the categories: namely Still, Animated, Simulated or Immersive. Knowing what kind(s) of visualization that the end-user requires will govern all of the subsequent efforts.

Audience sophistication

The level of knowledge of the intended audience will govern the extent of detail and/or information that has to be supplied along with the visualizations. For example, visualizations for a public meeting would have a different perspective from those for a technically oriented audience like design review teams.

Display platforms

The end products will depend on the platform that will be available for display. This will also govern development efforts and is a critical factor.

4.5.2. Data and its Sources

The available data for the visualization will determine the ultimate quality in terms of realism and concurrency. Some of the key issues include:

Data Accuracy

Visualizations can depict both the existing and alternative scenarios; therefore the accuracy of the data layers becomes paramount because accurate data will result in accurate depictions. Inaccurate datasets will introduce an element of spatial error in the resulting visualizations.

Spatial Resolution

Availability of high-resolution data will result in realistic visualizations, say in urban areas, but may not be useful when visualizing large amounts of areas, as this will put a considerable stress on the hardware resources.

Coordinate Systems and Map Projections

Usually, the data layers are in different coordinate systems and in different map projections. This requires converting the coordinate systems and projections into one suitable format so as to have consistency and ease of use of the data. Care should be taken to ensure that errors do not creep into the datasets because of coordinate system/projection transformations.

File formats

Usually different kinds of data will be in different formats, and then again the same kind of data can also be in different data formats. This happens because of the following reasons:

- Agencies that produce data have their own specifications.
- Software packages that use and create new data have their own proprietary data formats.
- Presence of legacy data systems.
- Data format standards usually evolve depending on the particular industry in consideration

Visualization production often involves using data from these and other sources, and hence in-depth understanding of the data formats is often necessary in order to produce quality visualizations.

Sources

Since data comes from a variety of different sources, it is important to take note of the metadata, the currency of the data, and if required, the future availability of incremental data.

4.5.3. Data Manipulation/Processing Procedures

Data manipulation, in this context, refers to all the processes that are employed to convert the original data to the final visualization products.

Highway corridor visualization primarily comprises of visualizing the terrain, roads and other cultural features like buildings and other landmarks in the study areas. The common data manipulation procedures that are usually necessary are:

Software Tools Selection

The selections of software tools that will be used for producing visualizations have a key impact on the outcome of the project. This selection is governed by factors such as:

- Data
- Visualization output
- Budget
- Personnel skill-sets.

Data Transformations

This data preparation step will primarily include file format conversions and coordinate transformations to enable the data sets to be consistent. Either custom written computer programs or commercially available software can accomplish file format conversions. However, commercially available software can save a lot of time.

Terrain

The most common type terrain data model is a Digital Elevation Models (DEM). The selection of the DEM type is dependent on the available data, resolution specifications, software limitations and knowledge of DEM formats. The common DEMs formats are

the United States Geological Survey (USGS) 30 meter DEMs, which are freely available for download from the USGS website, and their coverage includes most of the United States of America. Other terrain formats that are commonly used are Triangulated Irregular Networks (TINs), NIMA Digital Terrain Elevation Data (DTED) datasets, and other types of grid formats.

Land Cover

The display of land cover like forested areas, agriculture lands on the terrain will improve the realism of the visualizations. The land cover types are usually rendered by using textures

Roads

Roads both existing alignments and/or proposed alternative alignments can be overlaid on the terrain. In some advanced terrain generation software, the terrain is “stitched” around the roads to give a very realistic representation. The roads can be in different file formats depending on the visualization requirement and the software in use. The common formats include shapefiles, coverages, DFAD, VPF, and Microstation GEOPAK files.

Cultural Features

The other important cultural features that add realism to the landscape are the buildings, landmark structures, water areas, and green areas. These have to be imported into the model or the database, suitably extruded to realistic heights and correctly placed with respect to their geographic location. Textures are then applied to these features to add realism to the model.

Texturing

Texturing is the most important part in producing the realism in the visualizations but also introduces a lot of disk memory issues as they take up a large amount of disk space. The more detailed the textures are, the larger disk space they occupy. The textures that are used in 3D visualizations can be divided into 2 main categories:

- *Location specific textures*: These textures represent the nature of the study area that is being visualized. Location specific textures typically will include aerial imagery or satellite imagery of the study area.
- *Generic textures*: These textures capture the essence of the study area or the models, but need not necessarily be the exact texture as found in real-life. Generic

textures typically will include building facades, lawns and green areas, deserts, mountains etc.

4.5.4. Results/Visualization products

The final step is the decision phase for the output format, which would depend on the original client requirements analysis. The typical outputs of visualization projects are still renderings, animated walk-throughs, drive-throughs, fly-throughs; fly-throughs with customizable flight paths, walk-in interactive models, user specified simulated run-throughs etc. The types of output will also be determined by the display platforms for the visualization.

For efficient conveying of information, pertinent project information should accompany the visualizations along with a general technological perspective about the visualization technology, so that the audience can better understand what can be realistically shown and what cannot be.

4.5.5. Software Issues

In most cases, the software available, expertise of the people who operate that software and most importantly, the generic industry focus of the particular software will limit the quality of the corridor visualizations. Industry focus in this context is defined as the parent industry that the software was originally intended for.

Figure 4.3 illustrates the different industries that affect the technology applicable to corridor visualization. Software suites from each of the industries have been highlighted. It should be noted here that the each software package that is mentioned above has been built to address specific problems. For example, the GIS software like the ESRI products have excellent GIS capability, whereas the CAD software packages aid in engineering design. The gaming software packages are capable of scenario generation; the 3D modeling software packages have excellent architectural model creation and life-like rendering capability. The traffic simulation packages are capable of traffic simulation.

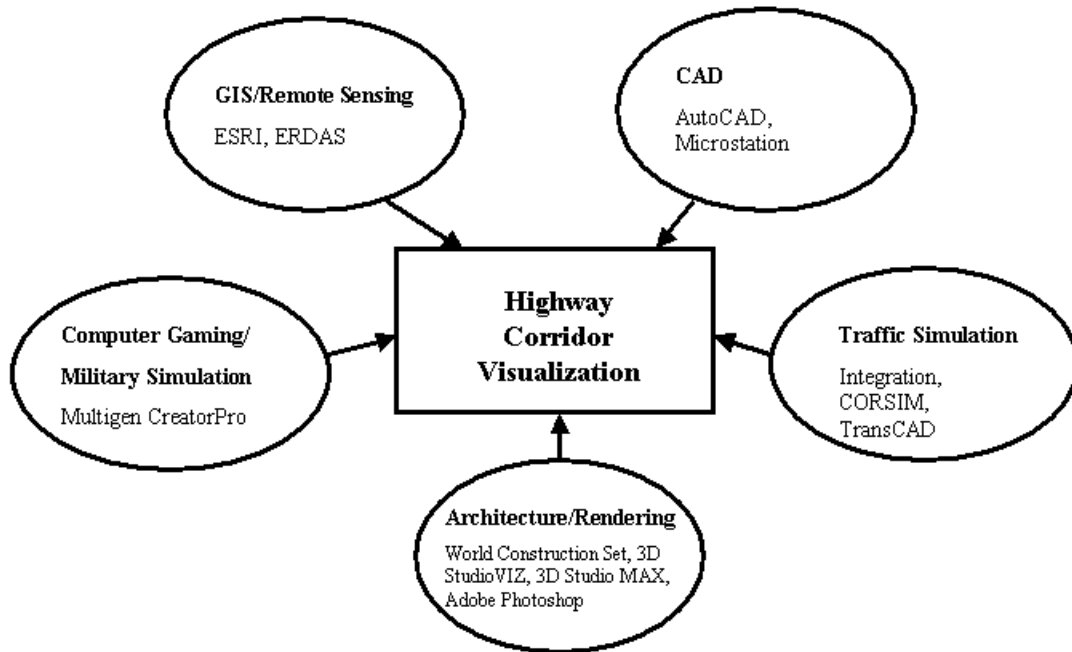


Figure 4.3: Multi-pronged Approach to Highway Corridor Visualization

However no single software is capable of meeting every requirement associated with highway corridor visualization. This requires a unique solution, which must be addressed by incorporating perspectives from GIS, engineering, simulation, rendering, and model creation.

4.6. THE I-77/81 CASE STUDY

4.6.1. Goals and Objectives of the project

The objective of this project is to present 3D visualizations of both existing alignments and also the proposed alternatives for the I-77/81 Relocation study, to the people of the town of Wytheville. The goal is to present these visualizations at public participation meetings and to the Citizens' advisory group to enable them to understand the alternatives to the situation.

The end products (deliverables) of this visualization project are:

- Fly-Throughs of existing alignment.
- Drive-Throughs of existing alignment.
- Fly-Throughs of proposed alternatives.
- GIS support for the other teams involved with various other aspects of the project like economic impacts, traffic simulation.

4.6.2. Introduction to the project

The Virginia Department of Transportation (VDOT) has commissioned a Relocation study for the 10-mile overlap of the Interstates 77 and 81 near the town of Wytheville, VA. The traffic growth rate has been steady from 15% to 40% in this overlap region. With a steady increase in traffic on this overlap segment, there has been an increase in the number of accidents, traffic congestion, noise pollution and air pollution. The alternative scenarios include building new alignments by separating the Interstates, adding more lanes to the existing alignments and a no-build option. The Civil and Environmental Engineering Geographical Information Systems (CEEGIS) Research group at the Virginia Tech Department of Civil and Environmental Engineering has been entrusted with the task of developing 3D Visualizations, and to provide GIS support to other teams involved with the project.

The commerce of the town of Wytheville is highly dependent on the revenues generated by business establishments serving the traffic flowing along I-77/81 overlap. Therefore, the changes in the roadway alignment and associated traffic volume and pattern changes will affect the town of Wytheville, both in terms of economy and community development. So, it is necessary that VDOT involves the community of Wytheville in the planning and execution of this relocation project.

4.6.3. Data sources

The data that was required for this project has been gathered from different sources with appropriate metadata about the ir scale, coordinate system, map projection and sources. A tabulated description of the data and its properties is given in Appendix A.

However, data available in a “plug and play” format is rarely, if at all, available. This project was no exception. A significant amount of preprocessing and manipulation was applied to the raw data to make it suitable for application deployment.

4.6.4. Data Manipulation Procedures

The three main components that were identified as critical to the project were:

- Software tools selection.
- Creation of terrain surfaces.
- Adding physical/cultural features.

A brief description is given below for each of the above components.

Software and Development tools selection

In order to determine the best available software for the project’s requirements, software packages ranging from core design packages like AutoCAD 2000, to GIS packages like ArcGIS 8.1 and 3D modeling packages like Multigen CreatorPro, have been used.

However, it was clear that no single software was suitable to develop all the components of visualizations. Different software tools had to be used at different stages of the visualization process to ensure quality visualizations, and for easy portability and scalability.

The complete list of software packages that were used and their evaluation as based on experiences with this project are given in Appendix A. A software evaluation matrix for highway corridor visualization was developed and each software has been rated on a scale of 1 to 5, with 1 being Not Available and 5 being Very Good.

Creation of Terrain Surfaces

DEMs were the commonly used terrain format on this project, however, other terrain formats like TINs were also used. These have been listed below along with the explanations about the issues that governed their selection:

USGS DEMs: The DEMs (30 meter resolution) for the Wytheville and Max Meadows quarter quads were acquired from the USGS websites. These two quads provided the complete coverage of the project area. The USGS DEMs were used for two reasons, primarily for the smaller file sizes and secondarily for the consistency of coverage for draping USGS Digital Ortho Quarter Quads (DOQQs).

LIDAR data: For small area visualizations like interchanges, DEMs generated from LIDAR data at 1-meter, 5-meter and 10-meter spatial resolution were used. This was done to facilitate easy porting of files into Multigen CreatorPro package.

Multigen CreatorPro was used as the main 3D-modeling package and OpenFlight 15.7 format was followed to develop the 3D databases. The main advantages are:

- OpenFlight file format makes it easier to port files across a number of platforms including Image generators like Vega, immersive environments like CAVE and other state-of-the-art visualization technologies.
- Capable of storing large amounts of data, made possible by tiling and other database utilities.
- The Level of Detail (LOD) can be controlled depending on the view distance and the resolution required.
- The 3D databases are scalable.

Triangulated Irregular Networks (TINs): TINs were built using the LIDAR masspoints. The main advantage in using this terrain format was that the roadway alignments could easily be outlined on the terrain and were suitably rendered using AutoCAD.

Adding physical and cultural features

To make any visualization look realistic, textures, images and/or features have to be added onto the terrain. These can come from a number of different sources and hence some manipulation may be needed before they can be added to the database. The following components have to be added to make realistic visualizations

Textures: In this project we have used both kinds of textures as described previously.

- *Location specific textures:* These textures were made from the satellite imagery and aerial photography. The DOQQs from the USGS were mosaiced and converted into JPEG files for use as textures in CreatorPro.
- *Generic textures:* Textures like grass, ground coverage, building faces etc were used.

Feature Models: Features like roads and buildings were included in the 3D database. A description of the models added is as follows:

- *Roads:* “Drivable” roads have been added, developed from the planimetrics file provided.
- *Buildings:* Building footprint files have been imported into the model and suitably extruded from the surface, and textures have been added to the building faces.
- *Models:* Separately created models in OpenFlight format were added along some sections of the database. These included the Factory Outlet Mall near Wytheville and some famous restaurants in the vicinity. Models of advertising boards have also been added to give a realistic reproduction of the scene.
- *Vegetation:* Vegetation like trees have been added to databases where appropriate.

4.6.5. Results

The resulting products from the visualization process can be summed up into the following categories:

Still Visualizations

Examples from the project have been illustrated in Figure 4.4 and Figure 4.5:

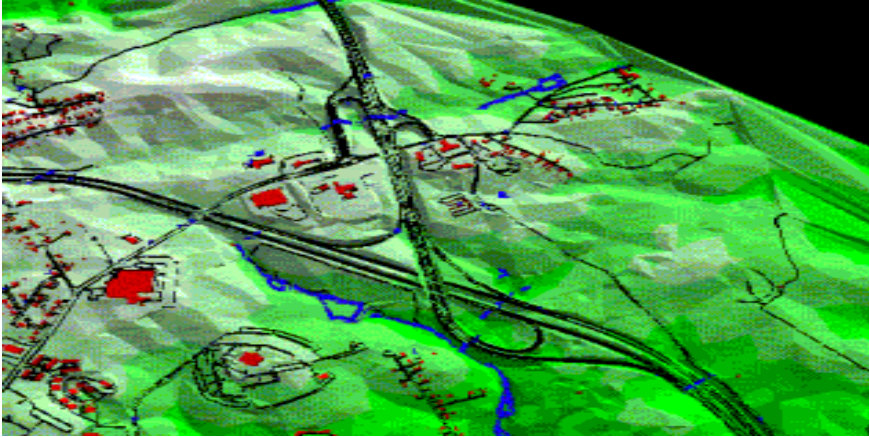


Figure 4.4: System Interchange at Exit 72 on I-81

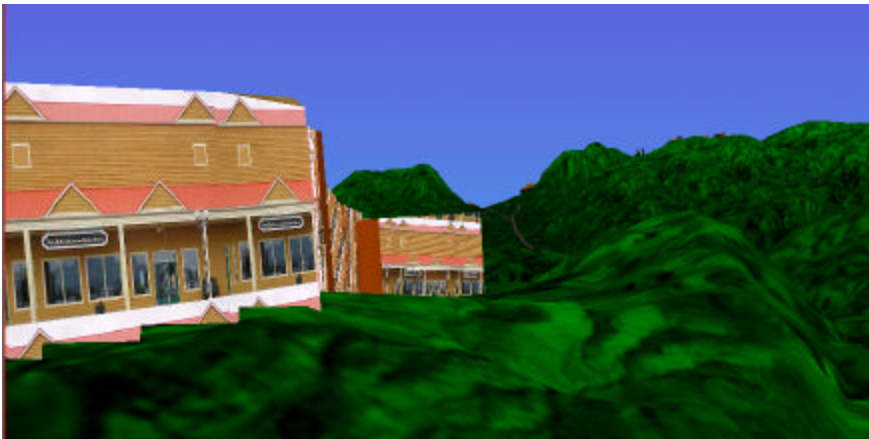


Figure 4.5: OpenFlight Model of the Factory Outlet Mall near Exit 81 on I-81

Animated Visualizations

Screen captures from the animations produced for this project are illustrated in Figure 4.6 and Figure 4.7. The actual animations can be seen in Media Objects 4.6 and 4.7.

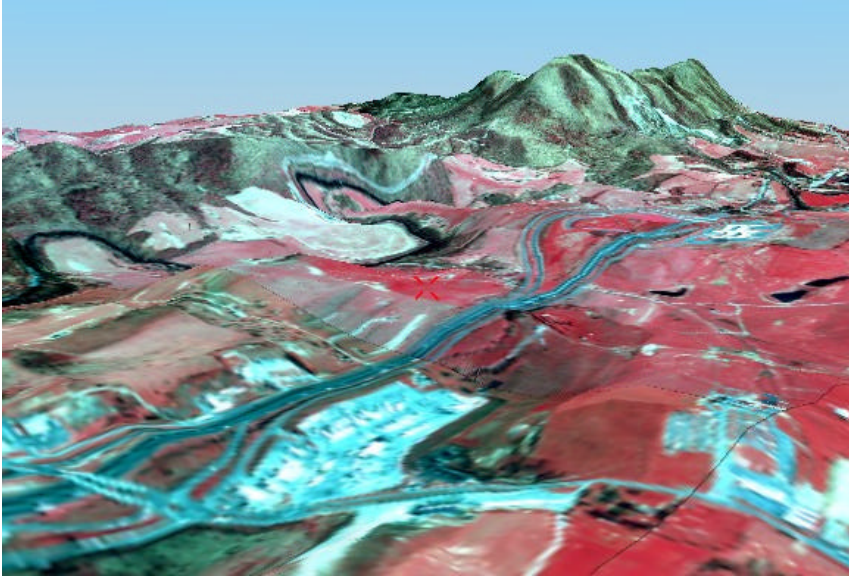


Figure 4.6: Screen Capture from a Fly-through of the Study Area: I-81 Southbound.
(MO46.avi, 53MB)



Figure 4.7: “Driving” on I-81 South Near Exit 73 (MO47.avi, 9 MB)

Simulation Visualizations

At this point of time, there are commercial software packages that produce these kinds of simulated visualizations, but our experience shows that these are still in the 2D realm. Development of software and/or software plug-ins that allow the visualization in the 3D realm is necessary.

Immersive Visualizations

To provide truly immersive visualizations for the project, the 3D databases were ported into the CAVE facility at Virginia Tech. To port these databases a custom API was used written at Virginia Tech by the University Visualization and Animation Group (UVAG). The API is called Device Independent Virtual Environment: Reconfigurable, Scalable and Extensible (DIVERSE), and is a freeware code (Kelso et al., 2002). A snapshot of the project area in the CAVE is shown in Figure 4.8.

Specifically, the CAVE(tm) is a theater 10x10x9 feet, made up of three rear-projection screens for the front, right and left walls and a down-projection screen for the floor. Electrohome Marquis 8000 projectors throw full-color workstation fields (1024x768 stereo) at 96 Hz onto the screens, giving approximately 2,000 linear pixel resolution to the surrounding composite image. Computer-controlled audio provides a sonification capability to multiple speakers. A user's head and hand are tracked with Ascension tethered electro magnetic sensors. Stereographics' LCD stereo shutter glasses are used to separate the alternate fields going to the eyes. A Silicon Graphics Power Onyx with three Infinite Reality Engines is used to create the imagery that is projected onto the walls and floor (<http://www.sv.vt.edu/future/vt-cave/whatis/>, March 31, 2002).

Potential uses of using a virtual immersive environment will be to present visualizations to high level planning committees and to citizens' advisory committees.



Figure 4.8: Viewing the 3D Database of the Study Area in the CAVE at Virginia Tech

4.6.6. Case Study Discussions

Issues

The 3D visualization of highway corridors, as observed during the course of the project presents a unique combination of issues and concerns. These issues have to be resolved in order to speed up the creation time. We have found that the following issues form the core:

- ***File sizes***

Because of the high spatial resolution of the LIDAR data sets and subsequent DEMs generated from this data, huge files were created. Some of these files had sizes over a hundred megabytes. Using the tiling capability of Multigen CreatorPro has solved a part of this problem.

Also, the texture files were also considerably very large running over hundreds of megabytes. Any technique that reduced these file sizes also reduced the resolution of the image thereby lowering the quality of visualizations.

These huge files put a considerable amount of stress on the computing hardware and decreased processing speed. This problem can be partly solved by using more powerful hardware.

- *Data formats*

There is a lack of a single tool for producing geographically consistent 3D visualizations using all types of spatial data. In this project, we encountered file formats belonging to AutoCAD, Microstation, ESRI, ERDAS, Multigen which use their propriety formats to process the data. Since, programming custom APIs to do the data conversion is not possible always, additional data conversion software has to be purchased.

- *Coordinate systems and map projections*

The different data sets that were used in this project come from different sources and are in different coordinate systems and projections. This involved applying geodetic transformations to change the projections of the datasets. This had aroused issues about the relative accuracy of the datasets.

4.7. FUTURE TRENDS

The future of highway corridor visualization holds a lot of promise considering the fact that efforts are now being made to address the problem of inter-related discipline approach to producing better, realistic and simulation oriented visualizations. Advances in hardware technology and the computing power will greatly influence the future of visualizations. Improved ease of access to supercomputing facilities and virtual reality equipment will enable the visualizations to be more interactive and dynamic. The display platforms also will see a tremendous improvement in their technology, and this in turn will enable better visualizations to be displayed to large groups of audiences.

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APPENDIX A: TABLES

The following table contains a description of the features and metadata about all the datasets that have been used in the I-77/81 Relocation Study's 3D visualization project. The attributes of each dataset have been laid out according to the issues that were discussed earlier in the visualization process framework.

	Components	Source	Description	Resolution	Coordinate System	File format
LIDAR	Masspoints	VDOT, Woolpert, Inc.	X, Y, Z points	~75 cms	VDOT project	*.dgn
	Breaklines		Roads			*.xyz
	Planimetrics		Linear features			
	Footprint Files		Buildings, Water, and Grass areas			
Imagery	B/W Orthophotos	VDOT	For Wytheville and the I-77/81 Interstate Corridor	-	VDOT project	*.tif *.hmr
	IRS	VDOT	Panchromatic	5 meter	VDOT project	*.hmr
	DOQQs	USGS	Color Infrared Imagery	30 meter	UTM – Meter Zone 17N	*.sid
CAD Data	Contours	Town of Wytheville	Town broken into 110 square grids, and data for each grid is provided.	-	SPCS – Virginia South (Foot)	*.dwg
	Planimetric					
	Utilities					
	Parcel Maps					
DEMs	USGS DEMs	USGS	Wytheville and MaxMeadows quarter quads	30 meter	UTM meter	*.dem
	LIDAR DEMs	LIDAR	Developed from LIDAR data	1 meter 5 meter 10 meter	SPCS – Virginia South (Foot) UTM meter	*.dem *.ded TINs

TABLE A.1: Data and its properties

The following table contains an evaluation of the features of the main software packages that have used in the I-77/81 Relocation Study’s 3D visualization project. The ratings are **subjective** and are based solely on the author’s perception of that particular software. These ratings should not be taken to make any decision for or against particular software. The ratings are on a scale of 1 to 5, with 5 being very good. For the evaluation feature titled “Learning Curve”, a rating of 5 means that the software is very easy to learn.

		EVALUATION FEATURES											
<i>INDUSTRY</i>	<i>SOFTWARE</i>	Terrain Generation	Data Conversion support	Rendering Engine	Texture support	Model Creation	GIS capability	Engineering design	Motion Control	Learning Curve	Portability	Traffic Simulation	Road Design
GIS/RS	<i>ArcView 3.2/ ArcGIS 8.1 3D Analyst</i>	4	3	3	3	2	5	-	4	5	4	-	-
	<i>ERDAS Imagine 8.4</i>	4	5	3	3	-	5	-	5	4	4	-	-
CADD	<i>AutoCAD 2000</i>	4	2	3	4	4	-	5	4	3	4	-	4
	<i>Microstation 7.1</i>	4	2	3	3	3	-	5	4	3	4	-	5
ARCHITECTURE	<i>World Construction Set 5.0</i>	3	2	5	5	4	-	-	4	3	3	-	-
	<i>3D Studio VIZ R 3i</i>	3	3	5	5	5	-	-	4	3	3	-	-
Gaming/ Military simulation	<i>Multigen CreatorPro 2.5</i>	5	3	5	5	5	-	-	5	1	5	-	2
Traffic Simulation	<i>Integration</i>	-	2	-	-	-	-	-	-	3	2	5	-
	<i>CORSIM</i>	-	2	-	-	-	-	-	-	3	2	5	-

TABLE A.2: Software Evaluation Matrix

APPENDIX B: DATA DESCRIPTION

The main datasets and a brief description of their components and other pertinent metadata are given in this appendix.

- **LIDAR data**

LIDAR (Light Detection and Ranging) data has been provided by VDOT. Woolpert, Inc. has acquired the LIDAR data for VDOT. The firm used tree-stripping algorithms to process the raw data for bare-earth representation. The LIDAR data was in the VDOT project coordinate system. This data contained the following datasets:

1. **Mass Points (x, y, z):** Masspoint files were supplied in Microstation (*.dgn files) format. These files contain points with latitude and longitude information along with their elevation information. These files were provided as strips of points across the entire study area, which was divided into eight longitudinal stripes. The spatial resolution of the Digital Elevation Models (DEMs) that were developed using this data can be made as high as 1 meter.
2. **Breaklines:** These files also included breakline information like streams, local roads and the Interstates. This information helped us to develop terrain surfaces from DEMs more realistically.
3. **Planimetrics:** The planimetric files that were provided included linear features (no elevation information) like roads, streets, streams, and the Interstates 77 and 81 across the entire study area.

4. **Footprint files:** Along with the planimetric files, the footprints of the buildings water areas and green areas were provided in a separate level. These proved very useful when extruding 3D features on terrain surfaces.

- **Aerial Photographs and Satellite Imagery**

1. Black and White aerial photographs of the study area.
2. 5-m resolution panchromatic IRS satellite images.
3. Color Infrared Digital Ortho Quarter Quads (DOQQs) from USGS.

- **CAD Data**

1. Contours.
2. Planimetrics.
3. Utilities.
4. Hand Digitized parcel maps.

- **Digital Elevation Models**

1. 30-meter USGS DEMs at a scale of 1:24,000.
2. Digital Elevation Models were developed from the LIDAR data in the USGS format, to varying spatial resolutions from 1 meter to 10 meters to be used for visualizations of varying terrain areas.

APPENDIX C: CASE STUDY PROCESS FLOWCHART

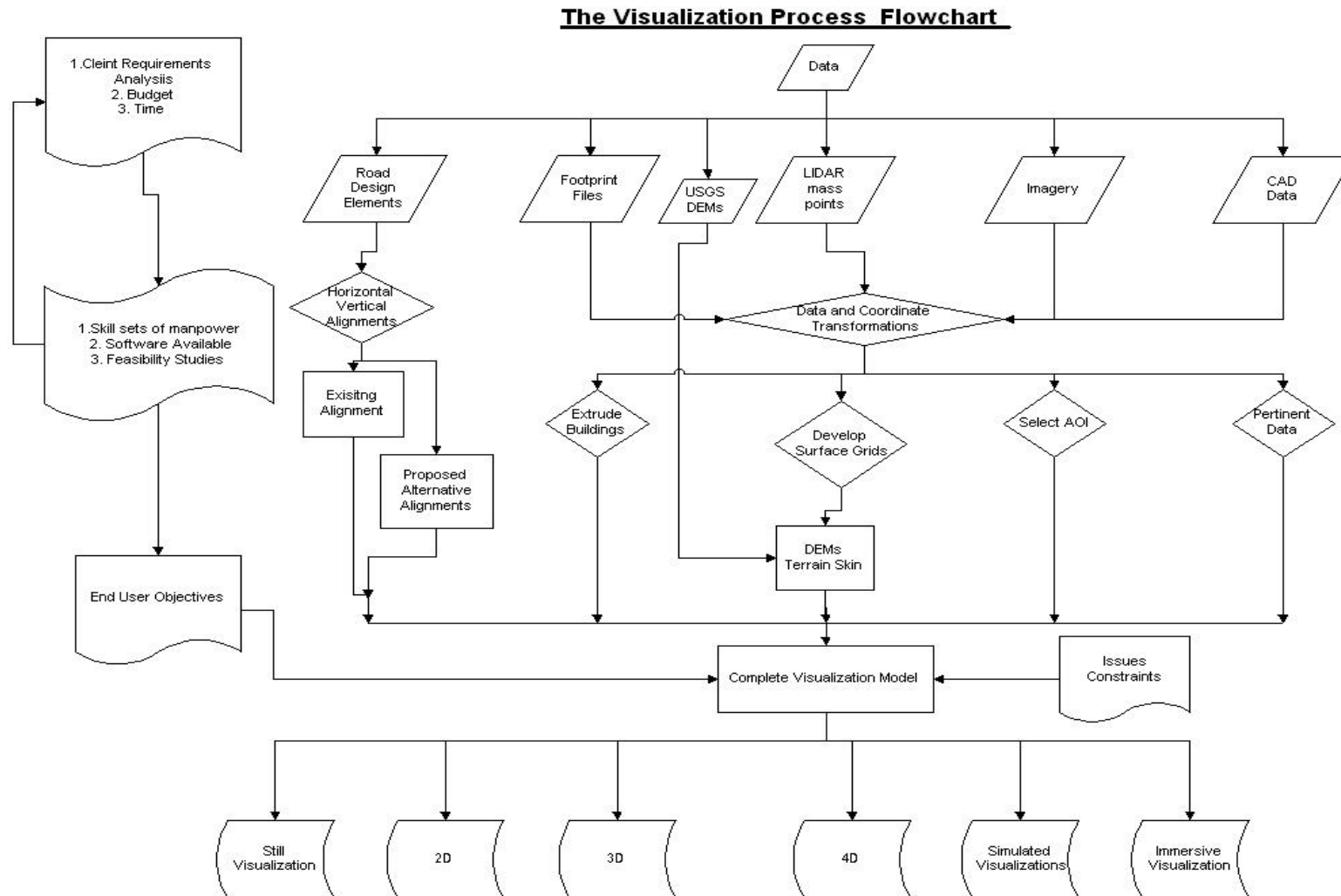


Figure A.1: The Visualization Process Flowchart

APPENDIX D: SOFTWARE FEATURES

As with any complex visualization project, this project involved the evaluation and use of a number of software packages. A brief description is provided below, which is completely based upon the experiences of using them for the project discussed in this thesis.

- **Multigen CreatorPro 2.4.1**

This was mainly used for developing 3D databases. This package is useful for creating terrains because of its support to various DEM formats when using the DED builder utility. It gives a choice of a number of terrain skin generation algorithms including Polymesh, Delaunay, CAT and TCT with options. Generates very smooth terrain surfaces, with the additional capability of dividing the terrain into independent tiles for better memory handling. This package was used to generate terrains, add database objects, build drivable roads, and drape satellite imagery. An excellent 3D database generation tool.

- **ArcGIS 8.1 with 3D Analyst and Spatial Analyst**

This package is the industry standard GIS software. This package was used to generate grid surfaces by interpolating mass points, building terrains, extruding buildings, fly-throughs and creating the GIS for the project. Terrain generation is primarily done by TIN process, but the rendering aspect of the terrain reveals clearly, triangulated faces on the terrain.

- **ERDAS Imagine 8.4**

Industry standard for image processing of satellite imagery. The Virtual GIS extension is very impressive, with the capability to stack up different layers and create a virtual world. This was used to generate fly-throughs using DEMs and satellite imagery. Additional functionality is provided with the capability to import vector files, and extrude buildings on the 3D model.

- **FME Suite 2002 (Evaluation Version)**

This program was used to change file formats, and make data ready for easy porting into CreatorPro. Supports almost all types of geospatial data formats, and is an excellent handy tool.

- **AutoCAD 2000**

Industry standard engineering design software. This was used to build TINs from masspoints, delineate alignments on the TIN. The rendering engine is satisfactory, with decent texture support. This was also used to apply grid transformations to the datasets convert them from the VDOT project coordinate system into the SPCS-Virginia South-Feet coordinate system.

- **Microdem Terrabase 5.0 Beta version**

A shareware program freely available in the market, and was used to build DEMs from various data sources and also the change the DEM formats. This is an excellent DEM generation tool, and also gives a wide variety of DEM data format conversions.

- **SiteBuilder 1.0:**

This works as an extension to ArcView 3.2. The software has good functionality, but has failed to produce any satisfactory results for data intensive visualizations.

APPENDIX E – CViz 1.0 (Features and Description)

CViz 1.0 is a software application that will take as input; the data formats for 4 main types of datasets (Terrain, Raster, Vector and Model) that are typically used in highway corridor visualization and gives as output the software solutions encompassing all the commercial softwares that can work with the data available with the user. The user can also specify if GIS querying capability and engineering precision are needed. The application generates a flexible grid that shows softwares recommended that work with dataset types the user selected, and also indicates whether that software is GIS capable or has engineering precision.

The solutions that are recommended by the application are driven by a database that has been developed which stores details about commercial softwares and the types of data formats that they support.

CViz 1.0 has been developed in Visual Basic 6.0 with MS Access as the backend database.

Example

A sample user request and the solution recommended is shown below, which will also explain how to use the application.

Suppose the following datasets are available:

Terrain data: USGS DEMs, USGS SDTS DEMs and DTED datasets.

Raster data: Aerial photographs as MrSID and JPEG format.

Vector data: Alternate roadway alignments as ESRI shapefiles

Model data: Building models of the study area as 3D Studio Viz files.

GIS capability: Required

Engineering Precision: Not Required

Visualization Types: 3D, 4D

Figure A.2 shows the input of the above scenario into the application:

The screenshot shows the CViz 1.0 application window with the following sections:

- Visualization Types:** A group box containing the question "What types of Visualization products are needed?" with five checkboxes: 2D (unchecked), 3D (checked), 4D (checked), Simulated (unchecked), and Immersive (unchecked).
- Data Formats:** A section with four dropdown menus:
 - Terrain Data Available:** USGS DEM (*.dem), USGS SDTS DEM (*.cel, *.dd), TIN, DTED Level 1 & 2 (*.dt1), Multigen DED (*.ded), GRID.
 - Raster Data Available:** MrSID (*.sid), JPEG (*.jpeg), BIL (*.bil), BIP (*.bip), BSQ (*.bsq), ERMapper (*.ers).
 - Vector Data Available:** Shapefile (*.shp), Arc Coverage, Autocad (*.dwg), VPF, USGS DLG, GRASS.
 - Model Data Available:** 3D Studio Viz (*.3ds), 3D Studio Max (*.max), STL Files (*.stl), WCS models, VML, OpenFlight.
- Additional Features:** A group box with two checkboxes: "GIS querying capability needed" (checked) and "Engineering precision needed" (unchecked). To the right are "Submit" and "End" buttons.
- Solution:** A large empty grid with approximately 10 columns and 10 rows.

FIGURE A.2: CViz Data Input Form

After selecting the data format types, click on the button “submit”. The application will then find out which softwares work with the formats that the user selected and will generate a grid showing the results.

The solution is shown in Figure A.3. For example from the results, ArcGIS 3D Analyst will work with all selected terrain, raster and vector formats, but will not work with the model format selected. It also shows that ArcGIS 3D Analyst is GIS capable.

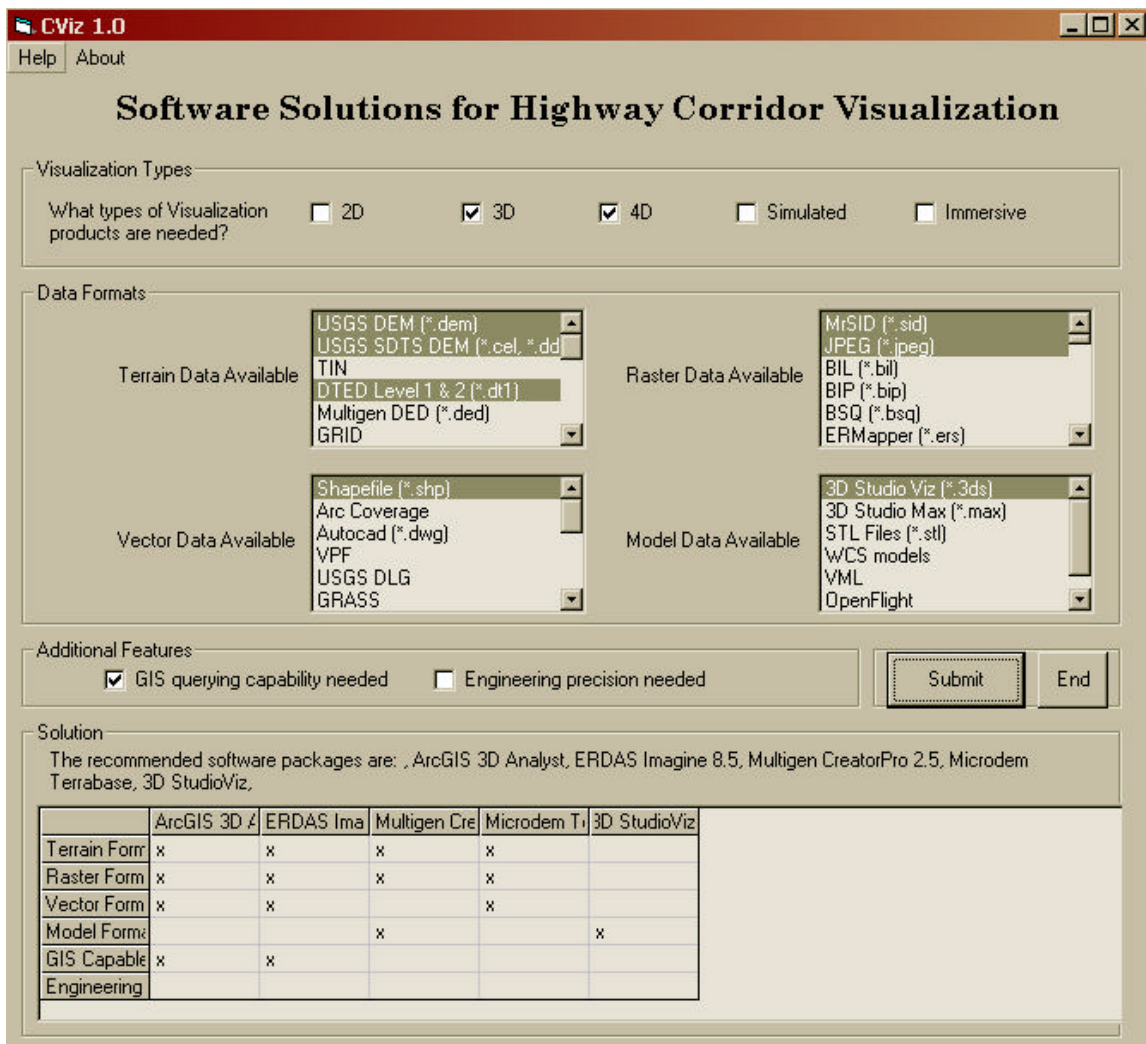


FIGURE A.3: CViz Solution

Application Code

'Statements starting with a single quotation mark should be considered as comments.

'Variable declarations

Option Explicit

Public cnnFormats As ADODB.Connection

Public strPath As String

Public strQuery As String

Public strConnection As String

Public rsTerrain As Recordset

Public rsRaster As Recordset

Public rsVector As Recordset

Public rsModel As Recordset

Public RS As String

Public LB As String

Public field As String

Public strVQ As String

Public Vformat As String

Public i As Integer

Public j As Integer

Dim rsGIS As Recordset

Dim rsEng As Recordset

Dim strError As String

Private Sub ErrorMessage()

strError = "Please make sure that you have selected all the data formats"

MsgBox strError, vbCritical, "Error"

End Sub

Private Sub cmdEnd_Click()

End

End Sub

```
Private Sub cmdSubmit_Click()
```

'Fill up the GIS Array

```
Dim arrGIS() As String
Dim strQueryGIS As String
Set rsGIS = New Recordset
strQueryGIS = "Select * from LU_GIS"
Set rsGIS = cnnFormats.Execute(strQueryGIS)
rsGIS.MoveFirst
    j = 1
    While Not rsGIS.EOF
        ReDim Preserve arrGIS(j)
        arrGIS(j) = rsGIS!Software
        j = j + 1
    rsGIS.MoveNext
Wend
```

'Fill up the Engineering Array

```
Dim arrEng() As String
Dim strQueryEng As String
Set rsEng = New Recordset
strQueryEng = "Select * from LU_ENG"
Set rsEng = cnnFormats.Execute(strQueryEng)
rsEng.MoveFirst
    j = 1
    While Not rsEng.EOF
        ReDim Preserve arrEng(j)
        arrEng(j) = rsEng!Software
        j = j + 1
    rsEng.MoveNext
```

Wend

'Populate the Terrain array

Dim arrSoftwareT() As String

Dim arrSolution() As String

Dim strQueryTerrain As String

Dim rsTerrainSoft As Recordset

Set rsTerrainSoft = New Recordset

For i = 0 To lstTerrain.ListCount - 1

 If lstTerrain.Selected(i) Then

 strQueryTerrain = " Select * from Software_Terrain where SID IN (select SID
 from STerrain where STformat = '' & lstTerrain.Text & '')"

 Set rsTerrainSoft = cnnFormats.Execute(strQueryTerrain)

 rsTerrainSoft.MoveFirst

 j = 1

 While Not rsTerrainSoft.EOF

 ReDim Preserve arrSoftwareT(j)

 arrSoftwareT(j) = rsTerrainSoft!Software

 j = j + 1

 rsTerrainSoft.MoveNext

 Wend

 End If

Next i

'Populate the Raster array

Dim x

Dim y

Dim arrSoftwareR() As String

Dim strQueryRaster As String

Dim rsRasterSoft As Recordset

```

Set rsRasterSoft = New Recordset
For x = 0 To lstRaster.ListCount - 1
    If lstRaster.Selected(x) Then
        strQueryRaster = " Select * from Software_Raster where SID IN ( select SID
        from SRaster where SRformat = "" & lstRaster.Text & "" )"
        Set rsRasterSoft = cnnFormats.Execute(strQueryRaster)
        rsRasterSoft.MoveFirst
            y = 1
            While Not rsRasterSoft.EOF
                ReDim Preserve arrSoftwareR(y)
                arrSoftwareR(y) = rsRasterSoft!Software
                y = y + 1
                rsRasterSoft.MoveNext
            Wend
        End If
    Next x

```

Populate the Vector array

```

Dim a
Dim b
Dim arrSoftwareV() As String
Dim strQueryVector As String
Dim rsVectorSoft As Recordset
Set rsVectorSoft = New Recordset

For a = 0 To lstVector.ListCount - 1
    If lstVector.Selected(a) Then
        strQueryVector = " Select * from Software_Vector where SID IN ( select SID
        from SVector where SVformat = "" & lstVector.Text & "" )"
        Set rsVectorSoft = cnnFormats.Execute(strQueryVector)
        rsVectorSoft.MoveFirst
    End If
Next a

```

```

        b = 1
        While Not rsVectorSoft.EOF
            ReDim Preserve arrSoftwareV(b)
            arrSoftwareV(b) = rsVectorSoft!Software
            b = b + 1
            rsVectorSoft.MoveNext
        Wend
    End If
Next a

```

'Populate the Model array

```

Dim m
Dim n
Dim arrSoftwareM() As String
Dim strQueryModel As String
Dim rsModelSoft As Recordset
Set rsModelSoft = New Recordset

For m = 0 To lstModel.ListCount - 1
    If lstModel.Selected(m) Then
        strQueryModel = " Select * from Software_Model where SID IN ( select SID
        from SModel where SMformat = '" & lstModel.Text & " ')"
        Set rsModelSoft = cnnFormats.Execute(strQueryModel)
        rsModelSoft.MoveFirst
        n = 1
        While Not rsModelSoft.EOF
            ReDim Preserve arrSoftwareM(n)
            arrSoftwareM(n) = rsModelSoft!Software
            n = n + 1
            rsModelSoft.MoveNext
        Wend
    End If
Next m

```

```

        Wend
    End If
Next m

'Populate the solution array
'Starting with the terrain array

Dim e, f, g, h, intflag As Integer
For e = LBound(arrSoftwareT) To UBound(arrSoftwareT)
    ReDim Preserve arrSolution(e)
    arrSolution(e) = arrSoftwareT(e)
Next e

'Add unique software names to the solution array.

For g = 0 To UBound(arrSoftwareR)
    intflag = 0
    For h = 0 To UBound(arrSolution)
        If arrSolution(h) = arrSoftwareR(g) Then
I            intflag = 1
        End If
    Next h
    If intflag = 0 Then
        ReDim Preserve arrSolution(UBound(arrSolution) + 1)
        arrSolution(h) = arrSoftwareR(g)
    End If
Next g
**

For g = 0 To UBound(arrSoftwareV)
    intflag = 0
    For h = 0 To UBound(arrSolution)

```

```

        If arrSolution(h) = arrSoftwareV(g) Then
            intflag = 1
        End If

    Next h
If intflag = 0 Then
    ReDim Preserve arrSolution(UBound(arrSolution) + 1)
    arrSolution(h) = arrSoftwareV(g)
End If
Next g
**
For g = 0 To UBound(arrSoftwareM)
    intflag = 0
        For h = 0 To UBound(arrSolution)
            If arrSolution(h) = arrSoftwareM(g) Then
                intflag = 1
            End If
        Next h
    If intflag = 0 Then
        ReDim Preserve arrSolution(UBound(arrSolution) + 1)
        arrSolution(h) = arrSoftwareM(g)
    End If
Next g

' Display the result
lblSolution.Caption = "The recommended software packages are: "
For f = 0 To UBound(arrSolution)
    lblSolution.Caption = lblSolution.Caption & arrSolution(f) & ", "
Next f

'Fill the grid columns and row headers
'Fill the Row headers first

```



```

grdSolution.Rows = 7
grdSolution.Cols = UBound(arrSolution) + 1
grdSolution.Col = 0
grdSolution.Row = 1
grdSolution.Text = "Terrain Formats Selected"
grdSolution.Row = 2
grdSolution.Text = "Raster Formats Selected"
grdSolution.Row = 3
grdSolution.Text = "Vector Formats Selected"
grdSolution.Row = 4
grdSolution.Text = "Model Formats Selected"
grdSolution.Row = 5
grdSolution.Text = "GIS Capable"
grdSolution.Row = 6
grdSolution.Text = "Engineering Design"

```

‘ Fill the column headers

```

grdSolution.Row = 0
For j = LBound(arrSolution) To UBound(arrSolution)
    grdSolution.Col = j
    grdSolution.Text = arrSolution(j)
Next j

```

Fill the cells in the grid

‘Row 1

```

Dim strCellText As String
grdSolution.Row = 1
For i = 1 To UBound(arrSolution)
    strCellText = ""
    For j = 0 To UBound(arrSoftwareT)
        If arrSolution(i) = arrSoftwareT(j) Then

```

```
        strCellText = "x"  
    End If  
Next j  
grdSolution.Col = i  
grdSolution.Text = strCellText  
Next i
```

Row 2

```
grdSolution.Row = 2  
For i = 1 To UBound(arrSolution)  
    strCellText = ""  
    For j = 0 To UBound(arrSoftwareR)  
        If arrSolution(i) = arrSoftwareR(j) Then  
            strCellText = "x"  
        End If  
    Next j  
    grdSolution.Col = i  
    grdSolution.Text = strCellText  
Next i
```

Row 3

```
grdSolution.Row = 3  
For i = 1 To UBound(arrSolution)  
    strCellText = ""  
    For j = 0 To UBound(arrSoftwareV)  
        If arrSolution(i) = arrSoftwareV(j) Then  
            strCellText = "x"  
        End If  
    Next j  
    grdSolution.Col = i  
    grdSolution.Text = strCellText
```

Next i

Row 4

grdSolution.Row = 4

For i = 1 To UBound(arrSolution)

strCellText = ""

 For j = 0 To UBound(arrSoftwareM)

 If arrSolution(i) = arrSoftwareM(j) Then

 strCellText = "x"

 End If

 Next j

grdSolution.Col = i

grdSolution.Text = strCellText

Next i

Row 5

If chkGIS Then

 grdSolution.Row = 5

For i = 1 To UBound(arrSolution)

strCellText = ""

 For j = 1 To UBound(arrGIS)

 If arrSolution(i) = arrGIS(j) Then

 strCellText = "x"

 End If

 Next j

grdSolution.Col = i

grdSolution.Text = strCellText

Next i

End If

Row 6

```

If chkEng Then
    grdSolution.Row = 6
For i = 1 To UBound(arrSolution)
strCellText = ""
    For j = 1 To UBound(arrEng)
        If arrSolution(i) = arrEng(j) Then
            strCellText = "x"
        End If
    Next j
grdSolution.Col = i
grdSolution.Text = strCellText
Next i
End If

```

ErrMess:

```

    Call ErrorMessage
End Sub

```

```

Private Sub Command1_Click()
    End
End Sub

```

```

Private Sub Form_Load()
'Open the ADO data connection
strPath = App.Path + "\Formats.mdb"
strConnection = "DRIVER=Microsoft Access Driver (*.mdb);" & "DBQ=" & strPath &
";"
Set cnnFormats = New Connection
cnnFormats.ConnectionString = strConnection
cnnFormats.Open

```

'Open the terrain recordset and populate the listbox

```
strQuery = "Select * from LU_Terrain"  
Set rsTerrain = New Recordset  
Set rsTerrain = cnnFormats.Execute(strQuery)  
rsTerrain.MoveFirst  
While Not rsTerrain.EOF  
    lstTerrain.AddItem rsTerrain!TFormat  
    rsTerrain.MoveNext  
Wend
```

'Open the raster recordset and populate the raster list box

```
strQuery = "Select * from LU_Raster"  
Set rsRaster = New Recordset  
Set rsRaster = cnnFormats.Execute(strQuery)  
rsRaster.MoveFirst  
While Not rsRaster.EOF  
    lstRaster.AddItem rsRaster!RFormat  
    rsRaster.MoveNext  
Wend
```

'Open the vector recordset and populate the vector list box

```
strQuery = "Select * from LU_Vector"  
Set rsVector = New Recordset  
Set rsVector = cnnFormats.Execute(strQuery)  
rsVector.MoveFirst  
While Not rsVector.EOF  
    lstVector.AddItem rsVector!Vformat  
    rsVector.MoveNext  
Wend
```

'Open the model recordset and populate the model listbox

```
strQuery = "Select * from LU_Model"
Set rsModel = New Recordset
Set rsModel = cnnFormats.Execute(strQuery)
rsModel.MoveFirst
While Not rsModel.EOF
    lstModel.AddItem rsModel!MFormat
    rsModel.MoveNext
Wend
```

‘Close all the recordsets

```
rsTerrain.Close
rsRaster.Close
rsVector.Close
rsModel.Close
rsTerrainSoft.close
rsRasterSoft.close
rsVectorSoft.close
rsModelSoft.close
RS.close
End Sub
```

```
Private Sub Form_Unload(Cancel As Integer)
    cnnFormats.Close
End Sub
```

```
Private Sub mnuAbout_Click(Index As Integer)
    frmAbout.Show
End Sub
```

```
Private Sub mnuHelp_Click(Index As Integer)
```

MsgBox "Please make sure that you select data formats that you have available in all the list boxes", vbOKOnly, "Instructions"

End Sub

VITA

Pramod Reddy Thota

Pramod Thota was born on June 7th, 1976 in Hyderabad, INDIA. He attended the Little Flower Junior College for high school. In 1999, he graduated First Class with Distinction from JNTU, Hyderabad and earned the degree of Bachelor of Technology in Civil Engineering. He then worked for one year as a Systems Engineer with Wipro Technologies, India. In Fall 2000, he enrolled in the graduate school at Virginia Tech to pursue education in Geographical Information Systems.