Computer-Aided Civil and Infrastructure Engineering **21** (2006) 136–147

Feasibility of Computer Visualization in Highway Development: A Fuzzy Logic-Based Approach

Manoj K. Jha*

Department of Civil Engineering, Morgan State University, 1700 E. Cold Spring Lane, Baltimore, MD 21251, USA

Abstract: *Building transportation infrastructure requires careful planning and design with due consideration to land and environmental impacts. Imprecise assessments of detailed design requirements, and land and environmental impacts lead to frequent scope changes of transportation infrastructure improvement projects. Computer visualization (CV) and geographic information systems (GIS) can greatly assist in understanding the detailed design requirements as well as land and environmental impacts. However, the application of CV is quite limited in transportation primarily because of the limited knowledge of its benefits over cost. This study investigates the feasibility of CV in modeling highway improvement sections. Two potential benefits are realized through the proposed modeling: (1) better representation of future improvements resulting in enhanced public and political support and (2) early identification of adverse environmental and land impacts as well as detail design requirements resulting in fewer scope changes. A fuzzy logic-based general approach is proposed to calculate the expected benefits of CV. A computer code called the Projection Option Processor (POP) is developed in Microstation's BASIC language to automate repetitive tasks in the visualization procedure. Two real highway projects from Maryland are visualized and the benefits and costs of the visualization are estimated using the proposed fuzzy logic-based approach. The results indicate that using POP is cost-effective resulting in higher benefit-cost ratios (B/C). Increasing the number of views, alternatives, and reevaluations for visualization may increase the total visualization cost significantly.*

*To whom correspondence should be addressed. E-mail: *mkjha@eng.morgan.edu*.

1 INTRODUCTION

Computer visualization (CV) and geographic information systems (GISs) are emerging technologies, which play significant roles in transportation problem solving. Although GISs have been extensively used in transportation (an application commonly known as "GIS-T") in the last two decades (Simkowitz, 1989; Abkowitz et al., 1990; Evans et al., 1993; Hammad et al., 1993; Lamm et al., 1994; Sarasua, 1994; Lee and Clover, 1995; Olivera and Maidment, 1998; Jourquin and Beuthe, 1996; Jong et al., 2000; Jha and Schonfeld, 2000a,b, 2004; Jha, 2001, 2003) CV application in transportation is still quite limited (Prevedouros et al., 1994; Carley, 1995; Larsen, 1995; Landphair and Larsen, 1996; McCall, 1999; Jha and McCall, 2001; Keister and Moreno, 2002). Limited knowledge of the benefits and costs of CV application in transportation has generally prevented its widespread use in the transportation community.

Traditionally, highway agencies and State Departments of Transportation (DOTs) perform extensive planning, design, and environmental analyses before making major transportation infrastructure investments. Despite these analyses, the scopes of transportation projects are often changed due to imprecise cost estimates and poor understanding of future enhancements (MDOT, 1999). Although it is a common practice to test models of complex structures before actual design (such as testing of airplanes, rockets, automobiles, bridges, and dams) to identify weaknesses in design features, highway sections are rarely modeled and tested before construction. Visualization of highway sections (Keister and Moreno, 2002; Bailey et al., 2002) can be thought of as a preprocess that can provide better understanding of unusual land, environmental, and design features before actual construction. A GIS (Keister and Moreno, 2002) can

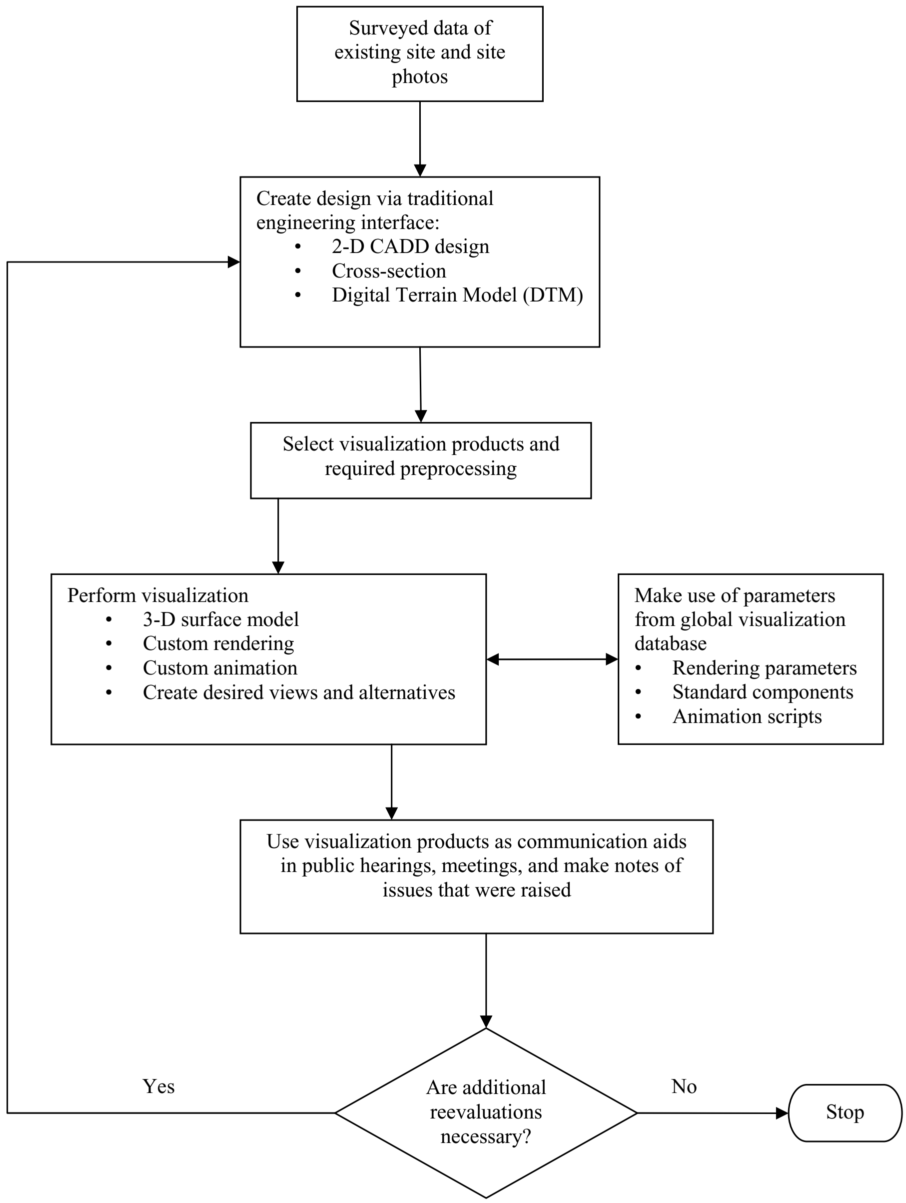

Fig. 1. A flowchart for CV application in highway projects.

also aid in identifying unusual land and environmental features and can work in conjunction with CV. Effective visualization of future enhancements can also aid in winning the public and political approvals necessary for transportation projects. Visualization is typically performed after an extensive site survey is performed followed by traditional engineering design (Figure 1). Visualization can be used as a communication aid and can be continuously modified based on public input.

Application of CV technology in transportation projects is limited primarily due to the widespread perception that it is an expensive technology and the total hardware and software expenses combined with necessary manpower to perform visualization far outweigh the benefits. Although studies (Jha and McCall, 2001; Jha et al., 2001, Bailey et al., 2001, 2002) have shown that visualization does enhance the overall understanding of future improvements (making it easier for the projects to win community and political support), no procedures have been developed to quantitatively measure its benefits.

In this research, first we seek to develop a microstation-based efficient batch process to automate repetitive procedures resulting in efficient visualization production. Later, we apply fuzzy logic to calculate benefits and costs of visualization that may allow us to calculate the benefit-cost (B/C) ratio. Fuzzy logic is particularly suited for benefit and cost calculations for two reasons: (1) while cost of visualization may be quantifiable it may be difficult to quantify visualization benefits due to their fuzzy nature. At best one can describe visualization benefits in linguistic terms (commonly known as "linguistic hedges" in fuzzy logic), such as "high," "medium," or "low." (2) By converting both benefits and costs in fuzzy form we can be assured that we are comparing apples to apples; thus, the resulting B/C ratio might make more sense because fuzzy representation of a quantity always lies between 0 and 1. Our extensive literature review found very limited applications (Neitzel and Hoffman, 1980; Kahraman, 2001; Dompere, 2004) of fuzzy logic in benefit cost assessment. Neitzel and Hoffman (1980) described benefits and costs in linguistic rather than numerical terms. Our procedure of fuzzy representation of visualization benefit and cost is similar to that application in that we also use linguistic terms in describing benefit and cost and then convert them into numerical values using triangular fuzzy numbers (described later).

Bailey et al. (2001) applied fuzzy logic to quantify public perception toward visualization in highway development. However, they did not quantify visualization benefits and costs. For highway economic analysis, the B/C ratio is generally calculated (FHWA, 2003) to assess if a proposed development is worth undertaking. The FHWA procedure uses actual numerical values using life-cycle costs and does not consider fuzzy characteristics of benefits. As noted earlier, in our analysis here we are proposing a fuzzy logic procedure to estimate CV benefits and costs that will entail whether CV is worth undertaking for a roadway improvement project. The objective is to derive a "general" fuzzy B/C calculation procedure and apply it to investigate the cost effectiveness of CV application in highway projects. Two case studies from Maryland are presented in which the proposed fuzzy B/C calculation methodology is applied.

2 VISUALIZATION COSTS

The total cost of visualization production in highway development includes (1) data collection including site survey and photography; (2) creation and maintenance of data management systems including hardware, software, and personnel (also includes costs associated with GIS modeling); and (3) cost associated with visualizing different views and options. The number of views and options for reevaluation have a large impact on total production time. Several viewpoints are established and simulated before the final view is chosen. Reevaluations may be necessary due to aesthetic aspects of the visualization or design changes. The total visualization cost, C_V (\$), is expressed as

$$C_V = cT_V + F \tag{1}$$

where c is the unit cost (in \$/hour) of visualization, T_V is the total visualization time (in hours), and F is the fixed cost (in \$) associated with visualization production (includes costs associated with data collection, site photography, and GIS modeling).

Depending on various intermediate visualization operations performed, the total visualization time, T_V (hours) required for n views, m alternatives, and r reevaluations ($n \subseteq m \subseteq r$) can be expressed as

$$T_V = \sum_{j=1}^{m}\left[(t_{aj} + t_{rj}) + \sum_{i=1}^{n} t_{cij}\right] + \sum_{k=1}^{r}\left\{\left[\sum_{j=1}^{m}\left[(t_{ajk} + t_{rjk}) + \sum_{i=1}^{n} t_{cijk}\right]\right]\right\} \tag{2}$$

where t_{aj} is the time required to develop the 3D model for the jth alternative (hours); t_{rj} is the time required to develop rendering materials for the jth alternative (hours); t_{cij} is the time required to develop, touch up, and process the ith view of the jth alternative (hours); t_{ajk} is the time required to develop the 3D model of the jth alternative for the kth reevaluation (hours); t_{rjk} is the time required to develop rendering materials of the jth alternative for the kth reevaluation (hours); and t_{cijk} is the time required to develop, touch up, and process the ith view of the jth alternative for the kth reevaluation (hours).

Alternatively, Equation (1) can be rewritten as

$$C_V = c * T_V(t_a, t_r, t_c, m, n, r) + F \tag{3}$$

Please note that the purpose of Equations (2) and (3) is to show how visualization cost depends on the number of views, alternatives, and reevaluations.

2.1 The Projection Option Processor (POP)

From Equation (2) it is obvious that increasing the number of views, alternatives, and reevaluations increases the visualization time tremendously. Therefore, before beginning visualization work, these should be narrowed down. This is especially true for 3D modeling and rendering tasks. Details can be created through either touch up or modeling. If a large number of views are required, the benefit of using modeling over touch up increases. It is noted that if the time required for making adjustments to any components in the visualization database is low, then iterations have less impact on total cost. These costs can be reduced by reusing portions of the database that do not need to be changed.

Automation results from identifying repetitive tasks within procedures and eliminating unnecessary human effort by hard-coding these tasks. Using databases of reusable components or cells is a common form of automation. A drawback is that using standardized components can limit flexibility in design and visualization. Instead of attempting to automate geometry creation, which has already been highly automated in CAD systems, we automate the processing of multiple views and scenarios for a single site for photo simulation. This automation can significantly save computing time. For this purpose a batch process called POP is developed in microstation's BASIC language. The POP can save multiple design scenarios including several settings in a single batch. The POP is developed as a macro in microstation that automates a series of manual steps to be performed for creating views, alternatives, and reevaluations in the visualization production. It is especially suitable for photo-simulation.

The POP is developed based on the knowledge of the photo-simulation process, and works by grouping the required microstation settings that must be repetitively selected. It is especially useful in cases where alternative solutions and views need to be shown because the scenario requires the processing of a large number of images. Moreover, it can facilitate the study of multiple alternatives and views. For example, without POP, saving a four view, three alternative scenario would require the manual selection of settings and processing of an image 12 times. A flowchart of processes followed in the POP is shown in Figure 2.

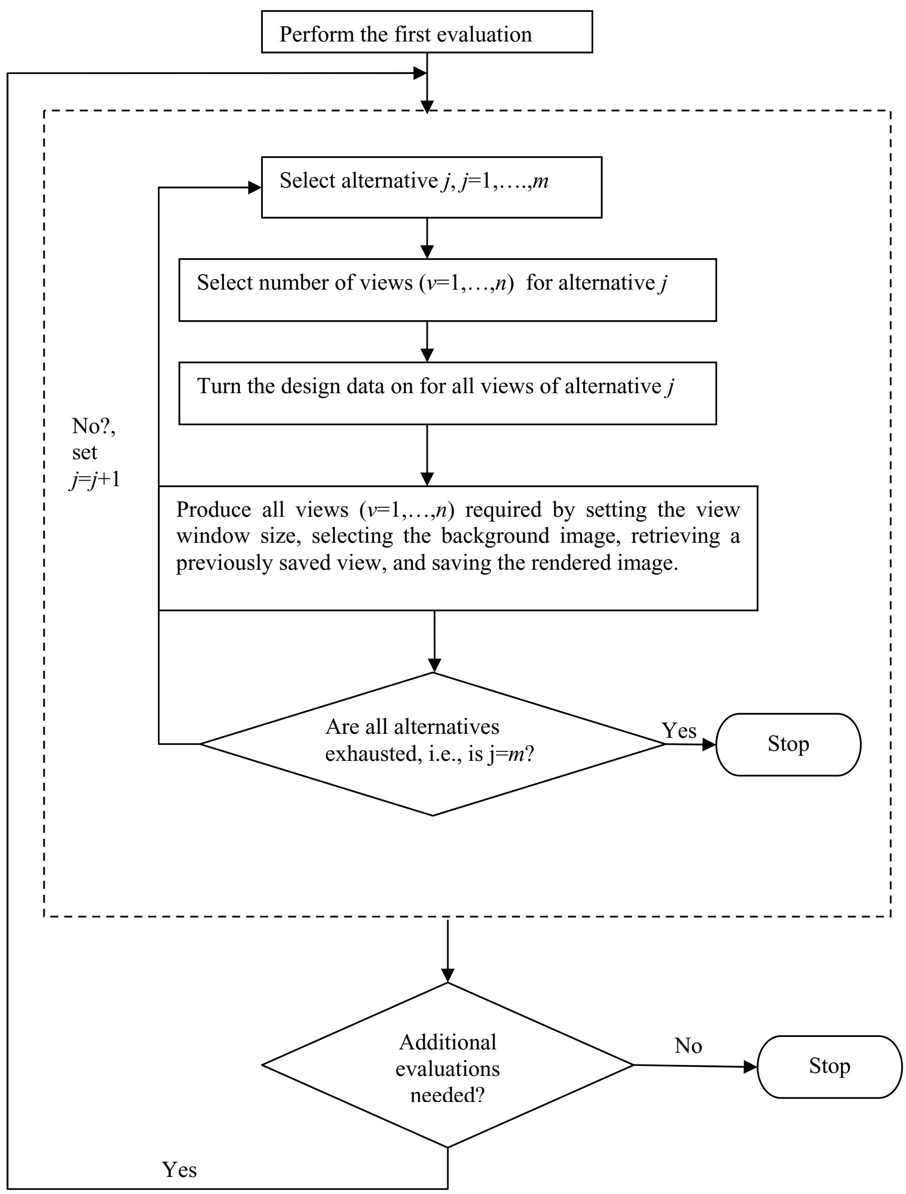

Fig. 2. Flowchart of the POP.

With the POP all processing is done in a single click by eliminating unnecessary human interventions and thereby achieving full automation for efficient visualization production. As the number of views, alternatives, and reevaluations increases the total time saved using the POP increases dramatically. The time saving is more significant when a single parameter, such as the viewing angle needs to be changed, which necessitates the reprocessing of all the options with that view. Conversely, if the 3D model or rendering materials of a particular alternative must be changed, the images for all views must be reproduced. The POP automatically processes all changes by making large groups of settings involved with the viewing and rendering of images easy to access.

3 ESTIMATING VISUALIZATION COSTS AND BENEFITS BY FUZZY LOGIC

Fuzzy logic is a superset of conventional (Boolean) logic that has been extended to handle the concept of partial truth, i.e. true values between "completely true" and "completely false." It was introduced by Zadeh (1965) who defined *fuzzification* as a methodology to generalize any specific theory from a crisp (discrete) to a continuous (fuzzy) form. Fuzzy logic is extensively applied in solving optimization problems, such as fuzzy linear programming and fuzzy multiobjective linear programming (Zimmermann, 1978; Vukadinovic et al., 1999). Many interesting applications of fuzzy logic in transportation problem solving can be found in Teodorovic and Vukadinovic (1998). Bailey et al. (2001) applied fuzzy logic to quantify public perception toward different visualization models of highway improvement projects.

3.1 Fuzzy benefit

For transportation improvements, detailed cost estimation needs to be performed. For example, the Maryland Department of Transportation develops an annual Consolidated Transportation Program (CTP) (MDOT, 1999) which contains a description of major transportation improvement projects, their approximate costs, and the appropriated funding levels. Quite often the original cost estimates are revised at later stages due to scope changes required as a result of factors, such as unnoticed land characteristics, design requirements, and environmental impacts. The final project cost, therefore, is generally higher than initial estimates. Projects are often delayed in completion due to difficulty in obtaining cost overruns caused due to scope changes. Effective visualization can minimize scope changes by revealing inaccurate design details during initial cost estimates.

It is a common practice to present major transportation improvement plans to community groups and seek their opinion regarding any changes. CV can be very helpful at this stage as it can show the post design details and alternatives through visual images that are more appealing (Bailey et al., 2002). If future enhancements can be effectively visualized and presented to the stakeholders project approval may be quick and construction can begin sooner (McCall, 1999). It can also expedite support for the proposed improvements by communities.

In our analysis, we assume that the benefits of visualization are a measure of reduced project delays and frequency of scope changes. But, CV alone cannot be responsible for the net reduction in project delays and scope changes. There may be other factors, such as attractiveness of a particular alternative to the decision-makers and stake-holders as well as a better understanding of the design complexities of the project, which lead to reduced project delays and scope changes. Thus, the above is a class of multi-benefits attributable to multi-factors. Such a case is well described by Dompere (2004). Dompere shows that benefits realized through multi-factors can be expressed linearly and are additive. Therefore, the total benefit of vector $\mathbf{B}$ can be expressed as

$$\mathbf{B} = \mathbf{B}_1 + \mathbf{B}_2 + \mathbf{B}_3 \tag{4}$$

where $\mathbf{B}_1$ is the benefit due to CV, $\mathbf{B}_2$ is the benefit due to natural willingness of the decision-makers and stakeholders to support the project; and $\mathbf{B}_3$ is the benefit due to better understanding of the design complexities. We measure project delays and frequency of scope changes as "low," "medium," and "high," which are subjectively determined as in any other fuzzy logic application.

In the proposed approach, we develop a model to estimate the expected visualization benefit, B_{E} $(=\mathbf{B}_1)$ using fuzzy logic. Let us introduce two sets $\mathbf{M}(x)$ and $\mathbf{N}(y)$ which represent delay (in months) in project completion and frequency of project scope changes, respectively. The corresponding fuzzy membership functions are $\mu_{\mathbf{M}}(x)$ and $\mu_{\mathbf{N}}(y)$, respectively, whose values range from 0 to 1. Thus, B_{E} can be expressed as

$$B_{\mathrm{E}} = 1 - \min\{\mu_{\mathbf{M}}(x), \mu_{\mathbf{N}}(y)\} \tag{5}$$

where $\min[\mu_{\mathbf{M}}(x), \mu_{\mathbf{N}}(y)]$ implies project delay and scope changes (implying that benefit is a measure of reduction in delay AND scope changes). The above equation implies that lower project delays and frequency of scope changes result in higher visualization benefit.

When applying the above CV benefit estimation formula to a new project one would generally assume that more detailed visualization (requiring several views, alternatives, and reevaluations) will lead to reduced ("low") delays and scope changes. A more precise correlation between visualization complexity and reduction is that delays and scope changes can be estimated by fitting a sufficient number of CV case studies and deriving a fitted correlation, similar to regression equations derived for trip generation characteristics (Jha and Lovell, 1999).

$\mathbf{M}(x)$ and $\mathbf{N}(y)$ can be described as linguistic variables, such as "low," "medium," or "high." For consistency in numerical analysis those linguistic variables can be represented on a scale of 0–10. For example, on a 0–10 scale, "low," "medium," and "high" can be described as 2, 5, and 7, respectively. Furthermore, $\mathbf{M}(x)$ and $\mathbf{N}(y)$ can be represented as triangular fuzzy numbers with difference confidence intervals (Teodorovic and Vucadinovic, 1998). A typical triangular fuzzy number is most often presented in the form

$$\mathbf{A} = (a_1, a_2, a_3) \tag{6}$$

where a_1 is the lower (left) boundary of the triangular fuzzy number, a_2 is the number corresponding to the highest level of presumption, and a_3 is the upper (right) boundary of the fuzzy number. The membership function of the fuzzy number $\mathbf{A}$ is:

$$\mu_{\mathbf{A}}(x) = \left\{ \begin{array}{cc} 0, & x \le a_1 \\ \left(\dfrac{x - a_1}{a_2 - a_1}\right), & a_1 \le x \le a_2 \\ \left(\dfrac{a_3 - x}{a_3 - a_2}\right), & a_2 \le x \le a_3 \\ 0, & x \ge a_3 \end{array} \right\} \tag{7}$$

By the similar notion assume that $\mu_{\mathbf{M}}(x)$ and $\mu_{\mathbf{N}}(y)$ can be represented as triangular fuzzy numbers with $\mathbf{M} = (m_1, m_2, m_3)$ and $\mathbf{N} = (n_1, n_2, n_3)$, respectively. For example, if $\mathbf{M} = (2, 6, 10)$ and $\mathbf{N} = (2, 4, 6)$, then $\mu_{\mathbf{M}}(x)$ and $\mu_{\mathbf{N}}(y)$ can be expressed as

$$\mu_{\mathbf{M}}(x) = \left\{ \begin{array}{cc} 0, & x \le 2 \\ \dfrac{x}{4} - 0.5, & 2 \le x \le 6 \\ -\dfrac{x}{4} + 2.5, & 6 \le x \le 10 \\ 0, & x \ge 10 \end{array} \right\} \tag{8}$$

$$\mu_{\mathbf{N}}(y) = \left\{ \begin{array}{cc} 0, & y \le 2 \\ \dfrac{y}{2} - 1, & 2 \le y \le 4 \\ -\dfrac{y}{2} + 3, & 4 \le y \le 6 \\ 0, & y \ge 6 \end{array} \right\} \tag{9}$$

The confidence intervals for membership functions $\mu_{\mathbf{M}}(x)$ and $\mu_{\mathbf{N}}(y)$ are user-specified; this has no effect on the general methodology developed here because the proposed methodology assumes a standard triangular fuzzy form for $\mu_{\mathbf{M}}(x)$ and $\mu_{\mathbf{N}}(y)$. The confidence intervals are interpreted as being "low," "medium," and "high" and quantitative measures of these linguistic variables are to be determined based on the characteristics of the project to which the analysis is being applied. The assumption of triangular fuzzy numbers in similar applications can be found in Teodorovic and Vukadinovic (1998) and Dompere (2004).

3.2 Fuzzy cost

As Equation (1) suggests the visualization cost, C_{V} will depend on complexity in the visualization procedure and number of views, alternatives, and reevaluations necessary. Let $\mathbf{V}(z_1)$, $\mathbf{A}(z_2)$, and $\mathbf{R}(z_3)$ be the sets representing number of views, alternatives, and reevaluations necessary for visualizing a highway project, respectively. $\mu_{\mathbf{V}}(z_1)$, $\mu_{\mathbf{A}}(z_2)$, and $\mu_{\mathbf{R}}(z_3)$ represent the corresponding membership functions having triangular fuzzy forms with confidence intervals $\mathbf{V} = (v_1, v_2, v_3)$, $\mathbf{A} = (a_1, a_2, a_3)$, and $R = (r_1, r_2, r_3)$, respectively. Using the similar analysis presented earlier about the "OR" operator the fuzzy visualization cost, C_{vf}, can be expressed as

$$C_{\mathrm{vf}} = \max\left[\mu_{\mathbf{V}}(z_1), \mu_{\mathbf{A}}(z_2), \mu_{\mathbf{R}}(z_3)\right] \tag{10}$$

Because C_{vf} is a combined measure of number of views ($\mathbf{V}$), alternatives ($\mathbf{A}$), and reevaluations ($\mathbf{R}$) in the visualization process, the use of "OR" operator is justifiable.

3.3 Fuzzy B/C ratio

Using Equations (5) and (10) the B/C ratio of visualization for a highway project can be expressed as

$$\frac{B_{\mathrm{E}}}{C_{\mathrm{vf}}} = \frac{1 - \min\{\mu_{\mathbf{M}}(x), \mu_{\mathbf{N}}(y)\}}{\max[\mu_{\mathbf{V}}(z_1), \mu_{\mathbf{A}}(z_2), \mu_{\mathbf{R}}(z_3)]} \tag{11}$$

4 FUZZY BENEFIT OF THE POP

Since the POP automates repetitive tasks involved in visualization resulting in timesavings in completing the required number of views, alternatives, and reevaluations, it will reduce the visualization cost. This will imply that the B/C ratio will be higher when using the POP. To correctly assess the advantage of the POP we use the fuzzy forms (such as "low," "medium," and "high," described earlier) of time interval to complete each view, alternative, and reevaluation. Let $\mathbf{V_t}(z_1)$, $\mathbf{A_t}(z_2)$, and $\mathbf{R_t}(z_3)$ be the time intervals to complete each view, alternative, and reevaluation, respectively, expressed as triangular fuzzy numbers with $\mathbf{V_t} = \mathbf{A_t} = \mathbf{R_t} = (t_1, t_2, t_3)$. Let $\mathbf{V'_t}(z_1)$, $\mathbf{A'_t}(z_2)$, and $\mathbf{R'_t}(z_3)$ be the fuzzy forms of time interval to complete each view, alternative, and reevaluation, respectively, when the POP is used, expressed as triangular fuzzy numbers with $\mathbf{V'_t} = \mathbf{A'_t} = \mathbf{R'_t} = (t'_1, t'_2, t'_3)$.

Then, the cost saving due to the POP can be expressed as

$$\Delta C_{\mathrm{vf}} = \max\left[\mu_{\mathbf{V}_t}(z_1), \mu_{\mathbf{A}_t}(z_2), \mu_{\mathbf{R}_t}(z_3)\right] - \max\left[\mu_{\mathbf{V}'_t}(z_1), \mu_{\mathbf{A}'_t}(z_2), \mu_{\mathbf{R}'_t}(z_3)\right] \quad (12)$$

The B/C ratio with and without POP can be expressed as

$$\left.\frac{B_{\mathrm{E}}}{C_{\mathrm{vf}}}\right|_{\mathrm{pop}} = \frac{1-\min\{\mu_{\mathbf{M}}(x), \mu_{\mathbf{N}}(y)\}}{\max\left[\mu_{\mathbf{V}'_t}(z_1), \mu_{\mathbf{A}'_t}(z_2), \mu_{\mathbf{R}'_t}(z_3)\right]} \quad (13)$$

$$\left.\frac{B_{\mathrm{E}}}{C_{\mathrm{vf}}}\right|_{\mathrm{non\text{-}pop}} = \frac{1-\min\{\mu_{\mathbf{M}}(x), \mu_{\mathbf{N}}(y)\}}{\max\left[\mu_{\mathbf{V}_t}(z_1), \mu_{\mathbf{A}_t}(z_2), \mu_{\mathbf{R}_t}(z_3)\right]} \quad (14)$$

5 EXAMPLES

Two examples are presented to demonstrate the applicability of the fuzzy logic approach in estimating visualization benefits. The first is streetscape rehabilitation of an existing road in Tacoma Park, Maryland. The second is a large-scale interchange design in Frederick County, Maryland.

5.1 Example 1: photo simulation of ground level details

Streetscapes and rehabilitation of existing roads are becoming a more important part of infrastructure investment. The space for new roads is scarce forcing DOTs on improvements that will encourage multi-modal transportation, improve local community environment, and increase capacity of existing roads.

The development of conceptual data was explored for various alternative solutions to the rehabilitation of a particular complicated stretch of Piney Branch Road (MD Rt. 320) in Tacoma Park, Maryland. The complexity results from the sharp slope downward to Piney Branch Creek and the steep slope upward and stairways to homes on the other side of the road. The three options that were being presented are shown in Figures 3–5. By having three different options in moderate detail, it was possible to present impacts and benefits of various solutions. In this way stakeholders were able to weigh the options without having to spend money on detailed data. The public does not care about precise coordinates and details as much as quick inspection of visual impacts and benefits.

The first option (Figure 3) attempts to incorporate all of the amenities that the public wanted, wider lanes, sidewalks, a median, and on-street parking. However, there are adverse impacts on residential yards and entrances, two old trees, utilities, and existing parking. Although option 2 (Figure 4) minimizes impacts, the community and government officials were not satisfied with the results, especially the reduced traffic capacity. The third option

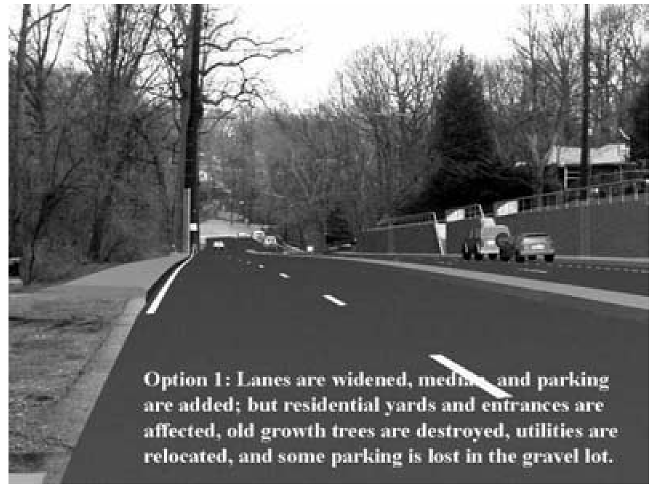

Fig. 3. Piney Branch Road example: option 1.

(Figure 5) only adds sidewalks. There was debate as to whether option 3 would require the removal of two old trees that towered over the neighborhood. The rapidly developed visualization model was based on a linear horizontal alignment. There was no need to explore the use of variable slopes, retaining wall, shifting of horizontal alignment, or other means to explore what was required to avoid tree removal. In conceptual modeling for photo simulation, it is only required that a model be developed in enough detail that a realistic visualization can be generated from the perspective of the photographs to be matched. Through visualization of different alternative solutions, the issue of how to present possible issues to the community and government officials could be debated until the last minute. The visualization process communicated possible implications of the conceptual engineering data and helped to achieve this decision.

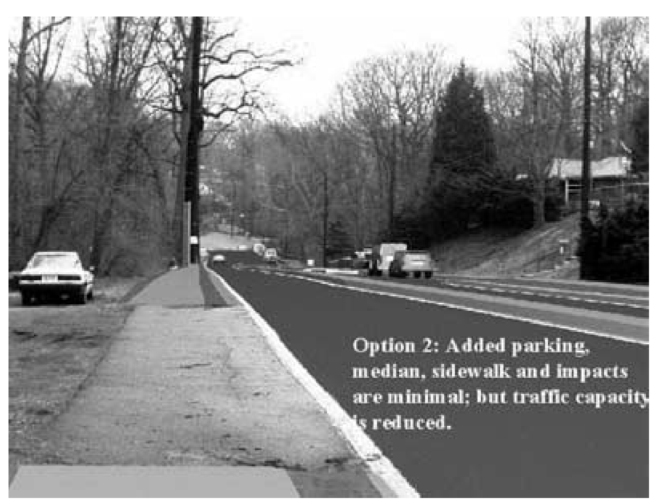

Fig. 4. Piney Branch Road example: option 2.

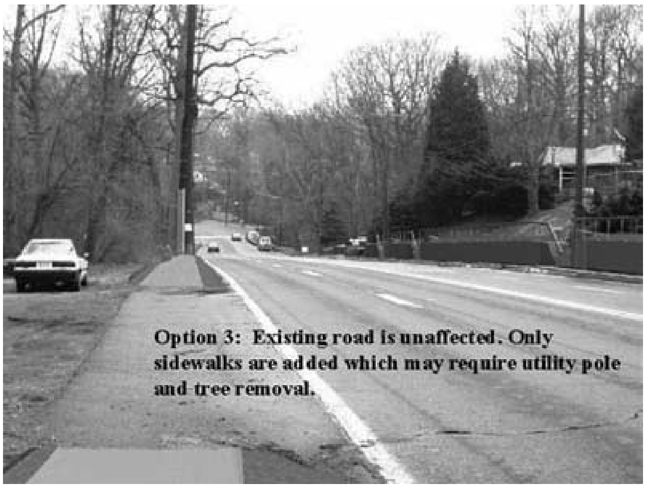

Fig. 5. Piney Branch Road example: option 3.

It is important to note that this occurred because the photo simulation techniques brought the issue to light. The giant tree (Figures 3–5) is very obvious on the site photo and must be accounted for during the visualization process.

5.1.1 Benefit and cost analysis. The benefit and cost analysis are performed for the three options using the procedures developed earlier. Based on the above description of the options the following fuzzy rules are developed:

Option 1: Much detailed visualization, time consuming, and expensive, resulting in expediton of project approval and fewer scope changes.
Option 2: Visualization in moderate detail, less time consuming, and inexpensive improvements, resulting in longer project approval duration and higher number of scope changes.
Option 3: Visualization in least detail, least time consuming, and very inexpensive developments, longest project approval duration and highest number of scope changes.

Table 1 shows the benefit and cost calculations for the three options. The expected fuzzy benefit of CV, B_E (=$\mathbf{B}_1$ in Equation (4)) is attributed to be 0.9 × total benefit, **B**. $\mathbf{B}_2$ and $\mathbf{B}_3$ account for 10% of the total benefit. Typically, a survey can be performed to estimate the percentage of CV contribution toward the total benefit. It can be seen that option 1 yields the highest B/C ratio compared to option 2 that yields the lowest B/C ratio. A comparison of B/C ratio under POP and non-POP indicates that the POP offers more than 100% increase in the B/C ratio for all three options and offers the highest

Table 1
Fuzzy benefit and cost calculations

	M: (2, 6, 10)			*N: (2, 4, 6)*			*V: (1, 2, 3)*		*A: (1, 3, 5)*		*R: (1, 5, 9)*	
	$M(x)$	$M(x)$	$\mu_M(x)$	$N(y)$	$N(y)$	$\mu_N(y)$	V	$\mu_V(z_1)$	A	$\mu_A(z_2)$	R	$\mu_R(z_3)$
Ex. 1-Option 1	Low	3	0.25	Low	2	0	3	0	4	0.5	9	0
Ex. 1-Option 2	Medium	7	0.75	Medium	3	0.5	2	1	3	1	5	1
Ex. 1-Option 3	High	9	0.25	High	5	0.5	2	1	2	0.5	2	0.25
Ex. 2	Low	3	0.25	Low	3	0.5	3	0	4	0.5	9	0

	$V_t, A_t, R_t: (25, 30, 35)$						$V'_t, A'_t, R'_t: (0.5, 1, 1.5)$					
	$V_t(z_1)$	$\mu_{V_t}(z_1)$	$A_t(z_2)$	$\mu_{A_t}(z_2)$	$R_t(z_3)$	$\mu_{R_t}(z_3)$	$V'_t(z_1)$	$\mu_{V'_t}(z_1)$	$A'_t(z_2)$	$\mu_{A'_t}(z_2)$	$R'_t(z_3)$	$\mu_{R'_t}(z_3)$
Ex. 1-Option 1	32	0.6	33	0.4	31	0.8	0.6	0.2	0.6	0.2	0.6	0.2
Ex. 1-Option 2	28	0.6	30	1	29	0.8	0.6	0.2	0.6	0.2	0.6	0.2
Ex. 1-Option 3	26	0.2	28	0.6	26	0.2	0.6	0.2	0.6	0.2	0.6	0.2
Ex. 2	30	1	30	1	30	1	0.6	0.2	0.6	0.2	0.6	0.2

	B_E	C^*_{vf}	$\frac{B_E}{C_{vf}}$	$C_{vf}\|_{non-pop}$	$C_{vf}\|_{pop}$	ΔC	$\frac{B_E}{C_{vf}}\|_{non-pop}$	$\frac{B_E}{C_{vf}}\|_{pop}$
Ex. 1-Option 1	1	0.5	2	0.8	0.2	0.6	1.25	5
Ex. 1-Option 2	0.5	1	0.5	1	0.2	0.8	0.5	2.5
Ex. 1-Option 3	0.75	0.5	1.5	0.6	0.2	0.4	1.25	3.75
Ex. 2	0.5	0.5	1	1	0.2	0.8	0.5	2.5

*POP and non-POP calculations use minutes as variables whereas the first C_{vf} (shown with an ∗) calculation uses numbers of views, alternatives, and reevaluations without considering the time taken to perform those views, alternatives, and reevaluations. For calculating POP benefit over non-POP it is necessary to use the “time-variable.”

increase for option 2. The cost saving realized for option 2 was the highest (80%) when POP was used.

5.2 Example 2: Visualization of a large-scale transportation project

The proposed visualization and B/C determination techniques are implemented on another highway project from Frederick County, Maryland. This project is fairly large and complex and is divided into several phases which were slated for construction along interstate route I-70 through Frederick, Maryland. We are interested in visualizing portions of the second phase of construction. A site-map including a zoomed map showing the second phase of construction is shown in Figure 6. The existing I-70/I-270 interchange has missing movements and is heavily used by truck traffic, thereby creating safety and traffic congestion problems, which affect the local roadway system. Currently, the connection from I-270 northbound to I-70 eastbound and the return movement is accomplished by leaving the interstate and using MD Rt. 85, an urban minor arterial. MD Rt. 85 is a high volume roadway with intense commercial strip development. The missing movements associated with this interchange force vehicles, especially trucks, to use circuitous routes (most notably US Rt. 40 through Frederick) to reach their destination. This creates additional congestion problems throughout a rapidly growing urbanized area. The proposed scope of work primarily includes construction of these two missing movements. Reconstruction of the interchange will relieve traffic congestion currently experienced during the morning and evening peak hours, and improve safety conditions at the interchange and the local roadway system. The improvements will result in a better functioning interstate, safer local roadway systems and improved access to the municipal airport and the industrial area located on the east side of Frederick. The total length of ramp and roadway construction is 9.21 km. The work will consist of the following phases:

1. Construction of two missing movements: I-70 westbound to I-270 southbound and I-270 northbound to I-70 eastbound.
2. Addition of a third through lane on I-70 east and westbound.

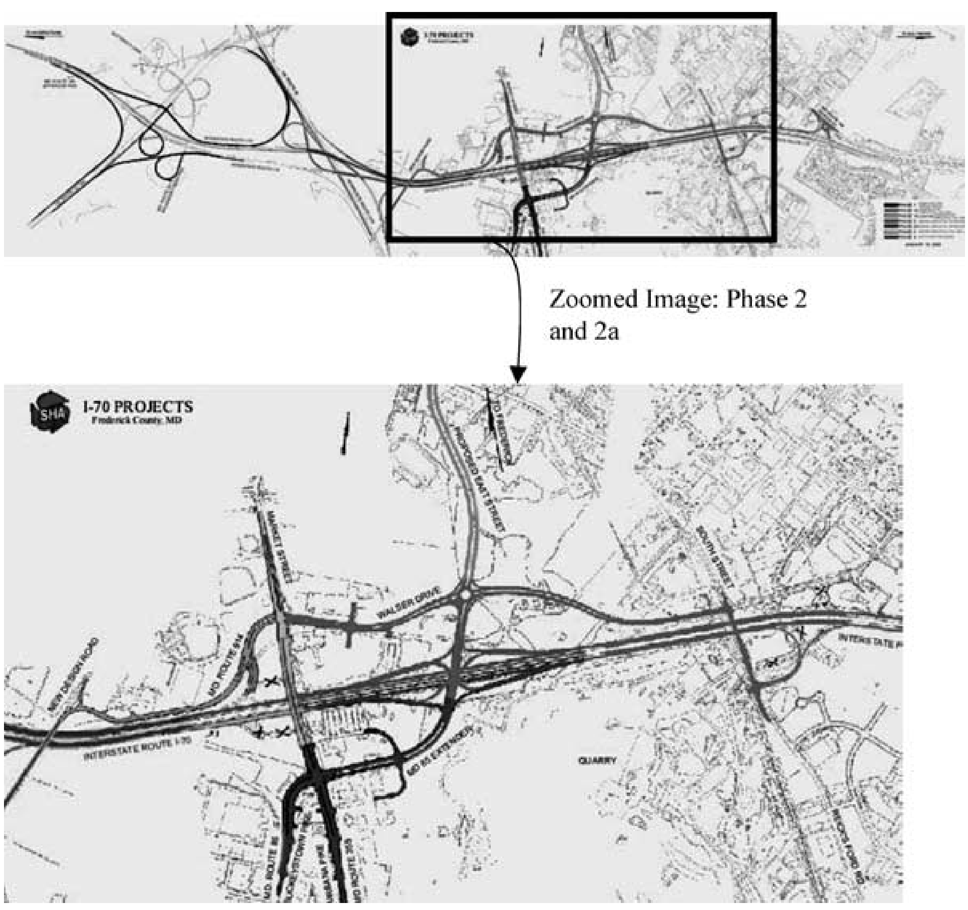

Fig. 6. Study region for the example from Frederick County, Maryland.

Fig. 7. Using GIS-based orthophoto to identify affected geographic features.

2A. Extension of state route MD Rt. 85.
3. Dualization of two existing ramps: US routes US 15/40 southbound to I-70 eastbound and I-70 westbound to US 15/40 northbound.
4. Construction of five new bridges and widening and/or redecking four bridges.
5. Drainage improvements, signing, lighting and pavement marking.

The visualization of portions of phase 2A enhancements is performed (Figure 6) showing the construction of the extension of MD Rt. 85, which ties into I-70. Visualization of side access roads in the nearby vicinity are also shown. GIS-based orthophoto is used to identify affected properties due to proposed enhancements, as shown in Figure 7. It can be seen that the proposed enhancements narrowly avoid existing structures but take up portions of existing parking lots.

The GIS-based floodplain maps are overlaid on the detailed CAD roadway design of the enhancements to investigate floodplain impacts, which is shown in Figure 8. The floodplains are represented by darker shades. It is observed that there are no floodplain impacts in the study area. Similarly overlaying wetlands with CAD roadway design revealed no impact to wetlands.

5.2.1 Benefit and cost analysis. Because a detailed visualization of phase 2A construction was performed requiring three views, four alternatives, and nine reevaluations, it was estimated that the project would be quickly approved with very few scope changes. Therefore, project approval duration and scope changes were considered to be "low" and changed to their fuzzy forms using triangular fuzzy numbers as described earlier.

The benefit and cost analysis for this example is also shown in Table 1. In this case, visualization benefit was attributed to 85% of total benefit. The results indicate that based on the number of views, alternatives, and reevaluations required for visualization, the benefits are equal to cost. Based on the time (in minutes) to complete each view, alternative, and reevaluations the benefit was half of cost. This is because in the preceding case the fact that different views, alternatives, and reevaluations may take varying degrees of time (depending on visualization complexity) was ignored. When this time dependence was considered in the calculation then visualization B/C ratio dropped. This implies that visualization B/C ratio decreases as the CV becomes "lengthier." Please note that we have calculated fuzzy visualization costs in two ways: one based only on the number of views, alternatives, and reevaluations and ignoring the time dependence, and the other based on total time taken (in minutes) to perform the required number of views, alternatives, and reevaluations. To compare POP and non-POP

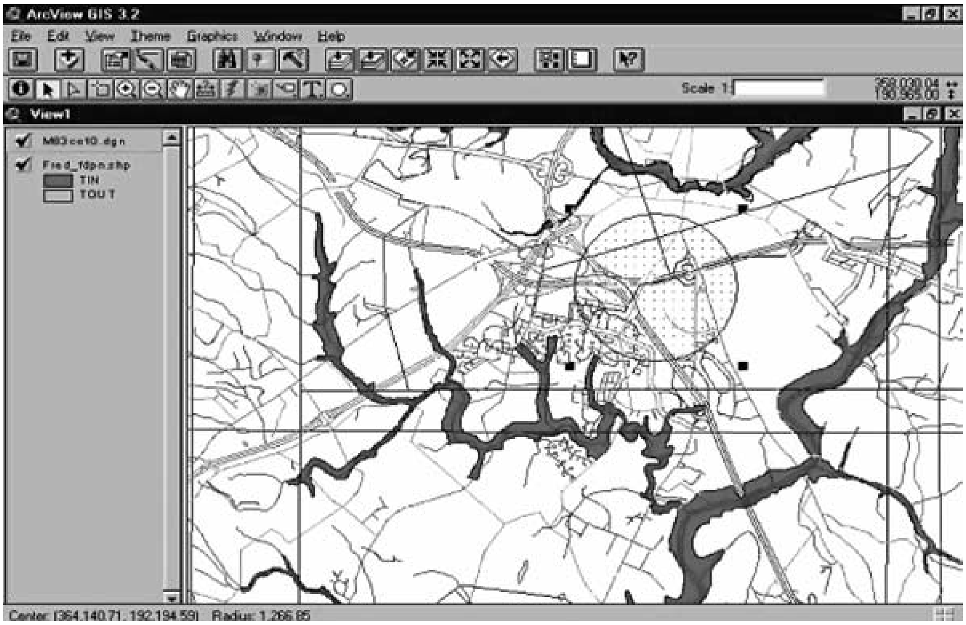

Fig. 8. Using GIS to identify environmental impacts.

costs it is necessary to formulate the fuzzy costs in terms of total time taken to complete the view, alternatives, and reevaluations.

A much higher B/C ratio (2.5) was achieved when POP was used. Also, there was a cost saving of 80% using the POP.

6 CONCLUSIONS

A general fuzzy logic-based approach is developed to calculate visualization costs and benefits of applying CV into highway projects. Benefit is assumed to be a measure of reduction in project approval delay and frequency of scope changes. Additional variables can be considered in future works. Triangular fuzzy forms of benefits and costs are assumed. The confidence intervals of the triangular fuzzy benefits are quantitative measures of subjective perceptions of “high,” “medium,” and “low.”

The developed formulation is applied to two highway projects to calculate the B/C ratio of visualization depending on the level of details of visualization. The results indicate that visualization may or may not be cost effective depending on the level of visualization details to be performed. The fuzzy B/C methodology developed here can also be applied to other similar situations where benefits and costs are not crisp.

A computer code called Projection Option Processor (POP) is developed in Microstation’s BASIC language to automate repetitive tasks for efficient visualization production. The results indicate that CV benefits can far outweigh the cost when POP is used. The proposed work will have a huge payoff because it may act as a yardstick for DOTs before making expensive investments in the CV process. Additional work is needed to investigate the robustness and widespread applicability of the developed procedure as well as to precisely estimate the correlation between visualization complexity and reduction in project delays and scope changes.

ACKNOWLEDGMENTS

The author wishes to thank the five anonymous reviewers whose valuable comments enhanced the quality of the paper. He also wishes to thank Cyrus McCall for his assistance with the development of the visualization procedure and the POP, and Dr. Dusan Teodorovic of Virginia Tech. for introducing many interesting applications of fuzzy logic. It is expected that a graduate student at the Morgan State University will extend the fuzzy logic concept for B/C assessment to other interesting applications. This work was completed at the Center for Advanced Transportation and Infrastructure Engineering Research at the Morgan State University.

REFERENCES

Abkowitz, M., Walsh, S., Hauser, E. & Minor, L. (1990), Adaptation of geographic information systems to highway management, *Journal of Transportation Engineering*, **116**(3), 310–27.

Bailey, K., Grossardt, T. & Brumm, J. (2001), Towards structured public involvement in highway design: A comparative study of visualization methods and preference modeling using CAVE, *Journal of Geographic Information and Decision Analysis*, **5**(1), 1–15.

Bailey, K., Grossardt, T. & Brumm, J. (2002), Enhancing public involvement through high technology, *TR News*, 16–17, May–June 2002.

Carley, R. (1995), Practical uses of visualization technology, *1995 Compendium of Technical Papers*, *Institute of Transportation Engineers*, *65th Annual Meeting*.

Dompere, K. K. (2004), *Cost-Benefit Analysis and the Theory of Fuzzy Decisions*, Springer-Verlag, New York.

Evans, T. A., Djokic, D. & Maidment, D. R. (1993), Development and application of expert geographic information systems, *Journal of Computing in Civil Engineering*, **7**(3), 339–53.

FHWA (2003), *Economic Analysis Primer*, U.S. Department of Transportation, Federal Highway Administration, Office of Asset Management, Washington DC.

Hammad, A., Itoh, Y. & Nishido, T. (1993), Bridge planning using GIS and expert system approach, *Journal of Computing in Civil Engineering*, **7**(3), 278–95.

Jha, M. K. (2001), Using a GIS for automated decision making in highway cost analysis, *Transportation Research Record*, **1767**, 260–7.

Jha, M. K. (2003), Criteria-based decision support system for selecting highway alignments, *Journal of Transportation Engineering*, **129**(1), 33–41.

Jha, M. K. & Lovell, D. J. (1999), Trip generation characteristics of free standing discount stores: A case study, *ITE Journal on the Web*, **69**(5), 85–9.

Jha, M. K. & McCall, C. (2001), Implementing visualization and GIS techniques in highway projects, *Proceedings of the 80th Transportation Research Board (TRB) Annual Meeting*, Paper No. 01-3284, Washington DC.

Jha, M. K. & Schonfeld, P. (2000a), GIS-based analysis of right-of-way cost for highway optimization, *Transportation Research Record*, **1719**, 241–9.

Jha, M. K. & Schonfeld, P. (2000b), Integrating genetic algorithms and GIS to optimize highway alignments, *Transportation Research Record*, **1719**, 233–40.

Jha, M. K. & Schonfeld, P. (2004), A highway alignment optimization model using geographic information systems, *Transportation Research-A*, **38**(6), 455–81.

Jha, M. K., McCall, C. & Schonfeld, P. (2001), Using GIS, genetic algorithms, and visualization in highway development, *Computer-Aided Civil and Infrastructure Engineering*, **16**(6), 399–414.

Jong, J.-C., Jha, M. K. & Schonfeld, P. (2000), Preliminary highway design with genetic algorithms and geographic information systems, *Computer-Aided Civil and Infrastructure Engineering*, **15**(4), 261–71.

Jourquin, B. & Beuthe, M. (1996), Transportation policy analysis with a geographic information system: The virtual network of freight transportation in Europe, *Transportation Research-C*, **4**(6), 359–71.

Kahraman, C. (2001), Fuzzy versus probabilistic benefit/cost ratio analysis for public work projects, *International Journal of Applied Mathematics and Computer Science*, **11**(3), 705–18.

Keister, M. S. & Moreno, D. (2002), Cutting-edge visualization tools, *TR News*, **220**, 9–15, May-June 2002.

Lamm, R., Guenther, A. K. & Grunwald, B. (1994), Environmental impact on highway geometric design in Western Europe based on a geographical information system, *Transportation Research Record*, **1445**, 54–63.

Landphair, H. C. & Larsen, T. R. (1996), *Applications of 3D and 4D Visualization Technology in Transportation*, NCHRP Synthesis of Highway Practice 229.

Larsen, T. R. (1995), Visualization technology: Application and purpose in the public forum, *1995 Transportation Association of Canada (TAC) Annual Conference Proceedings*. Vol. 5-Transportation Technology, Urban Transportation and Intelligent Transportation Systems (ITS) Sessions.

Lee, H. & Clover, P. (1995), GIS-based highway design review system to improve constructability of design, *Journal of Advanced Transportation*, **29**(3), 375–88.

McCall, C. G. (1999), Cost effective computer visualization for highway development, Master's Thesis, Department of Civil and Environmental Engineering, University of Maryland, College Park.

MDOT (1999), *Consolidated Transportation Program*, Maryland Department of Transportation.

Neitzel, L. A. & Hoffman, L. J. (1980), Fuzzy cost/benefit analysis, in P. P. Wang and S. K. Chang (eds.), *Fuzzy Sets: Theory and Applications to Policy Analysis and Information Systems*, Plenum Press, New York, pp. 275–90.

Olivera, F. & Maidment, D. (1998), Geographic information system use for hydrologic data development for design of highway drainage facilities, *Transportation Research Record*, **1625**, 131–8.

Prevedouros, P., Brauer, D. & Sykes, R. J. (1994), Development of interactive visualization tool for effective presentation of traffic impacts to non-experts, *Transportation Research Record*, **1463**, 35–44.

Sarasua, W. A. (1994), A GIS-based traffic signal coordination and information management system, *Microcomputers in Civil Engineering*, **9**(9), 235–50.

Simkowitz, H. J. (1989), GIS: Technology for transportation, *Civil Engineering*, **59**(6), 72–5.

Teodorovic, D. & Vukadinovic, K. (1998), *Traffic Control and Transportation Planning: A Fuzzy Sets and Neural Networks Approach*, Kluwer Academic Publishers, Norwell, MA.

Vukadinovic, K., Teodorovic, D. & Krcmar-Nozic, E. (1999), FMOLP approach to the inland water transportation problem, *Journal of Advanced Transportation*, **33**(3), 295–322.

Zadeh, L. (1965), Fuzzy sets, *Information and Control*, **8**, 338–53.

Zimmermann, H.-J. (1978), Fuzzy programming and linear programming with several objective functions, *Fuzzy Sets and Systems*, **1**, 45–55.