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Wide-Area, Four-Dimensional, Real-Time Interactive Transportation System Visualization

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The four-dimensional (4-D), wide-area traffic visualization tool provides incident management personnel, emergency management personnel, and the general public with the means to achieve situational awareness in as close to a real-world setting as possible. This research developed a system for visualizing 4-D (in which the fourth dimension is time), real-time transportation data for the entire Earth, although only data for the road networks of Washington, D.C.; Northern Virginia; and the entire state of Maryland are currently in the system. This effort employed a combination of technologies including OpenGL and various modeling techniques to develop a scalable, highly interactive 4-D model using available geographic information system (GIS) and transportation infrastructure data in conjunction with real-time traffic management center data. The prototype system interacts with real-time traffic databases to show animations of real-time traffic data (volume and speed) along with incident data (accident locations, lane closures, responding agencies, etc.) and weather data. A user can "fly" or "drive" through the region to inspect conditions at an infinite number of angles and distances. The program also allows users to monitor the status of and interact with traffic control devices such as dynamic message signs, closed circuit television feeds, and traffic sensors; users can even view the location of a fleet of vehicles equipped with Global Positioning System transponders. Because the system uses standard GIS data and relatively standard transportation databases to derive traffic measures, the system can be scaled to incorporate other states, agencies, or countries.

The primary function of a traffic management system is to monitor traffic conditions and manage incidents. To accomplish these goals, traffic management centers (TMCs) use large arrays of traffic sensors that measure vehicle speeds and flow rates, roadway weather stations to monitor pavement and atmospheric conditions, and closed circuit television (CCTV) cameras to monitor road conditions and verify incidents. Once a problem or incident has been identified, TMCs use real-time databases to help manage incident response. These databases may include data about the location of an incident, the number and type of vehicles involved, and the types of agencies responding to the incident. Engineers are faced with the significant challenge of designing a comprehensive, intuitive means to communicate this vast array of dynamic data to traffic management personnel and the traveling public.

These two groups have long since needed one cohesive place by which to visualize, analyze, and interact with all of these data. Two-dimensional "traffic maps" and more sophisticated geographic information system (GIS) databases have become popular means to visualize much of the data; however, typically these systems are capable of only two-dimensional data representations, which can be limiting. Some newer GIS databases can visualize 3-D data, but they are usually slow in rendering and do not currently provide the kind of real-time interaction that is necessary in a dynamic traffic management system. A usability analysis study conducted by the University of Virginia's Smart Travel Laboratory on dynamic transportation system condition maps noted that "there are numerous examples of functionally deficient [visualization] systems now in use throughout the world that do not meet the needs of users" (*1*).

In 2005 the University of Maryland published a paper in which a basic prototyped 4-D system was created to interact with TMC data sets and devices (*2*); however, the first prototype was extremely basic and did not incorporate many of the functions necessary to accurately show all necessary data elements that TMCs typically require to function properly. Furthermore, the prototype system was not designed to be scaled to incorporate data for areas larger than the Washington, D.C., metropolitan area.

The purpose of this research was to develop a more comprehensive, real-time, interactive, four-dimensional (4-D) visualization system that can be used by TMCs for operations and control and by traveler information systems to communicate traffic conditions to the public. The prototype system is capable of rendering the entire Earth. The globe is modeled fully; however, only real-time data that encompass the major roads monitored by the Washington, D.C.; Northern Virginia; and Maryland TMCs have been included in this paper. As additional real-time data and aerial photography become available, the system can easily expand to incorporate it. This research effort develops the framework around which other states will be able to integrate data into the system to create their own interactive 4-D visualization system.

LITERATURE REVIEW

Real-time transportation visualization systems have been slow to evolve. Most major urban areas with advanced traveler information systems (ATIS) and advanced traffic management systems (ATMS) still use two-dimensional traffic maps to display a graphic of the local roads that are color coded to communicate speed and volume. Many systems also overlay icons of an accident on the map in areas in which collisions have occurred or construction is taking place.

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Other areas of transportation engineering are exploring more sophisticated visualization techniques. It has been realized that traditional engineering plans, profiles, and cross-section diagrams are no longer satisfactory in presenting geospatial data and effectively conveying a clear understanding of transportation improvement alternatives and their associated effects (*3, 4*). As such, 3-D visualization is being used in the design process for planners to show design concepts to the public and to decision makers (*3, 5–6*) [R. G. Hughes. Visualization: Where Should Our Directions Lie? (unpublished paper)]. In general, state departments of transportation see visualization as a tool that can increase the likelihood of early public acceptance (*3*). These 3-D plans, although extremely helpful in visualizing a final product, are static representations of new infrastructure and are rarely capable of any type of dynamic interaction.

With the rapid advance of the computer gaming industry, it is now possible to move from 3-D static renderings (in which the third dimension is depth) to 4-D visualization systems in which textured displays of solid 3-D objects are capable of being viewed in a real-time, animated environment (*5*).

Driving simulators are used for prototyping new highway designs, placing traffic control devices, and analyzing potential safety hazards resulting from road geometry or otherwise poor road design (*7, 8*). Driving simulators allow an individual to “drive” a vehicle through a virtual environment or 3-D model. Because the 3-D environment changes as the user steers and accelerates, there is an added, fourth dimension of time. Such 4-D simulators, although expensive, are slowly gaining popularity with transportation engineers.

Because 3-D and 4-D visualizations have proved useful in the design process of transportation systems, it stands to reason that a real-time 4-D visualization system should also be useful for traffic management and traveler information systems. Such large-scale systems have yet to be developed because of the massive number of data (both static geospatial and dynamic traffic and incident) that would need to be integrated and manipulated and rendered in real time to represent an area covered by a regional TMC.

PROTOTYPE SYSTEM DESIGN

A prototype 4-D, fly-through visualization system was developed to incorporate the many types of dynamic transportation data that are used in daily TMC operations and are necessary for traveler information systems. The core purpose of the program is to serve as a real-time data modeler. Various sources of information are combined to synthesize a unified virtual world that mimics the behavior of the real world. These sources include (*a*) terrain and aerial photography; (*b*) building, road network, and transportation devices; and (*c*) the dynamic data visualization phase, which includes animations of flow and speed, accidents and responders, moving people, video, and weather data. The result is a fully interactive 4-D simulation focused on traffic-related modeling, which is extendable to other modes and data types.

Terrain and Aerial Photography Data

U.S. Geological Survey, 11-m digital elevation model data are used in conjunction with aerial photography to generate the base terrain model. The combination of these two data sets can present an accurate representation of the topological features of the entire Earth, although this prototype focuses on the surveyed area of Washington D.C., Northern Virginia, and Maryland. Typically, aerial photography for the metropolitan areas was of submeter resolution. The immense number of these raw data presented challenges in rendering and visualization.

Figure 1 shows the 4-D program rendering of the Earth from outer space. Using the keyboard, a mouse, or a joystick, the user can rotate the Earth and fly down to specific locations. Figure 2 shows that as the

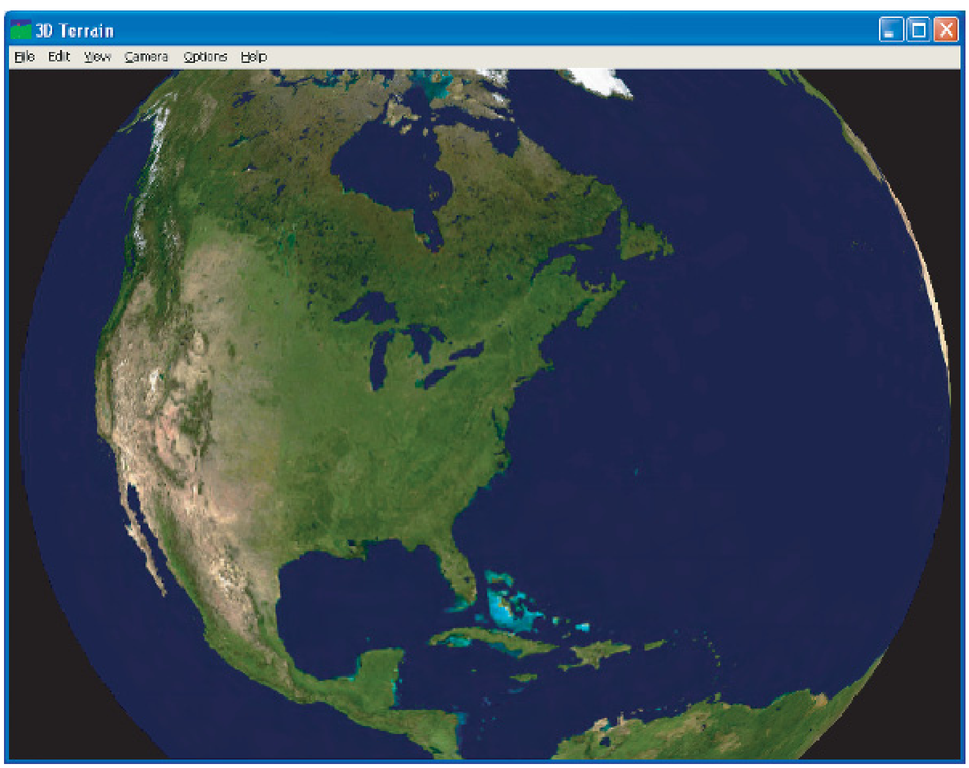

FIGURE 1 View from outer space. User can fly around Earth to any location.

FIGURE 2 User flies high above city. Varying levels of detail can be seen, depending on height of observer. Accident locations can be highlighted with different colors or beams of light.

user zooms closer to the Earth, the level of detail for that particular region increases.

This 4-D program preserves detail by storing its information in a clipmap data structure and taking advantage of graphical optimization methods such as frustum culling. In essence, this keeps the number of necessary loaded data to a minimum while maintaining a seamless 4-D environment. The result is a single rendering that is stitched together from several sources of dynamically loaded data.

Buildings, Road Network, and TMC Devices

Standard GIS shape files combined with state and local "device" and "road characteristic" databases were used to generate 3-D roads. Again, the sheer magnitude of the road data presents a challenge for real-time rendering; therefore, an efficient means to find all the roads in a given region in the user's field of view was needed. As the user changes location and viewing angle, the roads need to update dynamically. As with the terrain modeling portion, objects in the field of view should be displayed and everything else should be discarded.

Figure 2 shows how varying levels of detail for the road and building data can be scaled depending on one's zoom level or "need" to see certain types of data. Figure 3 shows the most detail, with building faces, colors, windows, and so on. Roads can be color coded on the basis of a large number of characteristics such as number of lanes, road classification, tunnel or bridge, and level of service. The user can effortlessly fly around the region in real time to view the world from various angles and zoom levels.

At present, the program is fed by several sources of data, both static and dynamic. The static data include buildings, roadways, and bodies of water; the dynamic data include CCTV, variable message sign, and detector data feeds.

Real-Time Traffic, Incident, Video, and Weather Data

The final component of the 4-D model is the addition of highly dynamic data including real-time traffic, incident, video, and weather data. Real-time traffic and incident data are queried from the Center for Advanced Transportation Technology Laboratory regional integrated traveler information system database. These data include point sensor data (speed and volume), incident (including accidents, construction, disabled vehicles) location, incident response (including police, fire, rescue) lane closures, dynamic message signs, weather, automatic vehicle location (AVL), and CCTV video.

The program animates the road condition based on the input from these data. For example, Figure 4 shows that if the database reports

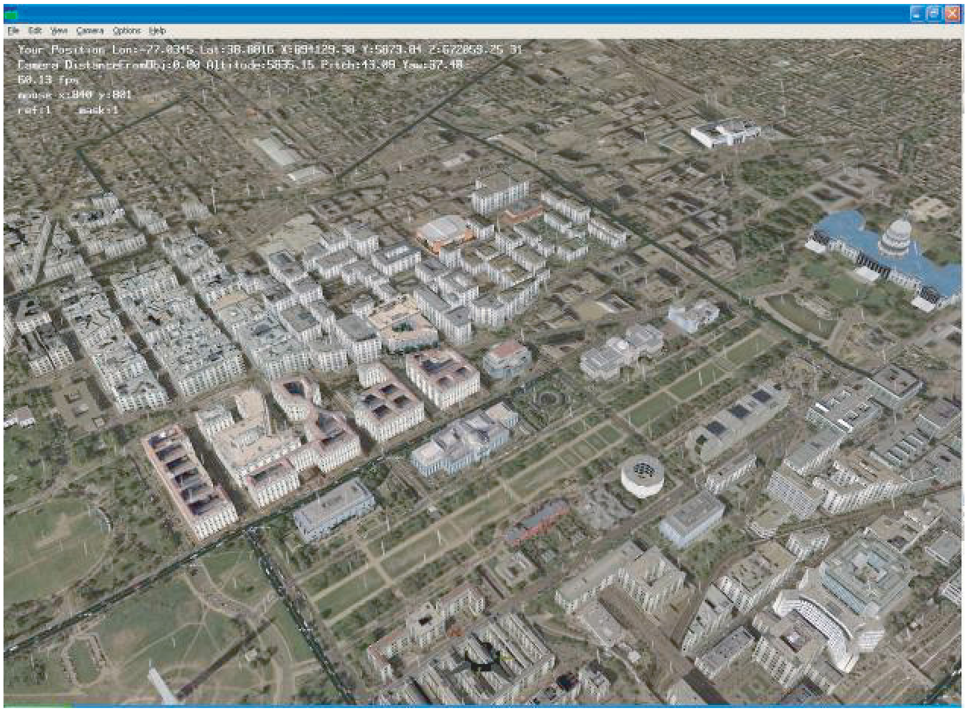

FIGURE 3 Once user is close enough, vehicle animations come into view.

FIGURE 4 Vehicles are animated on road at speeds and volumes equivalent to detector readings.

that a particular link of the road has 20 vehicles with an average speed of 45 mph, the program loads a distribution of 20 vehicles from preexisting vehicle models and sets them in a uniform speed of 45 mph. One can also fly up to a traffic detector or other device, click on it, and receive reports about the status of a device, traffic counts, logs, and so forth. Note, however, that the current version of the renderer animates the traffic based on very basic car and lane-changing models. A traditional microsimulation model, such as CorSim or DynaSmart, is not yet incorporated.

Because incident data are collected in real time by the regional TMCs, these data can also be used to dynamically visualize accidents on the roadway (Figures 5 and 6). The incident databases include data about the number of vehicles involved in the accident, including type (car, truck, etc.). Also included are data about how many and which lanes are blocked, the number and type of response vehicles on the scene, and the type of incident (vehicle fire, collision, disabled vehicle, etc.). Figures 7 and 8 show dynamic renderings of multivehicle collisions with responding vehicles (police cars, arrow trucks, ambulances, etc.) on the scene. This same type of visualization can be used to depict work zones. These renderings are approximations of vehicle locations based on TMC data and do not represent a one-to-one correlation to what may or may not be actually occurring on the road.

To locate incidents in the system, one can easily zoom out or fly around and look for large incident icons that hover over the incident scene. Alternatively, the user can simply use a drop-down menu (Figure 9) that shows a list of incidents and their details; a button can also be used to automatically transport the user to the incident scene.

Figure 10 shows how the real-time status of variable message signs can be shown in the system. Figure 11 shows how streaming AVI files from real-time CCTV feeds are placed over each CCTV camera location. These videos can be seen as the user flies past each CCTV tower.

Weather data are key components of the 4-D system. National Weather Service Radar images, alerts, and Roadway Weather Information Systems data can all be viewed in the 4-D application. Figure 12 shows how radar images of precipitation can be seen from above an area. Figures 13–15 demonstrate that when one is down closer to the road, clouds, rain, and snow can all be seen.

AVL-equipped vehicles, including airplanes, can also be visualized in the program. Similarly, if one needs to know exactly where a plane or a specific vehicle is, a drop-down and search menu can be used to show the user where that particular object is located.

Reenactment of Visualization via Demos and Movies

The terrain program is able to record and play back "demos." In essence, a demo is a real-time rendering of motion along a precalculated path in the 3-D environment. The program also has support for exporting movies. Note the difference between the two. A demo is merely a predefined set of locations between which the program is to move. The rendering is done in real-time in the 3-D environment. A movie, however, is a prerendered representation of the 3-D world that must be viewed on a separate player. Demos have the advantage that when the 3-D world is updated, these changes will be displayed the next time the demo runs. The disadvantage is that the demo must be run within the 3-D program, as opposed to a movie, which plays on another piece of software. Demos may be used as visual representations of actions. For example, a demo could be made showing an alternate route to take when a major highway is closed. It is

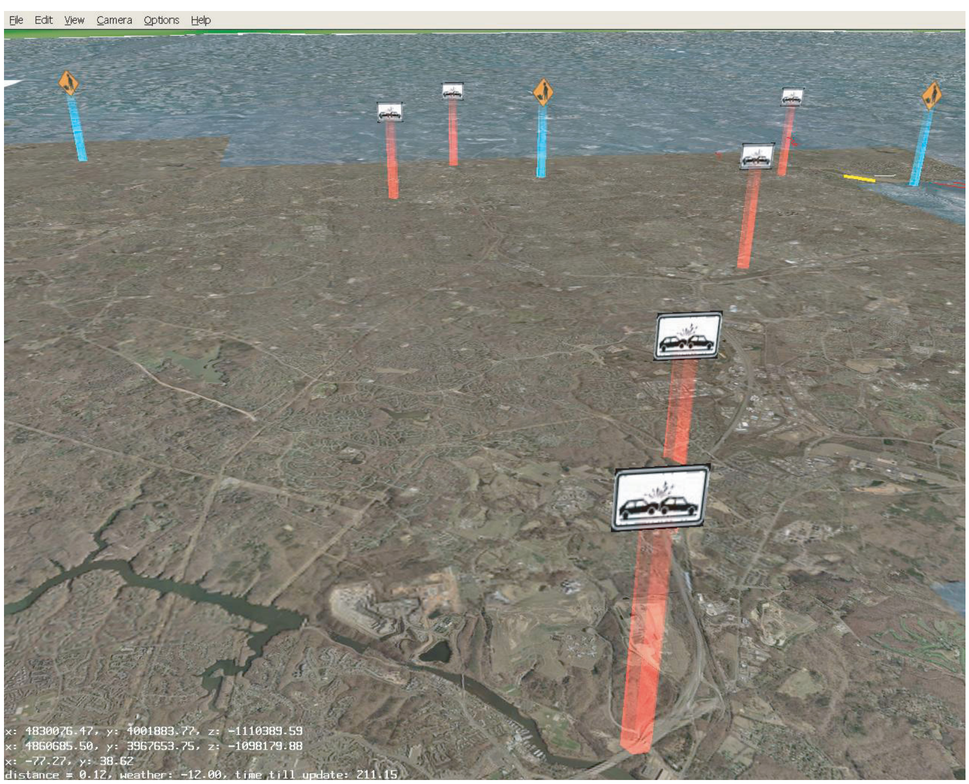

FIGURE 5 Incident markers seen from high above.

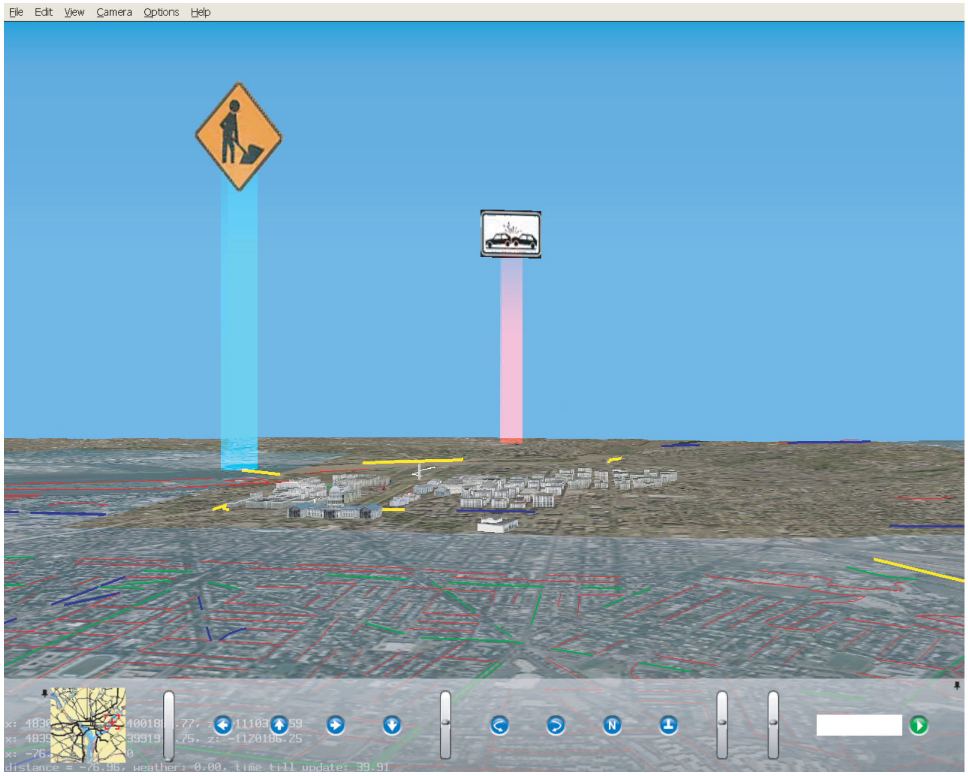

FIGURE 6 Incident and construction markers seen from ground level.

FIGURE 7 Real-time accident data rendered in 4-D application.

FIGURE 8 Second accident scene rendered in application.

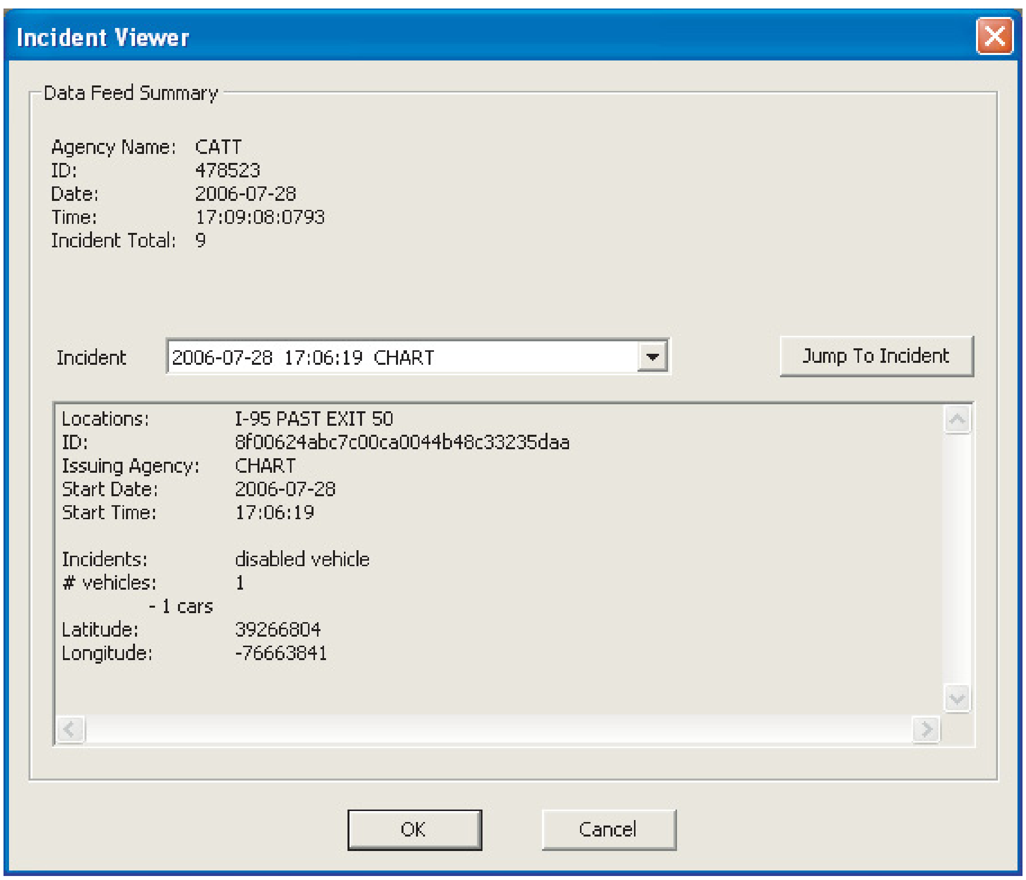

FIGURE 9 Screenshot of a basic incident report from within 4-D application.

FIGURE 10 Variable message signs and other traffic management center devices.

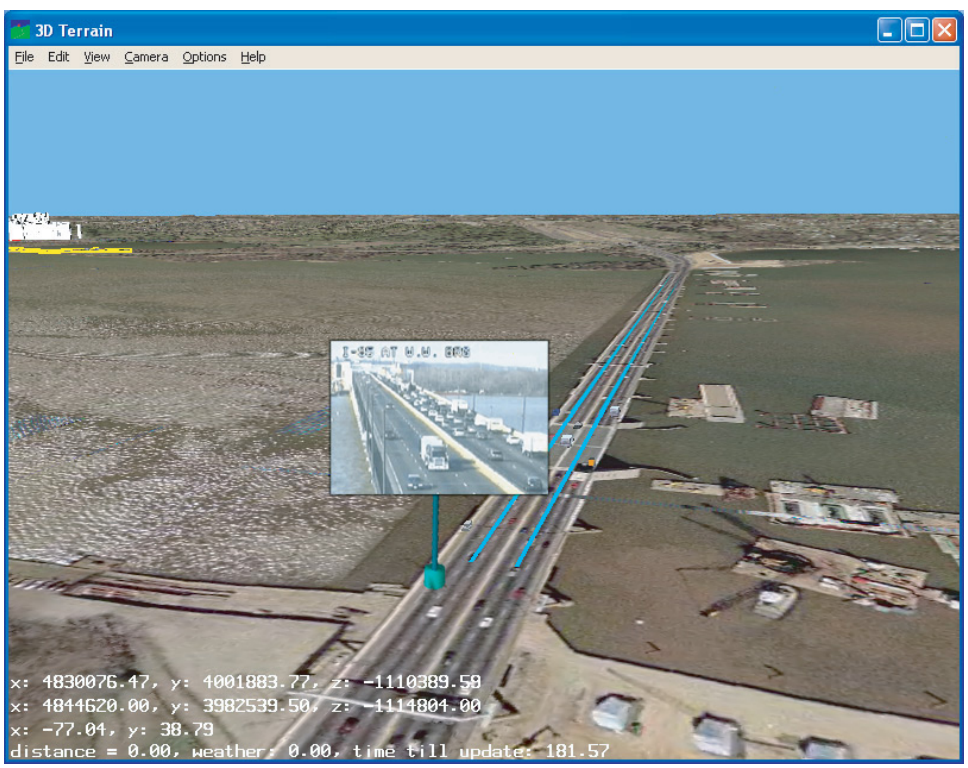

FIGURE 11 Live CCTV feeds viewed while flying in system.

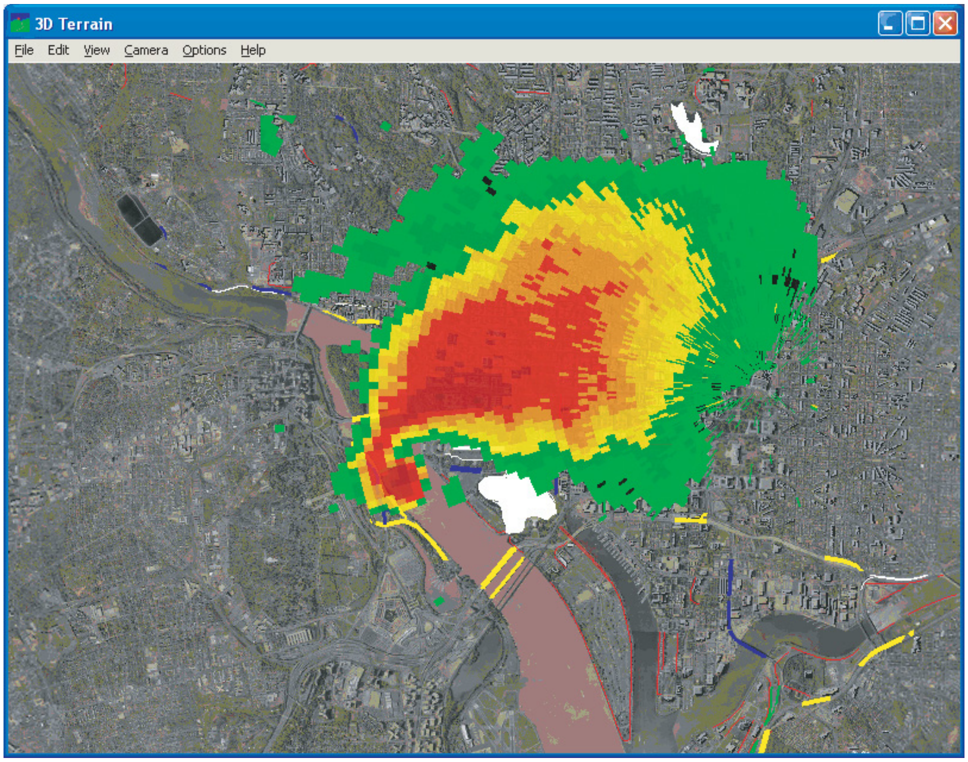

FIGURE 12 Doppler radar feeds from the National Weather Service visible from above.

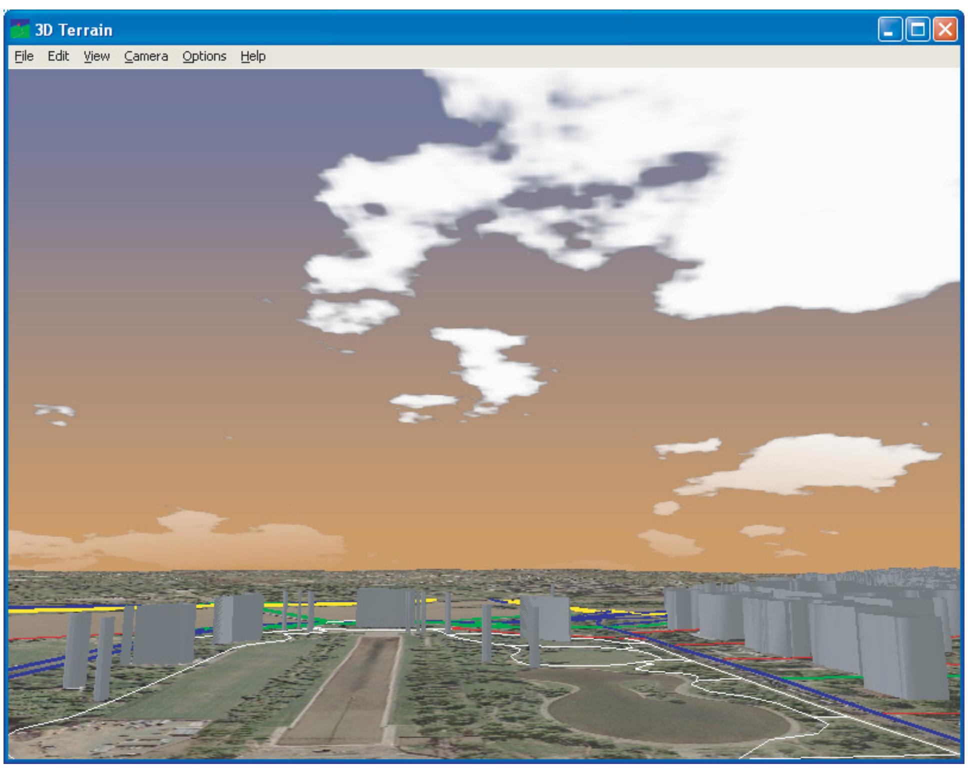

FIGURE 13 Sun and cloud positions seen from ground.

FIGURE 14 Rain and other weather features can be automatically turned on or off on the basis of radar weather data.

FIGURE 15 Snow can be rendered automatically.

advantageous to be able to watch the route being traversed when one is using local roads that may not be clearly marked. In addition to that, researchers and planners can use 3-D demos and movies to analyze the effect of a particular type of incident on surrounding traffic conditions. Operators can use 3-D demos and movies for training purposes.

SYSTEM SPECIFICATIONS

The underlying renderer has been developed in-house from the ground up. It does not rely on Google Earth or any other commercial service to provide its core functionality. It incorporates a number of open-source projects (e.g., ECW file format, OpenGL API) and relies on no commercial solutions. The hardware requirements include a graphics card supporting OpenGL 2.0 with a minimum of 256 MB ram, 400 MB hard disk space, and 1 GB ram. The client-server architecture of the program, seen in Figure 16, ensures that the bulk of the topological data, aerial photography, and real-time data reside on a number of central servers.

IMPLICATIONS

Although no formal user testing of the application has been conducted, initial feedback on the usefulness of this application from the three state departments of transportation has been overwhelmingly positive. TMC operators are particularly excited about the 4-D application because it will enable them to better visualize the state of the transportation system in areas in which they do not currently have cameras. CCTV installations are expensive, and current freeway coverage with CCTV is limited. The 4-D application makes it appear as if there are virtual CCTV cameras across the entire coverage area. This allows operators to obtain a better picture of the traffic conditions, possible problems, and most efficient problem solutions. Currently, traffic sensors send back volume and speed reports to the TMC that are displayed on a color-coded map. However, few operators truly understand what a volume of 500 vehicles/h, for example, really looks like on a road. This 4-D system shows vehicular traffic as an animation rather than as a number, graph, or color-coded map.

Because the 4-D program shows the geometry of the road, operators can have a better sense of how a particular incident or construction work might affect traffic. When emergency response vehicles are rendered and placed on the scene, a better idea of the magnitude of the incident is possible, which helps to give a much better sense of the scope of the problem. Essentially, the system gives everyone a "virtual helicopter" to inspect the world from every angle. Raw sensor and device data are converted from simple numbers (speed, volume, weather, etc.) into real pictures that much better convey the overall state of the system.

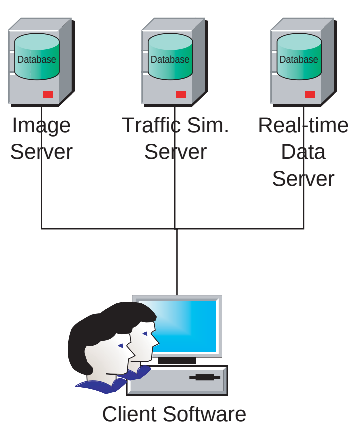

FIGURE 16 System architecture diagram.

Transportation engineers and researchers will also be able to use the application to visualize archived and current transportation data. The system easily combines standard spatial shape files with temporal data to make 4-D views in instances in which only 2-D data graphs and maps were previously available. Engineers will be able to examine the placement of road signs, pavement markings, and buildings as well as structural changes. Then, the engineer can "drive" through the virtual environment (much as one would using a driving simulator) to see the design before construction. Unlike driving simulators, however, this 4-D program renders its environment from existing shape files, digital elevation models (DEMs), and other readily available data. Thus, little funding need be allocated for expensive graphic artists and programmers. This approach can save many tens of thousands of dollars.

With the advance in graphics card technologies and processors, most of the public will soon have graphics cards that will allow them to run this program from home machines. In addition, the television media could easily adapt this program to be used for weather and traffic reports. Showing a flythrough of a city, state, or region would be much more understandable and beneficial to the public than a simplistic 2-D map or a fixed-position CCTV feed.

NEXT STEPS

The system was originally designed to view only real-time data; however, the 4-D visualization system is now being reconfigured to show archived transportation data. Additional work is being done to accept microsimulation model output so that the tool can be used to show predicted traffic volumes, speeds, queue lengths, and weather.

Animated models are being created to be merged with the terrain program. Pedestrians, traffic lights, particle systems (fire, smoke, precipitation), and realistic water effects will aid in creating a more immersive world.

A visual accident scene creation mode is being developed. In this mode, users can generate arbitrary accident scenes and observe the ensuing changes in traffic patterns. For example, a scene can be composed of three cars and a tractor trailer blocking two lanes on a three-lane highway for 1 h. The effects of this blockage will be simulated and can be helpful in determining delays.

To aid in the usability of the system, developers are exploring alternative controller options. For example, in the future the user could use a more intuitive controller, such as PlayStation 2, or other similar game controller, to navigate through the 4-D world. That will minimize the learning curve necessary to use this system efficiently.

CONCLUSIONS

The purpose of this research was to develop a comprehensive, real-time, interactive, 4-D visualization system that can be used by TMCs for operations and control and by traveler information systems to communicate traffic conditions to the public. The prototype system encompasses the major roads monitored by the Washington, D.C., Northern Virginia, and Maryland TMCs. Although more work is needed to automate the rendering of certain features, including overpasses and intersections, the initial prototype shows great promise in providing the ability to dynamically render large areas with real-time traffic data. This research effort developed the framework around which other states will be able to integrate data to the system to create additional interactive 4-D visualization systems.

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