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Integrating GIS, simulation models, and visualization in traffic impact analysis

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Abstract

Planners have a long history of using Geographic Information Systems, simulation models and three-dimensional (3D) visualizations in research and practice projects. Although some have successfully integrated GIS and simulation modeling or GIS and computer visualization, few have met the challenge of integrating the three technologies into one system in order to support planning and decision-making. In an effort toward reaching this goal, a prototype traffic impact analysis system has been developed. Automobile traffic and travel speed are predicted with a volume/capacity ratio model. Carbon monoxide (CO) concentrations along roadways are calculated using the US Environmental Protection Agency's CAL3QHC model. GIS is used to prepare data and execute the models and present the modeling results in a geographic context. A series of 3D models of street segments and buildings along the highway are developed and subsequently integrated with simulation results to allow a geo-referenced 3D presentation, including animations of driving experiences. This study documents the benefits and challenges of integrating the technologies.

Keywords: Transportation planning; Visualization; Air pollution; Congestion; Modeling; GIS

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1. Introduction

As the concept of sustainable development and the need for public involvement in planning by diverse groups become more widely accepted among politicians, policy-makers and the general public, it is critical to incorporate impact assessment and analysis into the planning and decision-making process. During such a process, all

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stakeholders in a region, including public/private organizations and residents, should work together to analyze, compare, contrast and prioritize different development alternatives for a sustainable future (Smith, Blake, & Davies, 2000; Wang, 2001). Planners, in particular, have the responsibility of accurately and realistically presenting future consequences of proposed actions to all stakeholders. The ability to select and present information to support decision-making is an integral part of such a process (Halls, 2001). Using information technology will enable planners to collect and analyze data in order to effectively design, simulate and present future scenarios using computers before the building phase. Such presentations are important to enable people to envision the future consequences of a proposed development, build a consensus among stakeholders and formulate appropriate proactive measures.

This paper reports on an effort toward integrating three specific components of information technology—Geographic Information Systems (GIS), simulation models and computer visualization—to support this planning process. The goal is to develop a system that enables policy makers, planners and citizens to better understand the impact of a proposed development through access to data collected by planning agencies and various government organizations, as well as to modeling results. The visualization features of such a system can present views of the present and future and provide a graphic user interface (GUI) to support interactions between the system and its users. The work reported here demonstrates the advantage of the integration and challenges that were faced.

GIS applications have been used to quickly and reliably process spatially referenced data as a decision support tool (Badard & Richard, 2001; Dangermond, 1989; Lee, 1990; Worrall, 1990). Many research projects have explored the potential of using GIS to store spatial data, to perform interactive spatial analysis, to sketch a city and to display data and modeling results through maps and tables (e.g., Bailey & Gatrell, 1995; Batty, Dodge, Jiang, & Smith, 1999; Gahegan & Lee, 2000; Grossmann & Eberhardt, 1993; Shamsi, 1996; Singh, 1999; Wang, 1997). Klosterman (1999) developed a scenario-based, policy-oriented planning support system (PSS), "What If?" that used GIS data to support community-based processes of collaborative planning and collective decision-making.

Various simulation models have long been used in planning practice. For example, surface and subsurface water models are used to address resource and environmental issues (Cowen et al., 1995; Darbar, Blood, & Choi, 1995; Merchant, 1994; Smith & Vidmar, 1994; Tim & Jolly, 1994; Warwick & Haness, 1994). Another set of models simulates the interactions between land use and transport to connect economic activities in space with accessibility as well as the demand and supply for flows (Barra, 2001). In general, simulation models provide the information necessary for analysis and evaluation among planning alternatives (Putman & Chan, 2001).

The importance of computer visualization for planning practice lies in its potential for improving the quality of decision-making. Ware (2000) points out that visualization helps to present large amounts of data, identify patterns or the problems with data, and facilitates understanding of data. Currently, most presentations to decision-makers and the public are made using two-dimensional (2D) maps, with occasional prospective views and static images. The physical nature of planning practice demands that three-dimensional (3D) images should be used to evaluate the effects of planning that takes place in space. Recent efforts demonstrate that 3D models can be used to visualize and quantify abstract policy and planning simulations (e.g., Batty et al., 1999; Kwartler & Bernard, 2001; Ranzinger & Gleixner, 1997). A visual representation, then, should help to avoid misunderstandings of the consequences of development (Hall, 1993). In other words, the future can be presented graphically and evaluated as the basis for discussing different planning alternatives.

Martin and Higgs (1997) suggest two areas of visualization application in planning—representations of the physical environment and abstract statistical relationships. In both cases, the use of 3D models provides a certain degree of realism that can help viewers link data to a particular physical setting.

The majority of examples in the literature fall into the first type of application. Lange (1994) produces a series of 3D images for evaluating the visual quality impact of a proposed major expansion of an existing hydroelectric power station in Switzerland, while Dykes (2000) uses geo-referenced 360° panoramic images as a means of representing geographic information in a visualization context. The common feature of these applications is that visualization is used as a tool to present plans (MacEachren, Bishop, Dykes, Dorling, & Gatrell, 1994).

As an example of the second type of visualization application, Martin and Higgs (1997) visualize socio-economic data in realistic environments, such as visualizing property values with physical features of location and neighborhood and displaying the buildings as 3D models with virtual reality tools. Batty et al. (2001) also present a similar study that adds utility lines under 3D building models and assigns different color to 3D building models to reflect attributes stored in a GIS database.

Langendorf (2001) argues that it is necessary to analyze the world from multiple viewpoints in order to understand any subject of consequence. Many applications of information technology use Computer Aided Design (CAD) software to develop 3D models and also use GIS to develop 3D terrains, and drape 3D aerial images on top for 3D visualization (Burrough & McDonnell, 1998; Hall, 1993). Such applications can be enhanced by the use of linkages to virtual reality and multimedia systems.

Shiffer (1992, 1999) uses images and multimedia to represent background information to improve understanding by viewing information from several different graphical perspectives. Digital movie files, 3D scenes, maps, sketches and plans are used as multiple views of the same abstraction (Dorling & Openshaw, 1992; Singh, 1999). In addition, the Internet has been used in a number of urban planning applications to display 3D images of urban settlements (Martin & Higgs, 1997; Mason, Baltsavias, & Bishop, 1997). These kinds of tools for visualization can help those who are affected by planning to interpret and understand complex information.

In the planning context, it is particularly important to support interaction among the many participants, who are involved with transforming data into information, than into knowledge and, finally, into action. In this respect, Shiffer (2001) discusses several projects that support collaborative planning with spatial annotation mechanisms, allowing users of an information system to relate their comments to a geographic area. Examples of such annotations are textual, audio, video and digital still images.

Although planners use GIS, simulation models and 3D visualization in various projects, the development of each has been primarily independent, and integrative uses are still at an early stage. In the following sections, current approaches to integrate GIS, simulation models and visualization are reviewed, then a prototype of such integration, using traffic impact analysis as an example, is presented. Lastly, the needs, benefits and challenges for such an integrated system are discussed.

2. Integration of GIS, simulation models and computer visualization

In an integrated system of GIS, simulation modeling and computer visualization, each technology contributes to the system with distinctive features. GIS provides the functions that allow a user to examine the spatial relationships among entities. Simulation modeling is capable of representing the dynamic relationships between cause and effect. The strength of visualization is to represent data in a way that may reveal patterns and relationships that are hard to detect using non-visual approaches such as text and tables.

The following paragraphs review the three different two-part integrations in the literature. The integration of GIS and simulation models allows analyses of temporal and spatial changes together. The integration of GIS and visualization provides a realistic presentation of spatial data. The integration of simulation models and visualization can represent the dynamics within a realistic visual environment.

The incorporation of analytical models into the GIS platform has emerged as a promising research area attracting planners and other resource managers (e.g., Bennett, 1997; Djokic & Maidment, 1993; Greene, 1996; Poiani & Bedford, 1995; Shamsi, 1996). Researchers have categorized the integration of GIS and simulation models as "loose" and "deep" coupling (Bell, Dean, & Blake, 2000). Most integration is in the loose coupling category that integrates GIS with simulation models through exchanging data files. This approach often requires human intervention, which can become a barrier in automating the operation process. The deep coupling approach links GIS and simulation models with a common user interface. While it appears to its user as one system GIS and simulation models can remain, in fact, separate systems (Fedra, 1996).

Significant amounts of software engineering are required to either add GIS functions to simulation models or to add simulation capabilities to a GIS. An example is the METROPILUS (Putman & Chan, 2001) that uses ArcView GIS to link DRAM/EMPAL (existing land use models) and descriptive and statistical analysis functions provided with Microsoft Excel. Landis (2001) presents several regional simulation models that use GIS for data manipulation and analysis, in addition to the presentation of modeling results. Engelen, Geertman, Smits, and Wessels (1999) demonstrate that the coupling of GIS and Cellular Automata (CA) models can be used to test and evaluate different policy alternatives. Fedra (1996) proposes that a deeper level of integration can be achieved by merging GIS and modeling so that GIS has analytical functions and; simulation models have spatial analysis capabilities. At present, planners primarily work in a two-dimensional analytical mode (Orford, Harris, & Dorling, 1999; Pietsch, 2000). Several studies have shown that 2D maps can be generated from model simulation (Klosterman, 1999; Kwartler & Bernard, 2001).

When the integration of GIS and visualization is examined, one can easily find that such integration can benefit both fields. On the one hand, GIS is a powerful analytical tool, with a legacy that dictates that graphical output is designed predominantly for representing static cartography of a relatively traditional nature. As Dykes (1997) noted, two limitations of GIS presentation are the quality of presentation and the level of interaction and/or flexibility associated with the graphics that are generated. On the other hand, visualization is often achieved independent of geographic data. Therefore, the images are often disconnected to the attributes.

Surprisingly similar to the loose and deep coupling of GIS and simulation modeling, Rhyne (1997) defined four levels of integration of GIS and Scientific Visualization—rudimentary, operational, functional and merged levels. The four levels represent the progress from two separate fields into one. Minimal amounts of data are shared between the two technologies at the rudimentary level. The operational level of integration tries to remove data redundancy and achieve data consistency. The focus of a functional level of integration is the transparent communication between the two technologies. At the merged level, a comprehensive system is developed from both technologies.

Many studies have demonstrated the effort to combine the strengths of GIS and visualization. For example, GIS is used to generate 3D scenes of land surfaces from a digital elevation model (DEM) with high geographical accuracy. 3D models of buildings and structures are then draped onto the surfaces. Using this approach, the UCLA Urban Simulation Laboratory has been developing a 3D visualization system that produces realistic photo-quality simulations. The system has interactive fly-through and walk-through capabilities for exploration of real environments (Jepson, Liggett, & Friedman, 2001; Liggett & Jepson, 1995). Pullar and Tidey (2001) use a 3D GIS for visual impact assessment (VIA), a formal process used to evaluate the visual merits of a proposed development. They generate 3D models of buildings from 2D features stored in a GIS database and enhance the models with structural details and photomontage as texture mapping on building features. Kidner, Sparkes, and Dorey (1999) present a study using GIS to determine the most suitable sites for wind energy development; considering the environmental impact, visibility and the quantitative and qualitative impacts on local populations. Verbree, van Maren, Germs, Jansen, and Kraak (1999) use a multi-view approach to integrate 3D GIS and virtual reality (VR). Three views—a 2D map view, a simplified 3D representation of data and a full immersive and photo-realistic 3D display are used simultaneously or intermittently. Dodge, Doyle, Smith, and Fleetwood (1998) present more examples of integrating VR and Internet GIS for Prban Planning. The joint project of the Massachusetts Institute of Technology Computer Graphics Group and iMAGIS, France, aims at the development of various visualization techniques for urban planning (Decoret, Schaufler, Sillion, & Dorsey, 1999). In addition, there are many cases of 3D GIS city models, such as Philadelphia, Washington, DC, New York, Tokyo, Berlin, Helsinki, and London. Almost all of these projects emphasize the 3D display and fly through of urban environments. In general, current software systems are still only achieving relatively low levels of integration as defined by Rhyne (1997).

The third connection is between simulation modeling and visualization. Although the National Science Foundation (NSF) initiated Scientific Visualization (SV) in the 1980s to enable researchers to observe simulation results visually, it has not impacted most areas of planning (Langendorf, 2001). Only recently have researchers started to pay attention to managing and presenting geographic information using true 3D representations and forms of analysis of the built environment (Kreuseler, 2000; Raper, McCarthy, & Williams, 1998) and to presenting the results in a VR environment (Germs, van Maren, Verbree, & Jansen, 1999; Huang, Jiang, & Li, 2001). Wood, Fisher, Dykes, Unwin, and Stynes (1999) construct several different versions of population density surfaces for visualizing the distribution of people and comparing them with other urban features, such as neighborhood boundaries, physical conditions and transport routes. Several visualization software packages have built-in functions to simulate the physical movement of an object, such as a bouncing ball, a moving cloud or a flowing fluid. The Visual MODFLOW 3D Explorer is a good example of displaying, in three-dimensional space, the modeling results of a widely used 3D groundwater flow model (Scientific Software Group, 2003). However, there is no other geographic features in a GIS database can be shown together with the model output.

While the integration of any two of the three technologies has been achieved with some success at various levels of sophistication, combining all three into an integrated system would significantly increase the understandability of simulation results within a geographic context. It is only possible to communicate temporal and spatial changes with realistic visual representations to a user when the three technologies are used collectively. Bishop and Gimblett (2000) present an example of analysis and prediction of visitor location and movement patterns in recreational areas. They use GIS for spatial information management, autonomous agent modeling (AAM) for spatial modeling, virtual reality for visualization and a series of models to assess visual impacts, recreational opportunities and erosion. Their work is the most advanced study reported in the literature.

The integration of GIS, simulation modeling and visualization can, as noted by Rhyne (1997), goes through levels of progresses from separated fields into a merged one. Currently, the integration process is at a rudimentary level. There is minimal data sharing. Normally, simulation models do not use GIS data directly or save model output into a GIS database. An operator often creates visualization and animations interactively and normally does not use a GIS database. Finally, the limitations of GIS with graphic presentation and temporal analysis are still far from being removed.

To explore the feasibility and the applicability of the three-way integration, this analytic study of traffic impact was designed and carried out with the three technologies. First, the graphic display and the "fly-through" speed of visualization were linked to simulation modeling output with geo-referenced data. Second, the analytical modeling-based visualization has a defined goal—to support urban planning objectives and decision-making. The following sections describe the study and discuss the needs and challenges of visualizing model simulations with GIS in a traffic impact analysis system.

3. A prototype traffic impact analysis system

An effective planning support system can significantly enhance the collaboration among stakeholders and facilitate agreement on the most appropriate alternatives. To achieve these goals, such a system ought to be used by diverse stakeholders to analyze and evaluate, both effectively and accurately, development alternatives. The integration of GIS, simulation modeling, and computer visualization is expected to greatly enhance the analytical capabilities of GIS-based spatial decision-making through a 3D format.

The traffic impact analysis system developed in this study incorporates environmental data directly into decision-making through a more integrated treatment of a variety of spatially referenced data for analysis. The integrated approach is expected to assist planners in their task of developing and analyzing options for physical development, help clarify, in a more intuitive manner, the implications of different alternatives for decision-makers, and better demonstrate to the public the benefits of the planning decisions that have been taken. The net effect will be to improve both the decision-making process and communication among planners, decision-makers and the various groups comprising the public, as well as to encourage citizen participation through graphical presentations that are familiar and easy to understand.

Mitigating congestion and estimating pollution emission are always primary issues faced by transportation planners. The significance of an integrated traffic impact analysis system is related to using the best available technologies to analyze spatial data and to both predict and present future scenarios and changes. Planning alternatives are to be evaluated and presented using various methods, including numerical data tables, two- and three-dimensional maps and images, and three-dimensional animations.

3.1. Transportation models

Two analytical transportation models were used in this study to predict the traffic conditions and hourly carbon monoxide (CO) concentration levels along a segment of Interstate highway 71 in the Cincinnati, Ohio region. Both models are applied to street segments called free flow links. A free flow link used in travel demand modeling is defined as a straight segment of roadway having a constant width, height, traffic volume, travel speed and vehicle emission factor. The coordinates of the two end nodes, $(X1, Y1)$ and $(X2, Y2)$ determine the location of a free flow link. The Ohio–Kentucky–Indiana Council of Governments (OKI) provided data used in this study. The data included highway link-based traffic monitoring data for 2001 and a

2020 travel demand simulation in the City of Cincinnati and surrounding eight-county Ohio–Kentucky–Indiana region. Another data set contained design capacity, speed at design capacity and the number of lanes for each link.

3.1.1. Traffic condition

Transportation planners use the level of service (LOS) designation to describe the quality of traffic conditions. Numerical results that are meaningful only to professionals (volume, v/c ratio and density) are converted to a letter grade from A to F (Dowling, 1997). LOS is calculated according to the volume/capacity ratio as shown in Table 1.

One of the most widely used models to predict link-based travel speed is a standard BPR curve model (Dowling, 1997). In the late 1960s, the Bureau of Public Roads (BPR), the predecessor to the Federal Highway Administration (FHWA), developed a standard BPR curve by fitting a polynomial equation to freeway speed-flow curves. As described by Dowling (1997), the standard BPR equation is expressed as:

$$Se = \frac{S_{\mathrm{f}}}{1 + a(v/c)^b}$$

where Se is the predicted mean speed (length/time); S_{f} is the free-flow speed (length/time); v is the volume (vehicles/time); c is the practical capacity (vehicles/time); $a = 0.15$; $b = 4$ (constant, from Dowling, 1997).

Both free-flow speed and practical capacity are derived from design capacity. The practical capacity is 80% of the design capacity. The free-flow speed is defined as 1.15 times the speed at practical capacity.

Automobile density (D_{A}) is defined as number of cars per lane per unit link length:

$$D_{\mathrm{A}} = \frac{N_{\mathrm{A}}}{N_{\mathrm{L}} * L}$$

where N_{A} is the number of automobiles; N_{L} is the number of lanes and L is the link length (length).

The time taken for a car to pass a link (t) can be calculated as L/Se. Multiplying the time (t) and volume (v) will yield the number of cars per link.

Table 1
Level of service classification

Level of service	Volume/capacity ratio	Description (TRB, 2000)
A	Less than 60%	Free-flow operation
B	60% to less than 70%	Reasonably free-flow
C	70% to less than 80%	Flow at or near free-flow speed
D	80% to less than 90%	Borderline unstable
E	90% to less than 100%	Operation at capacity
F	100% or greater	Breakdown

$$N_{\mathrm{A}} = v * t = v * \frac{L}{Se}$$

Therefore, the automobile density, D_{A}, can be calculated as:

$$D_{\mathrm{A}} = \frac{v}{N_{\mathrm{L}} * Se}$$

3.1.2. Carbon monoxide concentration

The concentrations of carbon monoxide along streets are calculated with the CAL3QHC model (Version 2.0), developed by the US Environmental Protection Agency (USEPA, 1995). CAL3QHC is derived from CALINE3, a line-source air quality model developed by the California Department of Transportation. The model is based on the Gaussian diffusion equation and employs a mixing zone concept to characterize pollutant dispersion over the roadway (Benson, 1979). The model predicts carbon monoxide (CO) or particulate matter (PM) concentrations from both moving and idling vehicles. In this study, only the moving vehicles are considered. Vehicle CO emission is a function of ambient temperature, vehicle type and travel speed. The model does not take into account the topography of the landscape, the built environment and elevated roads.

The inputs for CAL3QHC include roadway geometries, receptor locations, meteorological conditions and vehicular emission rates, among which meteorological variables are assumed to be spatially constant over the entire study area. Vehicles are assumed to be traveling without delay along free flow links. The link speed represents the speed of a vehicle traveling along the link. The CO concentrations are measured at receptors specified in X, Y and Z coordinates. The model requires receptors be located outside the "mixing zone" of free flow links (i.e., total width of travel lanes plus 6 m (20 ft) on both sides). In most applications, the height of receptors is assumed to be 1.8 m (6 ft). (For further discussion of the model, please refer to USEPA, 1995.) The CAL3QHC model calculates CO concentrations at each receptor location for all 360° wind directions.

In this study, only the highest concentration value was retrieved and used in the GIS database for display, regardless of the wind directions. This assumption is only used to reduce the data complexity. Once the integration is completed, new features, such as concentration along a predominant wind direction can be added to derive a more realistic system.

A vehicle emission factor table was obtained from OKI that contains emission factors for nine vehicle types and a composite emission factor (CEF) for all vehicle types at different travel speeds. These factors were determined for travel speed between 3 miles per hour and 65 miles per hour at an increment of 1 mile per hour. The ambient temperature range for the estimation was from 65 to 95 F. After discussing this issue with a transportation planner at OKI (Reser, 2001), the CEF at an ambient temperature of 83 F was used.

Travel speeds were divided into 5-mile intervals in order to reduce the processing time. The CEF for the lowest travel speed in a range was used for that range (Table 2). For example, for the speed range of 5–10 miles per hour, the CEF at 5 miles per

Table 2
Composite emission factors

Speed range (miles/h)	Composite emission factor (G m/mile)
0–5	43.57
5–10	29.12
10–15	17.52
15–20	12.95
20–25	10.98
25–30	8.54
30–35	6.91
35–40	5.77
40–45	4.93
45–50	4.30
50–55	3.87
55–60	4.04
60–65	5.78
>65	7.70

hour was used. The CEF estimated at 65 miles per hour was used for speeds greater than 65 miles per hour. Since the purpose of this study is to test the integration feature, only this limited set of model parameters was selected. Additional sets of parameters will be added to the system for more realistic simulations.

3.2. Geographic information systems

GIS was used to manage a digital database and to provide a connection to visualization and simulation models. Several GIS operations were performed with ArcView GIS 3.3 and ArcInfo, both products of the Environmental Systems Research Institute (ESRI, Redlands, CA). In order to represent the geometry of streets more accurately than the straight-line roadway links used in the simulation model, GIS street data were acquired from the Ohio Department of Transportation (ODOT). Then the connection between the GIS street data and the roadway links were established. During this process, the ArcInfo GENERATE command was first used to create a linear free flow link coverage, based on the *x*, *y* coordinates stored in the link table file from the OKI traffic model simulation. The DOT street lines were then edited (combining or breaking) to match the free flow links. Fig. 1 displays an example of the GIS street link data. The unique identification numbers (link-IDs) were assigned, finally, to the corresponding GIS street data features. In addition to a more realistic representation of street links, GIS data also allow more accurate calculation of link lengths, which directly affects the calculation of automobile density on each link.

The BPR traffic model was programmed with the ArcView GIS Avenue scripting language. The Avenue script shown in Fig. 2 illustrates the implementation of the GIS-BPR model. The "BPR.AVE" script file calculates the link-based automobile density, mean travel speed and volume/capacity ratio. Based on the calculation, the level of service classification is assigned for each roadway link.

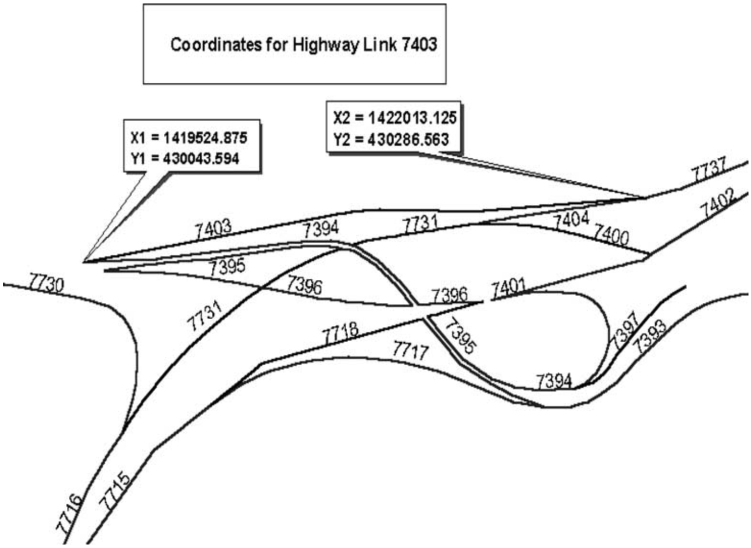


Fig. 1. Illustration of roadway links represented with more accurate GIS data.

The values stored in the buffer field consist of two parts. The integer portion represents the street width, which is calculated as the number of lanes multiplied by 12 ft (the assumed highway width). The digits after the decimal point correspond to a letter-coded level of service (LOS) classification, for instance, 0.01 for Level A and 0.02 for Level B. A street polygon shapefile is then created with the ArcView "Create Buffer" function, using values in the width field. Finally, another avenue script assigns level of service class to each polygon corresponding to the link width value. For example, a 48-ft-wide polygon is created for a link with width value of 48.02 and its LOS class is "B". This approach involves deep coupling as described in the literature on systems integration (e.g., Bell et al., 2000).

Receptor locations were created with ArcInfo as point coverage at four different distance intervals (Fig. 3). More receptors were used for downtown Cincinnati, where the street grid is dense. The distance between any two adjacent receptors in downtown was 33 m (100 ft). Outside the downtown area, receptors were 197 m (600 ft) apart within 866 m (half a mile) of roads, 394 m (1200 ft) apart between half a mile and 1 mile (1.7 km), and 787 m (2400 ft) apart for areas beyond 1.7 km (1 mile) from any highways. According to the CAL3QHC user manual, receptors should not be placed within the mixing zones, road width + 6 m (20 ft). Thus, GIS functions were used to create the mixing zone of the street links and remove any receptors falling inside the mixing zone.

Running the CAL3QHC model was more complicated than the BPR model. The executable CAL3QHC program was downloaded and linked to ArcView as a loosely coupled GIS-model. The effort was to prepare the CAL3QHC input data file for the model and convert modeling output to a text file that can be imported to ArcView as

```
`BPR.AVE
'BPR Model-Calculate Estimated Speed
'April.20.2001

theTableL=av.FindDoc("Attributes of Links.shp")
theVTabL=theTableL.GetVTab
theFld_L_V=theVTabL.FindField("Volume")
theFld_L_C=theVTabL.FindField("Capacity")
theFld_L_S=theVTabL.FindField("Speed")
theFld_BPR=theVTabL.FindField("Speed_bpr")
theFld_LOS=theVTabL.FindField("Los")
theFld_Buff=theVTabL.FindField("Buff")
theFld_Ratio=theVTabL.FindField("Vc_ratio")
theFld_lanes=theVTabL.FindField("lanes")

'Calculate the BPR Speed in Links Table
theVTabL.SetEditable(true)
if (theVTabL.IsEditable) then
  for each rec in theVTabL
    s=1.15*(theVTabL.ReturnValue(theFld_L_S,rec))
    v=theVTabL.ReturnValue(theFld_L_V,rec)
    c=0.8*(theVTabL.ReturnValue(theFld_L_C,rec))
    ratio=v/c
    es=s/(1+(0.15*((ratio)^4)))
    lane=theVTabL.ReturnValue(theFld_lanes, rec)
    theVTabL.SetValue(theFld_BPR,rec,es)
    theVTabL.SetValue(theFld_Ratio, rec, ratio)
    if (ratio<=0.35) then
      LOS = "A"
      width = lane * 12 + 0.01
    elseif ((ratio<=0.50) and (ratio>0.35)) then
      LOS = "B"
      width = lane * 12 + 0.02
    elseif ((ratio<=0.68) and (ratio>0.50)) then
      LOS = "C"
      width = lane * 12 + 0.03
    elseif ((ratio<=0.81) and (ratio>0.68)) then
      LOS = "D"
      width = lane * 12 + 0.04
    elseif ((ratio<=1.00) and (ratio>0.81)) then
      LOS = "E"
      width = lane * 12 + 0.05
    else
      LOS = "F"
      width = lane * 12 + 0.06
    end 'if (ratio<1)
    theVTabL.SetValue(theFld_LOS, rec, LOS)
    theVTabL.SetValue(theFld_Buff, rec, width)
  end 'for each rec
end  ' if (theVTabl.
theVTabL.SetEditable(false)
```

Fig. 2. Sample ArcView Avenue script for LOS designation using the BPR modeling.

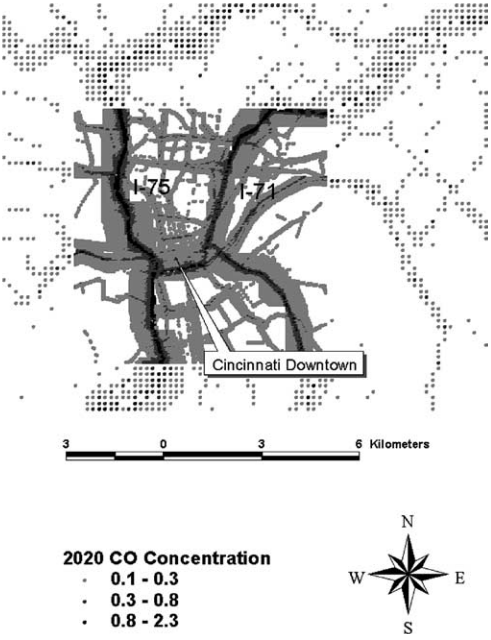


Fig. 3. Carbon monoxide (CO) concentration at simulated receptors (ppm).

a table to be joined to the street link file. The model requires data for each street link and receptor, including coordinates and other features, such as travel speed and traffic volume. The feature ID for each receptor point was used as a unique Identification Number. Those numbers were passed to the CAL3QHC model as the receptor names. An ArcView GIS Avenue script (cal3qhc_write.ave) was programmed to create input data files for CAL3QHC. Since the CAL3QHC model has a maximum limitation of 60 receptors and 120 roadway links, many input files had to be created by repeatedly selecting receptors and links and executing the Avenue script to cover the entire study area. Another Avenue script (cal3qhc_read.ave) was written to import CAL3QHC modeling results into ArcView and to join the data tables to street links and receptors. This script had to be executed separately from the ''cal3qhc_write.ave'' because ArcView GIS did not wait for the CAL3QHC model to finish before reading the model output file when the two steps were combined.

3.3. Visualization

Different traffic condition levels and carbon monoxide (CO) concentrations associated with present and future traffic scenarios were presented with maps, tables, 2D graphic images and 3D scenes. The most challenging aspect involved the development of 3D visual images to present information that is produced with model simulations at specific geographic locations.

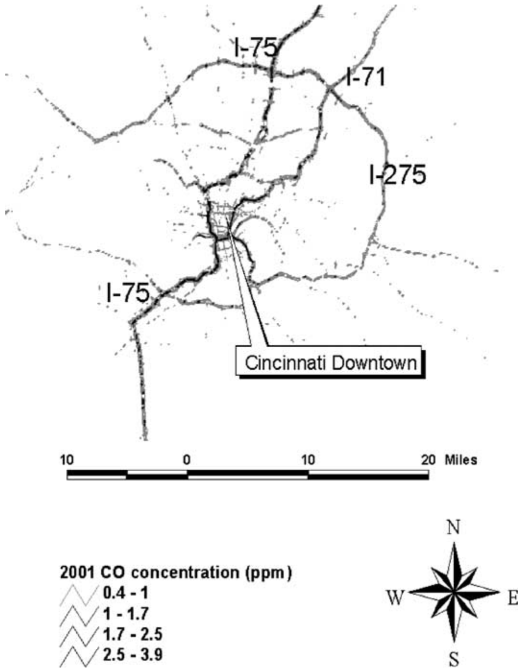


Fig. 4. A regional map of CO concentration contours.

Normally, the automobile generated carbon monoxide (CO) concentrations would be displayed as a color thematic map, such as color-coded mesh points (Fig. 3) or concentration isolines (Fig. 4). From the figures, one can see that the carbon monoxide concentrations in the downtown Cincinnati area consistently followed highway traffic. Traffic along small streets did not generate much carbon monoxide. The concentration distribution showed in Fig. 4 clearly portrays the major highways—Interstate Highway 71 and 75 and the ring road, I-275.

Fig. 5 is the result from another approach to display the CO concentration. Using the simulated receptor CO concentrations as the *z* value, a 3D surface was interpolated using the GIS 3D surface construction function. This approach is different from previous two approaches (Figs. 3 and 4). Here, the land surface is replaced with carbon monoxide concentrations. Highway segments that are experiencing a high level of CO concentration can be seen as passing an elevated surface, which allows the system's users to quickly prioritize their problem-solving efforts. For example, in 2000, the most troublesome place is found at the lower left corner of the map, where highway I-71 merges with I-75 before crossing the Ohio River. In the downtown segment, the CO concentration from automobile emissions is not very high. However, when the 2020 planning scenario is compared with that of 2000, one can see the overall increase of CO concentration, which is directly related to the increased traffic volume. In the section before a bridge crossing the Ohio River, which had already experienced poor air quality, has a CO concentration that will be three times as high

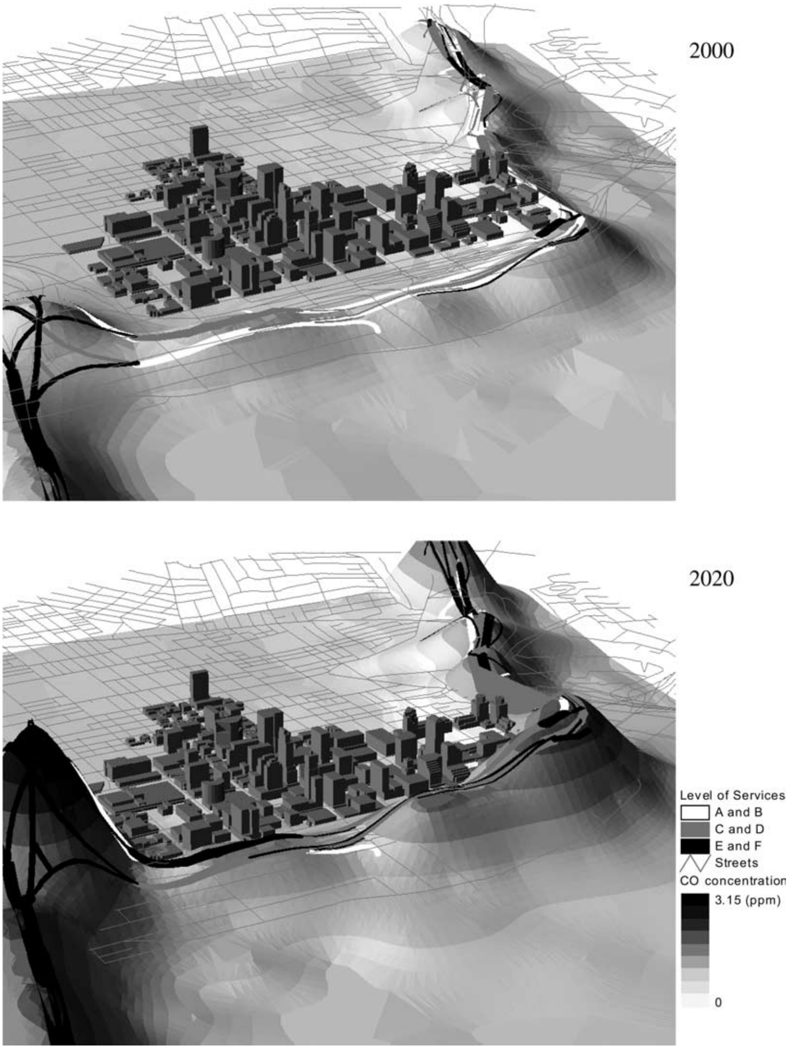


Fig. 5. Perspective views of CO concentration surface.

as that in 2000. The graphic display is useful in helping the stakeholders quickly focus on those segments or intersections in searching for alternatives to minimize air quality degradation. While examining the surface in the context of levels of service along the highways, one may see the need to examine the relationship between traffic conditions and the air quality at a local level.

Three visualization approaches were used to display traffic conditions. These choices were used to illustrate different ways of presenting data. Two of the choices can be accomplished easily within GIS and have been widely used. However, spatial visualization technology can facilitate more user-friendly and realistic presentations.

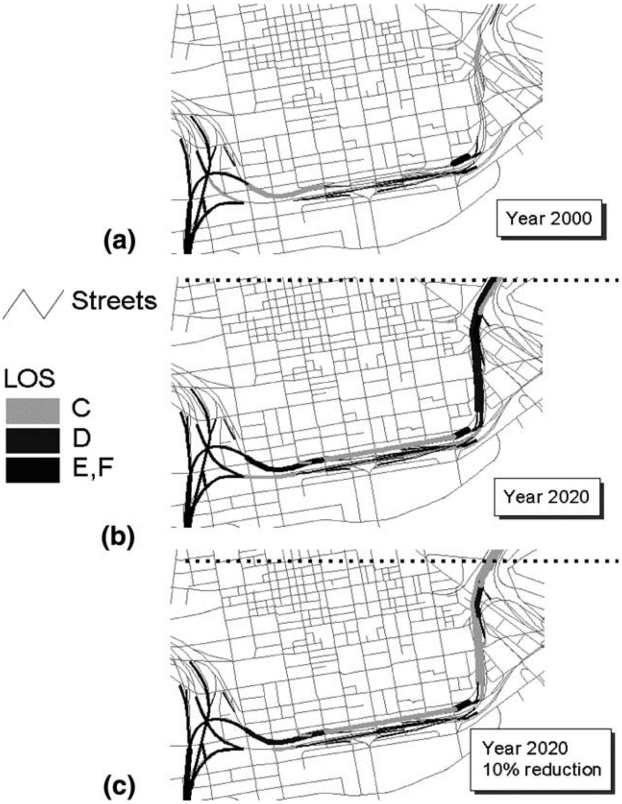


Fig. 6. Level of service (LOS) comparisons.

The first choice was to color code road segments, in which different colors were used to represent level of services for each link. Fig. 6 displays level of services at different conditions along the Cincinnati downtown portion of the Interstate 71 corridor. Fig. 6a reflects the 2000 traffic. Fig. 6b is for the 2020 condition, which is a 42% increase of the 2000 traffic volume. Fig. 6c presents a reduction of 10% of 2020 highway traffic volume. This reduction may be achieved by introducing alternative modes of transportation. A comparison of the 2000 and the 2020 scenarios demonstrates the impact of increased traffic on road travel conditions. Many links that were at Levels A–C in 2000 will become Level D or worse. When the two 2020 scenarios are compared, significant improvement in traffic conditions can be expected with reduced traffic volume, especially along the north–south sections of Interstate 71.

Fig. 7 displays the result from the second approach, whereby the color-coded road links are draped on a 3D terrain surface. This approach is similar to that used by Martin and Higgs (1997). The 3D physical models were created, based on data stored in a GIS database, to provide a sufficiently realistic scene for viewers to orient themselves. Added to such a scene are color-coded highways to reflect the level of

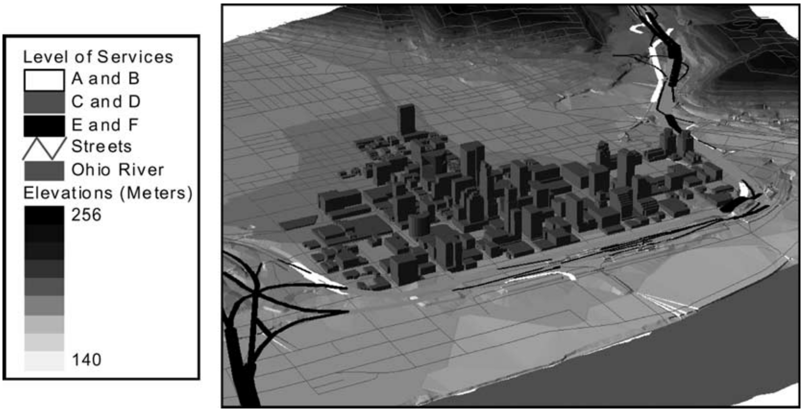


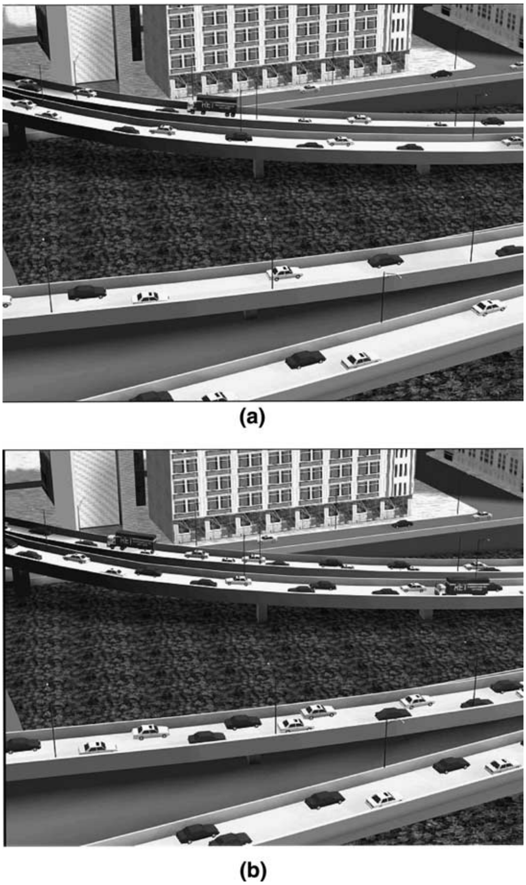
Fig. 7. A presentation of LOS in a perspective view with 3D buildings.

service classification. The 3D surface is created from elevation contours using GIS Triangulated Irregular Network (TIN) functions. The contour data, developed and maintained by the Cincinnati Area Geographic Information System (CAGIS), have a vertical interval of 0.6 m (2 ft). These are the most accurate data for the study area. The ArcView 3D Extension's "Create TIN" function is used with the default setting, using the contour lines as elevation mass points. The building footprint data also are obtained from the CAGIS database. The building height is derived from the number of stories stored as building data attributes, assuming 3 m (10 ft) high for each story. Suggested advantages of this method are that a reader can easily recognize the area by referencing it to familiar images of buildings in a three-dimensional view (Bishop, 1994).

The previous two approaches use abstracted colors to reflect traffic conditions. This often can be difficult for the general public and decision-makers to understand. Following Shiffer's (1999) idea of using digital video clips taken at various LOS conditions to represent traffic at a given LOS, the third option uses a more direct display method by creating animations related to predicted traffic conditions. The animations are developed from link-based automobile density and travel speed produced by the simulation model. This represents an effort to expand audiences and support space–time analysis (MacEachren et al., 1994; Openshaw, Waugh, & Cross, 1994).

Fig. 8 shows snapshots of animations for the 2000 and 2020 scenarios, which reflect the difference in automobile densities between the scenarios. The significance of these animations is that viewers can tie the animations to their everyday travel experience. One can easily see that there will be a lot more cars on the highway in 2020 than in 2000, and that, consequently, the travel speed will be much slower.

The number of frames for a fixed length highway link and the number of automobiles from model simulation results were calculated. These calculations were used with 3D-Studio Max, a product of AutoDesk, in creating the animations intended to


(a)

(b)

Fig. 8. A snap shot of animations of simulated 2000 (a) and 2020 (b) traffic conditions.

represent real world conditions. The number of frames for a 30 frames per second animation was calculated using the formula below:

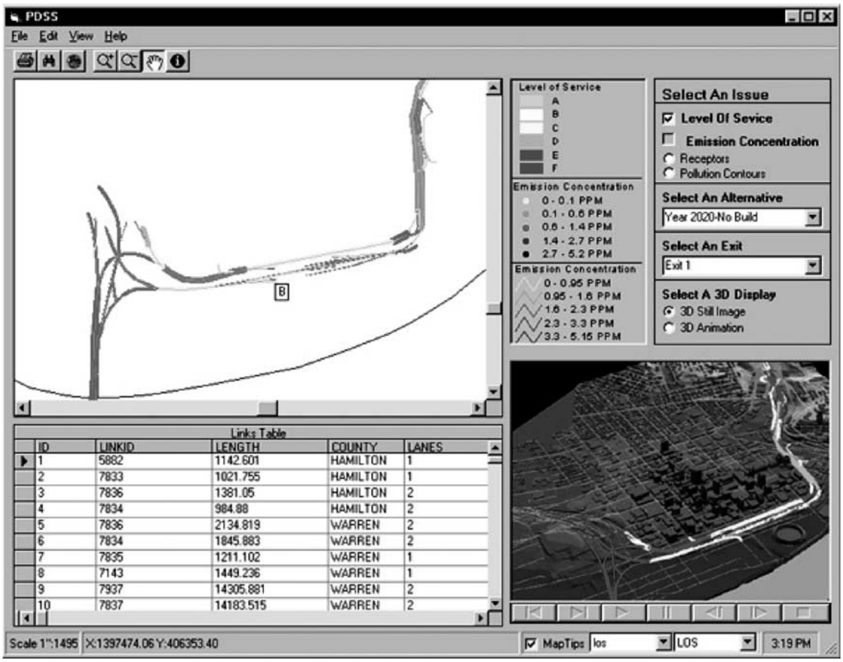
$$N = L/S * 30$$

where N is the number of frames used for simulation; L is the link length (length); S is the predicted mean speed (length/time).

The length is obtained from the highway link shapefile, while the travel speed is from the BPR model output, and the number of cars is derived from traffic volume values.

3.4. An integrated system

Simulation and visualization results are presented through a user-friendly graphic viewer. The graphic user interface (GUI) is programmed with Visual Basic and



Select An Issue
☑ Level Of Sevice
☐ Emission Concentration
○ Receptors
○ Pollution Contours

Select An Alternative: Year 2020-No Build

Select An Exit: Exit 1

Select A 3D Display
● 3D Still Image
○ 3D Animation

Links Table

ID	LINKID	LENGTH	COUNTY	LANES
1	5882	1142.601	HAMILTON	1
2	7833	1021.755	HAMILTON	1
3	7836	1381.05	HAMILTON	2
4	7834	984.88	HAMILTON	2
5	7836	2134.819	WARREN	2
6	7834	1845.883	WARREN	2
7	7835	1211.102	WARREN	1
8	7143	1449.236	WARREN	1
9	7937	14305.881	WARREN	2
10	7837	14183.515	WARREN	2

Scale 1":1495 X:1397474.06 Y:406353.40

☑ MapTips los LOS 3:19 PM

Fig. 9. Graphic viewer of the traffic analysis system.

MapObjects. The display of the system includes a map window, a data table window, an image/video window, legends, tool bars, a pull-down menu, a map tip bar and a set of check boxes and combo list boxes (Fig. 9). Tool Bars provide quick access to commonly used query functions. After a user clicks the "find" button, a pop-up window allows the user to query LOS for different planning scenarios, and locate a feature by highlighting it in the map. The system also provides a function to identify any features in the current map. The pull-down menu offers a convenient and consistent way to group commands. In the system, the menu bar appears immediately below the title bar and contains one or more menu items. A Map Tips bar at the bottom dynamically shows the current scale of the map, the coordinates of the current cursor's location on the map and current time. It also lets a user select the attribute field to be displayed in the map, which gives users a convenient way to identify features.

Assuming the task of this example is to examine the level of service (LOS) in a downtown Cincinnati area along Exit 1 of I-71 in 2020, a user would check on "Level of Service", "Year 2020 No Build", "Exit 1", and "3D Still Image". The viewer responds with a 2D map displayed in the upper-left window, a 3D image displayed in the lower-right window and highway link attributes table displayed in the lower-left part of the viewer. By using the "Zoom In", "Zoom Out" and "Pan" tools listed in the tool bar, the 2D map can be displayed at different scales. If the user chooses the

"3D Animation", the lower right window will be used to display the animation. A set of media control objects is activated to control the animation.

4. Discussion

Actions that modify the built environment often lead to significant and irreversible impacts. It is crucial, therefore, for people to understand the anticipated consequences of proposed changes before a decision is made. The most important purpose of integrating GIS, simulation models and visualization is to support such a decision-making process.

The integrated application of GIS, simulation modeling, and visualization described here has the potential of helping the planning and decision-making process. A simple model, the BPR traffic model, was successfully encoded within the GIS platform. Connections between the more complex CAL3QHC model and GIS were implemented through the ArcView Avenue scripting language. The visualization functions provided with GIS software—to drape LOS lines on 3D land surface and to construct CO concentration surface—were also used. ArcInfo, a more powerful software application from the same company, had to be used for more complicated tasks, for example, to create the points representing receptors with specified distance intervals and to establish node-line topology for roadway links. 3D models of highway segments and buildings were created with AutoCAD (AutoDesk, San Rafael, CA), based on the GIS data and field observations, and they were imported to ArcView for display in the 3D scenes. Animations were created manually based on the BPR model output, using 3D Studio Max, to reflect traffic flows with observed and predicted volume. Visual Basic (Microsoft, Seattle, WA) and MapObjects (ESRI) were used to build the presentation interface. The technologies for integrating GIS and simulation models have become more readily available for either loose or deep coupling. However, with existing software, it is still difficult to develop an operational system that can use existing data in GIS format, run existing simulation models, and present modeling output with easily understandable visual images or animations.

Among the different ways of presenting the modeling output, the tabular output provided by the simulation model was found to be the least clear and understandable. The dot map (Fig. 3) or contour lines (Fig. 4) improve the presentation by showing the spatial distribution of the CO concentration. The continuous CO concentration surface (Fig. 5) further shows the transition of concentration that is difficult to display with the thematic mapping that normally groups values into a few discrete categories. While most off-the-shelf GIS software supports 2D visualization, 3D visualization and animation capacity is quite limited. For example, ArcView GIS can easily produce maps and perspective scenes (Fig. 7). Yet, it cannot create 3D images and animations as 3D Studio Max does. On the other hand, visualization software is often designed for an operator to interactively manipulate the shape and behavior of an object.

There is no straightforward way of accessing variable values stored in a GIS database or results from a simulation model. This study shows that although showing the carbon monoxide concentrations at a given height as a surface helps to display the spatial variation of air quality (Fig. 5), it is cumbersome or impractical to construct an understandable 3D visualization of carbon monoxide concentrations from the air quality model output. A more realistic presentation could be a volume presentation in which the height of receptors is also a variable, instead of having them at a fixed height. However, such a presentation is currently unavailable with commercial GIS software. Most common visualization software perform volume rendering based on a set of built-in parameters.

The computational scientists have realized the importance of visualization as a valuable tool in the analysis and exploration of a variety of different types of data, and there is available visualization software that is capable of displaying simulation model output and accepting GIS data. Planners, in general, have not taken full advantage of these technological advances.

The most challenging effort was to integrate simulation models and visualization within a GIS platform. There is still no commercial software available for such integration. Some are capable of converting a GIS data file into a format that can be visualized. Geometry is the only thing that can be retained during the process. As a result, analysis and presentation are operated separately, just as they were in the Cincinnati project discussed here. In the analysis component, GIS, simulation modeling, and visualization are collectively used to prepare outcomes of planning scenarios. The presentation component combines GIS and visualization features to link maps, modeling results, 3D images and animations. This two-phase design provides a practical tool to planners since current technology is not ready for preparing real-time simulation and animation. To use this system as a planning decision support tool, an analyst would prepare maps, images, and animations for different planning scenarios. Any stakeholder can operate the system to assist in decision-making.

Building upon Martin and Higgs (1997) classification of visualizing physical characteristics and abstract statistics, researchers have tried to bring these two together. The study presented here provides one such example. Further, the abstract visualization in this study uses the output from analytical models, as shown in Figs. 5 and 7. This study has been primarily designed to illustrate the potential and importance of an integrated system that saves simulation model output into a GIS database and displays the results with visualization tools. The outcome can be an interactive tool for planners and decision-makers to review the modeling outputs and GIS data with maps and 3D scenes. For example, the traffic analytical modeling output may add moving objects (the automobiles traveling on the highways) to the static modeling output (the carbon monoxide concentration) for visual analysis. In addition, the visualization of the dynamic modeling output tested in this study has the potential to support the decision-making process, such as in Bishop and Gimblett's (2000) study of rule-driven autonomous agents in a virtual environment.

5. Conclusions

Planning as a field can benefit tremendously from the integration of GIS, simulation modeling and visualization. Planners always study issues with spatial and temporal significance. Proper use of visualization can enhance planners' ability for data exploration, analysis, and communication with stakeholders. When simulation models are used, GIS can help to increase efficiency and improve geographic precision, while visualization can help to increase the use and understandability of simulation models through graphic interface and visual display. When visualization is used, GIS can help to put images and animations within a geographical context, and simulation modeling can feed data for visualization of the future. When GIS is used for spatial analysis, simulation modeling can add a temporal dimension, while visualization can add more options for presentation and data exploration. These benefits would lead to an increased understanding of the outcomes of planning alternatives for a given place. In addition, such integration would make it possible to improve the process of planning and decision making through an interactive system for evaluating different planning scenarios.

Planners, however it appears, have not yet used computers as fully as possible in their professional practice (Klosterman, 2001). A review of the literature reveals that while there is a long history of using GIS, simulation models and visualization in various planning-related research and practice projects, integrated applications are a more recent phenomenon. In addition, such integration is often between any two of the three, such as GIS-simulation modeling, GIS-visualization, or simulation modeling-visualization integration. A true three-way integration is still elusive. An integration of all three technologies will provide solid support for planning and decision-making.

This traffic impact analysis study demonstrates that such integration could improve the efficiency and accuracy of simulation models and present modeling results in a more understandable visual fashion. For example, GIS roadway files can represent streets more accurately than the straight-line roadway links usually used in transportation network models. In addition, when roadways are changed, GIS functions can be used to quickly calculate the x, y coordinates of the new or modified links. When simulation-modeling results are displayed by a combination of maps, images and animations, with geographical data in addition to tables, more people may be able to understand the consequences of planning and design alternatives. In addition, 3D visualization may enable the detection of potential errors of simulation results, which is hard to achieve with tables and 2D maps.

While the study shows the benefit of integration of GIS, simulation modeling, and visualization it also shows that it is still an enormous challenge to integrate these three technologies in order to capitalize on the strengths of each for better planning and decision support. It is quite difficult to pass attributes stored in a GIS database into visualization software. Although technologies have provided a solid foundation for such integration, none of the off-the-shelf commercial software alone has sufficient functions across all three areas. Moreover, such software is often prohibitively expensive and requires significant training time. More effort from researchers and software vendors in all three fields is needed to achieve the smoother integration and closer coupling that is necessary to improve accessibility and uptake.

The objective of the study presented here is part of a long-term goal to apply information technology in planning. Such an objective is achieved by developing a system that is able to utilize geographical data and analytical modeling results to evaluate highway projects with computers before the construction phase. With such a system, people will be able to evaluate and compare traffic conditions and related environmental quality of different alternatives from animations of driving on the highway or seeing the area from the air, in addition to text, maps, and tables. It will give planners and citizens and policy makers a better understanding of how a major construction project will impact their community before they take a stand on the issue. Also possible to add to the mix are photographs, video images of streetscapes, urban contexts and related statistical data, and interactions between the system and its users. Such a system will convey a real sense of "intelligent" decision-making in which "what if" questions are answered on the spot. This will, hopefully, foster a sense of collaboration between stakeholders.

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