

2013

# An Economic Analysis Methodology for Project Evaluation and Programming

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## Recommended Citation

Jiang, Y., G. Zhao, and S. Li. *An Economic Analysis Methodology for Project Evaluation and Programming*. Publication FHWA/IN/JTRP-2013/17. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2013. doi: 10.5703/1288284315219.

# JOINT TRANSPORTATION RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION  
AND PURDUE UNIVERSITY



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## ACKNOWLEDGMENTS

This research project was sponsored by the Indiana Department of Transportation (INDOT) in cooperation with the Federal Highway Administration through the Joint Transportation Research Program. The authors would like to express gratitude to the INDOT study advisory committee members, John Weaver, Brad Steckler, Roy Numnally, Dwane Myers, Samy Noureldin, and Joe Gustin, for their valuable assistance and technical guidance. The authors also want to express appreciation to Professor Kumares C. Sinha for his suggestions and thoughtful insights.

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<b>1. Report No.</b> FHWA/IN/JTRP-2013/17	<b>2. Government Accession No.</b>	<b>3. Recipient's Catalog No.</b>	
<b>4. Title and Subtitle</b> An Economic Analysis Methodology for Project Evaluation and Programming		<b>5. Report Date</b> August 2013	
		<b>6. Performing Organization Code</b>	
<b>7. Author(s)</b> Yi Jiang, Guangyuan Zhao, Shuo Li		<b>8. Performing Organization Report No.</b> FHWA/IN/JTRP-2013/17	
<b>9. Performing Organization Name and Address</b> Joint Transportation Research Program Purdue University 550 Stadium Mall Drive West Lafayette, IN 47907-2051		<b>10. Work Unit No.</b>	
		<b>11. Contract or Grant No.</b> SPR-3429	
<b>12. Sponsoring Agency Name and Address</b> Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204		<b>13. Type of Report and Period Covered</b> Final Report	
		<b>14. Sponsoring Agency Code</b>	
<b>15. Supplementary Notes</b> Prepared in cooperation with the Indiana Department of Transportation and Federal Highway Administration.			
<b>16. Abstract</b>  <p>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. 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.</p>			
<b>17. Key Words</b> economic analysis, agency costs, user benefits, initial costs, routine maintenance costs, rehabilitation costs, travel time savings, vehicle operating cost savings, and crash reduction savings, probabilistic analysis		<b>18. Distribution Statement</b> No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.	
<b>19. Security Classif. (of this report)</b> Unclassified	<b>20. Security Classif. (of this page)</b> Unclassified	<b>21. No. of Pages</b> 40	<b>22. Price</b>

## EXECUTIVE SUMMARY

### AN ECONOMIC ANALYSIS METHODOLOGY FOR PROJECT EVALUATION AND PROGRAMMING

#### Introduction

The basic concept and methodology of economic analysis were developed at the beginning of 20th century and were applied in different industries. Economic analysis is now commonly applied in the evaluation of the cost efficiency of various types of projects, including highway and bridge 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. With this information, highway agencies are better able to target scarce resources to their best uses in terms of maximizing benefits to the public. 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, and 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 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. While INDOT recognizes the importance of economic analysis in an objective evaluation and selection of transportation projects, there were no uniform guidelines throughout the agency detailing how the analyses have to be performed, or what items should be considered when performing these analyses. This research was conducted to develop a uniform tool for evaluating life-cycle benefits and costs of highway projects.

The results of economic analysis enable highway engineers and planners to systematically and rationally prioritize highway projects in terms of expected benefits and costs. Consequently, the limited highway funds and resources can be allocated in such a manner that maximum benefit will be achieved. Life-Cycle Cost Analysis (LCCA) and Benefit Cost Analysis (BCA) are the two most commonly applied economic analysis methods for determining whether the proposed highway projects are worth undertaking. LCCA is used to evaluate the total cost differences within a facility's life-cycle among several proposed alternative projects. It does not, however, consider the benefits because the assumption is that the resulting benefits are identical among project candidates. By contrast, BCA not only considers the costs, but also the benefits incurred in the future. Thus, LCCA is usually considered a cost subset of BCA. The general research approach of this study was to review the current and past methods and practices of economic analysis of highway projects in Indiana and

in other state highway agencies, identify the cost and benefit items in economic analysis, develop a uniform algorithm for the economic computation, create the database that is necessary for the proposed model, and finally develop an Excel-based software for the economic analysis—the Indiana Highway Economic Evaluation Model (IHEEM).

#### Findings

The following tasks were completed during the course of this study.

- Reviewed the current methods and practices of economic analysis of highway projects in the state highway agencies as well as in other countries. The methods and practices utilized by the state highway agencies and other countries provide useful information on the strength and weakness of various methods. The major software packages for highway economic analyses were examined and compared in detail.
- Developed a consistent cost and benefit evaluation methodology. As the existing methods and the cost and benefit items were reviewed and identified, a uniform economic analysis methodology was then developed and the cost and benefit items for the economic analysis were determined.
- Developed an Excel-based software for the economic analysis methodology. The Excel based software enables INDOT staff to conduct economic analysis with the recommended cost and benefit items. A probabilistic economic analysis approach was included as a possible option.

#### Implementation

The IHEEM system includes a large number of default values for 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 were the national values selected to be included in IHEEM. The software provides flexibility for users to overwrite any default values if project-specific data are available. The output of the economic evaluation is presented as user-friendly tables and graphs.

The software can be used by INDOT to conduct economic analysis for highway and bridge projects. The input requirements indicate that 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 desirable to have project-specific information in order to produce accurate and meaningful economic evaluation results.

It is believed that this software will be a powerful and convenient tool for INDOT to evaluate highway and bridge improvement projects.

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## 1. INTRODUCTION

The basic concept and methodology of economic analysis were developed at the beginning of 20th century and were applied in different industries (*1*). Economic analysis is now commonly applied in the evaluation of the cost efficiency of various types of projects, including highway and bridge projects. 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, internal rate of return, or modified 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. INDOT recognized the importance of economic analysis in an objective evaluation and selection of transportation projects, so a standardized economic analysis model, developed by Joe Gustin, was used to evaluate proposed route transfers. Specifically, the model RTVAL is used for route transfers and the BTVAL is for bridge transfers. However, in order to improve module algorithm, update economic parameters, and expand the capacity to evaluate other types of highway project, this research was conducted to develop a uniform tool for evaluating life-cycle benefits and costs of 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 (*1*). It allows highway agencies to identify and quantify the benefits and costs of highway projects and programs over a multiyear timeframe. The results of economic analysis enable highway engineers and planners to systematically and rationally prioritize highway projects in terms of expected benefits and costs. Consequently, the limited highway funds and resources can be allocated in such a manner that maximum benefit will be achieved. Life-Cycle Cost Analysis (LCCA) and Benefit Cost Analysis (BCA) are the two most commonly applied economic analysis methods for determining whether the proposed highway projects are worth undertaking. LCCA is used to evaluate the total cost differences within a facility's life-cycle among several proposed alternative projects. It does not, however, consider the benefits because the assumption is that the resulting benefits are identical among project candidates. By contrast, BCA not only considers the costs, but also the benefits incurred in the future. Thus, LCCA is usually considered a cost subset of BCA. The general research approach of this study was to review the current and past methods and

practices of economic analysis of highway projects in Indiana and in other state highway agencies, identify the cost and benefit items in economic analysis, develop a uniform algorithm for the economic computation, create the database that is necessary for the proposed model, and finally develop an Excel-based software for the economic analysis.

The following tasks were completed during the course of this study:

- Reviewed the current methods and practices of economic analysis of highway projects in the state highway agencies as well as in other countries. The methods and practices utilized by the state highway agencies and other countries provide useful information on the strength and weakness of various methods. The major software packages for highway economic analyses were examined and compared in detail.
- Developed a consistent cost and benefit evaluation methodology. As the existing methods and the cost and benefit items have been reviewed and identified, a uniform economic analysis methodology was then developed and the cost and benefit items for the economic analysis were determined.
- Developed an Excel-based software for the economic analysis methodology. The Excel-based software enables INDOT staff to conduct economic analysis with the recommended cost and benefit items. A probabilistic economic analysis approach was included as a possible option.

## 2. LITERATURE REVIEW

### 2.1 FHWA Models

The Federal Highway Administration (FHWA) developed two primers for highway planners and analysts. One is called Economic Analysis Primer (*1*) and the other one is Life-Cycle Cost Analysis Primer (*2*). LCCA is an appropriate method when the transportation agencies seek the lowest investments among different alternatives that will achieve the same objectives, or generate the same amount of benefits. BCA is more widely used because it does not require the same resulting benefits of alternative projects. The major steps of BCA method include establishing objectives, identifying constraints and assumptions, defining "before and after" scenarios, estimating life-cycle benefits and costs, and making decisions. In addition to these two primers, FHWA also developed two models for economic analysis of highway projects. One of the methods is the Highway Economic Requirements System (HERS) (*3*), and the other is RealCost (*4*).

#### 2.1.1 HERS

The Highway Economic Requirements System (HERS) is a software package that combines engineering knowledge with applied microeconomics to estimate highway investment when pavement and capacity deficiencies need to be corrected. Through

HERS, those projects whose benefits will exceed initial costs will be selected. The benefits come from several aspects, including the reduction in user costs, highway maintenance costs, and emissions. The overall framework is represented in Figure 2.1. Design of alternatives, estimation of impacts, and project evaluation are three major steps that form the logical structure of HERS. This process is repeated for each highway section in each funding period. The analysis results are organized and summarized at the net-work level or system level. Once the performance level is set, HERS can identify the most cost effective set of highway improvements within the analysis period, and optimize the order to implement the improvements. Therefore HERS is extremely useful when applied in the net-work level analysis. Another feature of HERS is that it provides multiple forms of output documents to present analysis results, including charts, tables, geographical information system (GIS) maps, and reports.

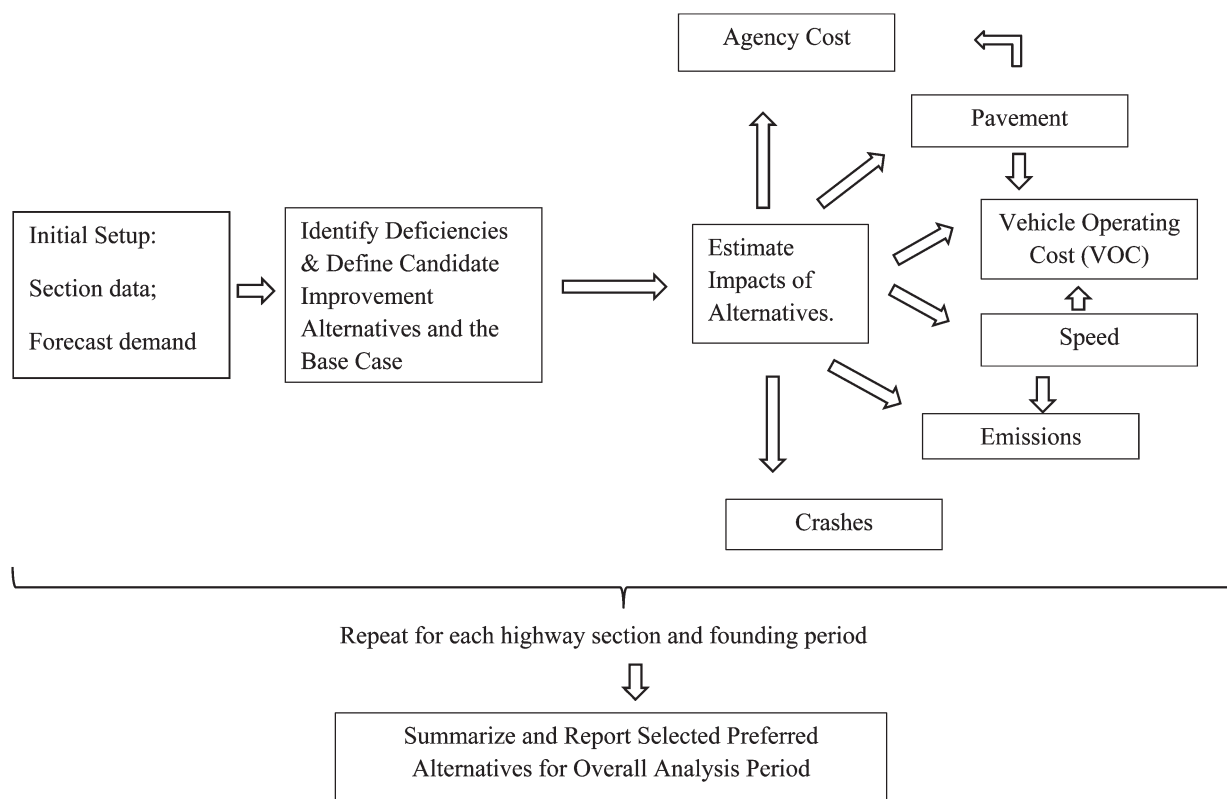
### 2.1.2 RealCost

RealCost is a software package for life-cycle economic analysis of project-level highway projects (5). It is used to evaluate and compare cost-effectiveness of proposed alternative projects and to help users choose the most cost-effective project among the alternatives. As shown in Figure 2.2, the model begins with the development of different alternatives with

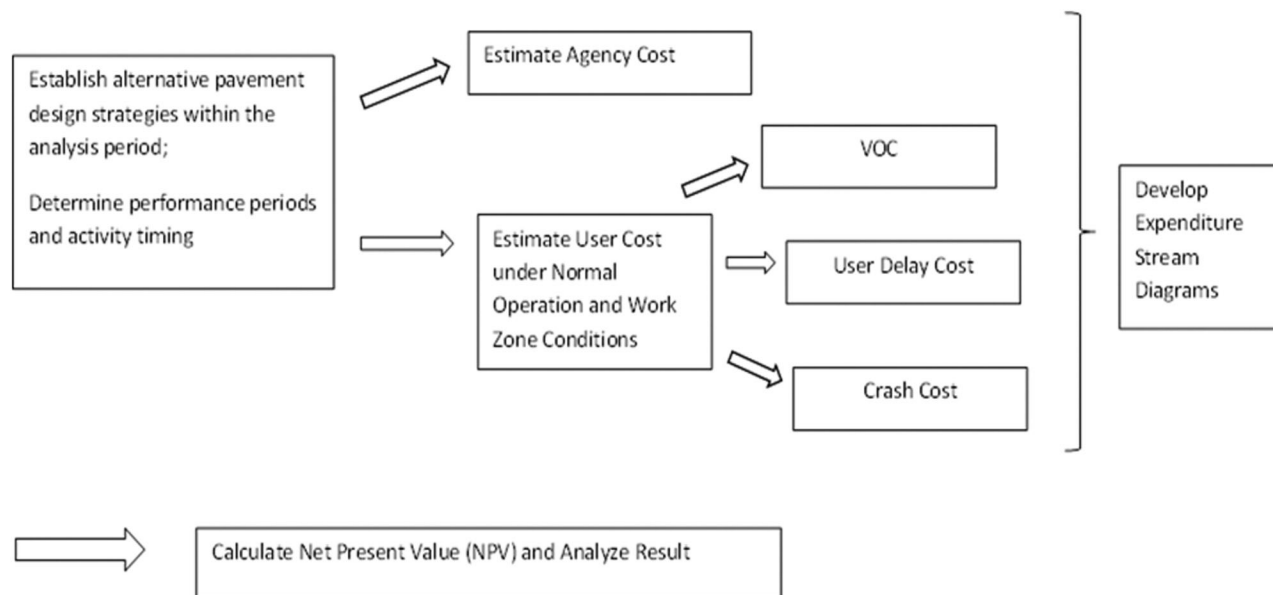
expected activities within the performance period of the proposed alternatives. Such costs as agency costs and user costs in the analysis period are estimated. User costs are estimated under normal operating and work-zone conditions. After developing expenditure stream diagram for all the cost items, the present values of cost items can be calculated for each proposed alternative. Based on the calculated life-cycle costs, the most cost-effective alternative can then be determined.

RealCost considers not only the direct agency costs incurred, but also the user costs caused by workzone operations. RealCost is a Microsoft Excel workbook with additional Visual Basic for Application (VBA) codes. The software has the ability to conduct Monte Carlo simulation during the analysis. The probabilistic functions incorporated in the software provide many of the input items with probabilistic options such as probability distribution, mean and standard deviation. The software also provides two user interfaces, the input dialogs and the worksheets, for users to choose as shown in Figure 2.3. With the two interfaces, users can easily monitor each worksheet to see the analysis process. This will help users to identify input and calculation errors during calculation process.

RealCost applies LCCA principles in its economic analysis. As LCCA assumes equal benefits among alternatives, it cannot evaluate alternatives with unequal benefits, which largely restricts its application in the economic analysis. The other limitation of RealCost is



**Figure 2.1** HERS framework.



**Figure 2.2** RealCost framework.

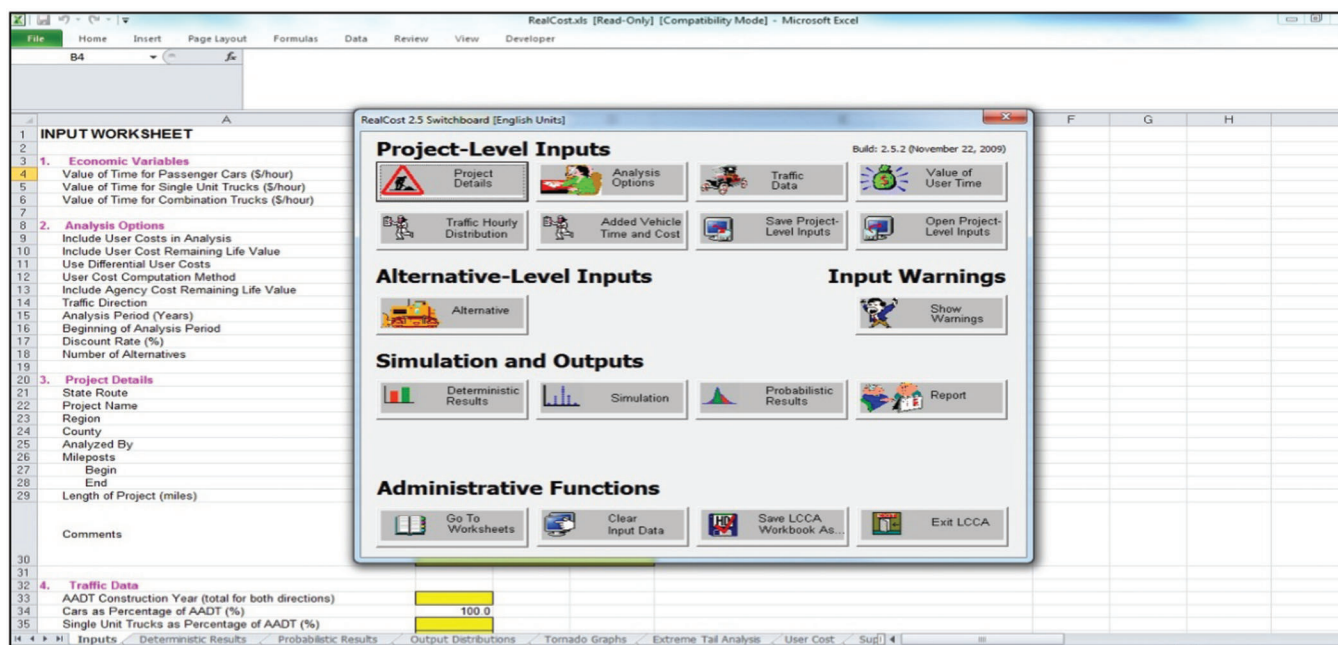
that it is designed to analyze only pavement projects without considering other transportation modes.

## 2.2 AASHTO Model

In 1977, the American Association of State Highway and Transportation Officials (AASHTO) published the Red Book, a Manual on User Benefit Analysis for Highways and Bus-Transit Improvements (6). In 2010, the third edition of the Redbook, User and Non-User Benefit Analysis for Highways (7), was published. This manual provides a comprehensive

framework considering all kinds of economic indicators in the process of economic analysis computation. An Excel-based software application named “Wizard” is attached in the manual to facilitate the implementation of the economic analysis. An example of its user interface is shown in Figure 2.4.

The framework of Redbook is illustrated in Figure 2.5. This model considers not only user benefits, but also indirect benefits or non-user benefits, such as environmental impacts, urban growth impacts, and economic influences. In the beginning of the analysis process, the alternatives and base case are defined and



**Figure 2.3** User interface of RealCost.

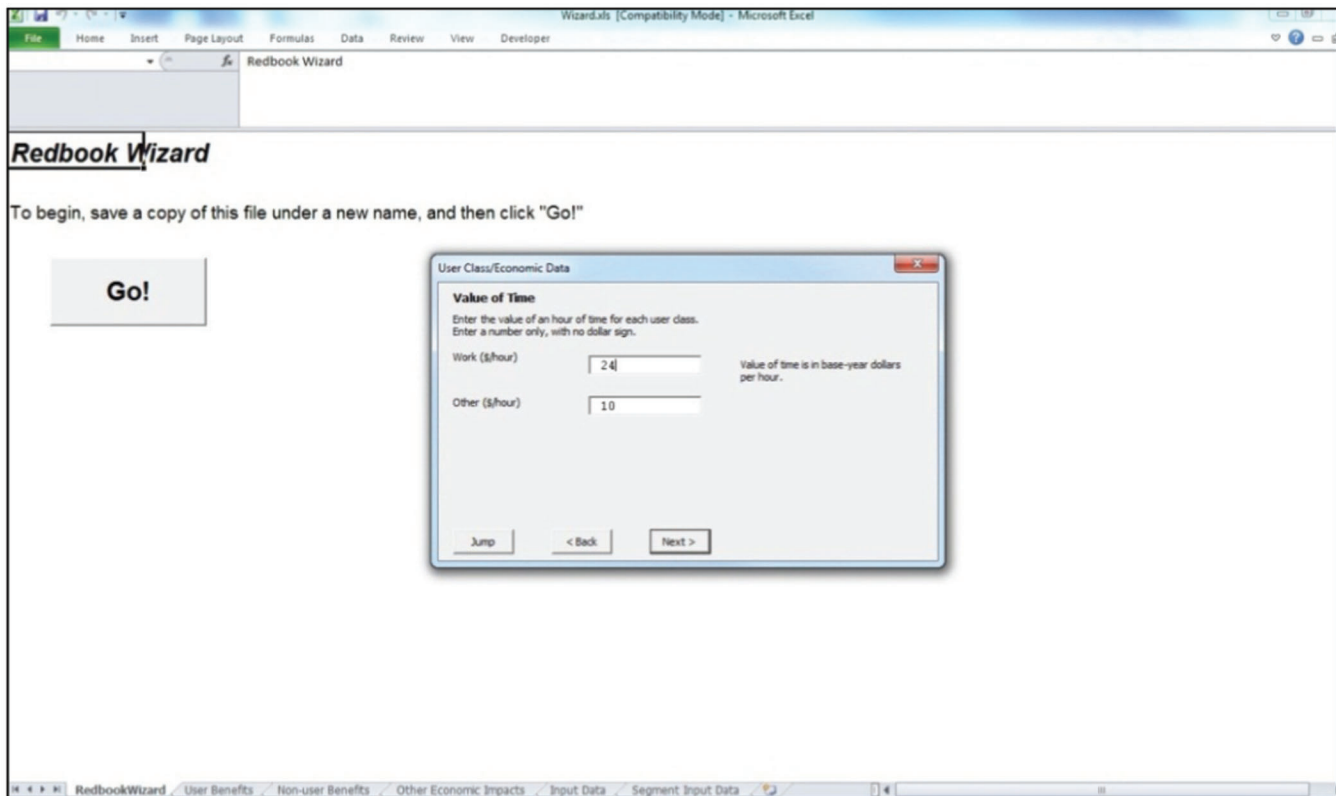


Figure 2.4 User interface of Redbook Wizard.

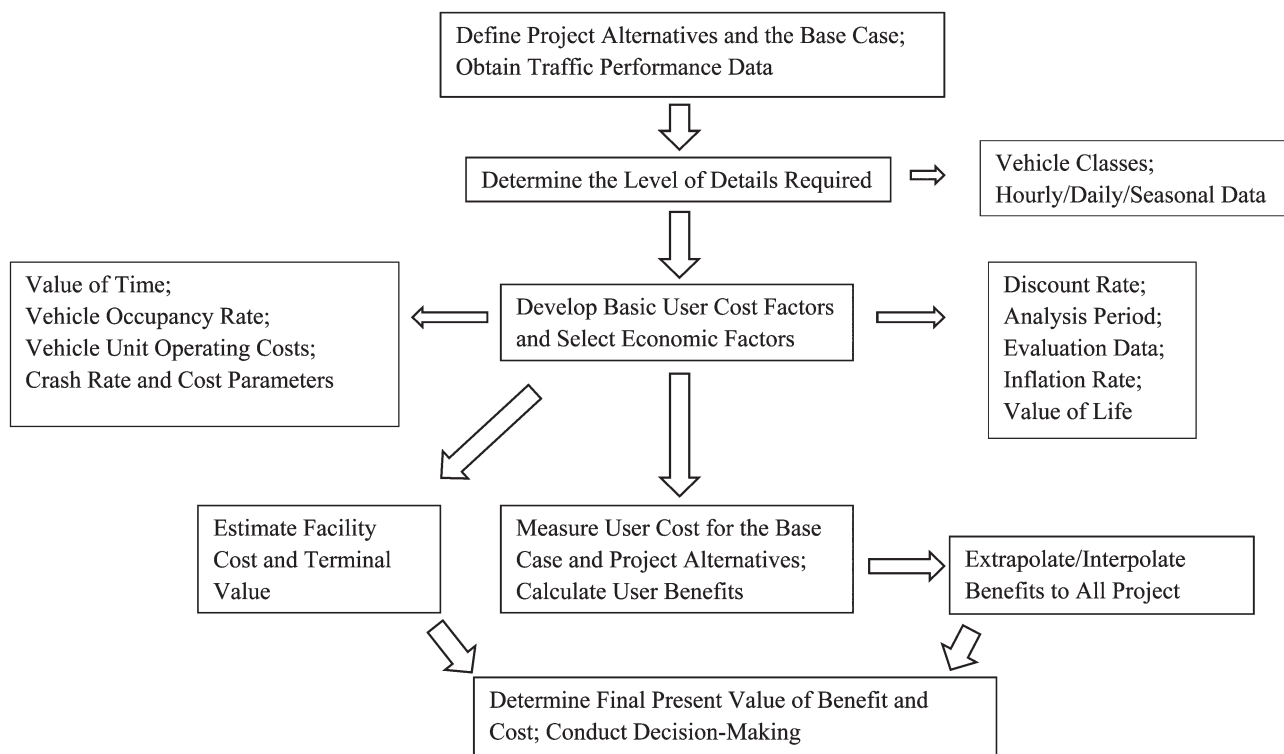


Figure 2.5 Redbook Wizard flow chart.

the level of analytical detail is specified. Then the economic factors are determined, including discount rate and analysis period, value of time and vehicle occupancy rate. The user costs and benefits are calculated with traffic data for the base case and alternatives. This step is followed by expanding benefits to all project years and estimating the terminal value of the facility. The final results are provided in terms of present values of costs and benefits within the service lives.

Although Redbook is a valuable resource for economic analysis of highway projects, its software is not sufficiently comprehensive to incorporate all of the functions contained in the book. The input items required for using the software require users to continuously input project information in a series of input dialogs without the ability to save in the middle of inputting, which is a big inconvenient and time-consuming limitation. The software contains many default values, but the software does not provide options for users to edit or revise the default values even if they have more realistic information.

## 2.3 Other Models

### 2.3.1 MicroBENCOST

The software package for highway projects, MicroBENCOST, was developed by the Texas Transportation Institute (TTI) (8). The software package can be used to analyze various types of highway improvement projects. The main components of MicroBENCOST are shown in Figure 2.6.

As one of the very early transportation models, MicroBENCOST is still a DOS based application as shown by the user interface in Figure 2.7. However, the software is powerful and can be used to analyze various types of transportation projects, including traffic capacity enhancement, intersection and interchange improvement, highway safety improvement, and bridge improvement. The software is flexible and allows users to specify agency costs in specific years, choose traffic

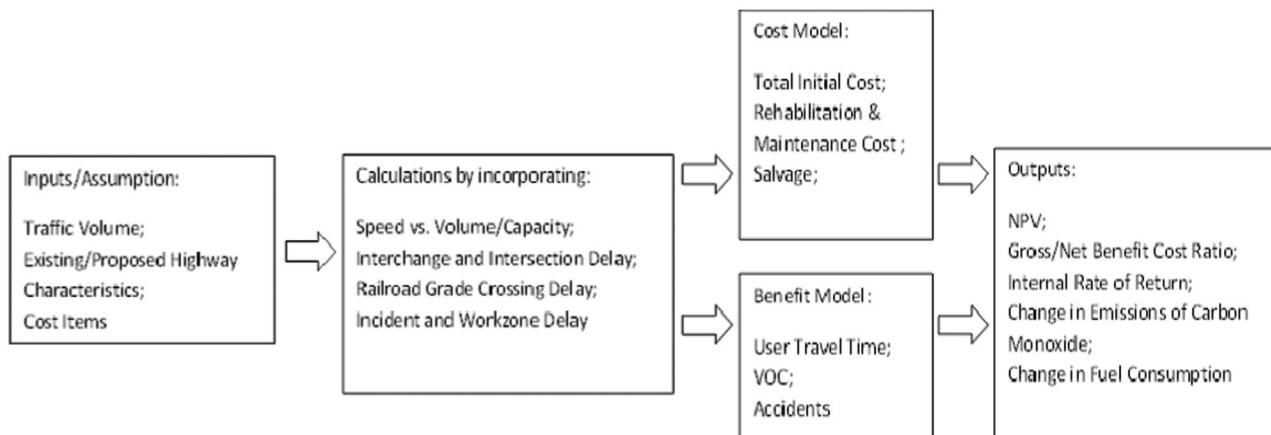
distributions, divide highway projects into segments, and modify default values. In addition, the software can also analyze interchange and intersection delays, railroad grade crossing delays, and incident and work zone delays. The main limitation of this software is that the software is old and some of the methods and formulas in it are not updated. As a result, the calculated results from the software may not be realistic or appropriate for current conditions.

### 2.3.2 Cal-B/C

The first edition of California Life-Cycle Benefit/Cost Analysis Model (Cal-B/C) (9) was developed by California Department of Transportation (Caltrans) in 1999. Cal-B/C is a spreadsheet-based tool. It simplifies the economic analysis process and offers a practical method for doing project-level analysis for California's transportation projects. The software is capable of conducting several common highway and transit projects such as highway capacity expansion, highway operational improvement, transportation management, and rail capacity expansion. Induced traffic benefits can be computed because the model incorporated consumer surplus principles. Users can override any default values of economic or engineering parameters and any calculated values in the middle of analysis. However, since the defaults inside the model are derived from data collected in the state of California, the model may not be fully applied to evaluate other states' projects. The simplified analysis process, such as roughly divided daily traffic values, may lead to unreliable result. Figure 2.8 and Figure 2.9 show a user input sheet and the model components of the software, respectively.

## 2.4 Comparison of Three Existing Software Packages

Three previously discussed software packages, MicroBENCOST, Cal-B/C, and the Redbook Wizard, are compared in terms of types of highway projects analyzed, input requirements, and produced results.



**Figure 2.6** Main components of MicroBENCOST.



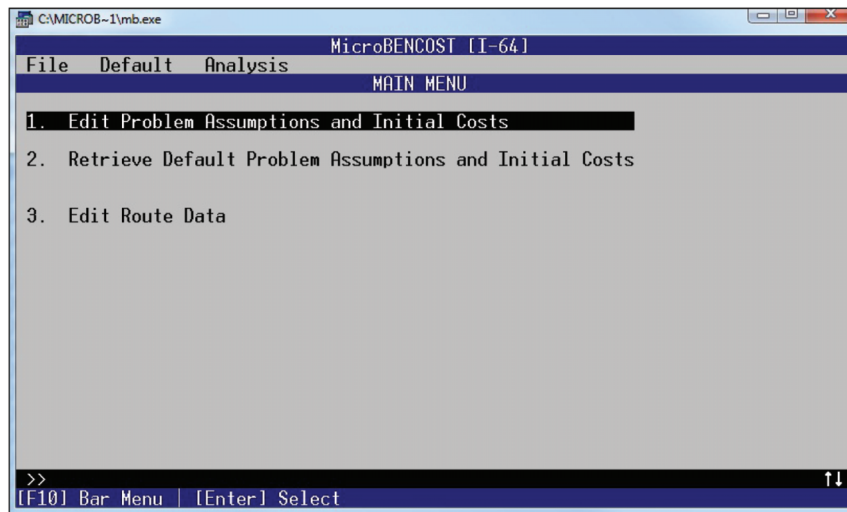


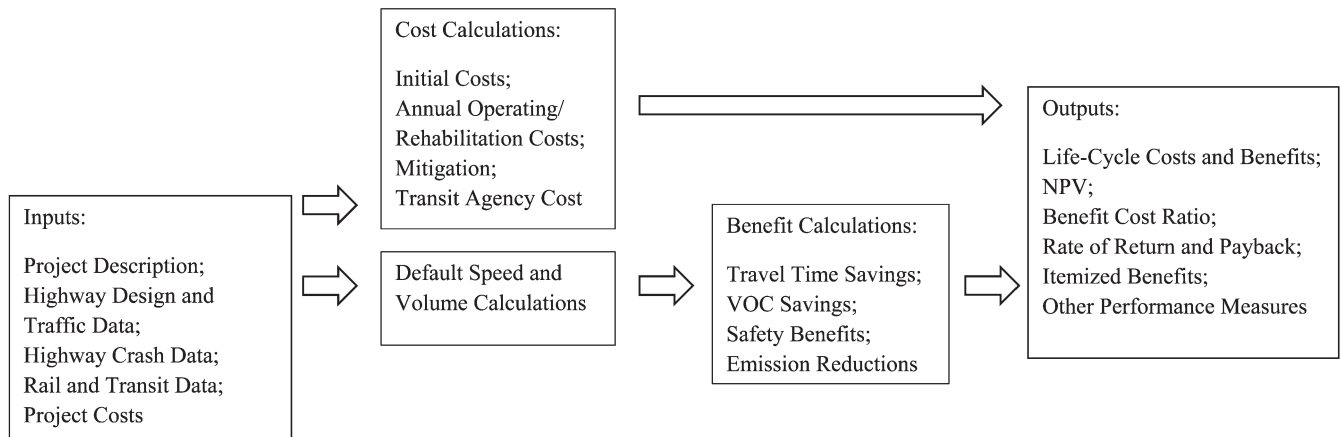
Figure 2.7 User interface of MicroBENCOST.

#### 2.4.1 Types of Highway Projects

Highway improvement projects are the common types for the three software packages to analyze their economic impacts. In addition to highway improvement projects, MicroBENCOST can also analyze bridge projects, safety projects, railroad crossing projects, and high occupancy vehicle (HOV) lanes projects. It also provides options for evaluating the impacts of work zones, incidents, and vehicle emissions. Cal-B/C can handle such projects as rail or

transit projects, highway operational improvement projects, and transportation management systems. The specific projects under these categories include passenger rail, light rail, auxiliary lane, freeway connector, ramp metering, and incident management. The Redbook Wizard has the ability to analyze the following types of projects: adding lanes, traffic control, signal control systems, intelligent transportation systems (ITS), roadside lighting, and pavement preservation or maintenance. The complete lists of project types that the three packages can analyze are

Figure 2.8 User interface of Cal-B/C.



**Figure 2.9** Main Cal-B/C components.

shown in Table 2.1. As can be seen in the table, the Redbook Wizard deals with only highway related projects, MicroBENCOST analyzes both bridge and highway projects, and Cal-B/C evaluate highway, rail, and transit projects.

#### 2.4.2 Input and Output

The input requirements depend on the functions and objectives of each software package. To fully utilize a selected software package, it is necessary to have all the required information on the project evaluated. The basic information on type of highway, type of

improvement, and traffic volume is similar for all three software packages (see Tables 2.2, 2.3, and 2.4). The details of other required information vary among the three packages.

Table 2.2 presents the input data required by MicroBENCOST. The required input includes project information, minor route cross street data, HOV project data, intersection or interchange data, bridge project data, work zone data, incident data, and railroad grade cross data. The partial input items for Cal-B/C are presented in Table 2.3. The input for Cal-B/C includes project feature data, project cost data, and highway design and traffic data. The three types of projects in

**TABLE 2.1**  
**Types of Projects Analyzed by Software Packages**

CAL B/C		Micro BENCOST	Redbook Wizard
Highway capacity expansion	Transportation management system	Bypass projects	Additional lanes
•General highway	•Ramp metering	Added capacity projects	Traffic control
•HOV lane addition	•Ramp metering signal coordination	Intersection/interchange projects	Signal control systems
•HOT lane addition	•Incident management	•Upgrading existed to higher design standards	ITS
•Passing lane	•Traveler information	Highway rehabilitation/pavement improvement projects	Geometric improvement
•Intersection	•Arterial signal management	•Improved horizontal and vertical alignment	Intersection improvement
•Bypass	•Transit vehicle location (AVL)	•Increase lane widths	Roadside or lighting
•Queuing	•Transit vehicle signal priority	•Add paved shoulders	Preservation or maintenance
•Pavement	•Bus rapid transit (BRT)	•Pavement rehabilitation/overlay	
Highway operational improvement	Rail or transit capacity expansion	Bridge projects	
•Auxiliary lane	•Passenger rail	•Functional or structural characteristics improved	
•Freeway connector	•Light rail (LRT)	•Build a new bridge	
•HOV connector	•Bus	•Major bridge rehabilitation	
•HOV drop ramp	•Highway-rail grade crossing	Safety projects	
•Off-ramp widening		Highway railroad crossing projects	
•On-ramp widening		•Railroad grade crossings	
•HOV-2 to HOV-3 conversion		•Warning device upgrade	
•HOV lane conversion		HOV projects	
		Emission option	
		Workzone option	
		Incident option	



TABLE 2.2  
Cal-B/C Design and Traffic Data Required

The Basic Inputs Needed in Every Project		Minor Route Cross Street Data	HOV Project Data	Intersection/Interchange Project Data
Area type	Type of intersection / interchange/structure	AADT, base year	Type of HOV facility	Percent major route volume with interrupted flow
Project category	Number of intersection / interchange/structure	Access control	HOV beginning hour, inbound and outbound direction	Percent minor route volume with interrupted flow
Alternate route switch	Number of lanes, inbound direction	Number of lanes, inbound/outbound direction	HOV ending hour, inbound and outbound direction	Ramp type
Total construction costs	Number of lanes, inbound direction	Median width	HOV operation data	Interrupted flow, end of ramp
Functional class	Number of lanes, outbound direction	Arterial class-design category		
Types of traffic distribution	Median width	Segment length to next intersection		
Initial AADT, base year	Degree curvature			
Average Annual Traffic	Percent no passing zones			
Growth Rate	Additional local AADT, base year			
Access control	Number of work zones			
Segment length	Number of Incidents			
Bridge Project Data		Work Zone Data	Incident Data	Railroad Grade Crossing Project Data
Type of bridge structure		Year of work zone closure	Number of incidents per 100 million vehicle-miles	Type of warning device
Diversion of traffic around bridge		Number of days work zone in place	Number of lanes closed	Number of trains per day
Bridge deck width, inbound/outbound		Number of lanes closed	Average duration of incident	Percent reduction in speed crossing tracks
Approach width greater than bridge width		Beginning hour of work zone closure		Time to lower and raised gates
Bridge length		Ending hour of work zone closure		Average train speed
Diversion distance				Train length

TABLE 2.3  
Cal-B/C Design and Traffic Data Required

Type of Projects		Highway Design and Traffic Data Item				
		HOV Restriction	Highway Free-Flow Speed	Ramp Design Speed	Highway Segment Length	Actual 3-Year Crash Data
Highway Capacity Expansion	General Highway		X		X	X
	HOV Lane Addition	X	X		X	X
	HOT Lane Addition		X		X	X
	Passing Lane		X		X	X
	Intersection		X		X	X
	Bypass		X		X	X
	Queuing		X		X	X
	Pavement		X		X	X
Highway Operation Improvements	Auxiliary Lane		X	X	X	X
	Freeway Connector		X		X	X
	HOV Connector	X	X		X	X
	HOV Drop Ramp	X	X		X	X
	Off-Ramp Widening		X		X	X
	On-Ramp Widening		X		X	X
	HOV-2 to HOV-3 Conversion	X	X		X	X
	HOV Lane Conversion		X		X	X
Transportation Mgmt. Systems (TMS)	Ramp Metering		X		X	X
	Ramp Metering Signal Coordination		X		X	X
	Incident Management		X		X	X
	Traveler Information		X		X	X
	Arterial Signal Mgmt.		X	X		

TABLE 2.4  
Redbook Wizard Input Requirements

Segment Data	Analysis Period	User Classes	Economic and Other Parameters	Construction Management Alternatives
Number of segments	Year construction begins	User class names	Real discount rate	Management alternative names
Name of each segment	Year operation begins	Vehicle types	Inflation rate	Project
Functional classifications	First year of AP	Vehicle occupancy	Financing rate	# of crashes
Improvement types	Last year of analysis period	Value of time	Financing term	Total travel delay during const.
Segment length	Base year	Fuel cost	Insurance cost	Total added VMT on detour route
		Fuel cost as % of operating cost	Traffic growth rate	Vehicle speed on detour route
			Growth of time value	
			Crash costs	
Unimproved Segment User Benefit Data	Improved Segment User Benefit Data			Traffic Conversion Factors
Delay calculation methods	Peak hour, peak direction traffic	Earlier model year		K factor
Daily two way traffic	Peak direction capacity	No-build travel time of later model year		D factor
Peak direction capacity	Free-flow speed	Build travel time of later model year		Weekday-to-week factor
Peak hour traffic	Additional peak hour change in delay	Later model year		Week-to-month expansion factor
Peak direction capacity	Highest exponent on volume	No-build travel time in the model year		Seasonality factor
Free-flow speed	% of traffic of each user class	Build travel time in the model year		
Daily two way traffic	Opening year crashes	Model year		
Peak direction capacity	Annual agency operating costs	Growth rate for delay		
Free-flow speed	No-build travel time in the earlier model year	Terminal value		
Annual number of crashes	Build travel time in the earlier model year			
Annual agency operating costs				

TABLE 2.5  
Outputs from the Packages

CAL-B/C	MicroBENCOST	Redbook Wizard
Life-Cycle Costs Life-Cycle Benefits Net Present Value Benefit/Cost Ratio Rate of Return on Investment Payback Period Additional CO <sub>2</sub> Emissions Additional CO <sub>2</sub> Emissions Itemized Benefits: •Travel Time Savings •Vehicle Operation Cost Savings •Crash Cost Savings •Emission Cost Savings •Person-Hours of Time Saved	Discounted Construction Cost Total Discounted User Benefits Net Present Value Gross Benefit-Cost Ratio Netted Benefit-cost Ratio Internal Rate of Return Discounted Remaining Value Discounted Increase in Maintenance and Rehabilitation Fuel Consumption Savings Fuel Savings, Adj. for Induced Traffic Carbon Monoxide Emission Reduction Carbon Monoxide Reduction, Adj. for Induced Traffic Itemized Benefits: •Delay Savings •Reduction of Vehicle Operating Costs •Reduction of Crash Costs	Capital Costs User Benefits from Operation User Benefits from Construction Total User Benefits Net Benefits Benefit-Cost Ratio Total Operation Delay Total Construction Delay Total Construction VMT Benefits Itemized Benefits: •User Value of Time Benefits •User Operating Cost Benefits •User Crash Reduction Benefits •Agency Operating Benefits

Cal-B/C are highway capacity expansions, highway operational improvements, and transportation management systems. The input requirements for the Redbook Wizard are shown in Table 2.4. The input includes cost, user class, benefit on improved segment and unimproved segment, and traffic information.

As shown in Tables 2.2 through 2.4, many of the general requirements are common or similar, but they differ in the specific items. The output items from the software packages are shown in Table 2.5. All three of the packages produce the expected costs and benefits from the proposed project. However, the individual items of costs and benefits differ in many aspects among the three packages. It was believed that through the review and comparison of the commonly used economic analysis software packages, a comprehensive model framework could be constructed for the State of Indiana.

### 3. THE INDIANA HIGHWAY ECONOMIC EVALUATION MODEL

#### 3.1 Outline of the Model

Through this study, an economic analysis tool entitled the Indiana Highway Economic Evaluation Model (IHEEM) was developed for INDOT to perform economic analysis for highway projects. Figure 3.1 shows the framework containing major steps to perform the economic analysis with IHEEM. For input requirements, 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' 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

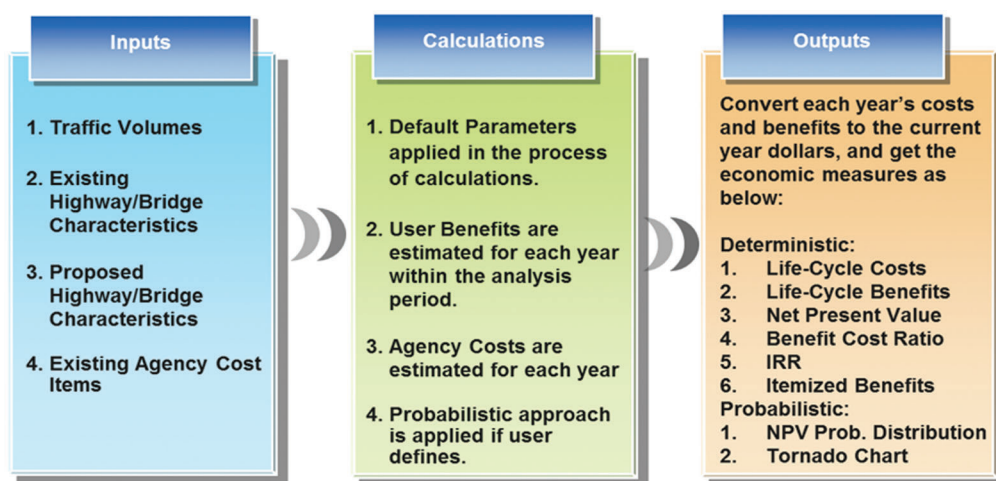


Figure 3.1 Framework of IHEEM.

Modified Internal Rate of Return (MIRR), Internal Rate of Return, 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.

### 3.2 Major Parameters of IHEEM

#### 3.2.1 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.

Interest is herein used to reflect the different values between the current value of money and the past or future value of money. In Indiana highway economic analysis, the interest rate for cost of capital and returns on reinvestment are different across all work types, so IHEEM is using both rates (see discount rate below).

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:

$$P = F \times \frac{1}{(1+i)^N} \quad (3.1)$$

Where,

P = Present Value;

F = Future Value;

i = Interest Rate/Discount Rate.

#### 3.2.2 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.

#### 3.2.3 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. Table 3.1 shows the analysis periods of pavement projects recommended by some states. 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.

#### 3.2.4 Discount Rate

The interest rate used to convert the future costs and benefits in terms of monetary values to the present value is called discount rate. In engineering economic analysis, real discount rate is always used, which excludes the effects of inflation. An appropriate value of real discount rate can be estimated by subtracting the rate of inflation (measured by a general price index like CPI) from a market (nominal) interest rate for government borrowing, which is derived from government bonds. The values of discount rate calculated this way ranges from 3% to 5% historically. Table 3.2 lists the discount rates that are used by some state DOTs, including INDOT. IHEEM uses a discount rate of 4% as its default to reflect the higher opportunity cost of funds. Users can input their own discount rates if they decide to use different values of discount rate.

#### 3.2.5 Average Vehicle Occupancy

The average vehicle occupancy (AVO) is the average number of persons occupying a vehicle. No study has

TABLE 3.1  
Analysis Periods of Pavement Projects in Other States

State	Analysis Period (Year)	State	Analysis Period (Year)
Colorado	40	Indiana	40
Kentucky	40	Louisiana	40
Maryland	40	Utah	30–55
Virginia	50	Washington State	50
West Virginia	30–55		

TABLE 3.2  
Discount Rate Used by Some State DOTs

DOT	Discount Rate	DOT	Discount Rate
California	4.0	Colorado	3.3
Illinois	3.0	Indiana	4.0
Kentucky	4.0	Missouri	2.3
Ohio	2.8	Pennsylvania	6.0
Virginia	4.0	Wisconsin	5.0

TABLE 3.3  
AVO in IHEEM

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

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 3.3 were used in HERS. The national average AVO values in Table 3.3 were also utilized in IHEEM.

### 3.3 IHEEM Application

IHEEM was developed for INDOT to conduct economic evaluations for Indiana highway and bridge improvement projects. The types of projects that can be evaluated with IHEEM include adding traffic lanes, pavement overlay and rehabilitation, bridge deck rehabilitation, and new highway and bridge construction. IHEEM aims to evaluate project-level transportation projects since it can only evaluate one project at a time. The impact of highway projects on the highway network mobility is not considered in evaluating new road constructions. The impact of highway projects on environment, such as air and noise pollution, is not part of the IHEEM evaluations.

## 4. AGENCY COSTS AND USER BENEFITS ANALYSIS

### 4.1 Agency Costs

In the primer of LCCA (2), FHWA specified the following agency cost items that should be considered in highway economic analysis: design and engineering, land acquisition, construction, reconstruction and rehabilitation, and preservation and routine maintenance. In practice, construction costs often include such roadway related costs as utility relocations and railroad crosses. In IHEEM, agency costs are divided into three major groups as shown in Figure 4.1, i.e., initial costs, routine maintenance costs, and rehabilitation costs.

#### 4.1.1 Initial Costs

Initial costs are those associated with initial project activity. Initial costs contain preliminary engineering

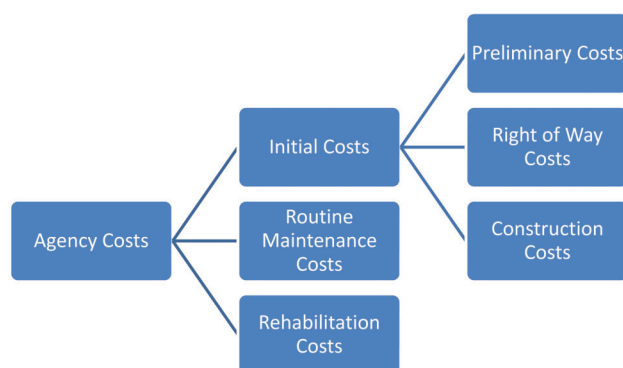


Figure 4.1 Agency costs of IHEEM.

costs, right of way costs, and construction costs. Preliminary engineering costs usually include expenditures of feasibility studies, geodetic and geotechnical investigations, design (engineering plans, drawings, and even bid documents), construction materials, and construction supervision. Right of way costs are the land acquisition costs, which typically include the purchase price, title acquisition, legal costs, and so on. Construction costs include all the expenditures regarding mainline and shoulder pavement, base and subbase, drainage, joint seals, earthwork, traffic control, time-related overhead, mobilization, supplemental work, and contingencies. It was estimated in MicroBENCOST that in the state of Texas construction costs accounted for 87% of total initial costs, while preliminary engineering and right of way were approximately 7% and 6% of total initial costs, respectively.

In order to examine the magnitudes of the agency costs of Indiana highway and bridge projects, the statistics of the total construction costs were computed with 1934 highway and bridge construction projects from INDOT records from 1995 to 2012. The average construction costs in terms of types of projects and types of highways are presented in Tables 4.1 and 4.2 in terms of 2012 dollars. The values in Table 4.1 are the average construction costs and those in Table 4.2 are the average construction costs per unit length of highway sections.

#### 4.1.2 Routine Maintenance Costs

Routine maintenance costs consist of the costs incurred at the condition of facility normal operation and the costs incurred during the maintenance activities. The costs during the normal operation condition include utility charges of the facility, such as the cost of electricity (traffic signals, lighting, and terminals), safety patrols, toll collection, ITS initiatives, and so on. The maintenance costs are associated with the activities of maintaining the facility at an acceptable performance level until rehabilitation is needed. For highway sections, maintenance activities typically include roadside vegetation clearing, ditches and culverts cleaning, patching, and pothole repair. Bridge

TABLE 4.1  
Construction Costs of Pavement Improvement Projects in Indiana

Project Type	Road Type	Area	No. of Projects	Mean
Bridge Deck Overlay	Interstate	Urban	40	\$1,276,756.03
		Rural	95	\$684,648.58
	Multilane	All	50	\$897,124.81
		Two-lane	167	\$508,245.87
Bridge Deck Replacement	Interstate	Urban	9	\$3,177,581.05
		Rural	12	\$2,501,441.04
	Multilane	All	12	\$1,791,898.53
		Two-lane	16	\$908,470.27
Bridge Maintenance and Repair	Interstate	Urban	9	\$2,307,008.00
		Rural	12	\$331,357.22
	Multilane	All	12	\$120,166.60
		Two-lane	16	\$194,362.85
Bridge Widening	Interstate	Urban	16	\$2,938,233.31
		Rural	2	\$1,798,548.41
	Multilane	All	1	N/A
		Two-lane	5	\$466,116.05

TABLE 4.2  
Construction Costs per Mile of Pavement Improvement Projects in Indiana

Project Type	Road Type	No. of Projects	Mean
Added Travel Lanes	Interstate	20	\$14,097,614.90
	US	12	\$6,440,628.67
	State Road	15	\$5,502,277.11
HMA Overlay, Functional	Interstate	15	\$1,069,419.81
	US	12	\$839,291.16
	State Road	13	\$470,455.63
		29	\$363,398.26
HMA Overlay, Preventive Maintenance	Interstate	36	\$728,156.54
	US	15	\$529,642.89
		52	\$436,967.89
		28	\$278,111.37
	State Road	102	\$395,904.04
		50	\$240,850.16
		19	\$183,510.52
Pavement Replacement	Interstate	4	\$9,255,303.93
	US	12	\$3,957,611.24
	State Road	12	\$3,372,094.54
Road Reconstruction (3R/4R Standards)	US	6	\$2,547,004.92
	State Road	23	\$4,701,593.40
Road Rehabilitation (3R/4R Standards)	Interstate	4	\$3,862,214.96
	US	9	\$2,398,782.89
	State Road	10	\$2,311,765.27
Surface Treatment, Microsurface	US	16	\$120,952.23
	State Road	14	\$138,907.71
Surface Treatment, Thin HMA Overlay	State Road	9	\$112,172.96
Surface Treatment, Ultrathin Bonded Wearing Course	US	10	\$185,574.56
	State Road	20	\$129,462.80



maintenance activities usually involve beam repairs, joint cleaning, deck patching, and scour prevention.

#### 4.1.3 Rehabilitation Costs

Rehabilitation means restoring or rebuilding an existing highway facility which is in a state of disrepair. Rehabilitation activities are capable of maximizing the life expectancy of the facility while minimizing the agency and facility user costs. The life-cycle benefit cost analysis needs to consider at least one rehabilitation activity, if the analysis period is well defined. The costs for rehabilitation could be derived from the historical project data, but deciding when to implement rehabilitation is affected by many factors, such as the type, condition, age of the facility, traffic condition, and so on. Due to its high complexity to predict rehabilitation activities, IHEEM provides users with input options to decide when to rehabilitate facility.

#### 4.1.4 Remaining Value

The analysis period of economic analysis is typically shorter than the service life of the facility. Thus, at the end of the analysis period, the worth of the remaining life of the facility is called remaining value or residual value. The measurement of remaining value can be estimated by taking a prorated share of the last construction or rehabilitation cost. The prorated share is based on the ratio between the remaining life and facility service life. For example, a rehabilitation activity provides a service life of 30 years for a highway section. After 20 years, the remaining life of the highway section will be 10 years, and so the remaining value will be calculated by multiplying rehabilitation cost by a ratio of 1/3.

#### 4.1.5 Use of Established Bridge Maintenance and Rehabilitation Costs

Sinha and Labi (10) conducted research on bridge deck maintenance and rehabilitation costs for INDOT and provided the cost estimates. The cost estimates in 2007 dollars and related formulas are presented in Tables 4.3 through 4.6. Bridge deck replacement and rehabilitation costs in Indiana are estimated in terms of bridge length and width as shown in Table 4.3. Deck patching costs in Table 4.4 are related to deck areas.

TABLE 4.3  
Bridge Deck Replacement and Rehabilitation Costs

Type of Rehabilitation	Activity Cost
Deck Replacement	$L \times W \times 35/1000$
Otherwise	$[(\text{Unit Cost 1}) \times L \times W/1000] \times [1 + (\text{Unit Cost 2})]$

NOTE: L = bridge length; W = bridge width.

Unit Cost 1 = unit cost of deck patching; see Table 4.4.

Unit Cost 2 = unit cost of deck reconstruction; see Table 4.5.

TABLE 4.4  
Deck Patching Costs

Extent of Patching	Relative Size of Deck Area	Unit Cost 1 (\$/ft <sup>2</sup> )
Patch % < 15	(Deck Area) < 500	13.74
	$500 \leq (\text{Deck Area}) < 2000$	9.09
Patch % $\geq 15$	(Deck Area) $\geq 2000$	5.73
	(Deck Area) < 500	16.09
	$500 \leq (\text{Deck Area}) < 2000$	10.11
	(Deck Area) $\geq 2000$	8.11

NOTE: L = bridge length; W = bridge width; deck area =  $(L \times W)/9$ .

TABLE 4.5  
Deck Reconstruction Costs

Condition	Unit Cost 2
$[(\text{Unit Cost 1}) \times L \times W/1000] < 100$	1.2331
$[(\text{Unit Cost 1}) \times L \times W/1000] \geq 100$	0.9311

The estimates of deck reconstruction costs are in Table 4.5, while bridge preventive maintenance costs can be estimated with the formulas in Table 4.6. As the formulas and values in Tables 4.3 through 4.6 were developed based on Indiana bridge cost data, they were incorporated into IHEEM in this study.

## 4.2 User Benefits

User benefits are the results of improved highway facility in terms of enhanced user safety and driving comfort, time savings, and reduction in fuel consumption and vehicle wear. The values of user benefits are calculated by comparing the performances of the highway facility before and after the improvement. User benefits are commonly measured by the improved highway performance in travel time savings, vehicle operating cost savings, and crash reduction savings. The savings in monetary values of the improved facility against the facility before it was repaired or rehabilitated are the benefits to the users. In most cases in reality, the user benefits are positive values. However, it is possible that some of the components of the user benefits can be negative values. A negative user benefit can be considered a user cost in the economic analysis process. In IHEEM, user benefits consist of three components, travel time saving, vehicle operating savings, and crash reduction saving, as shown in Figure 4.2.

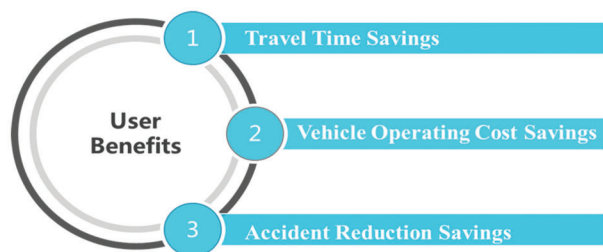
TABLE 4.6  
Preventive Maintenance Cost Models

Action	Cost
Deck Overlay	$48.14 \times (\text{Deck Area})/1000$
Deck Patching	$38.63 \times (\text{Patching Area})/1000$
(Deck Overlay) + (Joint Replacement)	$54.08 \times (\text{Deck Area})/1000$
(Deck Patching) + (Joint Replacement)	$44.57 \times (\text{Patching Area})/1000$
Joint Replacement	$595.42 \times (\text{Joint Length})/1000$

NOTE: Deck area = (Bridge Length)  $\times$  (Total Deck Width).

(Joint Length) = 2  $\times$  (Total Deck Width).





**Figure 4.2** User benefits in IHEEM.

#### 4.2.1 Traffic Volume Distribution and Characteristics

In order to estimate user benefits, it is essential to have accurate information on traffic volumes. INDOT has been collecting traffic data using weigh-in-motion (WIM), vehicle classification devices, and other methods. Therefore, the Annual Average Daily Traffic (AADT) data are available for most of the Indiana highways. In addition, more detailed traffic data, such as hourly traffic volumes and vehicle speeds, can be obtained with additional efforts from weigh-in-motion and vehicle classification data. The traffic volume distributions are essential information for user cost estimation.

**4.2.1.1 Traffic volume distributions.** In the economic analysis, it would not be accurate if only AADT is used to calculate user benefits because traffic volumes vary considerably at different hours within a day. In addition, traffic volumes of different types of vehicles should be separated in estimating user benefits because the time values of these types of vehicles differ significantly. It is thus necessary to obtain hourly traffic volumes and the proportions of different types of vehicles within the traffic volumes.

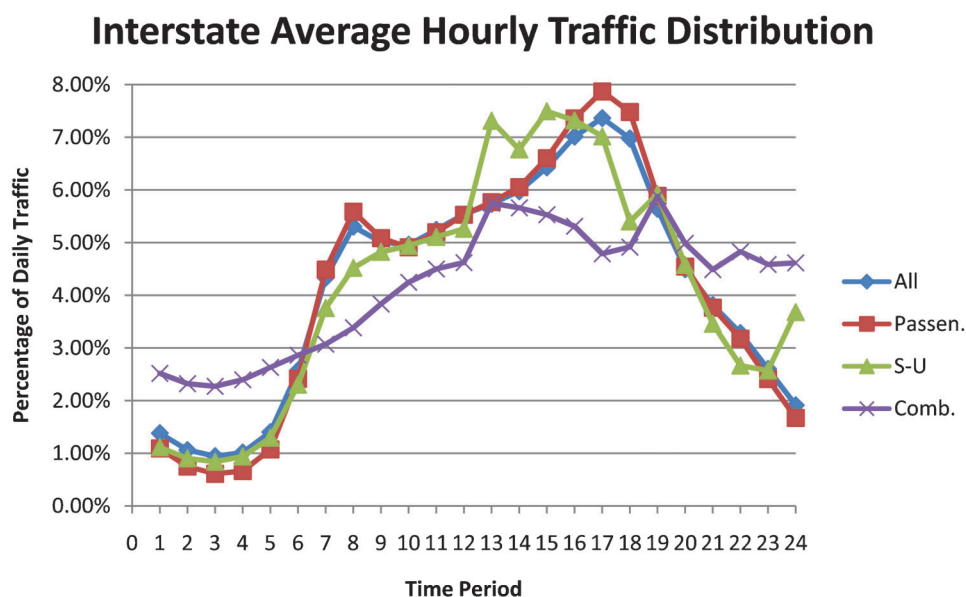
There are 47 WIM stations in Indiana distributed over the state's highway system along 18 interstate highways, 7 US routes, and 8 state roads. Even though the WIM generated reports provide only AADT values, the raw data contain detailed information on vehicle classifications, speeds, and volumes. In order to obtain hourly traffic volumes and vehicle type proportions, a computer program was coded to retrieve the desired information for user benefit computation. The obtained hourly traffic volume distributions are demonstrated as percent of daily traffic volume in each hour in Figure 4.3, 4.4 and 4.5 for interstates, US routes, and state roads, respectively.

Based on the characteristics of the traffic volume distribution, it was found that traffic volume distributions can be reasonably represented by three groups, i.e., interstate, multilane, and two-lane highways as shown in Table 4.7. In IHEEM, the values in Table 4.7 are used to convert AADT into hourly traffic volumes in the appropriate types of highways if hourly traffic volume data are not available for a given highway project.

**4.2.1.2 Traffic forecast.** Traffic volume is not constant, but tends to increase every year. To analyze costs and benefits of highway and bridge projects, it is necessary to estimate traffic volumes within the analysis period. Two methods are often used to estimate the future traffic volumes, one is the annual growth rate method, and the other is the intermediate and forecast volumes method. The annual growth rate method assumes the traffic volume increases by a fixed rate every year, using the following formula:

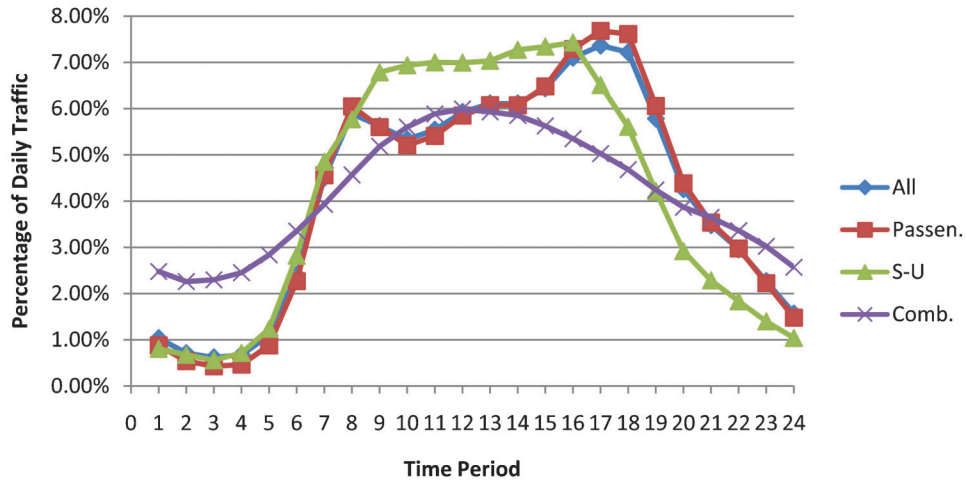
$$ADT_t = ADT_b(1+r)^n \quad (4.1)$$

Where,  
t = year t;



**Figure 4.3** Average hourly traffic volumes on interstate highways.

## US Highway Average Hourly Traffic Distribution



**Figure 4.4** Average hourly traffic volumes on US routes.

b = base year;

r = annual growth rate;

n = number of years between the base year and year t.

The intermediate and forecast volumes method requires the traffic volumes in the base year, intermediate year, and the forecast year. The formula for this method is as follows:

$$ADT_t = ADT_b + d(n)^c \quad (4.2)$$

Where,

$$c = \frac{[ \ln(ADT_f - ADT_b) - \ln(ADT_i - ADT_b) ]}{[ \ln(n_f) - \ln(n_i) ]};$$

$$d = (ADT_f - ADT_b) / [(n_f)^c];$$

$ADT_f$  = traffic volume in forecast year;

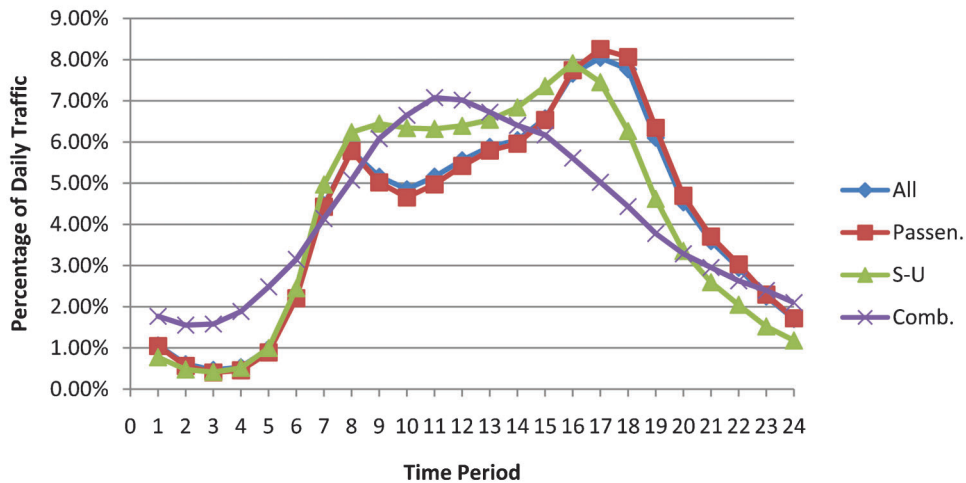
$ADT_i$  = traffic volume in intermediate year;

$n_f$  = number of years between the base year and forecast year;

$n_i$  = number of years between the base year and intermediate year.

In IHEEM, the annual growth rate method is used to estimate future traffic volume because of its simplicity. To use this method to estimate future traffic volumes, AADT values are readily available from INDOT database, and traffic growth rates can be determined using site specific historic traffic volume data.

## Indiana State Road Average Hourly Traffic Distribution



**Figure 4.5** Average hourly traffic volumes on Indiana state roads.

TABLE 4.7  
Average Hourly Traffic Volume Distributions

Hour	INTERSTATE				MULTILANE				TWO LANE			
	All	Auto	S-U	Comb.	All	Auto	S-U	Comb.	All	Auto	S-U	Comb.
0–1	1.48%	0.96%	0.09%	0.43%	1.11%	0.89%	0.05%	0.18%	0.97%	0.68%	0.06%	0.23%
1–2	1.14%	0.68%	0.07%	0.39%	0.68%	0.49%	0.03%	0.16%	0.67%	0.42%	0.04%	0.20%
2–3	1.00%	0.55%	0.06%	0.39%	0.55%	0.36%	0.03%	0.16%	0.63%	0.39%	0.04%	0.20%
3–4	1.06%	0.58%	0.07%	0.41%	0.61%	0.39%	0.04%	0.18%	0.69%	0.38%	0.04%	0.26%
4–5	1.39%	0.84%	0.10%	0.46%	1.02%	0.74%	0.07%	0.21%	1.22%	0.78%	0.11%	0.34%
5–6	2.38%	1.70%	0.17%	0.51%	2.31%	1.89%	0.16%	0.25%	2.39%	1.70%	0.22%	0.47%
6–7	3.92%	3.11%	0.27%	0.54%	4.42%	3.80%	0.31%	0.31%	3.68%	2.71%	0.40%	0.57%
7–8	4.88%	3.96%	0.34%	0.58%	5.81%	5.06%	0.37%	0.38%	5.19%	4.00%	0.53%	0.66%
8–9	4.82%	3.79%	0.37%	0.66%	5.40%	4.57%	0.40%	0.43%	5.17%	3.85%	0.53%	0.79%
9–10	4.88%	3.76%	0.38%	0.73%	5.05%	4.18%	0.40%	0.46%	5.56%	4.17%	0.50%	0.89%
10–11	5.18%	3.99%	0.40%	0.79%	5.28%	4.39%	0.40%	0.49%	5.91%	4.45%	0.51%	0.95%
11–12	5.48%	4.26%	0.42%	0.81%	5.67%	4.77%	0.40%	0.49%	6.46%	4.91%	0.59%	0.96%
12–13	5.88%	4.47%	0.50%	0.92%	5.95%	5.06%	0.41%	0.49%	6.40%	4.93%	0.56%	0.91%
13–14	6.08%	4.69%	0.48%	0.90%	6.02%	5.12%	0.42%	0.47%	6.38%	4.96%	0.57%	0.85%
14–15	6.41%	5.00%	0.52%	0.89%	6.40%	5.50%	0.45%	0.45%	6.64%	5.22%	0.62%	0.80%
15–16	6.89%	5.53%	0.52%	0.85%	7.32%	6.43%	0.47%	0.42%	7.47%	6.03%	0.71%	0.73%
16–17	7.12%	5.84%	0.50%	0.78%	7.73%	6.91%	0.43%	0.39%	7.76%	6.45%	0.67%	0.65%
17–18	6.74%	5.55%	0.42%	0.77%	7.63%	6.91%	0.37%	0.35%	7.03%	5.81%	0.64%	0.57%
18–19	5.81%	4.55%	0.40%	0.86%	6.11%	5.52%	0.27%	0.31%	5.52%	4.55%	0.47%	0.50%
19–20	4.75%	3.66%	0.32%	0.77%	4.48%	4.00%	0.19%	0.28%	4.33%	3.52%	0.36%	0.45%
20–21	4.01%	3.03%	0.26%	0.72%	3.58%	3.16%	0.15%	0.26%	3.57%	2.89%	0.28%	0.40%
21–22	3.50%	2.55%	0.20%	0.74%	2.96%	2.60%	0.12%	0.24%	2.88%	2.30%	0.21%	0.37%
22–23	2.85%	1.97%	0.18%	0.69%	2.26%	1.95%	0.09%	0.22%	2.07%	1.64%	0.14%	0.29%
23–24	2.37%	1.50%	0.20%	0.66%	1.66%	1.40%	0.07%	0.19%	1.39%	1.03%	0.10%	0.26%
Total	100.00%	76.51%	7.24%	16.25%	100.00%	86.12%	6.09%	7.79%	100.00%	77.77%	8.91%	13.32%

#### 4.2.2 Travel Time Savings

When evaluating highway improvement projects, travel time savings usually possesses large percentage of total user benefits, because project activities usually improve the traffic condition of existing highways and relieve traffic congestion, leading to the increase of average speed of vehicles. Although it is possible that the improved operating condition could induce traffic from other highways and result in

slower traffic, it is generally true that the newly repaired highway would most likely reduce travel time. As long as the traffic operates in an acceptable level, total travel time savings within the analysis period could be significant. Figure 4.6 illustrates the overall framework of calculating hourly travel time savings.

The travel time computation steps in IHEEM are described as follows:

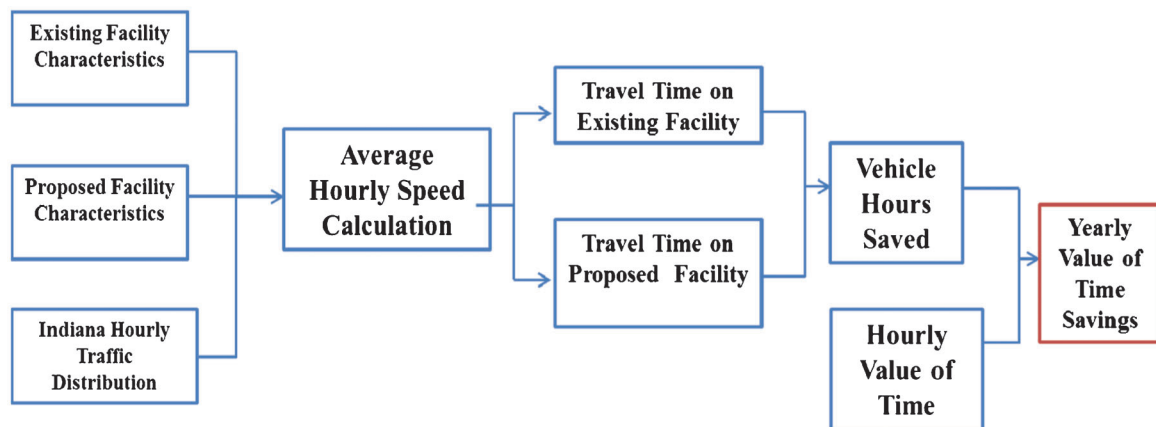


Figure 4.6 Travel time savings.

**Step 1: Determine hourly traffic volume for each vehicle class:.**

$$\text{Hourly Traffic Volume} = \text{AADT} \times \text{Hourly Traffic Distribution} \quad (4.3)$$

**Step 2: Determine hourly average speed for each vehicle class:.**

$$\text{Average Speed} = \text{Free Flow Speed} / \left( 1 + 0.15 \times \left( \frac{V}{C} \right)^4 \right) \quad (4.4)$$

Where:

V=Traffic volume (hourly traffic volume here);  
C=Capacity (number of vehicles per hour per lane × number of traffic lanes).

Note: Equation 4.4 is the Bureau of Public Roads (BPR) formula. Highway capacity values can be found in Highway Capacity Manual 2010.

**Step 3: Calculate travel time per trip for each vehicle class:.**

$$\text{Travel Time} = \frac{\text{Facility Length}}{\text{Average Speed}} \quad (4.5)$$

**Step 4: Calculate hourly travel time savings for each vehicle class:.**

$$\text{Hourly Person Trips} = \text{Hourly Traffic Volume} \times \text{AVO} \quad (4.6)$$

$$\text{Hourly TT Savings} = (\text{TT}_{\text{without}} \times \text{HPT}_{\text{without}} - \text{TT}_{\text{with}} \times \text{HPT}_{\text{with}}) \times \text{VT} \quad (4.7)$$

Where:

TT = Travel time (hours);

Without = The scenario that facility improvement activity is not implemented;

With = The scenario that facility improvement activity is implemented;

HPT = Hourly person trips;

VT = Value of time (\$/person-hour).

**Step 5: Calculate yearly travel time savings for year 1 and the last year of the analysis period:.**

$$\text{Yearly TT Savings} = \sum_{i=1}^{24} \text{Hourly TT Savings}_i \times 365 \quad (4.8)$$

**Step 6: Calculate intermediate yearly travel time savings by interpolation:.**

$$\text{Year } i \text{ TT Savings} = \frac{\text{YTTS}_N - \text{YTTS}_1}{AP - 1} \times (i - 1) + \text{YTTS}_1 \quad (4.9)$$

Where:

YTTS = Yearly Travel Time Savings;

AP = Analysis Period;

N = the last year within the analysis period;

i = the ith year within the analysis period.

**Step 7: Covert all travel time savings into present money value (current year) using Equation 3.1:.**

$$P = F \times \frac{1}{(1+i)^N} \quad (3.1)$$

Where:

P = Present Value;

F = Future Value;

i = Interest Rate/Discount Rate.

To estimate travel time savings, the values of time should be first determined for each type of the vehicles. Various values of time were used by highway agencies in economic analysis of highway projects. NCHRP (11) provided suggested values of time in terms of US dollars in 1970. Table 4.8 lists the values of time for passenger cars and trucks in 1970 dollars as well as in 1996 dollars. The default values of time in MicroBENCOST are presented in Table 4.9. The Office of the Secretary of Transportation (OST) provided values of time in terms of personal, business, mixed, and truck drivers as shown in Table 4.10. The values of time applied in HERS, RealCost, and Cal-B/C are included in Table 4.11. The values of time for Indiana were developed by Gkritza, Labi, and Sinha (12) as shown in Table 4.12. Since values in Table 4.12 were specifically generated for Indiana, they were converted to 2012 dollars and used as default values in IHEEM.

It should be pointed out that the reason for using the published values in Table 4.12 as default values was that they were derived based on Indiana data through an INDOT funded study. However, the software allows a user to overwrite the default values with available more realistic time values.

TABLE 4.8  
NCHRP Suggested Values of Time

Value of Time	Cars	Trucks	
		Single-Unit	Combination
1970	\$3.00	\$5.00	\$5.00
Factor 8/96	3.928	3.928	3.928
Aug-96	\$11.78	\$19.64	\$19.64

TABLE 4.9  
Value of Time in MicroBENCOST (in 1995 dollars)

Auto		Truck							
		2 or 3 Axle Straight Truck				Combination Truck			
Urban	Rural	Driver	Truck Time	Cargo	Total	Driver	Truck Time	Cargo	Total
\$12.17	\$12.17	\$23.48	\$8.89	\$0.04	\$32.41	\$26.30	\$20.31	\$0.33	\$46.94

TABLE 4.10  
OST Values of Hourly Travel Time per Person (in 1995 dollars)

Travel Category	Local		Intercity	
	Low	High	Low	High
Personal	\$6.00	\$10.20	\$10.20	\$15.30
Business	\$15.00	\$22.60	\$15.00	\$22.60
Mixed	\$6.40	\$10.70	\$10.40	\$15.70
Truck Drivers	\$16.50	\$16.50	\$16.50	\$16.50

TABLE 4.11  
Values of Time in HERS, RealCost, and Cal-B/C

HERS (in 1995 \$/veh-hr)	Small Auto \$15.71	Med. Auto \$15.75	4-Tire Truck \$17.84	6-Tire Truck \$19.98	3-4 Axle Truck \$23.66	4-Axle Comb. \$25.49	5-Axle Comb. \$25.24
RealCost (in 1996 \$/veh-hr)	Passenger Cars \$10 to \$13		Single-Unit Trucks \$17 to \$20		Combination Trucks \$21 to \$24		
Cal-B/C (in 2007 \$/per-hr)	Automobiles \$11.6		Trucks \$28.7				

TABLE 4.12  
Values of Time in Indiana (in 2003 dollars)

Type of Vehicle	Value of Time (\$ per person-hr)
Automobile	\$20.57
Single-Unit Truck	\$24.46
Combination Truck	\$29.55

#### 4.2.3 Vehicle Operating Cost Savings

Vehicle operating costs (VOC) are the costs to highway users for operating vehicles on highway, including costs of fuel, oil, tires, vehicle wear, and mileage-related depreciation. VOC savings are the difference between VOC values of a highway section before and after the improvement. An Indiana study by Gkritza, Labi, and Sinha (12) found that the fuel costs of highway users are directly related the total VOC. Based on their analysis, the fuel costs are about 70% of the total VOC in Indiana. Therefore, the total vehicle operating costs can be computed by multiplying the fuel costs by an adjustment factor of 1/0.7, or 1.43. The fuel costs fluctuate constantly, but they are readily available from the US government web sites. Table 4.13 lists the most recent average fuel costs as of September 10, 2012. Using fuel costs to estimate VOC in IHEEM greatly

facilitates the computing process. For trucks, VOC should also include inventory costs to reflect the costs related to cargo inventory with respect to travel time impact.

The process for estimating VOC savings in IHEEM is illustrated in Figure 4.7. The process consists of the following six steps as described as follows:

#### Step 1: Determine hourly fuel cost for each vehicle class:

$$VMT = AADT \times \text{Hourly Traffic Distribution} \times D \quad (4.10)$$

Where:

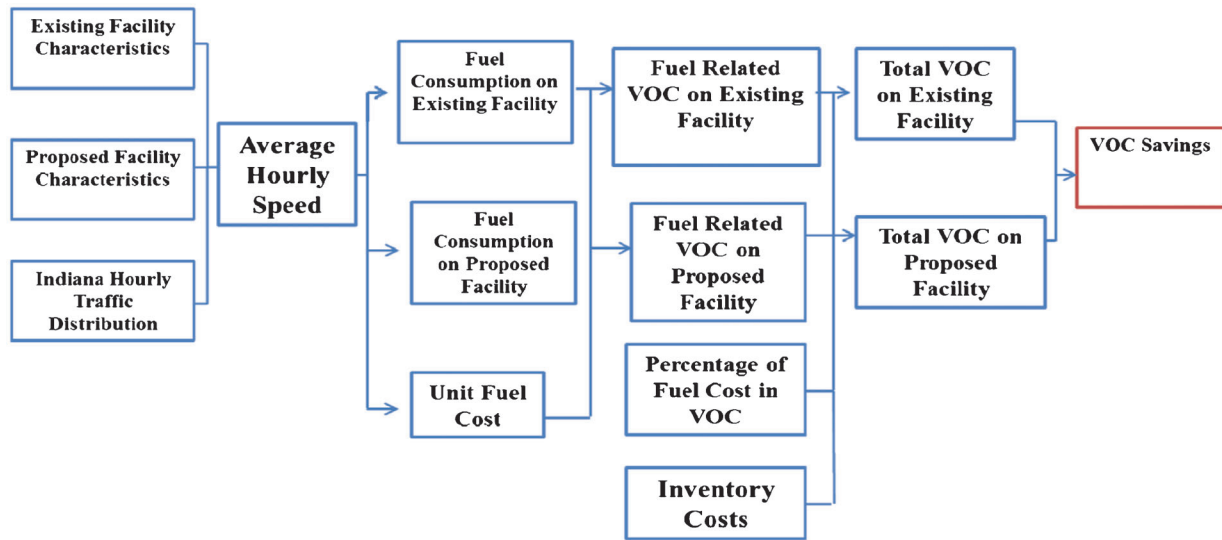
VMT = Hourly vehicle-miles traveled;

D = Distance of facility.

TABLE 4.13  
Average Fuel Costs

Vehicle Type	Fuel (\$/gal)
Automobile	3.847
Single Unit Trucks	4.132
Combination Trucks	4.132

Source: U.S. Energy Information Administration <http://www.eia.gov/petroleum/gasdiesel/>.



**Figure 4.7** Estimating process of VOC savings.

$$\begin{aligned} \text{Hourly Fuel Cost} &= \text{VMT} \times \\ &\text{Fuel Consumption Rate} \times \text{Unit Fuel Cost} \end{aligned} \quad (4.11)$$

**Step 2: Determine truck inventory cost:.**

$$\begin{aligned} \text{Hourly Truck Inventory Cost} &= \text{VMT} \times \text{Cargo Value} \\ &\times \frac{\text{Interest Rate}}{365 \times 24} \times \left( \frac{1}{\text{Average Speed}} \right) \end{aligned} \quad (4.12)$$

**Step 3: Determine hourly total VOC and VOC savings:.**

$$\begin{aligned} \text{Hourly Total VOC} &= \text{Hourly Fuel Cost} \times \\ &\text{VOC factor} + \text{Hourly Truck Inventory Cost} \end{aligned} \quad (4.13)$$

Where:

VOC factor =  $1/0.7 = 1.43$ , this is because fuel cost is 70% of the total VOC.

$$\begin{aligned} \text{Hourly VOC Savings} &= \text{Hourly Total VOC}_{\text{without}} \\ &- \text{Hourly Total VOC}_{\text{with}} \end{aligned} \quad (4.14)$$

**Step 4: Calculate yearly VOC savings for year 1 and the last year within the analysis period:.**

$$\begin{aligned} \text{Yearly VOC Savings} &= \\ \sum_{i=1}^{24} \text{Hourly VOC Savings}_i \times 365 \end{aligned} \quad (4.15)$$

**Step 5: Calculate intermediate yearly travel time savings by interpolation:.**

$$\begin{aligned} \text{Year } i \text{ VOC Savings} &= \\ \frac{\text{YVOCS}_N - \text{YVOCS}_1}{AP - 1} * (i - 1) + \text{YVOCS}_1 \end{aligned} \quad (4.16)$$

Where:

YVOCS = Yearly VOC Savings;

AP = Analysis Period;

N = the last year within the analysis period;

i = the ith year within the analysis period.

**Step 6: Covert every year's VOC savings into present money value using Equation 3.1, that is:.**

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

Where:

P = Present Value;

F = Future Value;

i = Interest Rate/Discount Rate.

It is essential to estimate fuel consumption rates of different types of vehicles in order to compute VCO. In Cal-B/C, the fuel consumption rates listed in Table 4.14 are used. These fuel consumption rates are adopted in IHEEM. As can be seen from the table, the fuel consumption rates are related to vehicle speeds. Therefore, as long as the average vehicle speeds are known, VOC can be calculated through corresponding fuel consumptions

#### 4.2.4 Crash Reduction Savings

It is expected that a highway improvement project will result in not only better highway condition, but also enhanced safety performance. Similar to other user benefits, crash reductions are also measured in terms of the facility's before and after performances. In IHEEM,



TABLE 4.14  
Fuel Consumption Rate in Cal-B/C

Speed (mph)	Auto (gal/veh-mi)	Truck (gal/veh-mi)	Speed (mph)	Auto (gal/veh-mi)	Truck (gal/veh-mi)
5	0.1519	0.2967	43	0.0417	0.1318
6	0.1442	0.2904	44	0.0415	0.1310
7	0.1365	0.2840	45	0.0412	0.1303
8	0.1288	0.2777	46	0.0412	0.1299
9	0.1212	0.2713	47	0.0412	0.1295
10	0.1135	0.2649	48	0.0412	0.1291
11	0.1083	0.2549	49	0.0411	0.1287
12	0.1032	0.2449	50	0.0411	0.1283
13	0.0980	0.2349	51	0.0414	0.1283
14	0.0928	0.2248	52	0.0417	0.1283
15	0.0877	0.2148	53	0.0420	0.1282
16	0.0842	0.2074	54	0.0423	0.1282
17	0.0808	0.2000	55	0.0426	0.1282
18	0.0773	0.1926	56	0.0432	0.1286
19	0.0739	0.1853	57	0.0438	0.1290
20	0.0704	0.1779	58	0.0444	0.1293
21	0.0681	0.1741	59	0.0450	0.1297
22	0.0658	0.1702	60	0.0457	0.1301
23	0.0634	0.1664	61	0.0467	0.1309
24	0.0611	0.1626	62	0.0477	0.1318
25	0.0588	0.1588	63	0.0487	0.1326
26	0.0572	0.1566	64	0.0497	0.1335
27	0.0556	0.1544	65	0.0507	0.1343
28	0.0541	0.1523	66	0.0514	0.1358
29	0.0525	0.1501	67	0.0521	0.1372
30	0.0509	0.1479	68	0.0528	0.1386
31	0.0499	0.1463	69	0.0535	0.1401
32	0.0489	0.1447	70	0.0542	0.1415
33	0.0478	0.1431	71	0.0542	0.1437
34	0.0468	0.1415	72	0.0543	0.1460
35	0.0458	0.1399	73	0.0543	0.1482
36	0.0451	0.1387	74	0.0544	0.1505
37	0.0445	0.1376	75	0.0544	0.1527
38	0.0439	0.1364	76	0.0545	0.1561
39	0.0433	0.1352	77	0.0545	0.1596
40	0.0426	0.1341	78	0.0546	0.1630
41	0.0423	0.1333	79	0.0547	0.1665
42	0.0420	0.1326	80	0.0547	0.1699

the types of crashes include fatal, injury, and property damage only (PDO). Compared to the previous two user benefits modules, calculations of crash reduction savings is relatively straightforward. Figure 4.8 illustrates the steps of calculating crash reduction savings.

The detailed calculation steps of crash reduction savings are described as follows:

**Step 1: Determine yearly vehicle-mile traveled (VMT):**

$$\text{Yearly VMT} = \text{AADT} \times 365 \times D \quad (4.17)$$

Where:

D = Distance of the facility.

**Step 2: Estimate crash rates with and without the project:**

Since there are no crash rates available for Indiana highways, the FHWA (3) established crash rates are used in IHEEM. The FHWA crash rates are listed in Table 4.15.

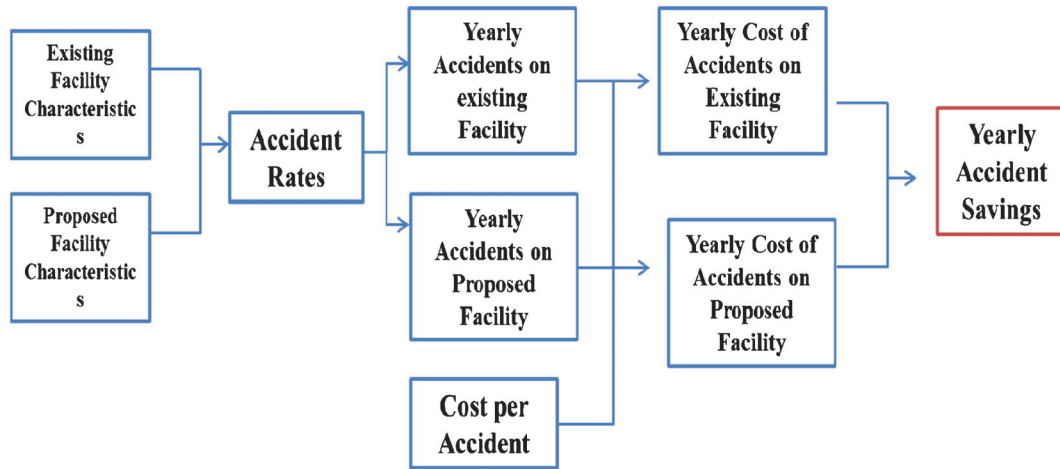
In order to estimate a highway project's impact on safety improvement, a crash reduction factor (CRF) is often used as a measure of the potential crash reduction resulting from the highway condition enhancement. In IHEEM, the Indiana crash reduction factors, as shown in Table 4.16, developed in a previous study by Tarko et al. (13) are used in calculation of the crash reduction savings.

**Step 3: Calculate yearly crash costs for with and without improvement scenarios:**

$$\begin{aligned} \text{Yearly Crash Costs} = \\ \text{Yearly VMT} \times \text{Crash Rate} \times \text{Crash Costs} \end{aligned} \quad (4.18)$$

The actual crash costs should be used in Equation 4.18 if the data are available. Otherwise, the Indiana average crash costs, as shown in Table 4.17, can be used. The crash cost values in Table 4.17 were obtained by





**Figure 4.8** Computation steps of crash reduction savings.

**TABLE 4.15**  
**Crash Rate per Million VMT (3)**

Road Type	Fatal	Injury	PDO
<b>Rural Area</b>			
Interstate	0.0119	0.2430	0.4000
Multilane Highway	0.0158	0.8100	0.6700
Two Lane Highway	0.0240	1.1690	1.0100
<b>Urban Area</b>			
Interstate	0.0120	0.3310	0.6100
Multilane Highway	0.0180	1.8430	2.4650
Two Lane Highway	0.0203	2.4710	4.0533

**TABLE 4.16**  
**Recommended Crash Reduction Factors (13)**

Improvement	Facility	CRF Total	CRF I/F	CRF PDO
Road widening	Rural interstate	0.74	0.75	0.70
Road widening	Urban interstate	0.70	0.75	0.74
Road widening	Rural multilane/two-lane	0.40	0.50	0.30
Road widening	Urban multilane/two-lane	0.30	0.50	0.40
Median construction	Rural facilities	n/a	0.13	0.00
Median construction	Urban facilities	n/a	0.11	0.00
Interchange construction	Rural/Urban facilities	n/a	0.87	0.74
New road construction	Rural interstate	0.34	0.52	0.30
New road construction	Urban interstate	0.24	0.13	0.25
New road construction	Rural multilane/two-lane	0.13	0.10	0.15
New road construction	Urban multilane/two-lane	0.33	0.18	0.34

TABLE 4.17  
Representative Crash Costs

Facility Type	Injury/Fatal	Property Damage Only
Rural Interstate	\$78,717	\$6,822
Rural Other Principal	\$81,866	\$6,822
Rural Minor Arterial	\$81,866	\$6,822
Rural Major Collector	\$81,866	\$6,822
Rural Minor Collector	\$81,866	\$6,822
Rural Local	\$59,300	\$6,822
Urban Interstates	\$54,577	\$6,822
Urban Other Freeways & Expressways	\$50,379	\$6,822
Urban Other Principal	\$50,379	\$6,822
Urban Minor Arterial	\$50,379	\$6,822
Urban Minor Collector	\$50,379	\$6,822
Urban Local	\$44,606	\$6,822

Gkritza, Labi, and Sinha (12). These crash cost values are used in IHEEM as default values, which can be changed by users if more realistic values are available.

**Step 4: Calculate yearly crash reduction savings for year 1 and the last year within the analysis period:**

$$YARS = YARS_{without} - YARS_{with} \quad (4.19)$$

Where:

YARS = Yearly crash reduction savings.

**Step 5: Calculate intermediate yearly travel time savings by interpolation:**

$$\begin{aligned} &\text{Year } i \text{ Crash Reduction Savings} \\ &= \frac{YARS_N - YARS_1}{AP - 1} * (i - 1) + YARS_1 \end{aligned} \quad (4.20)$$

Where:

AP = Analysis Period;

N = the last year within the analysis period;

i = the ith year within the analysis period.

**Step 6: Convert all crash reduction savings into present money value using Equation 3.1:**

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

Where:

P = Present Value;

F = Future Value;

i = Interest Rate/Discount Rate.

### 4.3 Effects of Pavement Condition on User Benefits

User benefits are directly affected by pavement conditions. As the pavement condition deteriorates with time, the user benefits generally decrease. In practice, pavement conditions are measured and represented by surface distress, ride quality, structural capacity, and pavement friction. Ride quality is normally represented by the international roughness index (IRI), present serviceability rating (PSR), or present serviceability index (PSI). The international roughness index is now the most commonly adopted indicator for pavement conditions. IRI was developed by the World Bank in the 1980s. IRI represents the vertical movements of a vehicle as the vehicle travels a unit distance on the pavement. Thus, IRI is an objective measurement and is generally deemed as the more prevalent index to quantify ride quality of pavement. In IHEEM, IRI is used as the indicator for pavement condition. If IRI is not available, PSI can also be used as an input in IHEEM. The software uses the formula developed by Al-Omari and Darter (14) to convert PSI to IRI in the calculation process. The formula is as follows:

$$PSI = 5e^{(-0.26IRI)} \quad (4.21)$$

It is necessary to have the ability of predicting future pavement conditions in order to conduct economic analysis for a highway or bridge project. A set of formulas were developed for predicting pavement conditions in the Indiana Pavement Management System in 2001 as shown in Table 4.18 With the

TABLE 4.18  
Indiana Pavement Condition Prediction Formulas

Road Type	Pavement Type	Formula
Interstate	Flexible	IRI=43+1.8 × AGE+0.0004 × AADT
	JCP	IRI=65+1.9 × AGE+0.0003 × AADT
	Thin overlay	IRI=37+10.4 × AGE+0.0002 × AADT
Non-Interstate	Flexible	IRI=64+4 × AGE+0.0008 × AADT
	JCP	IRI=93+1.1 × AGE+0.0012 × AADT
	Thin overlay	IRI=52+8.1 × AGE+0.0009 × AADT

TABLE 4.19  
Speed Adjustment Factors (from Cal-B/C)

IRI (inches/mi)	Auto	Truck
0	1.00	1.02
25	1.00	1.02
50	1.00	1.02
75	1.00	1.02
100	1.00	1.02
125	1.00	1.02
150	1.00	1.01
175	1.00	1.00
200	1.00	0.98
225	1.00	0.95
250	1.00	0.92
275	0.99	0.89
300	0.98	0.86
325	0.97	0.83
350	0.96	0.81
375	0.95	0.78
400	0.94	0.76
425	0.93	0.73
450	0.92	0.71

formulas in the table, the pavement conditions represented by IRI are predicted in terms of pavement age and AADT. As these formulas were developed for Indiana highways, they are readily applicable for economic analysis in IHEEM.

Pavement roughness affects vehicle speeds and fuel consumptions. In Cal-B/C, the adjustment factors for vehicle speeds and fuel consumptions related to IRI are used to reflect the effects of pavement roughness. The adjustment factors for vehicle speeds and fuel consumptions are presented in Table 4.19 and Table 4.20, respectively. These factors are used in IHEEM in estimating user benefits.

TABLE 4.20  
Fuel Consumption Adjustment Factors (from Cal-B/C)

IRI (inches/mi)	Auto	Truck
0	0.97	0.96
25	0.98	0.97
50	0.98	0.97
75	0.98	0.98
100	0.98	0.98
125	0.99	0.99
150	1.00	0.99
175	1.00	1.00
200	1.01	1.01
225	1.01	1.02
250	1.02	1.03
275	1.03	1.04
300	1.03	1.05
325	1.04	1.06
350	1.05	1.07
375	1.06	1.08
400	1.07	1.10
425	1.08	1.11

TABLE 4.21  
Unit Maintenance Costs (from HRES)

IRI (inches/mi)	Maintenance Cost (\$/lane mile)
50	77
75	292
100	589
125	944
150	1337
175	1755
200	2185
225	2619
250	3049
275	3469
300	3878
325	4270
350	4646
375	5003
400	5339
425	5657
450	5955
475	6236

Pavement maintenance costs are largely related to the pavement conditions. In HERS (2), the representative values of pavement maintenance costs as shown in Table 4.21. The values in Table 4.21 are included in IHEEM as default maintenance costs. These default values can be replaced by users if more reliable data are available. In IHEEM, the impact of pavement condition on maintenance costs is expressed in terms of the resulted changes in vehicle speed and fuel consumption. However, it should be emphasized that the effect of pavement condition on maintenance costs is considered only in a project level, not in a network level. Thus, maintaining the pavement condition of a highway network to a certain level is not included in IHEEM.

## 5. PROBABILISTIC APPROACH

The economic analysis methods discussed in the previous chapters 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 input 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 (5). Since then researchers have applied various methods in

probabilistic economic analysis for highway projects. Tighe (15) 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 (16) incorporated risk considerations into the life-cycle pavement cost analysis model. Setunge et al. (17) used Monte Carlo simulation in the risk-based life-cycle cost analysis for bridge rehabilitation treatments. Li et al. (18) developed a new uncertainty-based methodology to evaluate highway projects.

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. Figure 5.1 shows the probabilistic analysis process with respect to a random variable in IHEEM. In the process, the random variable is assigned to an appropriate distribution with an estimated coefficient of variance (CV). A simulation process is repeated a default 100 times or a user defined number of times by random numbers to generate an output with statistic ranges and confidence levels.

## 5.1 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.

### 5.1.1 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 statistical 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 determine if a data distribution is normal, a  $\chi^2$  (Chi-square) test can be conducted. Through data distribution analysis, it was found that the traffic volumes were normally or near normally distributed. Figures 5.2, 5.3 and 5.4 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,  $x_1, x_2, \dots$ , and  $x_n$ , the mean,  $\bar{X}$ , is calculated as:

$$\bar{X} = \frac{\sum_{i=1}^n x_i}{n} \quad (5.1)$$

The standard deviation,  $S$ , is estimated as:

$$S = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{X})^2}{n - 1}} \quad (5.2)$$

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 Figure 5.5, 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

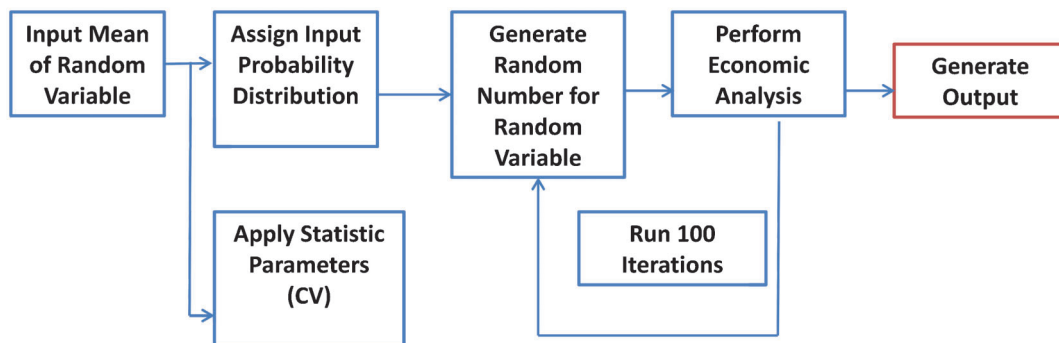
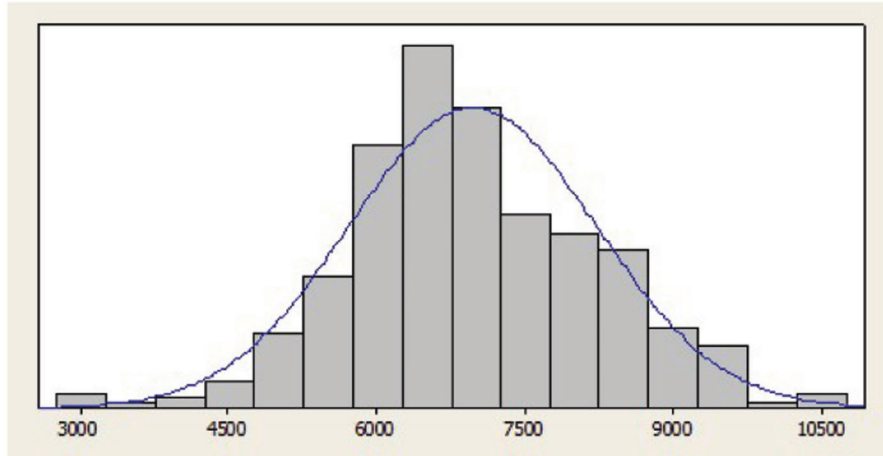
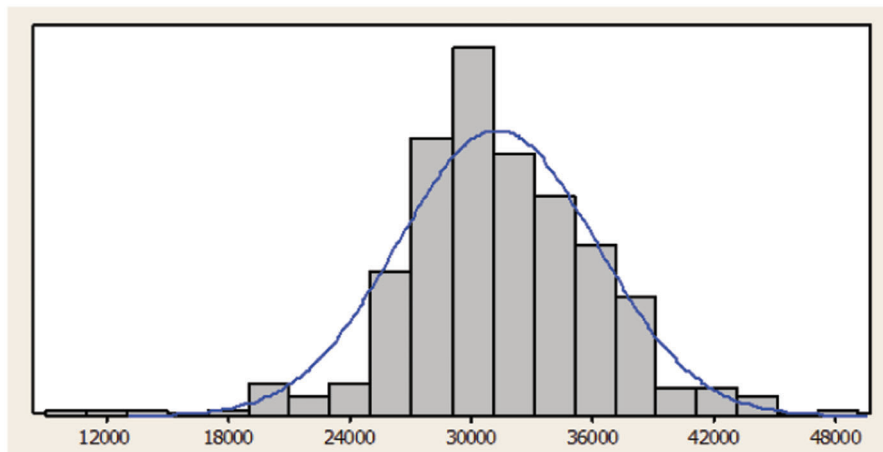


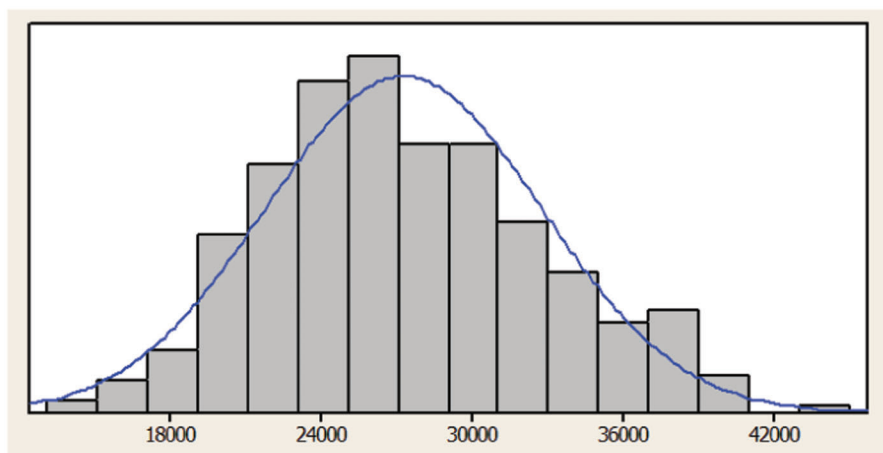
Figure 5.1 Probabilistic analysis process.



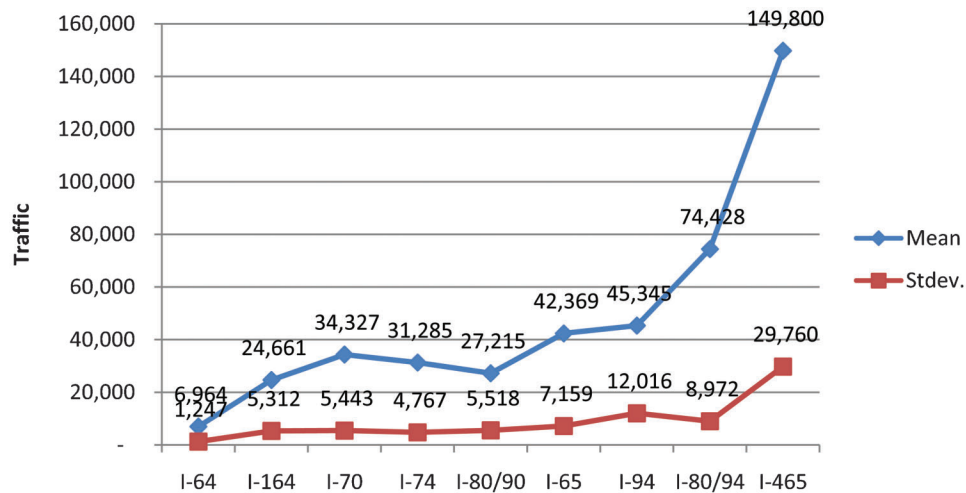
**Figure 5.2** Histogram of I-64 traffic volume.



**Figure 5.3** Histogram of I-74 traffic volume.



**Figure 5.4** Histogram of I-80/I-90 traffic volume.



**Figure 5.5** Relationships between mean and standard deviation of traffic volumes.

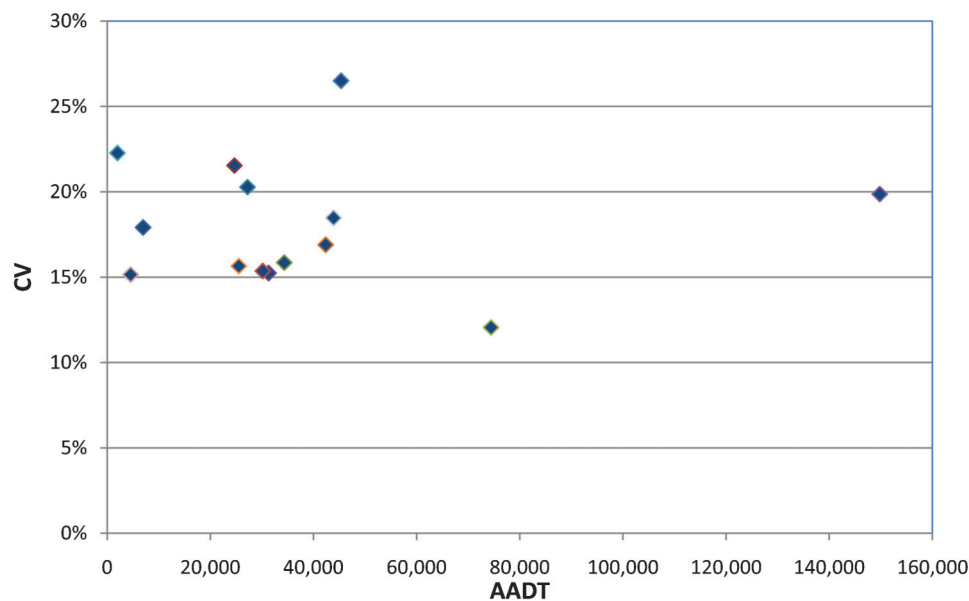
order to effectively measure the dispersion of the traffic volumes, the coefficients of variations (CV) are used in the probabilistic model in place of the standard deviations. A CV is the ratio of the standard deviation to the mean, as shown in the following formula:

$$CV = \frac{s}{\bar{X}} \quad (5.3)$$

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 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.

Figure 5.6 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 Figure 5.5. 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 5.1. The CV values in Table 5.1 along with their related means are used in the IHEEM probabilistic model.



**Figure 5.6** The relationship between the CVs and means of traffic volumes.

TABLE 5.1  
CV Values for Different Types of Roadways

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

### 5.1.2 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 5.2 presents the values of means, standard deviations, and CVs for highway projects. The results of the cost data analysis in Table 5.2 indicate that the dispersions of the cost variable are too great for

the probabilistic model since some of the CV values are greater than 80%. This is attributed to the fact that 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 predict construction costs for each certain length 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 5.3. The  $R^2$  values in the table 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

TABLE 5.2  
Statistics of Highway Construction Costs

Project Type	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 5.3  
Regression Functions of Highway Construction Costs

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

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. Although the regression functions can reduce the variability using size and cost relationship, the variability caused by project scopes cannot be reduced due to lack of detailed information. The regression functions, however, provide the mean values of construction costs at various lengths. These mean construction costs are used as the estimated construction costs if the actual costs are not available. For a highway project with accurate construction cost information, the cost information can thus be used in place of the cost value from the regression.

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 5.4 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.

## 5.2 Monte Carlo Simulation

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,  $y=(X_1, X_2, X_3, \dots X_n)$ , with a known distribution. In the simulation process, random number seeds ( $\xi_j$ , uniformly distributed) are created to assign values to the random variables,  $X_1, X_2, X_3, \dots X_n$ , 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

TABLE 5.4  
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	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	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	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	5	\$466,116	\$278,802	59.8%

number of iterations from 100 to a higher or lower number.

## 6. THE ECONOMIC ANALYSIS SOFTWARE

### 6.1 Main Features of the Software

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 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.

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. Figure 6.1 illustrates a

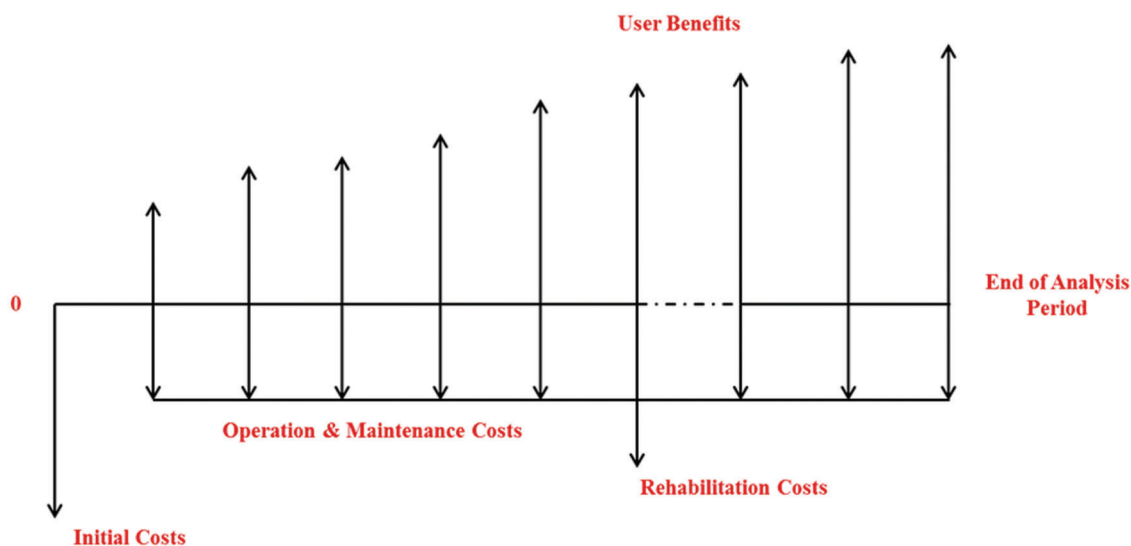


Figure 6.1 Cash flow diagram.

typical highway improvement project's cash flow 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 Figure 6.1 are in 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. However, if the total values of the sum of all

costs and benefits, which is also called the Net Present Value (NPV), are positive, the proposed project is not always economically justified to build. Rather, MIRR will be used based on the annual cash flows.

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 user can provide the necessary information for the highway or bridge project to be evaluated. Figure 6.2 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 provided to the software either by a user or through the predetermined default values that are

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	<b>USER INPUT INTERFACE</b>													
2														
3	<b>Note:</b>													
4														
5														
6	<b>Input Completion:</b>													
7	<b>In Progress...</b>													
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**GENERAL INPUTS**

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

**PROJECT DESIGN INPUTS**

	No Build	Build
26	Lane Width (ft)	12
27	Shoulder Width (ft)	6
11	No. of Traffic Lanes	
12	Length of Highway (mile)	
30	Base Free Flow Speed (mph)	55
31	Free Flow Speed (mph)	55
32	IRI	68
33	(inches/mile)	68
13	Pavement Age	144

**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
34		
35		

**AGENCY COST INPUTS**

23	Preliminary Costs	
24	Initial Costs	
25	Right of Way Costs	
26	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	-
	Probabilistic	
	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)

Inputs
Outputs-Deterministic
Outputs-Probabilistic
Agency Cost
Travel Time Savings
Vehicle Operating Costs Sav

Figure 6.2 User input interface of IHEEM.

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.

## 6.2 An Application Example of the Software

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

TABLE 6.2  
Economic Analysis Output

Economic Analysis Results	
Life-Cycle Costs	\$160.28146.77 Million
Life-Cycle Benefits	\$708.88461.69 Million
Travel Time Savings	\$651.88434.79 Million
Vehicle Operating Cost Savings	\$-32.4862.02 Million
Accident Cost Savings	\$89.4988.92 Million
Net Present Value	\$548.6314.92 Million
Benefit/Cost Ratio	4.423.15
Modified Internal Rate of Return	15.029.32%
Payback Period	813 years

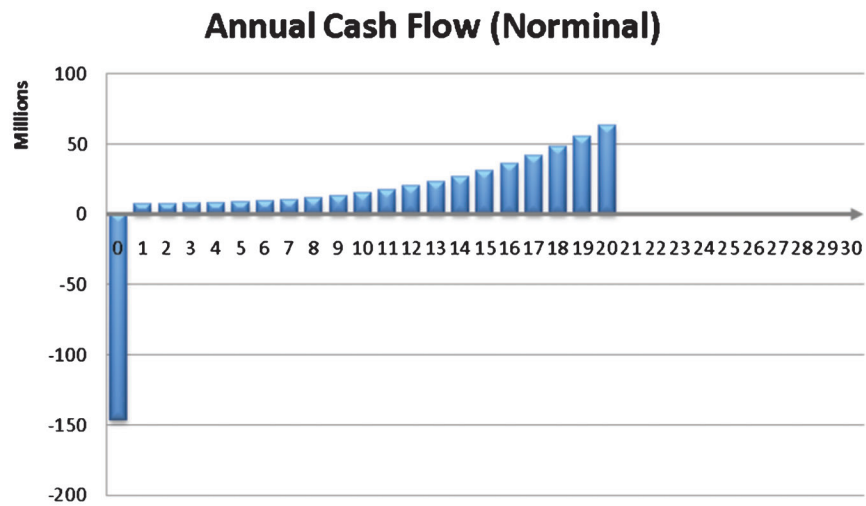
existing eight lanes to increase the traffic capacity of the frequently congested roadway section.

The input information is listed in Table 6.1. With the input in Table 6.1, the software generates the deterministic output for this project as shown in Table 6.2 as well as in Figures 6.3 through 6.6. 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 6.2 indicates that if the project is constructed, the MIRR is 9.32, expected NPV is \$314.9 million and the benefit/cost ratio is 3.1 with a 20-year analysis period. Therefore, this proposed improvement project is economically justified.

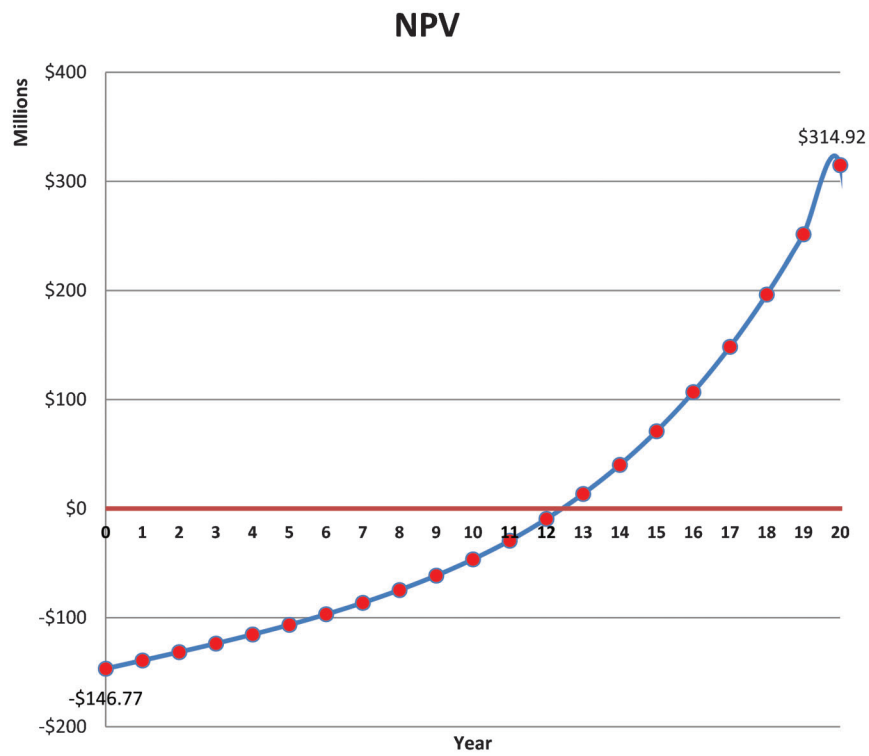
As previously indicated, this sample project is an example project in the Cal-B/C user manual. The life-cycle benefit, life-cycle cost, and benefit/cost ratio from Cal-B/C are \$162.8 million, 149.8 million, and 1.1 million, respectively. These values are compared with the corresponding values in IHEEM, which are \$461.7 million, \$146.8 million, and 3.1 million. Figure 6.7 shows the cost and benefit from both IHEEM and Cal-B/C. As can be seen, the two benefit

TABLE 6.1  
Highway Improvement Project Input Data

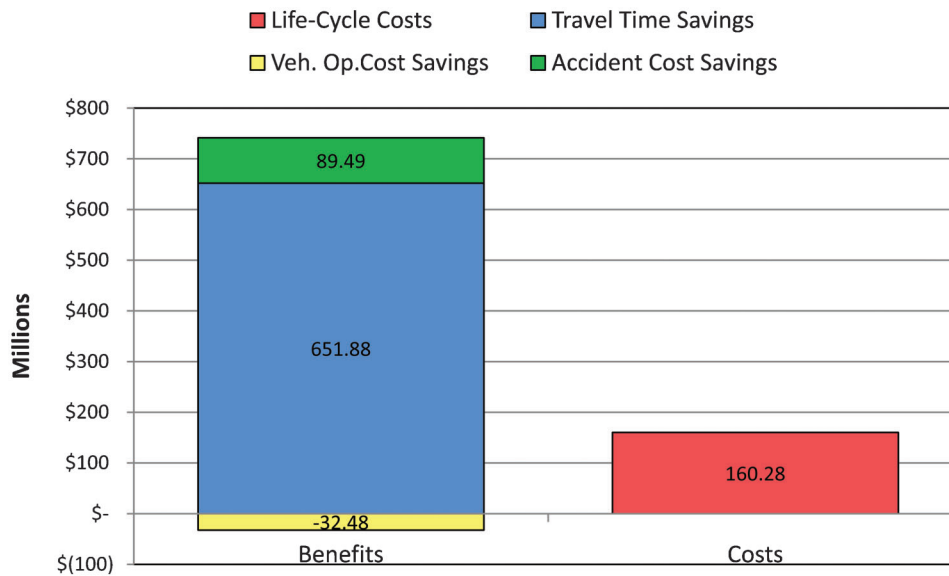
Project Information		Proposed Improvement		
Project Type	Adding Traffic Lanes		No Build	Build
Road Type	Interstate	No. of Traffic Lanes	8	10
Area Type	Rural	Length of Highway (mile)	3.9	3.9
Discount Rate	4%	Pavement Age (years)	10	
Reinvestment Rate	4%	Annual Traffic Growth Rate	0.015	0.015
Analysis Period	20	ADT in Year 1	199,317	199,317
Current Year	2007	Cargo Value	\$250,000	\$250,000
Base Year (Year 1)	2010	Market Interest Rate	4%	4%
Const. Period (year)	1	Analysis Period (years)	20	20
Preliminary Costs	\$24,705,000			
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			



**Figure 6.3** Expected cash flow.



**Figure 6.4** Net present during service life.

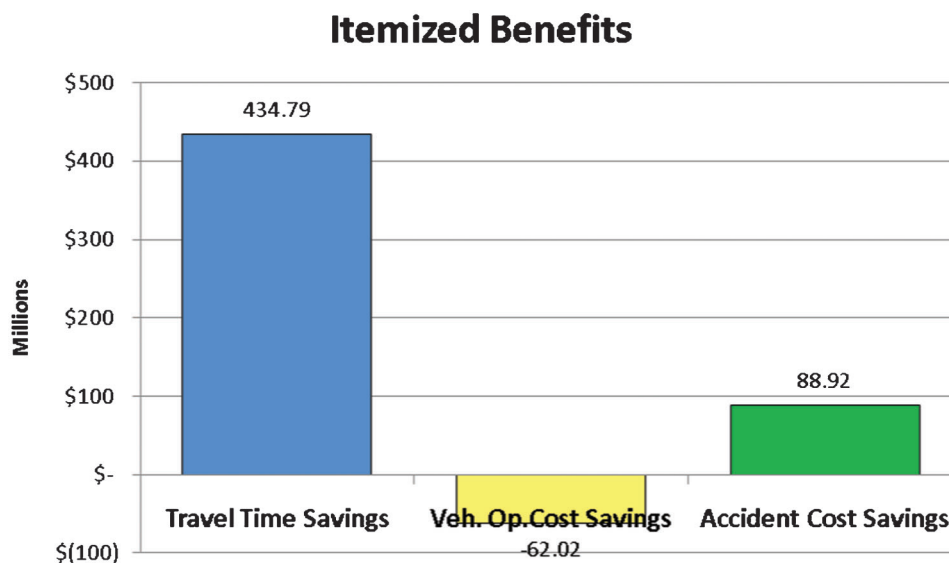


**Figure 6.5** Expected benefits and costs.

values differ much more significantly than the cost values. As shown in Figure 6.6, 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 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

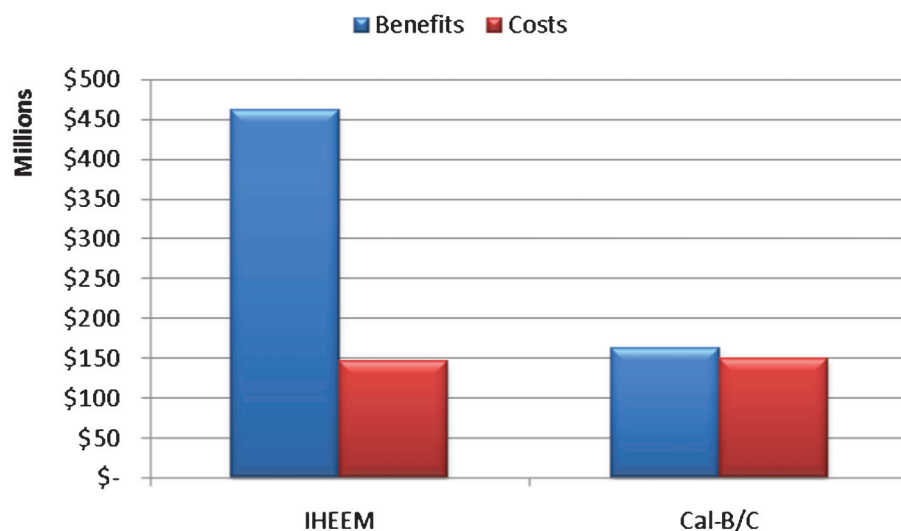
VOC calculations while Cal-B/C does not include truck inventory costs. In addition, in IHEEM most of the parameter values are updated, including crash reduction factor, value of time, fuel cost, and crash cost. Consequently, all of these differences would contribute to the great discrepancies in the analysis results from the two methods.

IHEEM is also capable of performing probabilistic economic analysis if a user desires to do so. Figure 6.8 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 deterministic mean of \$314.9 million. The

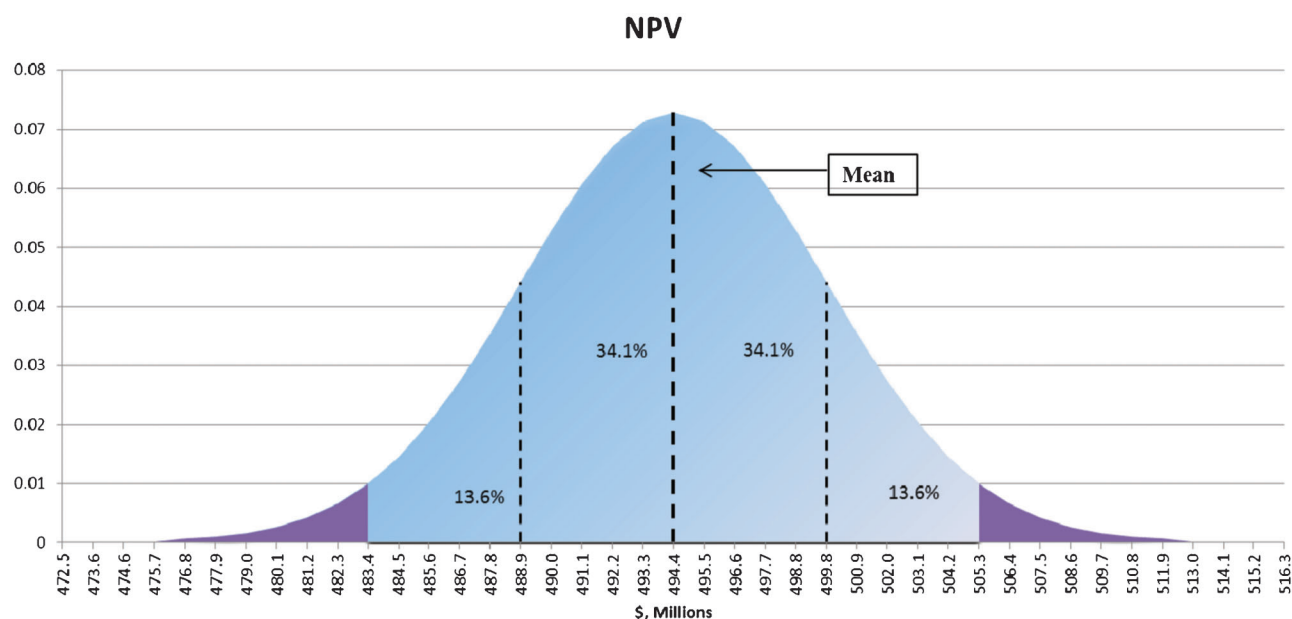


**Figure 6.6** Itemized benefits.





**Figure 6.7** Comparison of IHEEM and Cal-B/C results.



**Figure 6.8** NPV distribution generated by probabilistic economic analysis.

range of NPV for any given likelihood can be identified with the NPV distribution curve.

## 7. CONCLUSIONS AND RECOMMENDATIONS

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. 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 modified 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 and cost of 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 selected to include in IHEEM. The software provides flexibility for users to overwrite any default values if project specific data are available. The software can be used by INDOT 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 the previous chapter, 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 INDOT to evaluate highway and bridge improvement projects.

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## About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1 — evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: <http://docs.lib.purdue.edu/jtrp>

Further information about JTRP and its current research program is available at: <http://www.purdue.edu/jtrp>

## About This Report

An open access version of this publication is available online. This can be most easily located using the Digital Object Identifier (doi) listed below. Pre-2011 publications that include color illustrations are available online in color but are printed only in grayscale.

The recommended citation for this publication is:

Jiang, Y., G. Zhao, and S. Li. *An Economic Analysis Methodology for Project Evaluation and Programming*. Publication FHWA/IN/JTRP-2013/17. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2013. doi: 10.5703/1288284315219.