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A Model for Life-Cycle Benefit and Cost Analysis of Highway Projects

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Abstract: Economic analysis is a critical component of a comprehensive project or program evaluation methodology that considers all key quantitative and qualitative impacts of highway investments. It allows highway agencies to identify, quantify, and value the economic benefits and costs of highway projects and programs over a multiyear timeframe. This research was conducted to provide the Indiana Department of Transportation (INDOT) with a uniform economic analysis methodology. The developed economic evaluation model applies the methodology of life-cycle benefit cost analysis to perform economic analysis for proposed highway projects. As a result of this research, an Excel based computer program, the Indiana Highway Economic Evaluation Model (IHEEM), was developed to provide a convenient tool for INDOT personnel to implement the method. A probabilistic model was developed in IHEEM to provide an alternative option for economic analysis in addition to the deterministic model described in the previous chapters. Users of IHEEM can choose either one or both of deterministic and probabilistic methods in economic analysis of highway and bridge improvement projects. In the model, traffic volume and construction cost are treated as random variables with certain statistic characteristics. In the probabilistic process, the random variable is assigned to an appropriate distribution with an estimated coefficient of variance (CV). A simulation process is repeated for a user defined number of times by random numbers to generate an output with statistic ranges and confidence levels.

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***Key words**: Benefit and cost analysis; Construction Cost; Deterministic; Economic analysis; Life-cycle; Probabilistic; Traffic volume distribution.; User cost.*

Introduction

The commonly applied economic analysis methods are based on the estimated mean values of related parameters, such as pavement conditions, construction costs, and user costs. These methods do not consider the uncertainties of the input parameters and therefore are considered deterministic approaches. Different from deterministic approaches, a probabilistic approach includes uncertainties into the economic analysis process. In a probabilistic economic analysis method, some of the cost and benefit items are treated as random variables with estimated statistic characteristics, such as distributions, means, and standard variances. Consequently, a probabilistic economic analysis method will result in such output as life-cycle costs and benefits with possible ranges related to given levels of confidence. In 1998, risk analysis was first incorporated into life cycle cost analysis in pavement design process [1] Since then researchers have applied various methods in probabilistic economic analysis for highway projects. Tighe [2] proposed a probabilistic life-cycle cost analysis method for pavement projects by incorporating mean, variance, and probabilistic distribution of such variables as pavement thickness and unit costs. Reigle and Zaniewski [3] incorporated risk considerations into the life-cycle pavement cost analysis model. Setunge et al. [4] used Monte Carlo simulation in the risk-based life-cycle cost analysis for bridge rehabilitation treatments. Li et al. [5] developed a new uncertainty-based methodology to evaluate highway projects.

Economic analysis is a critical component of a comprehensive project or program evaluation methodology that considers all key quantitative and qualitative impacts of highway investments. It allows highway agencies to identify, quantify, and value the economic benefits and costs of highway projects and programs over a multiyear timeframe. This research was conducted to provide the Indiana Department of Transportation (INDOT) with a uniform economic analysis methodology. The developed economic evaluation model applies the methodology of life-cycle benefit cost analysis to perform economic analysis for proposed highway projects. As a result of this research, an Excel based computer program, the Indiana Highway Economic Evaluation Model (IHEEM), was developed to provide a convenient tool for INDOT personnel to implement the method. A probabilistic model was developed in IHEEM to provide an alternative option for economic analysis in addition to the deterministic model. Users of IHEEM can choose either one or both of deterministic and probabilistic methods in economic analysis of highway and bridge improvement projects. In the model, traffic volume and construction cost are treated as random variables with certain statistic characteristics.

Major Parameters of IHEEM

For input requirements in IHEEM, users need to collect the basic as well as some specific project data depending on the project type. To facilitate inputting, users can opt to choose model defaults for many input items. The economic parameters are defined to reflect users'

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objectives. The model calculates each module of agency costs and user benefits for each year using specified methods. The cost-effective performance measures in terms of Net Present Value (NPV) and Benefit Cost Ratio (BCR) are calculated for the whole analysis period. The model can also be used to conduct risk analysis with the probabilistic analysis approach.

Inflation and Interest

The fundamental principle in engineering economics is that the money has "time" value. On one hand, inflation, which is affected by the decreasing purchasing power of a certain amount of money, erodes the value of money over time. On the other hand, investment of money will also create opportunities to earn more money. In engineering economics, it is usually assumed that all costs and benefits will undergo the same effects of inflation. Thus, inflation is not considered in IHEEM.

Interest is herein used to reflect the different values between the current value of money and the past or future value of money. Interest is typically divided into simple interest and compound interest. When applying simple interest, the calculation will be based only on the original amount of money, while compound interest considers the principal and interest earned before. In economic analysis of highway projects, compound interest, or discount rate, is commonly used to convert the value of money between different points in time. The formula for converting the future value of money to present value is as follows:

$$P = F \times \frac{1}{(1+i)^N} \tag{1}$$

where,
P = Present Value;
F = Future Value;
i = Interest Rate/Discount Rate.

Vehicle and Highway Classifications

In the FHWA vehicle classification system, highway vehicles are classified into 13 types according to the vehicle dimensions and axle layouts. In terms of user costs in highway economic analysis, a practical and reasonable vehicle classification includes only three vehicle groups: passenger cars, single unit trucks, and combination trucks. In IHEEM, the highway vehicles are grouped as follows: 1). Passenger Cars include FHWA vehicle classes 1, 2 and 3; 2). Single Unit Trucks include FHWA vehicle classes 4 through 7; and 3). Combination Trucks include FHWA vehicle classes 8 through 13. In IHEEM, highways are classified as interstate, multilane highway, and two-lane highway.

Analysis Period

Analysis Period is the period of time during which the current and future costs and benefits for the specific project will be evaluated. For the life-cycle benefit cost analysis of highway and bridge projects, the analysis period should be long enough to include the initial construction, routine maintenance activities, and at least one subsequent rehabilitation activity. In common practice of highway economic analysis, the length of analysis period is usually shorter than the facility's service life. FHWA recommends a minimum of 35 years analysis period for pavement projects and a longer period of time for the bridge projects. A 20-year period is used in IHEEM as a default value of analysis period. The IHEEM software provides users an option to change the default value to any user specified value.

Table 1. AVO in IHEEM.

Vehicle Category	AVO
Passenger Cars	1.63
Single Unit Trucks	1.05
Combination Trucks	1.12

Discount Rate

The discount rate is an interest rate used to bring future values into the present when considering the time value of money. It may aslo defined as the interest rate the Federal Reserve charges to loan money to banks. The values of discount rate used by the state highway agencies ranges from 3 percent to 5 percent. IHEEM uses a discount rate of 4% as its default because it is currently used by INDOT in its economic analysis practices.

Average Vehicle Occupancy

The average vehicle occupancy (AVO) is the average number of persons occupying a vehicle. No study has been conducted to determine the AVO values in Indiana. The AVO values derived from the 1995 National Personal Travel Survey (NPTS) as shown in Table 1 were used in HERS. The national average AVO values in the table were also utilized in IHEEM.

Data Analysis

In the probabilistic model, traffic volume and construction cost are the main factors that significantly affect life-cycle costs and benefits. Therefore, they are treated as random variables in the probabilistic economic analysis model. To reveal the statistic characteristics of the two variables, the traffic volume and construction cost data obtained from INDOT were analyzed. The traffic data used in the analysis are the INDOT weigh-in-motion (WIM) data and automated vehicle classifier (AVC) data. From the INDOT construction project database, 1934 highway and bridge projects were selected to examine construction costs of various types of projects.

Traffic Data Analysis

For probabilistic approach, it is essential to find the types of distributions of the observed values of the random variables. The most common type of distribution is the normal distribution. Based on the statistic theory, it is most likely that a variable will follow a normal distribution if the sample size is sufficiently large. In reality, the observed data may not be perfectly normally distributed, but may closely follow a normal distribution to a certain degree. To

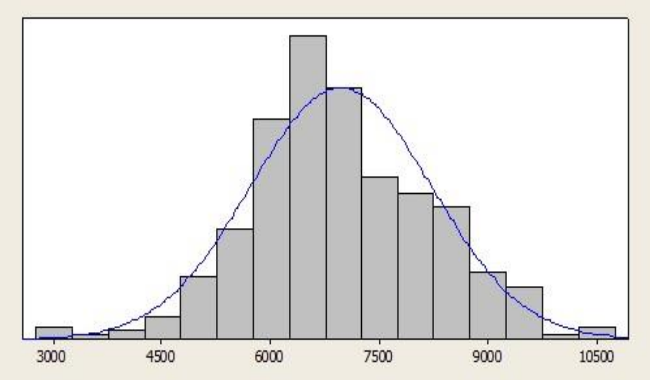


Fig. 1. Histogram of I-64 Traffic Volume.

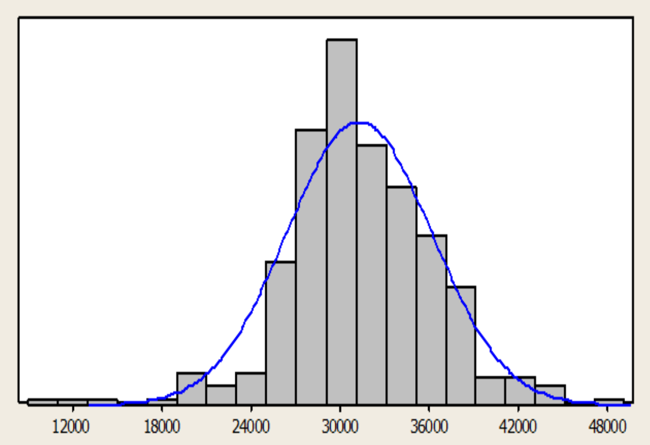


Fig. 2. Histogram of I-74 Traffic Volume.

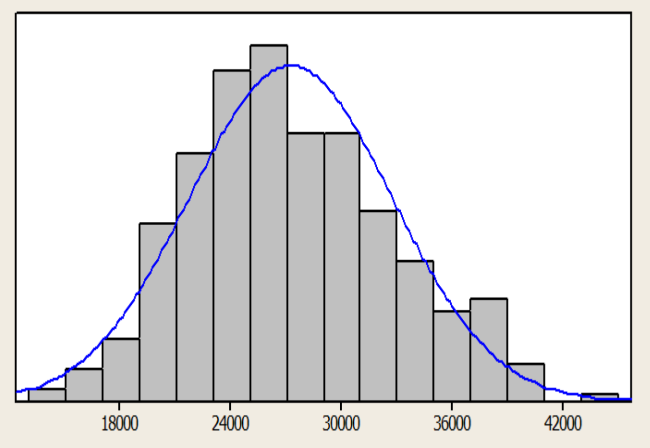


Fig. 3. Histogram of I-80/I-90 Traffic Volume.

determine if a data distribution is normal, a χ^2 (Chi-square) test can be conducted. Through data distribution analysis, it was found that the traffic volumes were normally or near normally distributed. Figs. 1, 2 and 3 are the histograms of traffic volumes on some highways. The figures clearly show that the traffic volume patterns are basically normal distributions.

The mean and standard deviation are the two most important values of a statistic distribution. The mean is the expected value of a random variable, while the standard deviation is a measure of variation or "dispersion" of the observed values from the mean. For a variable with N observed values, x_1, x_2, …, and x_N, the mean, $\bar{X}$, is calculated as:

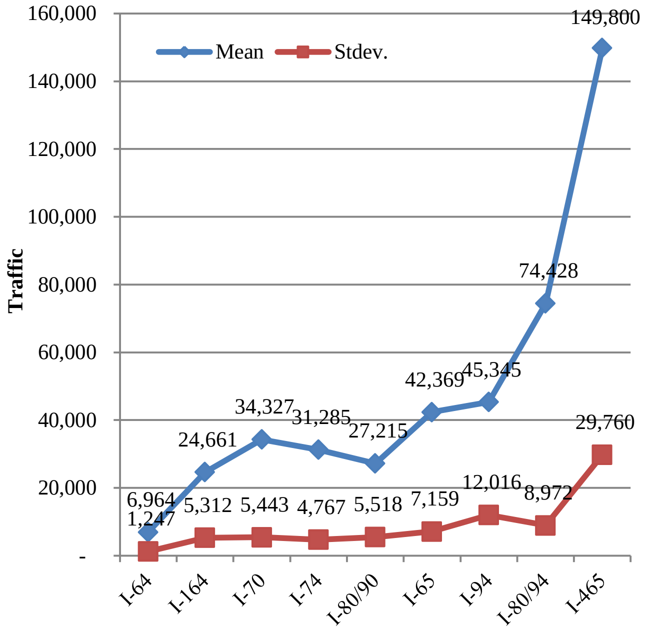


Fig. 4. Relationships between Mean and Standard Deviation of Traffic Volumes.

$$\bar{X} = \frac{\sum_{i=1}^{N} x_i}{N} \tag{2}$$

For a histogram with n intervals, if the frequency of the ith interval is f_i and the central value of the interval is x_i, then the mean of the grouped data is expressed as:

$$\bar{X} = \frac{\sum_{i=1}^{n} x_i f_i}{n} \tag{3}$$

The standard deviation, s, is estimated as:

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{X})^2}{n-1}} \tag{4}$$

Through examining the values of means and standard deviations of traffic volumes on Indiana highways, it was found that the highway sections with higher traffic volumes always had higher standard deviations. As shown in Fig. 4, the clear pattern is that as mean increases the standard deviation increases. With this pattern, it is hard to compare the standard deviations for low traffic volume highways and those for high traffic volume highways because they are affected by the magnitudes of their respective means. In order to effectively measure the dispersion of the traffic volumes, the coefficients of variations (CV) are used in the probabilistic model in place of the standard deviations. A CV is the ratio of the standard deviation to the mean, as shown in the following formula:

$$CV = \frac{s}{\bar{X}} \tag{5}$$

The coefficient of variation (CV) is a normalized measure of dispersion of a probability distribution. The standard deviations of two variables, while both measure dispersion in their respective variables, cannot be compared to each other in a meaningful way to determine which variable has greater dispersion because they may

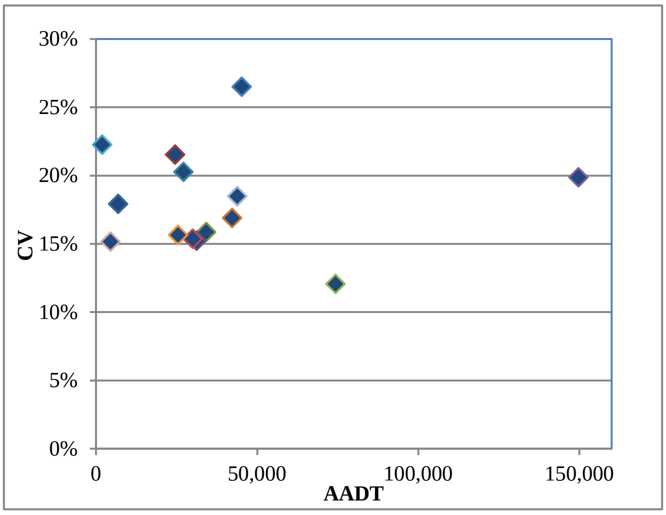


Fig. 5. The Relationship between the CVs and Means of Traffic Volumes.

Table 2. CV Values for Different Types of Roadways.

Roadway Type		Average CV
Interstate	Urban, 4 lanes	21.50%
	Urban, ≥ 6 lanes	19.90%
	Rural, 4 lanes	15.45%
	Rural, 6 lanes	21.30%
Multilane	4 lanes	18.83%
Two-Lane	2 lanes	15.10%

vary greatly in their units and the means about which they occur. Because the standard deviation and mean of a variable are expressed in the same units, the CV (the ratio of standard deviation and mean) cancels the units. The CVs of the traffic volumes can then be compared to each other in a meaningful way. A traffic volume distribution with a smaller CV is less dispersed than one with the larger CV.

Fig. 5 is plotted to illustrate the relationship between the CV values and the means of traffic volumes on Indiana highways. As indicated in the figure, the range of the CV values is much smaller than that of the standard deviations shown in Fig. 4. That is, the effects of means on the dispersions are minimized by the use of the CV values instead of the standard deviations. To improve the accuracy of the probabilistic model, the Indiana traffic volumes were divided into groups according to the types of roadways. The calculated CV values are listed in Table 2. The CV values in Table 2 along with their related means are used in the IHEEM probabilistic model.

Construction Cost Data Analysis

An effort was made to establish the relationship between the construction costs and quantities of work in terms of roadway lengths. The construction costs of a total 1,934 highway and bridge projects were used in this effort. Table 3 presents the values of means, standard deviations, and CVs for highway projects. the results of the cost data analysis in Table 3 indicate that the dispersions of the cost variable are too great for the probabilistic model. Some of the CV values are as great as more than 80%. This is attributed to the fact that the some initial cost items, such as field office cost and traffic control cost, are not fully related to the roadway length. The unit construction cost over a long section of roadway is relatively lower than that over a short section of roadway. Furthermore, any two highway projects under the same category may include very different amounts of work in terms of such items as pavement thicknesses, drainage utilities, shoulder widths, and roadside features.

Because of the large dispersions of the construction costs, the regression method was applied to establish the relationship between construction costs and roadway lengths of highway projects. In the regression analysis, the highway projects were grouped according to the types of work and classes of roadways. The regression functions developed based on the Indiana data are included in Table 4. The R^2 values in the Table 4 are relatively low, indicating the regression relationships between construction costs and roadway lengths are not as strong as desired. However, it is proposed that these regression functions are used for the present model because more detailed construction cost data are needed to improve the regression functions. With the regression functions, the distributions of construction costs for different lengths can be established and applied in the probabilistic analysis process.

The available construction costs for bridge projects do not contain information on bridge dimensions. Therefore, the statistic attributes were calculated without considering bridge lengths and widths. Table 5 shows the statistics of bridge construction costs. As can be seen, the dispersions of the cost distributions are considerably large. Because the bridge cost data lack more detailed information on bridge dimensions, the construction costs cannot be further divided into smaller groups to improve the distributions.

The Economic Analysis Software

An Excel based computer program, the Indiana Highway Economic Evaluation Model (IHEEM), was developed to provide a convenient tool to implement the economic analysis method. The main costs and benefits contained in the model are agency costs and user benefits. Agency costs include initial costs, routine maintenance costs, rehabilitation costs, and remaining value of the facility. User benefits contain travel time savings, vehicle operating cost savings, and crash reduction savings. In addition to the deterministic method for cost and benefit analysis, an alternative probabilistic approach was also developed and incorporated into IHEEM so that the outputs can be expressed as ranges of values with likelihoods of occurrence.

Main Features of the Software

The software includes various modules to process the complicated analysis and calculations. Each module in IHEEM contains default values, formulas, benefit and cost values, traffic attributes, and highway or bridge conditions. The appropriate benefit and cost formulas and values are applied by the program subroutines during the execution of the software. The cost and benefit in each year with the analysis period are expressed in monetary values. Fig. 6 illustrates a typical highway improvement project's cash flow

Table 3. Statistics of Highway Construction Costs.

	Road Type	Number of Projects	Length	Mean	Standard Deviation	CV
Adding Travel Lanes	Interstate	20	all	$14,097,615	$8,075,042	57.3%
	US	12	all	$6,440,629	$3,235,136	50.2%
	State Road	15	all	$5,502,277	$2,495,151	45.3%
HMA Overlay, Functional	Interstate	15	all	$1,069,420	$378,949	35.4%
	US	12	all	$839,291	$699,754	83.4%
	State Road	13	0-5 mile	$470,456	$208,517	44.3%
		29	>5 mile	$363,398	$145,346	40.0%
HMA Overlay, Preventive Maintenance	Interstate	36	0-9 mile	$728,157	$365,521	50.2%
		15	>9 mile	$529,643	$235,064	44.4%
	US	52	0-7 mile	$436,968	$161,434	36.9%
		28	>7 mile	$278,111	$128,015	46.0%
	State Road	102	0-5 mile	$395,904	$222,687	56.2%
		50	5-10 mile	$240,850	$113,434	47.1%
		19	>10 mile	$183,511	$82,293	44.8%
Pavement Replacement	Interstate	4	all	$9,255,304	$3,367,044	36.4%
	US	12	all	$3,957,611	$1,442,561	36.5%
	State Road	12	all	$3,372,095	$1,799,720	53.4%
Road Reconstruction	US	6	all	$2,547,005	$1,727,119	67.8%
	State Road	23	all	$4,701,593	$3,576,239	76.1%
Road Rehabilitation	Interstate	4	all	$3,862,215	$1,578,625	40.9%
	US	9	all	$2,398,783	$1,109,332	46.2%
	State Road	10	all	$2,311,765	$1,884,505	81.5%
Surface Treatment, Microsurface	US	16	all	$120,952	$50,552	41.8%
	State Road	14	all	$138,908	$96,220	69.3%
Surface Treatment, Thin Overlay	State Road	9	all	$112,173	$70,083	62.5%
Surface Treatment, Ultrathin Bonded Wearing Course	US	10	all	$185,575	$74,835	40.3%
	State Road	20	all	$129,463	$54,450	42.1%

Table 4. Regression Functions of Highway Construction Costs

Project Type	Road Type	Number of Projects	Regression	R^2
Adding Travel Lanes	Interstate	20	y=-1E+07ln(x)+2E+07	0.5883
	US	12	y=-3E+06ln(x)+8E+06	0.2998
	State Road	15	y=-2E+06ln(x)+6E+06	0.3369
HMA Overlay, Functional	Interstate	15	y=-4E+05ln(x)+2E+06	0.4149
	US	21	y=-7E+05ln(x)+2E+06	0.6568
	State Road	42	y=-68913ln(x)+503180	0.1124
HMA Overlay, Preventive Maintenance	Interstate	51	y=-4E+05ln(x)+1E+06	0.3248
	US	80	y=-85318ln(x)+502632	0.2177
	State Road	171	y=-1E+05ln(x)+454431	0.2095
Pavement Replacement	Interstate	4	y=-5E+06ln(x)+2E+07	0.6743
	US	12	y=-9E+05ln(x)+4E+06	0.2440
	State Road	12	y=-1E+06ln(x)+4E+06	0.5675
Road Reconstruction (3R/4R Standards)	US	6	y=-1E+06ln(x)+3E+06	0.8032
	State Road	23	y=-3E+06ln(x)+7E+06	0.7253
Road Rehabilitation (3R/4R Standards)	Interstate	4	y=-3E+06ln(x)+9E+06	0.9238
	US	9	y=-9E+05ln(x)+3E+06	0.4822
	State Road	10	y=-1E+06ln(x)+4E+06	0.6959
Surface Treatment, Microsurface	US	16	y=-49743ln(x)+211195	0.5859
	State Road	14	y=-59443ln(x)+243065	0.2428
Surface Treatment, Thin HMA Overlay	State Road	9	y=-38482ln(x)+163162	0.3789
Surface Treatment, Ultrathin Bonded Wearing Course	US	10	y=-98670ln(x)+379591	0.1535
	State Road	20	y=-58836ln(x)+238231	0.1352

Table 5. Statistics of Bridge Construction Costs

Project Type	Road Type	Area	Number of Projects	Mean	Standard Deviation	CV
Bridge Deck Overlay	Interstate	Urban	40	$1,276,756	$667,191	52.3%
		Rural	95	$684,649	$408,050	59.6%
	Multilane	all	50	$897,125	$472,761	52.7%
	Two-Lane	all	167	$508,246	$369,802	72.8%
Bridge Deck Replacement	Interstate	Urban	9	$3,177,581	$2,431,563	76.5%
		Rural	12	$2,501,441	$1,166,525	46.6%
	Multilane	all	12	$1,791,899	$703,824	39.3%
	Two-Lane	all	16	$908,470	$483,530	53.2%
Bridge Maintenance And Repair	Interstate	Urban	9	$2,307,008	$1,544,053	66.9%
		Rural	12	$331,357	$232,045	70.0%
	Multilane	all	12	$120,167	$74,138	61.7%
	Two-Lane	all	16	$194,363	$143,447	73.8%
Bridge Widening	Interstate	Urban	16	$2,938,233	$1,918,029	65.3%
		Rural	2	$1,798,548	$233,356	13.0%
	Multilane	all	1	N/A	N/A	N/A
	Two-Lane	all	5	$466,116	$278,802	59.8%

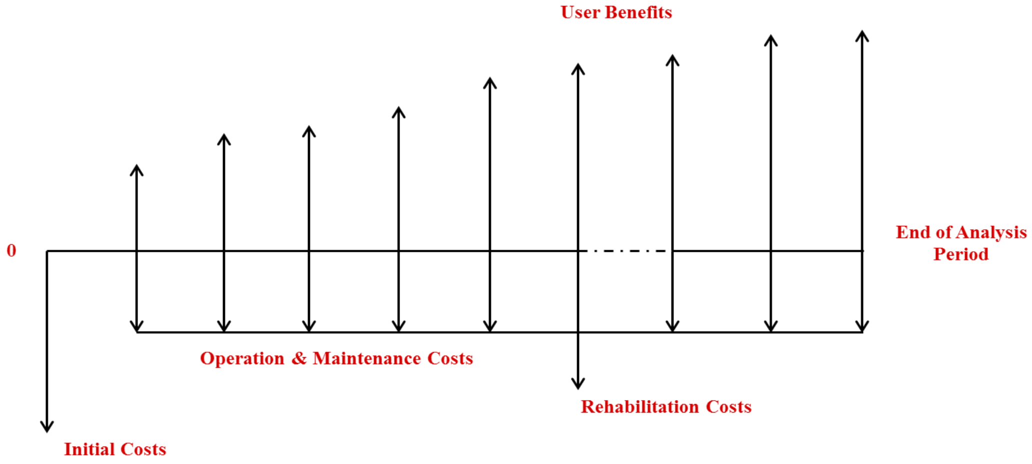


Fig. 6. Cash Flow Diagram.

condition. The benefit values are denoted with the upward arrows and the cost values are denoted with the downward arrows. The benefits and costs in Fig. 6 are in the constant dollar values. In the final step of the calculations, all of the benefits and costs within the analysis period are converted to the present value (the monetary values at year 0) based on the discount rate. The output of the software provides the following economic measures for the improvement project: the life-cycle costs and benefits in terms of Net Present Values (NPV), benefit cost ratio, rate of return on investment, and itemized benefits (travel time savings, VOC savings, and crash cost savings). If the probabilistic method is selected by a user, the ranges of the expected economic measures and the related confidence level will be provided in the output..

Life-cycle costs and benefits are the sum of all the costs and benefits within the analysis period expressed in the present value of money. The benefits are treated as positive values and the costs are treated as negative values. If the total values of the sum of all costs and benefits, which is also called the Net Present Value (NPV), are positive, then the proposed project is economically justified to build. Otherwise, the project is not economically justified to build. The internal rate of return (IRR) is the interest rate at which a zero NPV is reached at the end of the analysis period. An IRR is obtained by changing the interest rate in the economic analysis while other input items remain unchanged. Fig. 7 shows an example of relationship between interest rate and NPV of a highway improvement project. As can be seen from this figure, when the interest rate is 14% the NPV is zero, indicating that the IRR is 14% for this project.

In the Excel-based IHEEM software, there are eight sheets that are interconnected in order to perform the complicated evaluation and computation tasks for the economic analysis. The eight sheets are Input, Parameters, Agency Cost, Travel Time Savings, Vehicle Operating Costs Savings, Crash Reduction Savings, Output-Deterministic, and Output-Probabilistic. All of the eight sheets are integrated so that the software can operate smoothly and produce accurate and meaningful economic analysis output. Through the interface of the input sheet, a use can provide the necessary information for the highway or bridge project to be evaluated. Fig. 8. shows a screen of the input interface sheet of the IHEEM software. As discussed in the previous chapter, many variables are involved in IHEEM. The values of these variables are

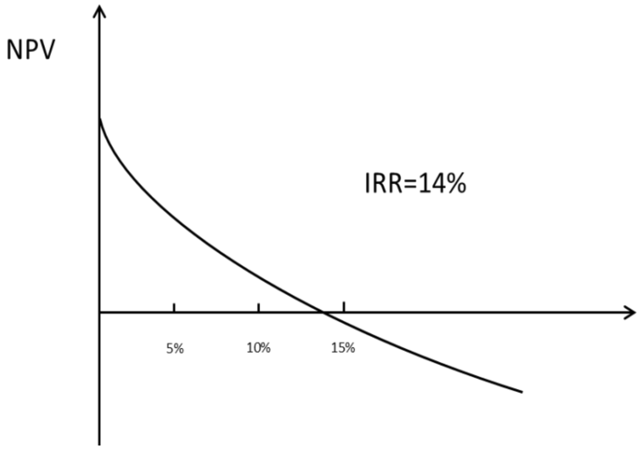


Fig. 7. Internal Rate of Return.

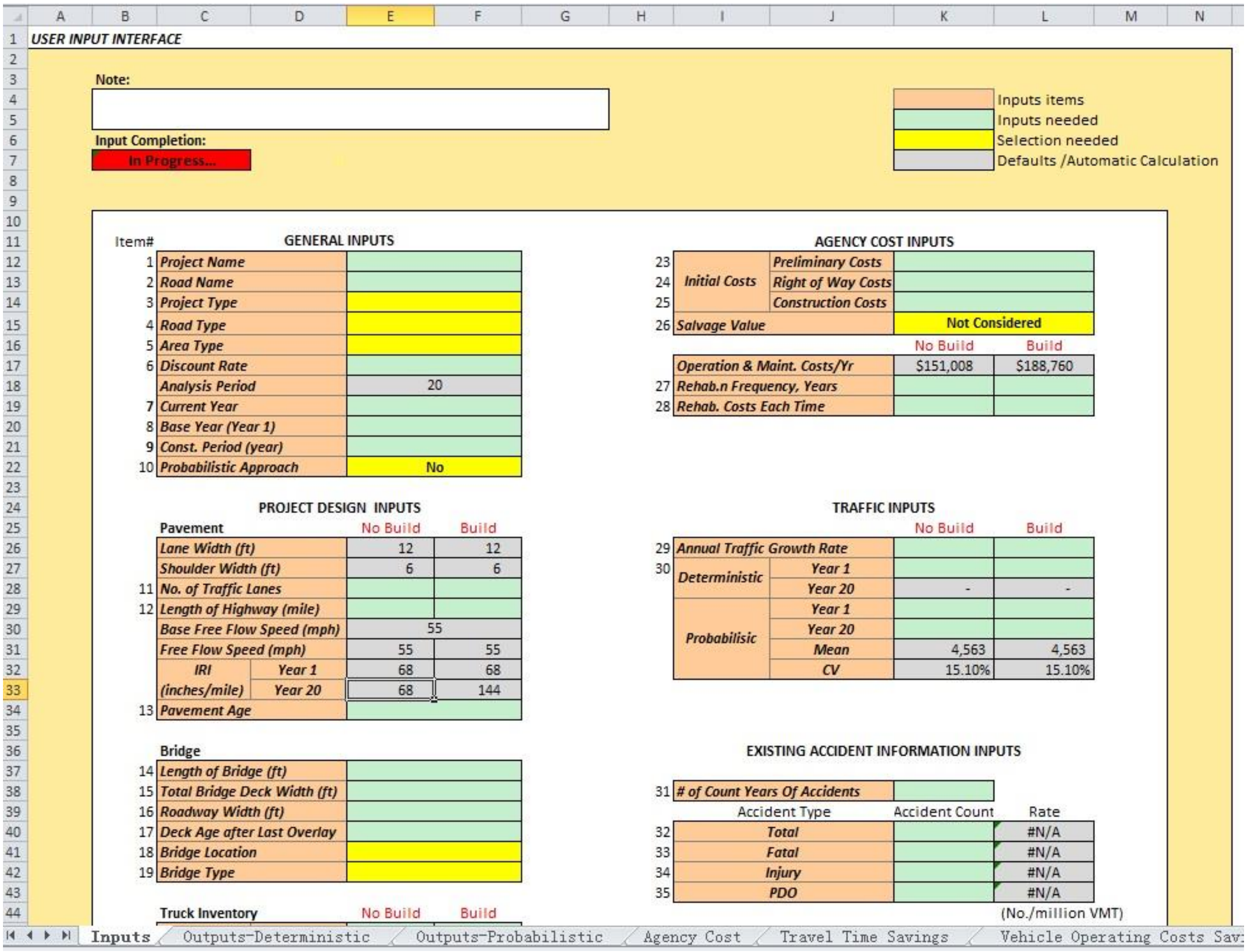
provided to the software either by a user or through the predetermined default values that are incorporated into the software. The default values were obtained from the historical data and recognized reliable results. In many cases, default values are the national or statewide representative or average values. It is possible that users have more specific and reliable values than the default ones. Therefore, the software provides the flexibility for users to overwrite the default values. In HEEM, there are three categories of input as described below.

1. Basic assumption inputs: discount rate; analysis period; and area type (urban or rural).
2. General project-related inputs: project type; road type; construction period; traffic volume; annual traffic growth rate; number of crashes (fatal, injury, and property damage only); free flow speed; facility length; number of lanes; initial costs (preliminary, right of way, construction costs); remaining value; operation and maintenance costs per year; rehabilitation frequency and costs; and truck cargo value.
3. Specific project-related inputs: IRI of pavement; length of bridge; total bridge deck width, length of detour, number of closed lanes, bridge type.

Once all of the required input cells are filled by a user, the software starts to process the evaluations and calculations and the output is then generated almost instantly in the output sheet.

An Application Example

To demonstrate the usage of the software, a sample project was selected to conduct economic analysis with IHEEM. In order to compare the analysis results of IHEEM with those of the Caltrans model, Cal-B/C, a sample project from the Cal-B/C's user guide was adopted. The sample project was a 3.9-mile section of an interstate highway located in Northern California. The proposed project was to add two new lanes to the existing eight lanes to



USER INPUT INTERFACE

Note:

Input Completion:
In Progress...

🟧 Inputs items
🟩 Inputs needed
🟨 Selection needed
⬜ Defaults /Automatic Calculation

GENERAL INPUTS

Item#		
1	Project Name	
2	Road Name	
3	Project Type	
4	Road Type	
5	Area Type	
6	Discount Rate	
	Analysis Period	20
7	Current Year	
8	Base Year (Year 1)	
9	Const. Period (year)	
10	Probabilistic Approach	No

PROJECT DESIGN INPUTS

	Pavement		No Build	Build
	Lane Width (ft)		12	12
	Shoulder Width (ft)		6	6
11	No. of Traffic Lanes			
12	Length of Highway (mile)			
	Base Free Flow Speed (mph)		55	
	Free Flow Speed (mph)		55	55
	IRI (inches/mile)	Year 1	68	68
		Year 20	68	144
13	Pavement Age			

	Bridge	
14	Length of Bridge (ft)	
15	Total Bridge Deck Width (ft)	
16	Roadway Width (ft)	
17	Deck Age after Last Overlay	
18	Bridge Location	
19	Bridge Type	

Truck Inventory	No Build	Build

AGENCY COST INPUTS

23	Initial Costs	Preliminary Costs		
24		Right of Way Costs		
25		Construction Costs		
26	Salvage Value		Not Considered	
			No Build	Build
	Operation & Maint. Costs/Yr		$151,008	$188,760
27	Rehab.n Frequency, Years			
28	Rehab. Costs Each Time			

TRAFFIC INPUTS

			No Build	Build
29	Annual Traffic Growth Rate			
30	Deterministic	Year 1		
		Year 20	-	-
	Probabilisic	Year 1		
		Year 20		
		Mean	4,563	4,563
		CV	15.10%	15.10%

EXISTING ACCIDENT INFORMATION INPUTS

31	# of Count Years Of Accidents	

	Accident Type	Accident Count	Rate
32	Total		#N/A
33	Fatal		#N/A
34	Injury		#N/A
35	PDO		#N/A
			(No./million VMT)

Fig. 8. User Input Interface of IHEEM.

Table 6. Highway Improvement Project Input Data.

Project Information		Proposed Improvement		
Project Type	Adding Traffic Lanes		No Build	Build
Road Type	Interstate	No. of Traffic Lanes	8	10
Area Type	Rural	Length of Highway (mile)	3.9	3.9
Discount Rate	4%	Pavement Age (years)	10	
Analysis Period	20	Annual Traffic Growth Rate	0.015	0.02
Current Year	2007	ADT in Year 1	199,317	199,317
Base Year (Year 1)	2010	Cargo Value	$250,000	$250,000
Const. Period (year)	1	Market Interest Rate	4%	4%
Preliminary Costs	$24,705,000	Analysis Period (years)	20	20
Right of Way Costs	$20,844,000			
Construction Costs	$104,220,000			
Remaining Value	Not considered			
Number of Count Years Of Accidents	3			
Total Number of Accidents	977			
Fatal Number of Accidents	3			
Injury Number of Accidents	230			
PDO Number of Accidents	744			

Table 7. Economic Analysis Results.

Economic Analysis Results	
Life-Cycle Costs	$160.28 Millions
Life-Cycle Benefits	$708.88 Millions
Travel Time Savings	$651.88 Millions
Vehicle. Operating Cost Savings	$-32.48 Millions
Accident Cost Savings	$89.49 Millions
Net Present Value	$548.6 Millions
Benefit/Cost Ratio	4.42
Internal Rate of Return	15.02%
Payback Period	8 years

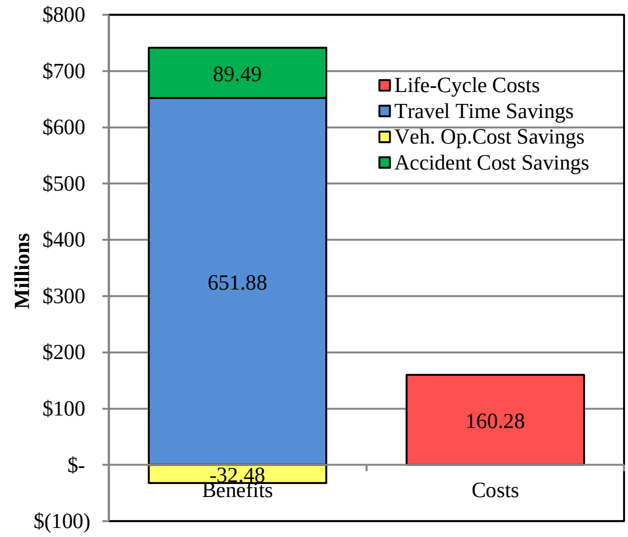


Fig. 9. Expected Benefits and Costs.

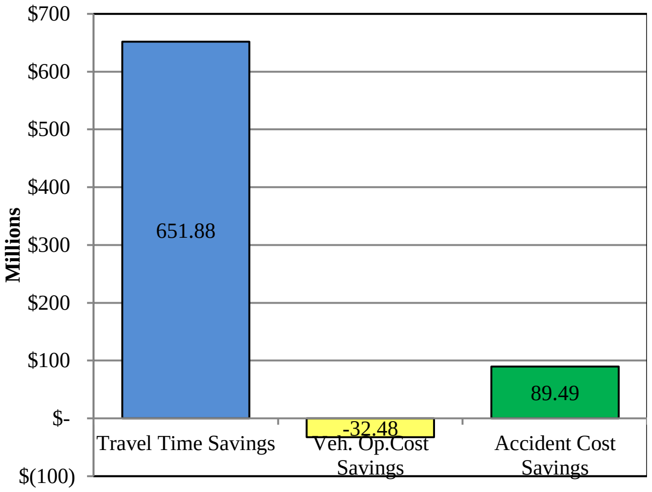


Fig. 10. Itemized Benefits.

increase the traffic capacity of the frequently congested roadway section.

The input information is listed in Table 6. With the input in Table 6, the software generates the deterministic output for this project as shown in Table 7 as well as in Figs. 9 and 10. The bar charts in the two figures are provided in the output sheet to graphically illustrate the itemized benefit and cost values. The output information in Table 7 indicates that if the project is constructed, the expected NPV is $548.7 million and the benefit/cost ratio is 4.42 within the 20-year analysis period. Therefore, this proposed improvement project is economically justified.

As previously indicated, this sample project is an example project in the Cal-B/C user manual. The life-cycle benefit, life-cycle cost, and benefit/cost ratio from Cal-B/C are $454.4 million, 147.7 million, and 3.1, respectively. These values are compared with the corresponding values in IHEEM, which are $708.88 million, $160.28 million, and 4.4. Fig. 11 shows the cost and benefit from both IHEEM and Cal-B/C. As can be seen, the two benefit values differ much more significantly than the cost values. As shown in Fig. 11, the dominating part of the benefits is the travel time savings. Therefore, the considerable difference in results from the two methods might be caused by the calculations of the travel time savings. A noticeable difference in computing VOC is that in Cal-B/C the traffic volumes in a day are divided into peak period and non-peak period, while in IHEEM the daily traffic volumes are

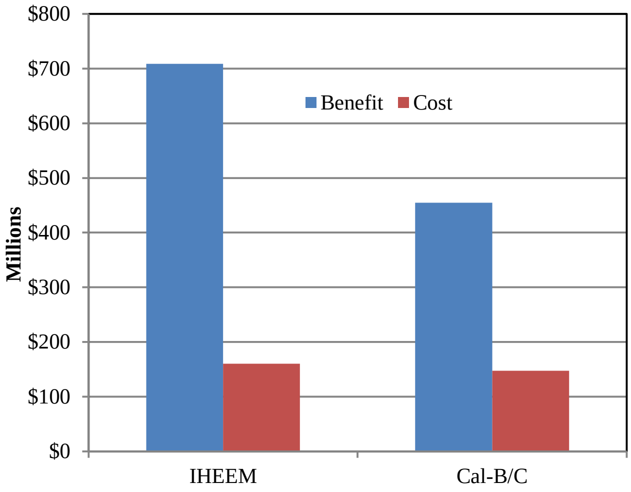


Fig. 11. Comparison of IHEEM and Cal-B/C Results.

converted to the 24 hourly traffic volumes. Use of 24 hourly traffic volumes in IHEEM is obviously more realistic than use of the peak and non-peak periods in Cal-B/C. The different traffic volume distributions would result in huge differences because VOC values are heavily affected by traffic volumes and vehicle speeds. IHEEM considers truck inventory costs in VOC calculations while Cal-B/C does not include truck inventory costs. In addition, in IHEEM most of the parameter values are updated, including crash reduction factor, value of time, fuel cost, and crash cost. Consequently, all of these differences would contribute to the great discrepancies in the analysis results from the two methods.

Monte Carlo Simulation

IHEEM is also capable to perform probabilistic economic analysis if a user desires to do so. In the probabilistic model, the Monte Carlo technique is adopted to simulate the stochastic nature of traffic volume and construction cost in highway projects. The Monte Carlo is used to simulate a process expressed as a mathematic function, $y = (X_1, X_2, X_3, \ldots X_n)$, with a known distribution. In the simulation process, random number seeds (ξ_i, uniformly distributed) are created to assign values to the random variables, $X_1, X_2, X_3, \ldots X_n$, according to the statistic distribution and related attributes. There are many methods for random number generation. In IHEEM, the pseudorandom number generator (PRNG) technique is applied to generate random numbers. The values assigned to the random variables are determined based on the cumulative distribution functions with the statistic attributes such as mean, standard deviation, and CV. In IHEEM, the two random variables are the traffic volume and the construction cost. The random variables with the assign values are then used to perform the benefit and cost analysis. In the IHEEM software, this process is repeated for 100 times. The output values of life-cycle costs and benefits from the 100 iterations can then be organized to form ranges with respect to confidence levels. If necessary, users can change the default number of iterations from 100 to a higher or lower number.

Fig. 12 is the distribution of NPV generated by IHEEM for the same sample project. The NPV distribution can be used by engineers and planners to analyze the likelihood of the expected benefit and cost values in the 20-year analysis period. It is interesting to notice that the mean value of the NPV is $494.4 million, which is different from the deteministic mean of $548.6 million. The range of NPV for any given liklihood can be identified with the NVP distribution curve.

Conclusions

Economic analysis is a critical component of a comprehensive project or program evaluation methodology that considers all key quantitative and qualitative impacts of highway investments. It allows highway agencies to identify, quantify, and value the economic benefits and costs of highway projects and programs over

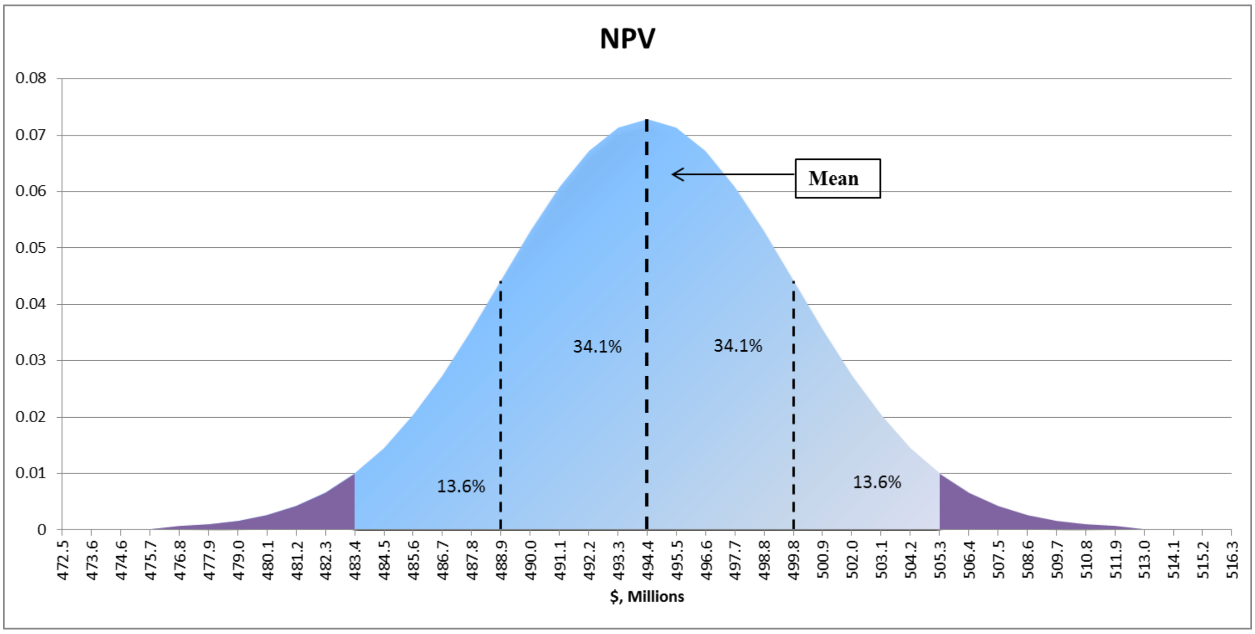


Fig. 12. NPV Distribution Generated by Probabilistic Economic Analysis

a multiyear timeframe. With this information, highway agencies are better able to target scarce resources to their best uses in terms of maximizing benefits to the public and to account for their decisions. It is important in the transportation development process that each transportation alternative is properly evaluated for its costs and benefits during its entire life-cycle. Highway agencies make use of measures such as the net present value of costs and benefits, benefit-cost ratio, or the internal rate of return to compare different competing alternatives. The alternative that gives the highest net present value, benefit-cost ratio or return on investment is selected and is placed to be funded, programmed, and eventually implemented. Cost items in the economic analysis include capital, operating, maintenance and preservation costs while the considered benefits are travel time savings, reduction in vehicle operating costs, and safety benefits. Other benefits such as economic development, improvement in air quality, reduction in energy use, and improvement of the quality of life are not included in the economic analysis framework because these items are considered external and they are difficult to be monetized.

This study was conducted to provide INDOT with a uniform economic analysis methodology. As a result, the Indiana Highway Economic Evaluation Model (IHEEM) was developed with an accompanying software package. The software is an Excel-based tool that completes the complicated economic analysis instantly as soon as a user inputs the required project data. The software contains both a deterministic module and a probabilistic module, so that a user can choose to conduct the economic analysis using either or both of the methods. By properly monetizing project costs and benefits, a consistent economic analysis among different competing highway improvement alternatives can be performed.

As presented in this report, the IHEEM system includes large amount of default values of traffic volumes, agency costs, user benefits and costs, pavement conditions, and bridge conditions. These values are obtained either through data analysis in this study or adoption of previous study results of recognized national or statewide representative values. Efforts were made to use the Indiana established values or to develop the necessary default values with Indiana data. Only if it was impossible to obtain these values pertinent to Indiana, the national values were applied in IHEEM. The software provides flexibility for users to overwrite any default values if project specific data are available. The software can be used to conduct economic analysis for highway and bridge projects. The input requirements indicate it is essential to obtain accurate information on traffic volumes and vehicle speeds, agency costs, maintenance costs, and future rehabilitation costs. Although many default values are provided in the computer program, it is desired to have project specific information in order to produce accurate and meaningful economic evaluation results. As shown in this paper, the output of the economic evaluation is presented with user friendly tables and graphs. It is believed that this software is more suitable to Indiana highway system than other available economic analysis software packages and that this software will be a powerful and convenient tool for evaluating highway and bridge improvement projects.

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