

# MODULE 11. ECONOMIC ANALYSIS

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## MODULE 11. ECONOMIC ANALYSIS

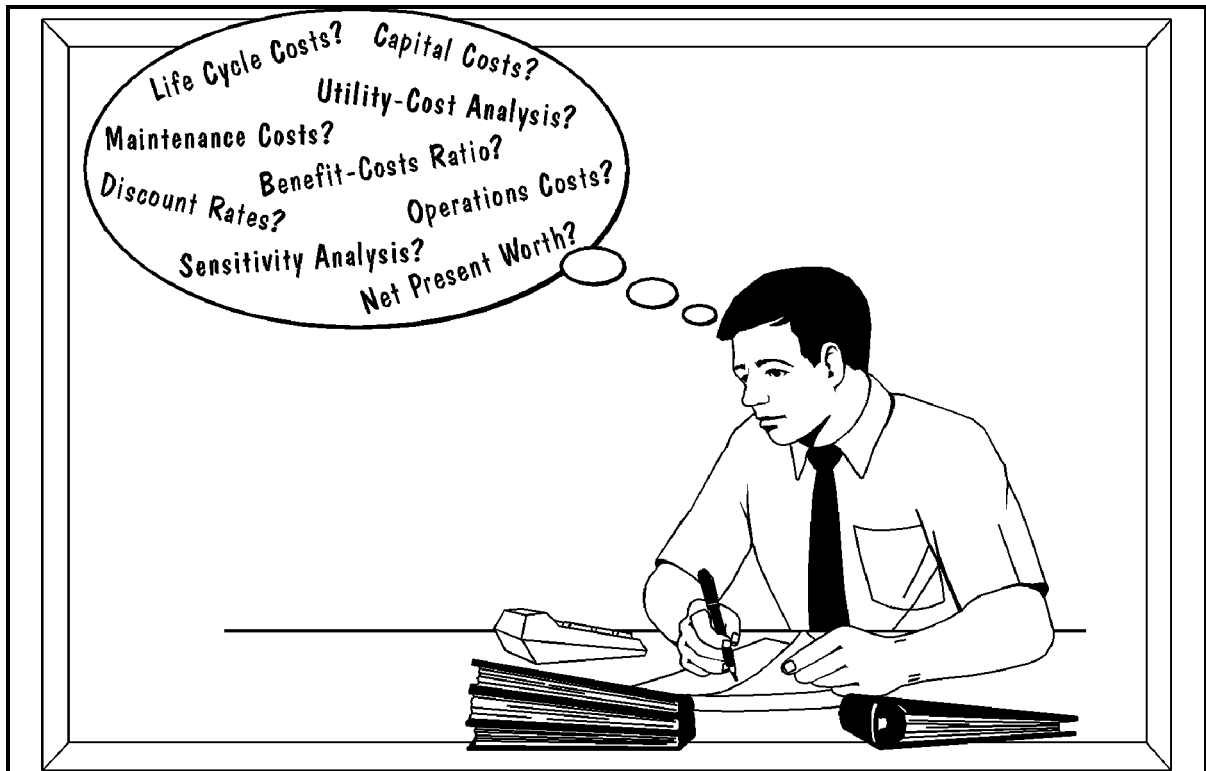


Figure 11-1. An Economic Analysis Has Many Components.

### 11.1 INTRODUCTION

Since freeway management systems are designed, constructed, and operated and maintained with public funding, it is critical that economic analyses are conducted to ensure that public funds are spent prudently. In addition to being used to determine which alternative system offers the most potential, economic analyses serve to justify the cost-effectiveness of system installations to elected officials who oversee public funding, as well as to the public whom these elected officials serve. If funding for new freeway management systems, or funding for operating and maintaining existing systems is to continue, it is critical that elected officials and the public be made aware of the benefits of the freeway management system.

### PURPOSE AND SCOPE

This module serves to give guidance to planners and designers responsible for the economic justification of freeway management systems. Planners and designers must be familiar with the costs and benefits expected from freeway management systems in order to justify the installation and continued operation of these systems. This module provides typical capital costs associated with the design and construction of freeway management systems, as well as typical continuing costs associated with their operation and maintenance. Also provided in this module are typical quantifiable and nonquantifiable benefits that can be expected from the implementation of freeway management systems.

## **SYSTEM GOALS AND OBJECTIVES**

The primary function of freeway management systems is the real-time management of recurrent and nonrecurrent congestion. It is the goal of planners and designers to provide efficient, cost-effective freeway management systems that meet defined system goals. A successful freeway management system meets or exceeds defined system goals, thus producing benefits such as delay reductions and increased safety to freeway users that outweigh the system's initial capital costs and its associated lifetime operating and maintenance costs.

## **INTERRELATIONSHIP OF SYSTEM ELEMENTS**

Costs associated with freeway management systems, whether capital costs or operation and maintenance costs, are readily available and easily measured in monetary terms. However, benefits accrued from various freeway management system elements are sometimes more difficult to quantify, due to the interrelationships that exist among the various system elements. For example, dynamic message signs ([Module 7](#)) and ramp meters ([Module 5](#)) both contribute to reducing freeway congestion. The benefits of each of these elements could be measured (via travel time studies, vehicle counts, etc.) if they were implemented alone within the freeway section. However, the benefits of stand alone systems are not necessarily additive. Rather, the effects of these components interact with each other. In the above example, the provision of real-time information via dynamic message signs might cause some drivers normally intending to enter the freeway to utilize another route to their destination. This would reduce the traffic demands at the entrance ramps, and influence the magnitude of benefits that

would be achieved with a ramp metering system that was also implemented in the freeway corridor.

## **STRUCTURE OF MODULE**

The next section of this module, Estimating Costs and Benefits, describes the types of costs and benefits normally associated with freeway management systems. The section that follows, System Evaluation, describes the different economic analysis techniques that are available to evaluate and justify freeway management system expenditures, and to compare various system alternatives. Using the cost and benefit estimating procedures described subsequently, designers and planners can utilize their cost and benefit data to conduct economic analyses.

## **11.2 ESTIMATING COSTS AND BENEFITS**

### **SYSTEM COSTS**

#### **Types of Costs**

Costs associated with freeway management systems can be classified as follows:

- Capital costs.
- Continuing costs.

Capital costs include all costs associated with the design and construction of freeway management systems (or component thereof). Items classified as capital costs include:

- Design costs.
- Right-of-way costs.
- Equipment costs.

- Construction costs.
- Software development costs (including system integration).

Continuing costs are those associated with ongoing operations of the freeway management system. These costs include the following:

- Equipment and infrastructure maintenance costs.
- Equipment replacement costs.
- Staffing costs to operate the system (operations personnel, clerical personnel, public information personnel, etc.).
- Utilities costs.
- Leasing costs (communications, control center space, etc.).

### **Sources of Cost Information**

Each freeway management system is (presumably) a compilation of components and techniques designed to meet specific goals and objectives of the region. Technology used for freeway management is constantly being improved. In addition, the unique characteristics of each system (the components employed, the method of their integration, etc.) heavily influence the costs of previous systems. Consequently, “typical” costs associated with freeway management systems are generally not available.

Those involved in the planning, design, and evaluation of such systems are well-advised to communicate directly with vendors of the various system components to obtain the most recent cost estimates. As an alternative, personnel in other locations who have recently implemented freeway

management systems with components of interest can serve as a source of cost information. However, the reader must be cautioned that these cost experiences can be heavily influenced by site-specific factors, and so may have little (if any) relevance to the freeway management system project of interest.

### **SYSTEM BENEFITS**

#### **Types of Benefits**

An economic analysis requires the measurement of the benefit of a new or improved system relative to the existing system. To do this, the analysis compares existing conditions with those anticipated from the improvements. It must always be remembered that a freeway management system can produce a number of benefits, some of which can be quantified (e.g., the reduction in total system delay) and some of which cannot (e.g., improvement in driver perception of the transportation agencies in the region). Furthermore, while some of the quantifiable benefits can be converted to monetary value (e.g., a reduction in fuel consumption and motorist delay), other benefits do not easily lend themselves to monetary conversion (e.g., the reduction in vehicle emissions).

Traditionally, benefits analyses for traffic operations projects such as freeway management systems have typically focused on the reduction in road user costs, which can be categorized as follows:<sup>(1)</sup>

- Reductions in motorist travel time.
- Reductions in vehicle operating costs.
- Reductions in accident costs.

Vehicle operating costs typically are broken down as follows:<sup>(2)</sup>

- Fuel consumption.
- Lubricants.
- Vehicle maintenance (labor and parts).
- Vehicle depreciation.
- Interest on loans.
- Other wages.
- Overhead.

In many instances, analysis of alternative accident costs is problematic because of a lack of available data. Consequently, an evaluation may be limited to travel time and vehicle operating costs only.<sup>(3, 4)</sup>

Although not easily quantifiable in terms of dollar benefits, the effect of a traffic control system on vehicle emissions is typically a key issue. Improved traffic control systems often provide the potential for emission reductions. Fortunately, most traffic simulation models available for evaluating traffic control systems include vehicle emissions estimates as part of the measures-of-effectiveness outputs. Because of the complexities and variabilities associated with vehicle emissions, these values should be used primarily for order-of-magnitude comparisons between the various alternatives.

### Sources of Benefit Information

As with cost estimates, estimates of benefits of a freeway management system cannot simply be obtained from the literature. Existing traffic conditions before system implementation, the existence and stability of working relationships between agencies, the specific combination of subsystems incorporated into the overall freeway management system all contribute to its

overall success and impact in the region. Experiences with past projects indicate that benefits of freeway management may be quite substantial.<sup>(5,6)</sup> However, the analyst should focus his or her attention on identifying recent projects that bear some resemblance to his or her own situation.

Generally speaking, traffic simulation analyses provide an objective mechanism to help assess the traffic impacts of certain combinations of freeway management subsystems (traffic simulation models are discussed briefly in **Module 2**). Unfortunately, one of the major limitations of most of these models is the limited representation of how drivers actually respond to the introduction of these subsystems with respect to their route, departure time, and mode choice decisions. These limitations should be taken into consideration when interpreting the outputs of simulation. Again, sensitivity analyses are important to developing an understanding of how reasonable the simulation estimates are, and how much confidence the analyst should place in them accordingly.

### IMPORTANCE OF LIFE CYCLE COST CONSIDERATIONS

Frequently, in efforts to secure capital funding for freeway management systems, the continuing costs associated with operating and maintaining these systems are not given proper consideration. Continuing costs are just as important as, if not more important than, capital costs. Adequate funding for operations and maintenance, including funding to replace system components when their useful lives have expired, is essential for successful freeway management.

When conducting economic analyses for freeway management systems, a system's continuing costs must be accounted for

along with its capital costs. Along this note, capital cost savings resulting from low bid procurement procedures can often result in greater continuing costs down the road. Capital cost savings associated with installing equipment that is inferior in terms of constructability and design features may ultimately increase the system's costs over its useful life, due to a reduced capability to handle future technology advances, more frequent replacement of equipment, etc.

Another reason for using life-cycle costs is to account for the fact that different system components often have quite different useful service lives. For example, Table 11-1 presents estimated service lives of some common freeway management system components. As the table illustrates, component service lives can range from 5 years or less to as much as 20 years.<sup>(8)</sup>

### **11.3 SYSTEM EVALUATION**

The evaluation of the economic viability of the alternatives selected for consideration provides an objective basis for deciding which alternative, if any, should be funded. It also provides information that can be used to gain political and public support of the alternative determined to be the most beneficial (indicating the expected reduction in motorist costs or burdens for the money that will be invested). The alternatives evaluated represent a trade-off between various combinations of system components or subsystems, and can become quite complex.

A number of different considerations are required in any economic analysis of a freeway management system. The analysis itself can involve one or more of the analysis tools available. Some of the major considerations and analysis tools available are discussed in the following sections.

### **DEFINITION OF SYSTEM ALTERNATIVES/COMPONENTS**

The decision process described in **Module 2** and emphasized in each of the other modules in this handbook is intended to provide an objective, systematic method of determining appropriate analysis alternatives. Once again, it is worth reiterating that the analyst and/or designer must base alternatives on the goals, objectives, and functions that the freeway management system is intended to achieve. The development of alternatives for analysis then evolves naturally from these intended functions. One of the options that should be evaluated is the "do nothing" alternative. This is an important benchmark to be used for evaluating the benefits of investments in freeway management alternatives.

As indicated earlier in this module regarding system benefits, a key consideration during this alternative development phase is to fully recognize the synergies that can develop from implementing certain combinations of components or subsystems of a freeway management system. For example, the implementation of closed-circuit television may not only assist in the detection and verification of an incident, but also prove useful to agencies in verifying whether a real-time traffic message is properly displayed on a nearby changeable message sign. At the same time, it is important to realistically assess how certain components or subsystems will actually perform, given the presence of other components in the system. For instance, it may be inappropriate to consider a series of inductive loop detectors installed over a section of freeway as detecting X number of incidents per day (estimated from previous incident experiences elsewhere) when a toll-free telephone hotline has also been established for cellular telephone users in the region to call in and report incidents.

**Table 11-1. Selected Freeway Management System Component Service Lives <sup>(8)</sup>**

Freeway Management System Component	Estimated Service Life (yrs)
Surveillance:	
<i>Inductive Loop Detectors</i>	5
<i>Automatic Vehicle Identification</i>	10
<i>Automatic Vehicle Location</i>	10
<i>Video Imaging/Closed Circuit Television</i>	10
<i>Vehicle Emissions</i>	10
<i>Call Boxes</i>	10
Toll Facilities:	
<i>Plazas</i>	20
<i>Readers</i>	10
Ramp Control:	5
<i>Ramp Meters</i>	
Information Dissemination:	
<i>Dynamic Message Signs</i>	20
<i>Highway Advisory Radio</i>	20
<i>Information Kiosks</i>	7
Communications	
<i>Wireline</i>	20
Transportation Management Center	
<i>Computer Hardware</i>	5
<i>Computer Software and Integration</i>	5-20

Experience suggests that the vast majority of incidents will likely be detected from the hotline, rather than from the loop detectors.<sup>(7)</sup> Additional information concerning incident detection technologies is presented in **Module 8**.

### ASSIGNING BENEFITS TO ALTERNATIVES

Also, as stated earlier in this module, it is sometimes very difficult to properly assess the benefits associated with the implementation of a freeway management system, when the system is comprised of several different components which interact and affect traffic in some unknown manner.

The possible interrelationship between dynamic message signs and ramp metering subsystems was offered as one example. On the other hand, truck lane restrictions and a ramp metering subsystem could generate possibly adverse interactions (e.g., by having all trucks in the lane where ramp vehicles were attempting to merge).

Unfortunately, no hard and fast rules are available to determine how the introduction or elimination of specific components or subsystems affects the impact of other components in a freeway management system. The analyst must rely on judgement and experience to generate a best-guess in these instances. The uncertainty inherent in



the analysis of benefits is why sensitivity analyses are so important to include as part of the analysis plan. (Sensitivity analysis is discussed briefly later in this module.)

### **ESTIMATING LIFE-CYCLE COSTS**

When estimating the costs of a freeway management system alternative, it is critical to include not only the capital costs associated with designing, purchasing, and/or constructing the system alternative, but also the ongoing operating and maintenance costs that will be required to keep the alternative operational until it reaches the end of its useful life cycle. These life-cycle costs are the most appropriate way to evaluate freeway management system components.

Data from vendors or other operating agencies should be consulted when attempting to identify the various costs associated with a particular freeway management system alternative. In the absence of available data, some analysts have taken a percentage of the capital costs of a component as a measure of the operations and maintenance costs. The recent *ITS Architecture Cost Analysis*, for example, estimates operations and maintenance costs for many of the ITS technologies to be implemented in the future as between 2 and 10 percent of expected capital costs of those technologies.<sup>(8)</sup>

### **ANALYSIS TECHNIQUES**

#### **Net Present Worth**

##### *Description*

Computation of an alternative's net present worth involves a conversion of all costs and benefits of an alternative that are incurred at the alternative's initiation and throughout its useful life (life-cycle) to an equivalent

current value.<sup>(9)</sup> The current value of the equivalent costs is subtracted from the current value of the equivalent benefits of the alternative. If the benefits exceed the costs, the alternative can be justified economically. Furthermore, comparisons among alternatives are straightforward; the alternative that provides the greatest additional benefits over costs (sometimes referred to as "excess benefits") is said to have the greatest net present worth.

##### *Example*

An analysis of alternative communication systems for a traffic control system in a central business district provides an excellent example of the application of the net present worth method to alternatives evaluation.<sup>(10)</sup> Alternatives considered included installed twisted-wire pair (TWP), lines leased through the telephone company (TELCO), or installed fiberoptic lines. Table 11-2 summarizes the estimated capital and maintenance costs for each alternative over its 15-year lifespan. As the table illustrates, the TWP alternative provides the lowest net present worth of costs to the agency (\$1,925,764).

##### *Other Considerations*

This analysis approach is perhaps the simplest to explain and the most understandable to the general public. Unfortunately, the net present worth method does not necessarily convey the relative economic merits of various alternatives as compared to the risk associated with the investment in that alternative. Most freeway management systems must compete for limited funds with other types of transportation improvement projects. Two alternatives may be capable of generating the same amount of excess benefits over their costs. However, if one alternative requires only a fraction of the cost of the other

**Table 11-2. Example of a Net Present Worth Evaluation** (Adapted from 10)

Alternative	Capital Costs(\$)	Annual Maintenance Costs(\$)	Maintenance Net Present Worth (\$) <sup>a</sup>	Total Net Present Worth (\$)
<b>Twisted-Wire Pair (TWP)</b>				
Conduit: 15,600@\$50	780,000	39,000	367,501	
RCU: 196@\$1,200	235,200	23,520	221,631	
Modems: 33@\$180	5,940	594	5,597	
Cable: 76,000@\$1	76,000	3,800	35,808	
1,600@\$1.50	2,400	120	1,131	
2,000@\$2	5,000	250	2,356	
Prep: 62,400@\$3	<u>187,200</u>	0	<u>0</u>	
<b>TOTAL NPW</b>	<b>1,291,740</b>		<b>634,024</b>	<b>1,925,764</b>
<b>Leased Telephone Lines (TELCO)</b>				
Conduit: 3,920@\$50	196,000	9,800	92,346	
RCU: 196@\$1,200	235,200	23,520	221,631	
Modems: 33@\$180	5,940	594	5,596	
Cable: 3,920@\$1.80	7,056	353	3,326	
3,920@\$3.30	12,936	647	6,096	
Other: 196@\$143	28,028	0	0	
Annual Lease Charges:	<u>0</u>	138,336	<u>1,303,553</u>	
<b>TOTAL NPW</b>	<b>485,160</b>		<b>1,632,548</b>	<b>2,177,708</b>
<b>Fiberoptic Lines</b>				
Conduit: 15,600@\$50	780,000	39,000	367,501	
RCU: 196@\$1,500	294,000	29,400	277,039	
Modems: 33@\$415	13,695	1,370	12,910	
Cable: 78,000@\$3	234,000	11,700	1010,250	
Prep: 62,400@\$3	<u>187,200</u>	0	<u>0</u>	
<b>TOTAL NPW</b>	<b>1,508,895</b>		<b>767,700</b>	<b>2,276,595</b>

<sup>a</sup> Annual Maintenance Costs multiplied by present worth factor (7%, 15 years) of 9.4231

RCU = Remote Communications Unit

alternative, the partners receive a better return on the investment by choosing the lower-cost alternative (and are risking a lower amount of capital in so doing). Consequently, a benefit-cost analysis, as described in the next section, provides a more accurate picture of the relationship between the potential benefits and costs of freeway management system alternatives.

### **Benefit-Cost and Incremental Benefit-Cost Analysis**

#### *Description*

The Benefit-Cost (B/C) analysis technique is perhaps the most widely accepted methodology for evaluating transportation improvement alternatives. The B/C ratio is simply the equivalent benefit of an alternative divided by the equivalent cost of that alternative:

$$B/C = \frac{\text{(benefits of alternative i)}}{\text{(costs of alternative i)}}$$

Benefit-cost comparisons are possible when the benefits of an improvement can be assigned a monetary value. If the benefits of an alternative exceed its costs, the improvement is economically justifiable. Furthermore, the ratio of each alternative provides a convenient basis for comparison, providing a measure of the dollars of expected benefit of an alternative for each dollar spent on that alternative.

If system alternatives being analyzed build upon each other in terms of the costs, quantities, complexities, etc. of components that meet the system goals and objectives, it may be more appropriate to consider an incremental benefit-cost analysis. For this approach, the benefits and costs considered for each alternative are not the totals, but rather the additional benefits achieved and costs incurred over the next expensive (and

presumably effective) alternative. This analysis considers, in effect, whether an investment necessary to achieve the next incremental step in the system can be justified in terms of the incremental benefits that would be achieved.

#### *Example*

Table 11-3 presents the results of a benefit-cost sketch-planning analysis of alternatives to address mobility and congestion problems in Salt Lake City, Utah.<sup>(11)</sup> Analysts identified five alternative improvement categories:

- Highway capacity expansion (HWY) to add freeway lanes.
- Transportation system management (TSM) actions (enhanced bus service in the corridor).
- HOV lane addition.
- Light Rail Transit (LRT) addition to the corridor.
- Travel Demand Management (TDM) action to collect tolls within the corridor.

Capital, operation, and maintenance costs for both the highway and transit agencies were calculated for each alternative, based on available literature. Benefits estimated for each alternative consisted of estimated travel time savings, vehicle operating cost reductions, reduced vehicle emissions, accident cost reductions and other external benefits, and revenues generated through additional parking fees. Based on the assumptions made, some of the alternatives were estimated to experience negative benefits (sometimes referred to as dis-benefits) in one or more of these categories.

**Table 11-3. Example of a Benefit-Cost Analysis <sup>(11)</sup>**

	Benefits and Costs (in millions of dollars)				
	HWY	TSM	HOV	LRT	TDM
Benefits					
<i>User</i>	22.5	21.8	24.1	20.6	-16.6
<i>Revenues</i>	0.0	0.0	0.0	2.5	33.1
<i>External</i>	-21.0	2.0	4.3	5.7	22.7
<i>Emissions</i>	<u>-0.9</u>	<u>0.6</u>	<u>2.3</u>	<u>1.9</u>	<u>5.0</u>
<i>TOTAL</i>	0.6	24.4	30.6	30.7	44.2
Costs	4.7	5.9	8.	48.1	14.7
B/C Ratio	0.12	4.14	3.45	0.64	3.01

As table 11-3 illustrates, the TSM alternative was estimated to provide the highest B/C ratio (4.14). This indicates an expected \$4.14 benefit to be received for every \$1 spent by the public agency on the alternative. The HOV and TDM alternatives also provided a reasonable B/C ratio, returning \$3.45 and \$3.01, respectively, for every \$1 invested on that alternative.

The HWY and LRT alternatives, however, resulted in B/C ratios less than 1. This indicates that these alternatives are not attractive investments, providing only \$0.12 and \$0.64 benefits per \$1 invested. It should be noted that significant external disbenefits (expected accident increases due to increased vehicle demand on the facility) caused the relatively poor result for the HWY alternative. For the LRT alternative, the high capital cost required was the main factor causing the low B/C ratio.

As an example of the incremental B/C analysis, suppose that the TSM alternatives described above had initially consisted of potential bus service improvements on four different routes in the corridor. Estimated benefits and costs for each route might have

been as shown in table 11-4. Examining the economic viability of each route separately clearly shows that the expenditures on routes 1 through 3 would be justified (B/Cs for each greater than 1), whereas those for route 4 would not (B/C less than 1). Furthermore, if the analyst had only considered the four routes together without analyzing them incrementally (using the numbers in the last column of table 11-4), he or she would have incorrectly concluded that the TSM improvements should be made to all four routes.

#### ***Other Considerations***

The benefit-cost (or incremental benefit-cost) analysis methodology provides an objective means of comparing the quantifiable and monetarily-based benefits of an alternative to the costs of that alternative. Unfortunately, not all quantifiable benefits are easily converted to a monetary value (the reduction in vehicle emissions, for example). Likewise, some benefits are not easily quantified (e.g., the improvement in public perception of a transportation agency due to improving the availability of traffic information in the freeway corridor).

**Table 11-4. Example of an Incremental Benefit-Cost Analysis**

	TSM Components (Bus Service Improvements)				
	Route 1	Route 2	Route 3	Route 4	Total
Benefits	7.1	10.0	7.3	2.0	26.4
Costs	1.0	2.0	2.9	4.0	9.9
B/C Ratio	7.1	5.0	2.5	0.5	2.7

Because of this, alternative analyses are often needed to help assess which alternative systems or subsystems meet their objectives in the most economical manner. The utility cost analysis, described below, is one such analysis approach.

### Utility-Cost Analysis

#### *Description*

Although a benefit-cost (or incremental benefit-cost) analysis is a direct method of determining whether a freeway management system alternative is economically viable, such an analysis can be performed only if the benefits to be accrued can be estimated in monetary terms. For many goals and objectives of freeway management, this is not possible. In these cases, a utility-cost analysis approach is commonly utilized. The term cost-effectiveness is sometimes used interchangeably with the term utility-cost analysis.<sup>(12)</sup>

In a utility-cost analysis, utility measures of performance goals or objectives are created to estimate system benefits. Typically, a project team or expert panel subjectively rates (from 0 to 10 or on a similar scale) how well an alternative is expected to achieve each of the objective or performance criteria. Weighting factors (summing to unity) are also estimated for each of the

objective or performance criteria, and multiplied by the rating given to that objective/criterion. These “utilities” of each of the objective/criteria are then summed to determine the total system utility. Dividing the system utility by total system cost represents the utility-cost factor for a particular system. The basic steps in a utility-cost analysis are as follows:<sup>(4, 9)</sup>

- Define goals and subgoals (done as part of the decision process).
- Weigh each goal.
- Weigh each subgoal.
- Rate the utility of each goal/subgoal.
- Compute utility-cost ratio.

#### *Example*

Figure 11-2 illustrates a computational procedure presented elsewhere, that rates each alternative of a traffic control project against the specified requirements for that project.<sup>(13)</sup> The ability of each alternative system to meet each requirement is rated 0 to 10. Zero indicates that the system does not satisfy the requirement at all, while 10 indicates total satisfaction. This internal rating scale measures how well an alternative system satisfies a requirement. Multiplying

the individual rating by a relative weight creates the utility value for that requirement. The sum of individual utility values gives an overall utility rating for each alternative.

### ***Other Considerations***

It is tempting to use the utility cost ratio only to compare alternative system designs, selecting the one with the greatest ratio. However, this conclusion may prove faulty because a simple, inexpensive system with low utility and low cost may have the same ratio as a sophisticated, but more expensive system with high utility and satisfying all defined requirements. The analyst must also assess whether the low-cost option satisfies all of the system objectives and functions. Conversely, the analyst must determine if funds are available to implement the more expensive alternative. If the alternative exceeds available funds, one or more of the components may need to be removed or modified, leading to a new rating of expected performance and a new utility cost ratio.

### **Value Engineering**

#### ***Description***

Value engineering is an organized effort directed at analyzing the function of an item with the purpose of achieving the required function at the lowest overall cost.<sup>(14)</sup> The relationship between value and function is expressed as follows:<sup>(15)</sup>

$$\text{Value} = (\text{Functional Performance})/\text{Cost}$$

From this equation, it is evident that value is increased in one of two ways:

- Value is increased by reducing costs, if performance is maintained.

- Value is increased by increasing performance (but only if increased performance is needed and the user is willing to pay for it).

A critical step in any value engineering is to identify and assess the function(s) of the item or service under study. These functions are categorized as basic or secondary. Basic functions are those which are absolutely essential in order for the item or service to perform its purpose. Secondary functions are those related to esteem, appearance, or convenience. Finally, the basic functions are organized into a logical, hierarchical sequence. This makes it possible to identify the principle function(s). It is these principle function(s) which are used to judge value.<sup>(16)</sup>

#### ***Example***

An evaluation of candidate channelizing devices to be used during a work zone lane closure on a section of freeway are presented in tables 11-5 and 11-6. Six alternative channelizing devices are considered:

- Type I Barricades.
- Type II Barricades.
- Vertical Panels.
- Cones.
- Tubes.
- Drums.

Key measures of functional performance to be included in the analysis are mean detection of an array of each type of device at the closure, and the mean distance at which drivers change lanes upstream of the closure when each device is present. Table 11-5 summarizes these distances.<sup>(16)</sup> Table

Requirement	Relative Importance of Each Requirement Sum = 100	Ability of Alternative Systems to Meet Each Requirement Rating (0 to 10)					
		Alternative System 1		Alternative System 2		Alternative System 3	
1. Intensity of CCTV coverage	25	4	100	7	175	10	250
2. Spacing of mainline monitoring station	25	2	50	6	150	8	200
3.	8	5	40	4	32	7	56
4.	4	10	40	6	24	6	24
5.	16	10	160	7	112	7	112
	etc.						
	—		—		—		—
	100		390		493		642

- ➔ **Relative weight scale**  
How important is this requirement in this jurisdiction? The total of these values must equal 100.
- ➔ **Internal rating scale**  
How well does this alternative system satisfy this requirement? The range of this value is between 0 and 10 where 0 means the system cannot accomplish this function, and 10 means the requirement is totally satisfied.
- ➔ **Utility value**  
Obtained by multiplying the internal rating scale by the relative weight of each requirement. These values are summed to determine the total utility of each alternative.

Figure 11-2. Example of Utility Cost Analysis. <sup>(13)</sup>

11-6 then provides the costs and resulting value estimates for each device.

Engineering judgement must be used to some degree in value engineering analyses. As can be seen in table 11-6, no one device provides the best value for both functional performance measures in both day and night conditions. In this analysis, vertical panels and drums were said to be “good values” (entailing lower costs for unit functional performance) for combined day and night use at freeway work zones. They were at or near the bottom of cost per unit of detection distance or lane change distance for both day and night conditions.<sup>(16)</sup>

### ***Other Considerations***

A project team or expert panel approach is used in this analysis process, just as for a utility-cost evaluation. The principal difference between value engineering and utility cost evaluation is in how item performance is accounted for in the analysis. Whereas the utility cost approach assigns a subjective measure of utility to otherwise nonquantifiable performance measures, the value engineering approach depends on the ability of the analyst (or project team) to define a quantifiable measure of performance for the primary function(s) of the alternative being evaluated.

**Table 11-5. Mean Detection and Lane Change Distances for Channelizing Devices.** <sup>(16)</sup>

Device Type	Mean Array Detection Distance (ft)		Mean Lane Change Distance Before Taper (ft)	
	Day	Night	Day	Night
Type I Barricades	4,250	3,150	640	660
Type II Barricades	4,100	2,800	400	810
Vertical Panels	4,400	3,300	370	500
Cones	4,400	1,450	460	250
Tubes	3,200	1,900	620	350
Drums	4,200	3,000	540	560



**Table 11-6. Example of Alternative Channelizing Device Values.** <sup>(16)</sup>

Device Type	Device Array Cost (\$)	Cost Per 100 ft Array Detection Distance (\$)		Cost Per 100 ft Mean Lane Change Distance (\$)	
		Day	Night	Day	Night
Type I Barricades	40	0.94	1.27	6.25	6.06
Type II Barricades	45	1.10	1.61	11.25	5.56
Vertical Panels	22	0.50	0.67	5.95	4.40
Cones	18	0.41	1.24	3.91	7.20
Tubes	22	0.69	1.16	3.55	6.29
Drums	25	0.60	0.83	4.63	4.46

### Sensitivity Analysis

#### *Description*

Uncertainty is a part of most economic analyses of freeway management system alternatives. Quickly changing technology results in cost estimates during construction and operations that may differ from those obtained during the data collection phase of the analysis. Estimates of benefits are commonly based on simulation analyses or upon documented experiences of other agencies that have implemented similar alternatives. The extent to which these experiences will be realized in the project of interest are generally not known until after implementation.

It is always tempting to avoid an explicit evaluation of uncertainty by basing the analysis on a “conservative” estimate of the uncertain variables. Unfortunately, the analyst may not always know whether a conservative estimate—in the sense that it is supposed to lead to an underestimate of net benefits—requires a value that is higher or lower than the most likely estimate.<sup>(12)</sup> The simplest way of allowing for uncertainty is by means of a sensitivity analysis:

systematically varying the value of key assumptions and parameters to objectively evaluate their importance. A sensitivity analysis is appropriate for any type of economic analysis (net present worth, benefit-cost, utility-cost, or value engineering).

#### *Example*

The example presented earlier for the benefit-cost analysis provides an excellent example of the importance of conducting sensitivity analyses in economic evaluations. The results presented in table 11-3 indicated that bus scheduling improvements (labeled as the TSM category) provided the best benefit-cost ratio, followed closely by the addition of an HOV lane and transportation demand management (TDM) alternatives. Building additional freeway capacity (HWY alternative) and a light rail transit (LRT alternative) were computed to have benefit-cost ratios less than 1. However, these results assumed that a significant increase in vehicle demand would be generated by the addition of freeway capacity, and that this would increase accident rates and costs significantly. Likewise, TDM actions were assumed to result in significant decreases in

travel demand, significantly reducing travel demands.<sup>(11)</sup>

Analysts tested the sensitivity of the results to this assumption by computing a benefit-cost ratio for each alternative without assuming significant changes in demand. In other words, they evaluated the effects of these alternatives upon existing travel demand patterns. The results, shown in table 11-7, indicate extreme sensitivity to the assumption about changes in future demand. Whereas the HWY alternative was not viable (benefit-cost ratio less than 1) when significant accident cost increases were assumed to occur, the alternative becomes the most attractive alternative (benefit-cost ratio of 4.60) when accidents are not assumed to increase significantly over the existing levels.<sup>(11)</sup>

### ***Other Considerations***

The range of variation of key assumptions and parameters in a sensitivity analysis can either be a specified amount, say 10 percent above and below the central estimate, or can be related to the inherent uncertainty associated with the central estimate itself. In

the latter case, the ranges would represent best-guess estimates of possible “high” and “low” values of the parameters, not necessarily uniformly distanced from the most likely value.

A properly conducted sensitivity analysis quickly shows which estimates are most important and gives the engineer a general idea of the following:<sup>(2)</sup>

- Those aspects which justify further work to narrow the range of uncertainty.
- The qualitative uncertainty associated with the scheme as a whole.

When a quantitative evaluation of uncertainty about benefits associated with freeway management is required, traffic simulation may be useful (although it is possible to evaluate uncertainty using mathematical expectations, this approach is usually too complicated for all but the simplest applications). The analyst can vary each of the parameters systematically, and determine the influence of that parameter upon the overall estimates of performance obtained with simulation.

**Table 11-7. Example of Sensitivity Analysis of Benefit-Cost Ratios.** (Adapted from 11)

	Benefit-Cost Ratio				
	HWY	TSM	HOV	LRT	TDM
Benefit-Cost Ratio (with accident increases)	0.12	4.14	3.45	0.64	3.01
Benefit-Cost Ratio (without accident increases)	4.60	4.42	4.25	0.74	3.94

## 11.4 REFERENCES

### REFERENCES

1. *A Manual on User Benefit Analysis of Highway and Bus Transit Improvements.* American Association of State Highway and Transportation Officials, Washington, DC, 1978.
2. Heggie, I.G. and Thomas, S. Economic Considerations. In *Transportation and Traffic Engineering Handbook.* W.S. Homburger, Editor. Second Edition. Institute of Transportation Engineers. Prentice-Hall, Englewood Cliffs, NJ, 1982.
3. Memmott, J.L. and Dudek, C.L. *A Model to Calculate the Road User Costs at Work Zones.* Report No. FHWA/TX-83/20+292-1. Texas Transportation Institute, College Station, TX, September 1982.
4. Blumentritt, C.W., Pinnell, C., McCasland, W.R., Ross, D.W., and Glazer, J. *Guidelines for Selection of Ramp Control Systems.* NCHRP Report No. 232. TRB, National Research Council, Washington, DC, May 1981.
5. Intelligent Transportation Infrastructure Benefits: Expected and Experienced. Report No. FHWA-JPO-96-008. FHWA, U.S. Department of Transportation, Washington, DC, January 1996.
6. McDermott, J.M., McLean, C.H., and Smith, A.T. Three Decades of Progress: Freeway Traffic Management in Illinois. *ITE Journal*, Vol., 62, No. 3, March 1992, pp 27-31.
7. McLean, C.H. Cellular Phones—A Key Traffic Management Component. *Compendium of Technical Papers*, Institute of Transportation Engineers, Washington, DC, 1991.
8. *ITS Architecture Cost Analysis.* FHWA, U.S. Department of Transportation, Washington, DC, June 1996.
9. Collier, C.A., and Ledbetter, W.B. *Engineering Cost Analysis.* Harper & Row, New York, NY, 1982.
10. Gordon, R.L., Reiss, R.A., Dunn, W.M., and Morehead, D.R. *Communications Handbook for Traffic Control Systems.* Report No. FHWA-SA-93-052. FHWA, U.S. Department of Transportation, Washington, DC, April 1993.
11. Decorla-Souza, P., Cohen, H., and Bhatt, K. Using Benefit-Cost Analysis to Evaluate Across Modes and Demand Management Strategies. *Compendium of Technical Papers*, Institute of Transportation Engineers 66th Annual Meeting, Minneapolis, MN, September 1996, pp 439-445.

12. Gordon, R.L., et. al. *Traffic Control Systems Handbook*. Report No. FHWA-SA-95-032. FHWA, U.S. Department of Transportation, Washington, DC, 1996.
13. Wilshire, R., et al. *Traffic Control Systems Handbook Revised Edition - 1985*, FHWA-IP-8511, FHWA, U.S. Department of Transportation, Washington, DC, April 1985.
14. Miles, L.D. *Techniques for Value Analysis and Engineering*. McGraw-Hill, Inc., New York, NY, 1972.
15. *Value Engineering Conference: Summary Report*. Report No. FHWA-TX-80-246. FHWA, U.S. Department of Transportation, Washington, DC, October 1980.
16. Richards, S.H., and Dudek, C.L. *Selection of Work Zone Channelizing Devices Using the Value Engineering Approach*. Report No. FHWA/TX-85/06+292-3. Texas Transportation Institute, College Station, TX, January 1984.

### **SUGGESTED READING**

*Cost and Effectiveness of Transportation Control Measures (TCMs): A Review and Analysis of the Literature*. Prepared by Apogee Research, Inc. for the National Association of Regional Councils, January 1994.