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Assessing the Benefits and Costs of ITS Projects: Volume 1 Methodology

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Joy Dahlgren, Elva Chang**

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Assessing the Benefits and Costs of ITS Projects: Volume 1 Methodology*

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ABSTRACT

In this document a framework for evaluating ITS projects is developed. One of the central issues addressed is whether ITS projects are distinctly different from other more conventional transportation projects and thus the traditional decision methods such as Benefit-cost analysis cannot be used. The answer is mixed. The decision models used in the past are still relevant, however, these have been applied in an environment in which there was a well developed data base. The models identified, selected, assembled and evaluated data to make judgements as to whether the proposed projects were good or less good public investments. With ITS there is not the history of data on either the cost or benefit (demand) side. Therefore, ITS projects are much more model oriented than data collection oriented. In effect the data or information to be used in the decision models applied to ITS project evaluation must be generated through the use of models including simulation models.

A number of conclusions can be drawn from this study. First, the evaluation framework provides basic guidelines for conducting a benefit-cost analysis. The lists of ITS benefits and costs are useful in helping evaluators identify the specific benefits and cost of a specific ITS project. While the cost estimation is relatively easy, the benefit estimations are difficult tasks. They require sophisticated assumptions and modeling techniques to provide inputs for the estimations. Different assumptions and modeling techniques will result in different inputs for calculation of benefits. They can alter the outcomes of the evaluation. This implies that ITS project evaluators should be fully aware of these limitations. Great effort should be placed in making and disclosing the assumptions for estimations of benefits and costs. There is an urgent need for collecting data from ITS deployments and developing models that can be used to accurately predict demands and benefits of ITS applications.

There are two fundamental conclusions from this work. First agencies need to put in place an information system that is oriented to the collection of more business and economic data and not simply engineering data if they are to establish a database for evaluating ITS projects in the future. Second, there would appear to be great value in estimating some well constructed demand models associated with ITS transportation projects as once the parameters contained in these models are estimated they can be used in simplifying the evaluation of potential ITS projects.

EXECUTIVE SUMMARY

Intelligent Transportation Systems (ITS) represent a quantum change in transportation technology. Over the last decade, many ITS ideas have been transferred from concepts to realities. ITS technologies have been improved rapidly. Some technologies, such as Automated Vehicle Identification (AVI) technology, have experienced several generations of improvements. However, ITS transportation professionals are facing a difficult task in assessing benefits and costs associated with ITS projects because in many cases such information is simply not available because the technologies have not been implemented.

In a financially constrained environment, information on the benefits and costs of ITS projects is vitally important for planning and implementing ITS programs and setting priorities for future ITS deployments. Anticipating the needs for supporting the management decisions of the advanced transportation systems in California, PATH, working with the California Transportation Department (Caltrans), has launched a series of research projects. The purpose of these projects is fourfold; developing comprehensive performance measures of transportation system, identifying data sources for using the performance measures, building a web site for the ITS benefit-cost database, and developing an evaluation framework for assessing the benefits and costs of ITS applications.

As a continuing effort supporting ITS management decisions, this research seeks to apply the evaluation framework developed in previous research to the evaluation of Electronic Toll Collection (ETC) project in the Carquinez Bridge. The main purpose of this study is to assess and illustrate the evaluation framework so that it can effectively facilitate the assessment of benefits and costs of ITS projects. Specifically, this study will show the step-by-step procedures for project evaluations and discuss issues arisen in the process of evaluation.

This study is important for several reasons. First, it will demonstrate the practical application of the evaluation framework developed previously. The evaluation framework provides a set of methods and concepts for measuring and valuing impacts of alternatives. However, there is a gap between concepts and applications. This study can fill this void.

Second, it will serve as an example for the use of the evaluation framework so that planners and engineers can use the framework for project evaluations without having too much difficulty. The Carquinez Bridge is the first among the nine state-owned toll bridges to install the ETC system. There are a number of opportunities for implementing the ETC systems on other non-state owned toll bridges and roads, parking facilities, as well as many high-occupancy-vehicle (HOV) lanes if they are converted to high-occupancy-toll (HOT) lanes. An illustration of the evaluation method using the case of the ETC system at Carquinez Bridge will certainly help the evaluations of potential ETC systems in the future.

Third, it is one of the important steps to accomplish Caltrans' research agenda set in its

Advanced Transportation Systems Program Plan (1996). Caltrans recognizes the limits of available information on costs and benefits of ATS technologies and the needs for research on assessing the costs and benefits of different ATS elements in order to provide information for future implementations of ATS plan. The plan states:

"ATS technologies are still being developed. Therefore, only preliminary estimates of their benefits and costs are now available. ... Over the next several years, ongoing efforts will continue to assess the costs and benefits of the different ATS elements (pp. 120)."

A study on the implementation of the ETC can help realize Caltrans' research agenda. In addition, it will contribute to research on benefits and costs of ITS applications by providing additional information and amplifying our knowledge in the field.

Finally, the study provides additional information about the benefits and costs of ETC systems. ETC systems have been used in many states through out the country. Some studies have investigated specific aspects of the ETC benefits (Zavergiu, *et al.* 1997?; Al-Deek, *et al.* 1996; Sisson, 1995; Pesesky, 1990; Klodzinski, *et al.*, 1998; Chang and Chang, 1993). However, almost none of them systematically evaluates the costs and benefits. By identifying the magnitude and distribution of ETC benefits, this study can contribute to ITS studies.

In this report, we have followed steps provided in the Evaluation Methodologies for ITS Applications and conducted a benefit-cost analysis for the ETC project in Carquinez Bridge. We laid out the temporal and spatial framework for the evaluation, identified and quantified the benefits and costs of the ETC project based on established assumptions, and finally analyzed the total effect and its distribution among the toll agency, users, and society. In addition, we examined the effects of ETC market share, time value, and fuel consumption on the net benefits of the ETC project.

A number of conclusions can be drawn from this study. First, the evaluation framework provides basic guidelines for conducting a benefit-cost analysis. The lists of ITS benefits and costs are useful in helping evaluators identify the specific benefits and cost of a specific ITS project. While the cost estimation is relatively easy, the benefit estimations are difficult tasks. They require sophisticated assumptions and modeling techniques to provide inputs for the estimations. Different assumptions and modeling techniques will result in different inputs for calculation of benefits. They can alter the outcomes of the evaluation. This implies that ITS project evaluators should be fully aware of these limitations. Great effort should be placed in making and disclosing the assumptions for estimations of benefits and costs. There is an urgent need for collecting data from ITS deployments and developing models that can be used to accurately predict demands and benefits of ITS applications.

Secondly, this study found that based on our assumptions, total benefit of the ETC project would exceed its costs over the evaluation period. The total net benefit would be about \$11.1 million in the FY95 constant dollar. Major benefits are time saving and fuel reductions. The project also generates environmental benefit, though the magnitude is relatively small. The finding suggests that from the viewpoint of whole society, the ETC project is worth pursuing.

Third, ETC users are the major winners of the ETC project. Although ETC users would have to pay for renting transponders and forego the interests generated in deposits, the benefits resulting from time saving and fuel reduction far exceed than those costs. In addition, the ETC increases travel convenience. Hence, the ETC project certainly fulfills one of its objectives: "provide an acceptable level of service for toll patrons."

Fourth, the evaluation results indicate that while the ETC system will save the toll agency operating and maintenance cost after the fourth year, the saving in subsequent years could not offset the initial capital cost in constant dollars. Although the ETC project does generate additional operation revenue to the agency, the cost saving and operation revenue would not offset the cost of the ETC project over the entire evaluation period. From this point of view, the ETC system does not meet the original expectation about reducing the overall toll collection cost. However, the ETC system would enable the toll agency to collect data on traffic volume, traffic speed, and type of vehicles from vehicles equipped with ETC transponders. It will also allow the toll agency to set real time tolls. Hence, it does "increase the quality of data collection and provide information currently not available."

Fifth, the study reveals that the cost of ETC transponders is a significant expenditure for the toll agency. If the cost can be reduced or transferred to the ETC users without affecting the demand for ETC, it would reduce the agency cost substantially.

Finally, sensitivity analyses indicate that the change of assumption on ETC market share would have a relatively large effect on the result of the benefit-cost analysis. It alters not only the total net benefit, but also the distribution of the net present value among the toll agency, ETC users, and society. In comparison, the effects of changing assumptions on time value and fuel consumption are relatively minor. They affect the total net benefit, but not the distribution of the benefit. The finding implies that the market share of ETC usage is an important factor for success. The Toll agency should consider substantial marketing efforts.

SECTION 1: INTRODUCTION

The introduction of Intelligent Transportation Systems [ITS] projects into the highway system has raised some concern and confusion among transportation planners, policy-makers and professionals as to how they can and should be evaluated. Unlike other types of transportation investments, there are relatively few examples of the application of ITS technology upon which to draw some experience. ITS represents a technological change which makes it fundamentally different than simply adding capacity within a given technology. Proper evaluation is therefore at risk and Caltrans is rightly concerned that good projects will not be implemented and bad ones will not be rejected. Because of a lack of information to provide direction for evaluation, there is a risk that significant investments will be made with little economic payoff. How then should one proceed? What are the important considerations and what should be ignored? Finally, how should these projects be evaluated?

The purpose of this document is to provide a comprehensive step by step framework for identifying the relevant impacts of ITS projects, placing a value on the impacts, selecting the appropriate method for evaluation and identifying and interpreting the decision criteria. The document is not intended to provide a complete description of evaluation methods, this is contained in a detailed technical appendix document. Rather this document should provide the transportation professional with an understanding of what is involved in undertaking an economic assessment of [proposed] ITS projects and should be sufficient to guide evaluators through an analysis. An application to illustrate use of this framework is contained in Section 7 with calculations contained in a set of appendices.

SECTION 2: BACKGROUND

California's Transportation Plan [CTP] was designed to set the course for the future of transportation in California.¹ At the heart of the plan are three comprehensive policies; (1) promoting the economic vitality of California by assuring mobility and access for people, goods, services and information, (2) providing safe, convenient and reliable transportation and, (3) providing environmental protection and energy efficiency. The Caltrans Strategic Plan in keeping with the CTP creates a vision of a balanced, integrated multimodal transportation network to move people, goods, services and information freely, safely and economically. In order to realize this vision, Caltrans has invested in the Advanced Transportation Systems Program [ATS] a multimodal research and development program. This program provides a foundation for the application of advanced technologies to transportation in California. The objective of the program is to accelerate implementation of advanced transportation technology applications. A sub-component of ATS is the Intelligent Transportation Systems, (ITS) which was the designation given to the multimodal package of transportation innovations. Here, it more narrowly designates the use of advanced technologies in electronics and information to improve the performance of vehicles, highways and transit systems.

¹ See, California Department of Transportation, New technology and Research Program, *Advanced Transportation Systems Program Plan: 1996 Update*, December 1996

ITS projects are designed primarily to enhance the productivity of the existing highway system. Only on rare occasions does an ITS project result in physical expansion of the system. For example, an individual traveler a traffic information system may provide knowledge of an alternate less congested route for a trip; the traveler completes her trip at a lower cost than otherwise. The traffic information system is ancillary to the roadway system yet certainly contributes to an increase in productivity of the roadway system. An electronic toll collection investment replacing a set of tollbooths reduces the travel time of most if not all travelers using a facility so they complete their trips using less time as well. This is another example of how additions to or modifications of, the existing network allow it to be more efficient.

Among the various categories of ITS applications will be projects dealing with traveler information systems, traffic management systems, vehicle safety systems, public transportation systems and commercial vehicle operations to name a few. In some cases these projects will require significant capital [hardware] investments and continuing operations and management expenses while other projects will represent relatively small capital investments. Some projects will cover a metropolitan urban area while others may be specific to a particular road segment. Simply put the projects will vary in a number of dimensions from size, capital intensity, geographic coverage, to the people and agencies affected. The variety and coverage creates a challenge for project analysis.

Investments in infrastructure and their related management strategies under the new technology program will generate different types, magnitudes and longevity of costs and benefits. Both costs and benefits will have different degrees of risks associated with them. Certainly in the case of infrastructure development the loss of resources from making a bad decision are not easily recovered or reversed. Hence, the risks are perceived to be higher. The variability of both benefits and costs will also create a degree of uncertainty regarding the evaluation of projects as well as concern to develop accurate values for benefits and costs. These features create an important challenge since California's transportation needs are designed to be met through public/private partnerships, private initiatives and public investment. In each case the investment dollars will be available from the private sector only if it can be shown that these projects will meet California's transportation needs now and into the future in an efficient or cost effective way.² If these projects do not meet financial and economic tests in a transparent manner, including a compensation for greater risk and uncertainty, the private sector is unlikely to undertake the development of new ATS products. This does not mean all projects must generate at least a market rate of return, indeed there may be some argument for subsidy. What it does mean is that significant policy issues can only be addressed if the benefits, cost and risks can be identified for each project. Indeed, the lack of or failure to use aids that help guide the public use of scarce resources will threaten the quality of decisions.

² Funds are available from earmarked government sources such as gasoline taxes and federal transfers. Nonetheless not all projects can be undertaken and they need to be ranked in terms of economic returns.

Therefore, there appear to be two major reasons for undertaking a careful analysis of proposed ITS projects. First, the projects represent an expenditure of [scarce] public funds and planners and policy makers would want to ensure they are obtaining the greatest benefits from their investments. Those who have to make decisions about whether to undertake a project or to decide among competing projects need to understand the differences in the benefits that the projects generate. A second reason for a careful analysis of projects is the projects will have positive impacts as well as negative consequences. The decision-maker would like to select the appropriate design to maximize the difference between them.

2.1 THE PROCESS OF BENEFIT-COST ANALYSIS

The process of any evaluation involves comparing at least two mutually exclusive alternatives. Sometimes one of the alternatives is the status quo or base case. For any alternative the base case defines the values of the variables before any changes to the system. The values of the variables are forecast for the length of the project. Next calculations of the values of variables over the lifetime of the project should the project be undertaken are made. The differences in the values of the variables in the presence and absence of the project provide the measure of net gains due to the project. These net gains are compared to the costs and some measure of return to the project is calculated. If there are two mutually exclusive projects the values of the alternative projects are forecast and compared.

The decision analysis framework is used to compare two or more alternatives on the basis of their gross benefits and gross costs. The question that is asked, “do benefits exceed costs” and in the case of multiple alternatives, “ by how much?” In the case of the application of cost effectiveness methods the assumption is that benefits are the same in magnitude and distribution and the focus is on costs. Since the projects will impact a broad cross section of society, all benefits and costs need to be considered not simply private or direct benefits. While the summing up of the benefits and costs are quite simple as is the decision criteria, identifying and measuring the benefits and costs is not. This is particularly the case with ITS projects because they require new data collection and analyses. The steps to be used in the decision analysis framework are set out in Figure 1.

**Figure 1
Decision Analysis Framework**

	Any Benefit-Cost or Cost Effectiveness Analysis requires four essential steps:
Step 1:	Define the alternatives to be compared including a base case
Step 2:	Identify and measure the impacts on Benefits & Costs for each alternative
Step 3:	Value each of the impacts
Step 4:	Sum all benefits & costs, compute NPV & B/C ratios and rank them

In step 1 if the case is to compare two mutually exclusive alternatives the comparison is relative straightforward in terms of what the choices are. If, however, the decision is to undertake the ITS project or not the ‘alternative’ or counter-factual in this case would be ‘what would happen in the absence of the ITS project’? This is the base case and is a more difficult scenario to represent. In step 2 the measurement of impacts requires the inclusion of all benefits and costs. Typically, in Benefit-Cost analysis the cost side is somewhat easier to measure since costs have been well documented over time. With ITS projects this is not the case since the technology and its’ implementation are both new and identifying and measuring the costs are as challenging as identifying and measuring the benefits.

The conversion of benefits (and costs) to dollar values requires two steps. First, a dollar value that reflects current market valuation of each type of benefit must be placed on each of the benefit categories for each of the users identified in the analysis. Therefore, market values based on willingness-to-pay (or prices) will differ across customers, markets and locations.³ For example, time valuation will differ between people based on considerations of trip purpose, trip distance and time saved. Input costs such as labor will vary from market to market to reflect differences in given market settings. In step two the dollar values must be placed in real terms. This means inflation must be taken into account over the period that benefits and costs are expected to occur. In periods of high inflation such as the late 1970’s and early 1980’s this was an important consideration. More recently, as inflation had abated and macroeconomic policy has focused on keeping it low, this step is less onerous.

Prior to applying decision criteria to the benefit and cost values each category must be discounted. This means the value of future benefits and costs must be adjusted by a ‘discount factor’ to account for the fact they occur in the future and a dollar of benefits (or costs) in the present is valued differently than a dollar of benefits (or costs) some years hence. The discount factor is generally selected to be the interest value of the 5 to 10 year government bonds.⁴

2.2 IS A NEW OR MODIFIED EVALUATION FRAMEWORK REQUIRED FOR ITS ASSESSMENTS?

The fundamental project evaluation framework, in particular Benefit-Cost Analysis has been well documented and used for some time. However, the introduction of ITS projects has raised some concerns that the conventional framework is not directly applicable. There are two sources of concern. First, there is the claim that some categories of benefits not previously counted will be forgotten and hence aggregate benefits will be understated. Second, there is the argument that the value of the benefits will change with ITS and again the value of aggregate benefits will be understated. It is useful to examine each of these arguments in turn but before doing so the basis of economic decision analysis is outlined. The reason for illustrating this is to provide a basis for the central argument of this work that ITS projects do

³ Dollar values may also vary for other reasons such as income or individual preferences.

⁴ Discount rates and their selection are discussed at length in the technical document accompanying this framework document.

not differ substantially from conventional projects and therefore does not require any form of special project evaluation. ITS represents a technological change and the only real issue is the measurement of benefits and costs in the absence of historical information.

There are, as detailed below, two ways by which to measure the benefits. If there are well-known demand relationships, these will provide an accurate and complete measure of benefits. Cost equations can be used to measure the cost side of the analysis. If this information is not available, it will require identifying the range of sub-markets where ITS projects may have some impact. One way of identifying these sub-markets is to list the goals of ITS and the parties that are impacted. The five broadly framed goals of ITS provide the categories for [benefit] measurement; (1) safety, (2) efficiency, (3) accessibility and mobility, (4) productivity and, (5) environmental and energy improvements. These categories are not mutually exclusive or independent. For example, efficiency, productivity and mobility would include the same measures if it is possible to use the travel demand functions. The value in identifying the goals is that it provides a set of sub-markets to build up the measures of benefits and costs.

2.3: WILLINGNESS-TO-PAY AS THE BASIS OF MEASURING USER BENEFITS

Benefits are measured by how much value is placed on a good or service. How much people pay, or total revenue, is not a complete reflection of how much value a person places on a good or service.⁵ The reason is that the value of each unit used or consumed will differ from the first to the last unit.⁶ A method of measuring this ‘value’ is to use a concept termed ‘willingness to pay’ (WTP). The height of the demand curve measures WTP for more - an additional unit - of the good because it reflects the value the user places on a good or service. The demand for travel will be composed of money paid for operating a vehicle plus the time costs. The latter are measured by how much time is used in the trip(s) times the value placed on that time. Some people have quite high values of time while others have somewhat lower ones. The value people place on their time is related to income but not perfectly. Rather the value of time reflects both the *income value of time* and the *utility* they place on a particular use of time. The composite of these two factors will determine the dollar value placed on time. This dollar value is used to monetize time and to create a full cost measure.

The WTP for a decrease in the full price (money plus time costs) of transport is correctly measured by the change in consumer surplus which is defined as the area under the demand curve and between the old and new price lines. This applies whether the same individual is

⁵ The concept is that price reflects the value of the marginal or last unit of a good or service consumed.

⁶ One can consider two ideas here. Consider a drive in the country on a Sunday afternoon. Most people would agree that the last hour of a three-hour drive in the country is valued less than the first hour. Therefore, one would also generally agree that the amount someone would pay for the first hour will be more than what they would pay for the third hour. If it costs the same in terms of time and operating costs for the vehicle, multiplying these measures of cost per hour times number of hours ignores the differing values. In other words, expenditure is not a complete measure of value. This is the same idea that the amount one pays for an article at an auction reflects the second highest bidder’s value not how much the winning bidder would have paid. Willingness-to-pay is the measure of how much they would have paid. It is this fact of differing values of units that we want to ensure we capture in our measure.

making trip adjustments or if people are shifting from one trip type to another. WTP is also applicable to suppliers in that a change in producers' surplus will measure their valuation of a change in the cost of providing transportation.

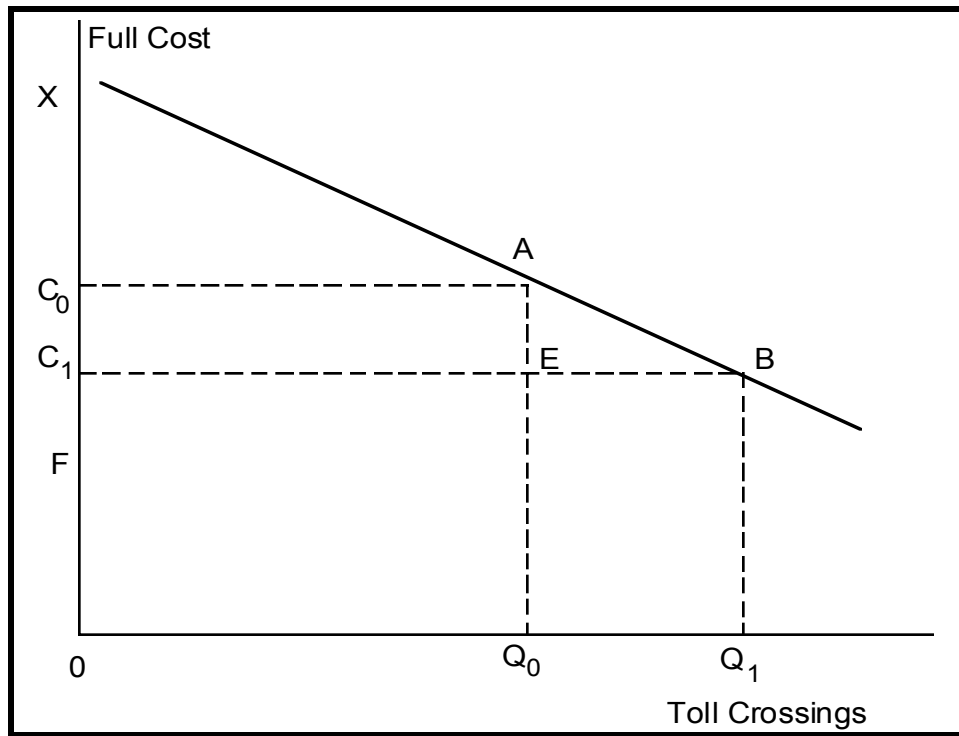
WTP is central to BCA because it provides a dollar metric on the basis of how much people (consumers or producers) would be willing-to-pay to change their circumstances. The simple idea is that if a project were to improve a person's welfare by say, \$1000/year by reducing travel costs, and if the person had to pay \$1000 to access the change, they would be indifferent to the change. As Small (1998) has argued this approach provides a consistent principle for dealing with a large number of measurement issues that at first seem confusing and intractable.⁷

2.3.1 Measuring User Benefits with Consumer Surplus

The use of consumer and producer surplus to value full price changes is illustrated (but only for consumer surplus) in Figure 2. The demand for use of a facility (roadway, for example) is illustrated as a 'conventional' downward sloping demand relationship that reflects willingness-to-pay for the full cost of travel. Suppose through the introduction of an ETC system the enroute time is reduced so the full cost declines from C_0 to C_1 . There are Q_0 existing users and they would receive a change in benefit of C_0C_1EA . This area is a measure of their change in consumer surplus.

Figure 2

Benefits to Current and New Users



⁷ See. K. Small. "Project Evaluation", Chapter 5 in , *Transportation Policy and Economics: A Handbook in Honor of John R. Meyer* (Jose A. Gomez-Ibanez, William Tye and Clifford Winston (eds)), forthcoming 1998

There are Q_1Q_0 'new' users. The area ABE measures the net benefit to these users (again this is the measure of consumer surplus) - if the demand is approximately linear area ABE is approximated by $[\frac{1}{2} \cdot (Q_1Q_0) \cdot (C_0C_1)]$. Note this measure of consumer surplus fully accounts for all of the benefits and it would be double counting if the timesaving and the change in consumer surplus were added.

2.3.2 Measuring Agency Benefits: Using Producer Surplus

When a transportation agency such as Caltrans undertakes an ITS project, such as ETC, the benefits will accrue not just to the users but may also result in lower operating and maintenance costs. These cost savings through increased productivity, improvements in efficiency or the use of fewer resources such as labor should be identified and measured. In principle if the transportation agency were to pass on all cost savings to the users through lower tolls or lower taxes by an amount reflecting the lower costs, the cost savings should not be included since it would represent double counting.⁸ However, cost savings are generally not passed on and taxes are not lowered so the agency cost savings need to be counted.

Therefore, if we have clear and well established measures of the demand for transportation and the cost to agencies supplying transportation services, there is really no difficulty in calculating measures of the benefits for this ITS project just as there is no problem in calculating the benefits of conventional projects. If there were benefits to the broader community from such things as less pollution or higher levels of safety, these would be measured and added to the benefits to users and the transportation agency. However, the fundamental problem is that we do not have estimates of the measures of demand.

2.4 RE-ORGANIZATIONAL AND PRODUCTIVITY BENEFITS; WHAT TO COUNT

One of the most contentious issues in the evaluation of ITS projects is the claim that benefits tend to be undervalued because gains to consumers in the form of enhanced mobility or increased information and to producers in the form of greater productivity are not included or incompletely included. This is not correct and to incorporate these in addition to the measures of consumers' and producers' surplus discussed in earlier sections would result in an over estimate of gains.

The direct impacts of an ITS project are 'relatively' straight forward to measure as illustrated earlier. However, a more interesting category of benefits often discussed in the ITS literature as 'benefits' of ITS are industrial re-organizational and time re-organizational benefits. Again if we stay with the example of the ETC ITS project. A reduction in line haul time may permit an increase in the ease of shipping freight and goods. Shippers can re-organize their production and distribution facilities, such as consolidating warehouses and reducing inventories, to take advantage of the transportation improvement. In effect transportation is being substituted for other inputs in the production and distribution process. These benefits are non-trivial and should certainly be considered in the measures of economic benefits. However, the benefits to 'industrial re-organization' are benefits attributable to using the

⁸ Of course a tax cut would benefit all residents of California and not just the ETC users.

improved transportation in new ways. The increased use of transportation will show up, if we use the figures in Figure 2, as new users (or increased use from current users) $Q_1 - Q_0$ and the benefits of industrial organization are equal to area measured by ABE.

A similar argument can be made for the individuals' time or activity re-organizational benefits from ITS. The claim is sometimes made that a transportation improvement, particularly one associated with ITS, will allow people to access more destinations or be able to better plan their day because of more or better information. Just as with a firm people will re-organize their time allocation and use more transportation, they may change their destinations and may make more frequent trips or make fewer high cost trips with costs exceeding benefits.. Again if we utilize Figure 2 to illustrate how the gains could be measured, existing users will obtain the benefits of the reduction in full costs and any new users (or new trips by existing users) will be measured by the area, ABE.⁹

Now suppose we make the argument that the ITS project provides better traffic or trip information and nothing changes in terms of selected mode or destination or frequency of trip. Is there not a problem of under valuation? The user simply feels better because they now have more complete traffic information yet this does not show up in user statistics; i.e. VMT or AADT or the number of toll crossings does not change. Our explanation would go something like this. The individual will invest in information until the incremental benefits from information equal the incremental costs. This is so because information gathering is not costless and there are diminishing returns to information. If the individual invests in information about traffic the value of their trip will be increased because they are more comfortable knowing traffic levels or the like. In effect the 'quality' of the trip has increased and this will make it more valuable. As with any good or service an increase in value is represented as an upward shift in the demand (or willingness-to-pay) curve. What this says is that people will be willing to pay more for a higher quality good even if they consume the same number of units.¹⁰ So the way the increased information gets valued is represented by an upward shift in the demand for travel curve. This is illustrated in Figure 3. The area XZYZ measures the added value of information.

Note that Q_0 and C_0 may still be the same, nothing else has changed.¹¹ A practical way in which to view this upward shift is the individual has a higher utility and hence value of time when undertaking the trip because of the greater information. The measure of the gain in benefit would be the area XZYZ if existing users did not change the amount of roadway use and there was no induced or additional travel. If the amount of roadway or facility use did increase the new equilibrium would be reflected by point e and the new full cost C_F and level of demand Q_F .

⁹ Two classic references for these arguments are: H. Mohring and H. Williamson, "Scale and Industrial Re-organization Economies of Transport Improvements", *Journal of Transport Economics & Policy*, Vol. 13 (Sept 1969) pp. 251-271 and Sergio R. Jara-Diaz, "On the Relation between Users' Benefits and the Economic Effects of Transportation Activities", *Journal of Regional Science*, Vol. 26 (May 1986) pp. 379-391

¹⁰ A simple example is that we are willing to pay more for fresh fish than frozen fish (given that you enjoy eating fish) because it is higher quality.

¹¹ This measure is the same as what one would find if the measure was taken under the demand for information curve.

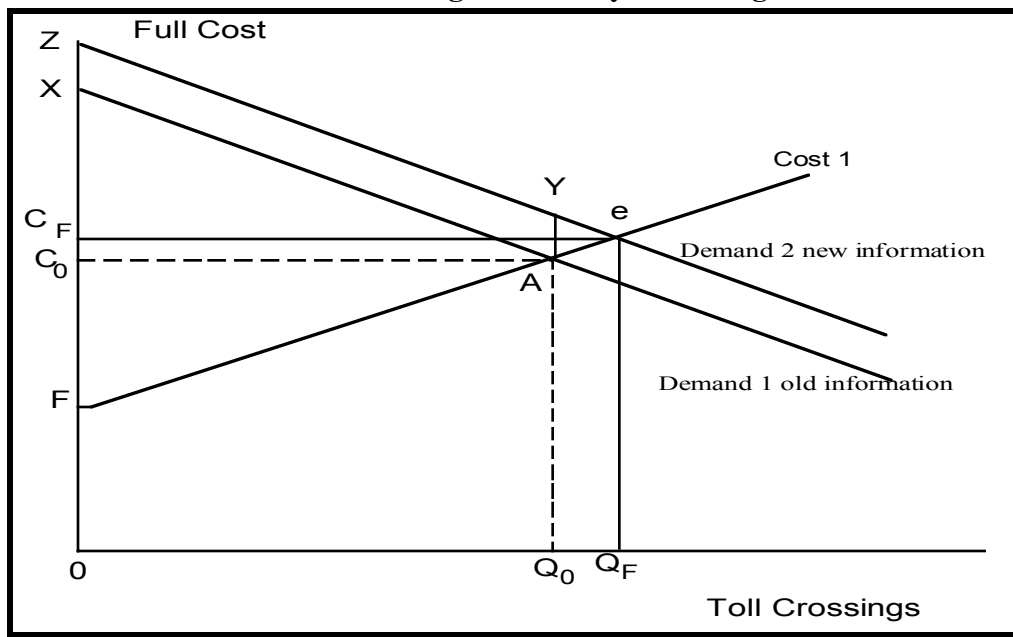
The measure of benefits from the use of consumer surplus, as in Figure 2 and Figure 3, requires knowledge of the demand curve in the area of the current situation (equilibrium). The benefit from a change in the full cost of travel for user group i is calculated as:

$$B_i = \frac{1}{2} \cdot \eta_{k,i} \cdot \left(\frac{\Delta C}{C} \right)^2 C_0 Q_0$$

where $\eta_{k,i}$ is the elasticity, or sensitivity, of usage of user group i with respect to the kth component of full price C. The change in full cost is the impact of the change as a consequence of the ITS project. The three key pieces of information required to complete this calculation are the amount of change in full costs, ΔC , the source of the change in full cost and the measure of sensitivity, (elasticity), of road usage with the change in full costs. Notice the source of the change in full costs is very important since users will have a different level of sensitivity to different components of full cost. For example, if the ITS project reduces waiting time in a queue users will respond in one way while if the ITS project will increase information and allow them to plan their trips more efficiently they would be expected to react in a somewhat different way.

While a great deal of work has been completed that measures the degree of sensitivity¹² of user demand to the changes in full cost, these may be incomplete particularly for ITS projects. Certainly there are measures of time and price elasticities but for such things as improved reliability or increased information or greater safety, there is somewhat sparse information. Therefore, it may not be possible to use the demand approach outlined as the means of calculating all the benefits both direct (to current users) and indirect. If this is the case an alternative set of procedures must be used. These are set out in some detail below.

Figure 3
Information means Higher Quality - Shifting Demand



¹² The measure of sensitivity is called an 'elasticity'.

Again it should be clear that if the demand curves are well defined the calculation of benefits is quite straightforward. However, and this is the key point in this research, we do not have good clear measures of the demand or cost curves as illustrated in Figure 2 and Figure 3. A key conclusion of the research is that there will be significant value in investing in estimating these relationships in order to measure the benefits from alternative ITS projects. So the clear conclusion is that, in principle, with well-defined demand for transportation curves, it is possible to fully value the benefits of ITS projects by simply examining the demand from transportation curves. If there are externalities such as pollution (negative) or network (positive), these would have to be integrated. However, the point is that we do not have good measures of these curves so a ‘clever’ means must be devised that allows us to measure the benefits by looking at the specific markets in which they occurs. Section 3 and 4 provide the detail to develop these measures for benefits and cost respectively. Section 5 describes the strengths and weaknesses and uses of alternative decision analysis methods, benefit-cost analysis and cost effectiveness. In section 6 the decision rules for each of these two methods are presented with some detail to ensure analysts understand the options and their meaning. Section 7 presents a detailed application of the benefit-cost methodology to ETC with many of the calculations placed in an appendix. Section 7 is a good illustration of the application of the thinking and the methods.

SECTION 3: ALTERNATIVE EVALUATION APPROACHES

If the demand relationships discussed earlier were well defined and had been estimated, the calculation of the benefits from the ITS investments would be quite straight forward. The reason the demand relations are sufficient to measure the benefits from a project, and particularly an ITS project, is because the impact the project has on households and firms travel and production decisions will ultimately show up in the use of transportation decision. The importance of the project for either households or firms will be reflected in how much travel demand changes. If, for example, there is little or no effect current VMT or AADT are good proxies for the traffic levels or road usage after the project is in place.¹³

However, given that this information is not yet available it is necessary to assemble information from those categories of benefits that would have made up the demand impact. In principle the two measures would be equivalent. In the following sections the categories of benefits are described and developed. Following this the same is completed for costs.

3.1: CATEGORIZING AND MEASURING THE BENEFITS

Until it is possible to have reliable estimates for travel demand relations (curves) and measures of the parameters that permit direct and simple measures of the benefits, it is necessary to identify the areas or sub-markets in which ITS projects will have some impact. This will be source of the measures of benefits and costs. To proceed there are two

¹³ As another example, if an improvement in an interchange is being considered, we have good information on how it will affect travel times and that information can in turn be used to assess how demand will change, if at all, with this change in this type of travel time

complementary tracks to follow. First is to categorize benefits according to the five goals of undertaking ITS projects and secondly on the basis to whom the benefits accrue. The goals for ITS have been listed as (1) improving efficiency (of the roadway system), (2) mobility, (3) safety, (4) productivity and (5) reducing environmental impacts. As we argued earlier these provide a useful way of identifying sources of benefit categories.

Safety, air pollution, fuel use and efficiency improvements can be measured using existing operational, and environmental data and traffic engineering statistics. That is current and forecast usage provides reasonably good measures of benefits. However, improvements in mobility and productivity are somewhat more difficult to measure since the introduction of an ITS project may lead to a behavioral shift in travel.¹⁴ The benefits may result from more reliability, less congestion and more opportunities, for example. The existing information base of current users will not be sufficient to fully capture the benefits resulting from such an ITS project. Induced travel may mean more VMT as would modal substitution and destination substitution; as reflected in the earlier discussion regarding demand curves. The latter may occur, for example, because the provision of in-vehicle information systems would allow people to visit more destinations. These are genuine benefits that are not captured by current AADT measures.¹⁵ Similarly, ITS projects that lead to increases in productivity of some industries can lead to lower prices, higher profits (or both) and in the longer term some expansion of output through greater market penetration.¹⁶ To measure the consumer benefits requires re-evaluating the value of time. The productivity effects can be measured using information on transportation as a factor of production in firms' production functions. An example is provided in an appendix to this framework report.

Some of the benefits that accrue from ITS projects can be viewed as being more or less reliably measured using current VMT data, as has just been explained. To sharpen this distinction and provide a means of evaluating the importance of the 'as yet unmeasured' benefits, it is useful to distinguish benefits by the different user groups as well as other agencies and groups in society. It is easiest to think of projects providing benefits to three groups; (1) the users of the facility, (2) the agency that provides the facility and (3) the community in which the facility is situated. General representation of the economic impacts of an ITS project is set out in Figure 4.

3.2 DIRECT BENEFITS

The measurement of each of the categories of benefits generally contains two components, the quantity and the value. For example, how much time is saved and how is the time valued would be the quantity and valuation respectively. The direct benefits will tend to be immediate and will generally be [relatively] easily quantifiable. They will fall into three

¹⁴ Whether productivity improvements should be included is considered in greater detail below.

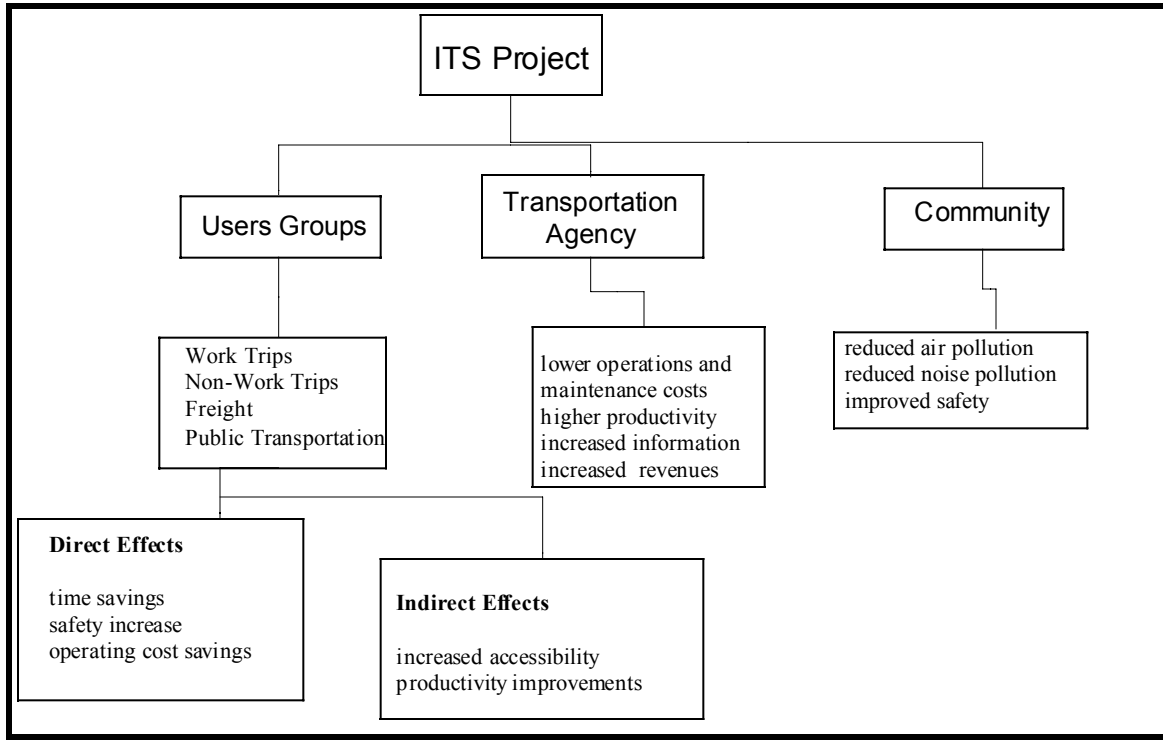
¹⁵ Using current VMT or AADT would imply a belief the demand for travel is completely inelastic (i.e. a vertical demand function)

¹⁶ The essential message from this discussion is that for some ITS project evaluation some sophisticated modeling will have to be undertaken to ensure benefits are not underestimated.

categories; (1) savings in user operating costs, (2) savings in travel time and, (3) increases in safety. Each of these benefits will need to be measured for each user group. These would include work trip users, non-work trip users, freight shipments and, if applicable, users of public transportation such as bus or transit. For current users existing VMT or AADT statistics can be used as the basis to measure benefits. For those who may increase travel or for induced travelers a [simple] model that links increases in demand to changes in relative prices or quality or transactions costs can be employed.¹⁷

Figure 4

Benefits Framework for ITS Projects



The direct benefits to the agency should also be fairly straightforward to measure. These represent resource cost savings of providing the level of highway services that were or are being provided. Cost savings will result from the use of less labor, increased productivity and less capital. Over the longer-term lower maintenance costs will contribute to savings in materials, labor and operations. Direct community benefits arise from less air and noise pollution and higher levels of safety. In all cases existing traffic data will provide a first step in calculating benefits.

3.3 INDIRECT BENEFITS

Measuring indirect benefits as noted earlier is more difficult because in many cases travel

¹⁷ One might argue that non-ETC users benefit from some portion of traffic using ETC since it reduces the queue at the tollbooths. This would be true but it is a transitory phenomena and disappears as ETC use increases to 100 percent.

behavior or structural adjustments will take place as a result of the ITS project. Therefore, existing traffic levels will under-estimate overall benefits if travel demand is at all sensitive to changes in any of these factors. The benefits to users arise from increased accessibility and mobility. The benefits to producers arise from increased savings in production costs as greater use of transportation is substituted for other factors. For example, a firm may have several plants scattered across its various markets. An ITS project may improve transportation sufficiently that plants can be consolidated. This is, in effect, a substitution of more transportation for less plant and equipment capital as well as labor for greater use of transportation. In both cases additional information is required and some [simple] models are needed to estimate benefits. Knowing the attributes that have been changed and the determinants of travel behavior, from a demand or choice model, the dollar value of benefits can be quantified.¹⁸ This will still somewhat underestimate benefits since the ‘value’ measured is an access or option value not a use value. Unless relatively sophisticated models are used with additional information, this underestimate will continue to exist.

The quantification of benefits be they direct or indirect requires two measures, the physical quantity of the change of the type of benefit and the dollar value of the unit of quantity by the user effected. For example, consider the introduction of electronic toll collection as a representative ITS project. In general there are three key values; how much time is saved, if any, for each user group, what level of safety is achieved for each user group and what components of air pollution change.¹⁹ We can measure how much time will be saved and how safety will improve with less queuing and less variance in speed. We can also measure by how much air pollution will be reduced but all of these must be valued in some dollar measure in order to compare them to costs and to alternatives. Therefore, the physical quantity change is multiplied by the dollar value of each unit of physical quantity. Some representative dollar values are illustrated in Table 1 through Table 3.

Different agencies use different values of time in evaluating projects. The FHWA is using 60% of the wage for highway evaluation while California uses \$7.42/vehicle-hr and Florida uses \$13.72 for valuing non-work time. Texas Transportation Institute recommends using a value of \$9.92 per person-hr (1985\$’s) or alternatively, 70-80 percent of the wage rate. Clearly an identical project could be ranked quite differently in different jurisdictions.²⁰

¹⁸ In each of these cases the purpose of the particular model is to provide information on the value that people place on the good, or service. The value can be an aggregate of four different values. A private use value is an indication of how much people are willing to pay (WTP) for consuming. It reflects the utility or revenue obtained by private use. An option value reflects a value placed on the option to use or consume the good at some future point rather than right now. People have a different WTP from that just noted for use value. An existence value reflects people’s valuation, and WTP, for having the good, service or facility available even if they do not plan to use or consume it. The fourth value is a bequest value. This reflects the value people place on a good, service or resource for availability for the future. I may, for example, value a new HOV lane because it will reduce air pollution and I want a cleaner environment for my family. The difficulty with current models is they generally reflect only use value.

¹⁹ In some cases noise pollution may be reduced and would be included in the measure.

²⁰ While neither empirical evidence nor professional practice provide clear cut answers as to the correct valuation of time savings, the situation does imply a valuable use for risk analysis and the selection of a range of values of time.

The valuation placed on freight transportation timesaving would be a composite index of driver time, vehicle capital costs and cargo valuation. The measure is in essence a measure of the opportunity costs of the resources. If the total VMT does not change, the cost savings are measured in a straightforward way; time savings per vehicle times the variable cost per unit time. If the cost savings are used to produce more output (more VMT) the measure is more complex since the benefit is the value of the output to the shipper and to calculate this the shipper demand function must be known.²¹

Table 1
Values Used in Benefit Calculation
Costs per Person in Accidents by Component Category

Cost Component Category	All Reported Accidents
Hospital/Medical	\$588
Vocation/Rehabilitation	7
Household Production	503
Wages	1993
Insurance Administration	379
Workplace Costs	117
Emergency Services	50
Travel Delay	100
Legal/Court	429
Property Damage	1351
<u>Human Capital Subtotal</u>	<u>5517</u>
Pain and Suffering	11788
<u>Comprehensive Subtotal</u>	<u>17305</u>
<u>Direct Costs</u>	<u>3021</u>
Years Lost	0.13

Source: Miller (1991) p 42

Table 2
Values Used in Benefit Calculation
Comprehensive Costs by Severity of Accident

Accident Severity	Cost Per Person	Cost Per Crash
K-Fatal	\$2,392,742	\$2,722,548
A-Incapacitating	169,506	228,568
B-Evident	33,227	48,333
C-Possible	17,029	25,288
O-Property Damage	1,734	4,489
Unreported	1,601	4,144
A-B-C reported nonfatal	46,355	69,592
K-A-B-C reported injury	77,153	115,767

Note: assuming 1988 dollars and 4% discount rate
Source: Miller 1991 (p39)²²

²¹ If the elasticity of shipper demand is close to unity the two measures will be approximately the same.

²² These costs are in general higher than estimates previously used by NHTSA (1983), Miller discusses the

Table 3
Values Used in Benefit Calculation
Macroscopic Estimates of Cost of Pollution

	CO	HC	NO _x	SO _x	PM10
Tolerance Factor	7800	788	330	373	260
Severity Factor, (vs. CO)	1	10	24	21	30
Total US Emissions (million tons)	113.4	29.8	24.8	30.2	15.5
Severity Tonnage	113.4	298.0	595.2	634.2	465
Cost Allocation, ? = 1	0.0539	0.1414	0.2826	0.3012	0.2208
Cost (\$ million)	1,184	3,110	6,212	6,621	4,853
Cost per ton (\$/ton)	\$10	\$104	\$250	\$219	\$313
Cost per kilogram (\$/kg)	\$0.012	\$0.12	\$0.28	\$0.24	\$0.35

Sources: Small (1977) and Fuller et al (1983)

SECTION 4: COSTS: CATEGORIES AND MEASURES

Costs in any decision framework should represent the true value of all resources used in the construction and continued use of the facilities that are part of the ITS project. The *value* is based on the concept of ‘opportunity cost’. This means, ‘what is the value of investments or projects given up by using resources in this use rather than the next best alternative’? The way value is measured is through ‘willingness-to-pay’ which is generally reflected in the market prices.²³ Local labor markets, for example, would provide a value for pricing labor services. Similarly with materials, energy and other inputs used in producing and maintaining the ITS project, local prices would reflect their opportunity costs. It is with the valuation of capital that most care must be taken since the ‘value’ of capital will not necessarily be reflected in an accounting measure.²⁴ Capital as a scarce resource like other resources should be valued at its opportunity cost; what it could earn in its next best alternative. These concepts are illustrated in the application of the use of these decision analysis frameworks in the last section of this manual.

Implementing cost measurement is generally straightforward in any decision analysis framework. However, with ITS projects this is not the case. In evaluating conventional highway projects there is a well-established set of information on the construction, operations and maintenance costs of different types of roadways and bridges. ITS projects represent the application of new technologies and although it may be possible to assemble construction costs the operations and maintenance costs will be speculative. This is because

differences in depth.

²³ This issue is discussed at length in the technical document accompanying this manual. If market prices are not available then shadow prices must be developed.

²⁴ Again, the issue of accounting versus economic measures of capital is discussed in the technical appendix to this manual.

there is not sufficient experience with the application and implementation of ITS technologies. It will be necessary to undertake pilot studies, surveys and utilize forms of risk analysis in developing cost estimates.

The categories of costs for the user classes, agency and the community would include:

- ◆ facilities and roadway construction, including computer hardware and software
- ◆ facilities operations, including technological training and updating
- ◆ facilities maintenance, including continuing software upgrading
- ◆ user operating costs; direct and time expenses
- ◆ environmental, safety

These are broad cost categories and specific projects will have different amounts of detail. However, these categories are sufficient to provide guidance to the evaluator. In Section 8, ETC is used to illustrate the use of the framework, and the presentation of the cost categories provides a concrete example of the use of this general framework.

SECTION 5: DECISION ANALYSIS METHODS

Caltrans and regional decision-makers both face the prospect that demands for ITS projects compete with alternative projects within Caltrans and regional governments as well as across other projects in the California government.²⁵ The value of alternative projects needs to be established and a way of judging them against one another and in some cases against the status quo. There are a variety of evaluation techniques ranging from the highly quantitative to case studies. ITS projects represent enhancements to an existing system and so do not constitute such large projects that they might result in a significant change in the nature of the system or economy.²⁶ Two approaches to project evaluation that can fit within the benefit - cost evaluation category are benefit-cost analysis and cost effectiveness analysis.

Benefit-cost analysis is a unifying framework by which to combine the costs and benefits accruing to different groups into a single measure. The unifying principle of benefit-cost analysis is ‘willingness-to-pay’ which is the measure of value of the project to the society that is funding and benefiting from it. This principle can be found in the welfare economics tradition, the micro-economic tradition and public choice yet there is the common bottom line; when choosing among projects, the best all purpose rule is to select that one that maximizes *net social benefits*. This is defined as the sum of consumers and producer surplus less all resource costs of constructing, implementing and maintaining the project. The fundamental criterion used in these measures is one of efficient resource use, efficient in the sense of producing at lowest cost and in the sense of producing what gives consumers the greatest value as measured by satisfaction. Thus the fundamental basis for benefit-cost

²⁵ Caltrans has a split role. It is an owner/operator of the interregional highway system and thus makes decisions about this asset. At the same time it can and does influence decisions of statewide concern.

²⁶ Some projects such as the Alaskan pipeline project of the 60’s did have a profound impact on the Alaskan economy.

decision models is one of economic efficiency and assumes consumer sovereignty. It treats those who gain and those who lose equally and compensation need not be considered or paid between those who gain and those who lose.

Cost effectiveness analysis is most useful when information regarding benefits is incomplete or inaccurate. If there are two projects, for example, and consumer benefits cannot be measured but the two projects are substitutes for achieving the same end, the basis of comparison would be the costs of completing and operating the project. A cost effectiveness evaluation looks at two or more ways of accomplishing the same objective, and selects the cheapest. Note that cost effectiveness analysis is not useful if only one project is being considered against the status quo or 'do nothing' alternative. The implicit assumption under this decision framework is that the benefits are the same or sufficiently similar, in size and coverage, that they can be treated as a constant between the two projects.²⁷ Minimizing costs is the only consideration with cost effectiveness analysis.

SECTION 6: DECISION CRITERIA

The better known of the decision methods is benefit-cost analysis yet this can be a highly data intensive exercise if carried out in a comprehensive way. In some cases this is neither possible nor desirable. There are alternatives that can be used in assessing alternative projects. Which methodology is used is a matter of what is the objective and how much information is available as has just been discussed in the previous section.. Two alternatives are described below, benefit-cost analysis and cost-effectiveness analysis.

6.1 BENEFIT-COST ANALYSIS

Benefit-cost analysis has been considered everything from a boon to a boondoggle by [public] decision-makers. Many have found the approach and the estimates provided valuable in establishing the nature of the effects of alternative project and policy choices. Some argue that the quantification and systematic evaluation required by analysis exposes the important issues in the policy decision and subjects them to critical appraisal. Others argue that B/CA is an unnecessary impediment to the political decision-making process. Public decisions, they argue, are based upon political support and this may or may not require economic efficiency. Overly zealous advocates of both extremes have to a large extent, fueled the debate. Too often analysts have been overcome by quantification and the pursuit of economic efficiency, and have held to the belief that the whole issue can be summarized in a benefit-cost ratio, a net benefit statement, a rate of return on investment, or some other singular evaluative statement. Many adherents of the political role, unduly enamored by power bargaining, have overreacted to what they see as (and which sometimes is) "meaningless quantification" and reject altogether the economic impact. The justified role of B/CA is somewhere in between these two extreme positions and, depending on the issue at hand, sometimes rests closer to one than the other. B/CA is a tool for providing information to decision-makers in a consistent and logical way. The significance of that information in the

²⁷ By coverage is meant that the benefits are the same in terms of categories; e.g. direct, indirect and social.

decision-maker's analysis may vary depending upon the nature of the issue under study. Although there are important limitations to the approach, it is basically an attempt to outline the positive and negative effects of a choice, the weightings of which, however, are often left to the decision-maker himself.

Benefit cost method should be used when the paramount concern is with the efficient use of scarce resources.

An essential and often difficult task is to determine the pattern of benefits and costs over the project's life, but once accomplished, the analyst has a time stream of benefits, $B_0, B_1, B_2, \dots, B_{t-1}, B_t$, and a time stream of costs $C_0, C_1, C_2, \dots, C_{t-1}, C_t$ from the present period, 0, to the termination date t or some future point such as the lifetime of the project. B_0 are the benefits in the current year, B_1 the benefits next year and so on until B_t are the benefits in year t . Similarly for costs, C . The money value of the respective time stream cannot simply be summed and compared to determine the project's viability since the time patterns of benefits and costs are likely to differ. Usually the bulk of the costs occur in the early years when the investment is first made, while benefits are generated over a number of years once process becomes operational. The difference in the timing of benefits and costs would not matter if people valued a dollar today and a dollar in the future equally.²⁸

Because a dollar is valued differently at different periods of time, it is necessary to relate the value of benefits and costs in different years to a common period. Discounting future benefits and costs to their present value does this. The present-value of one dollar available in period t and discounted at the rate i is ²⁹

$$PV = \frac{\$1_t}{(1+i)^t}$$

Hence the present value of the benefit stream can be established as

$$PV_B = \frac{B_0}{(1+i)^0} + \frac{B_1}{(1+i)^1} + \frac{B_2}{(1+i)^2} + \dots + \frac{B_t}{(1+i)^t} = \sum_{t=0}^t \frac{B_t}{(1+i)^t}$$

and the present value of the cost stream is calculated in precisely the same way as

$$PV_C = \sum_{t=0}^t \frac{C_t}{(1+i)^t}$$

Once discounted to the present, benefits and costs can be compared. In CBA this comparison is most commonly expressed either as a benefit-cost ratio

²⁸ However, they do not, as evidenced by the fact that borrowers are willing to pay interest which is a premium for the use of money today rather than waiting for the future. Lenders require the interest as compensation for foregoing their use of money today and postponing its use until the future. This is the reason that we find, for example, that a \$1,000 bond payable one-year hence has a market value of \$925.93 when the rate of interest is 8 percent.

²⁹ This is easily calculated using any common spreadsheet program such as Excel© or Lotus© or Quatro©.

$$\frac{B}{C} = \frac{\sum_{t=0}^t \frac{B_t}{(1+i)^t}}{\sum_{t=0}^t \frac{C_t}{(1+i)^t}}$$

or as net present value

$$Net\ PV = \sum_{t=0}^t \frac{B_t}{(1+i)^t} - \sum_{t=0}^t \frac{C_t}{(1+i)^t} = \sum_{t=0}^t \frac{B_t - C_t}{(1+i)^t}$$

The project is viable on economic efficiency grounds if the B/C is greater than one or if its net present value is positive.³⁰ The former value provides a measure of the rate of return; the benefits per dollar of expenditure. The latter gauge gives a measure of the magnitude of the return; how big it is in dollars.

The major advantage of the net present value (NPV) criterion is that it shows the absolute magnitude of the returns from a project. This is in contrast to the benefit-cost ratio (B/C) which only reflect relative returns. Absolute magnitudes, while an essential consideration, are not the whole story for projects with the same dollar benefits (\$10M, for example) may have much different relative returns. For example, \$10M net benefits might accrue from projects with benefit-cost ratios of \$20M/\$10M = 2, or \$200M/\$190M = 1.05. As a result, one cannot usually select projects on the basis of a single criterion, as both absolute and relative measures deserve consideration.

After consideration of these criteria and their relative merits, the reader may wonder which of these is the appropriate one to employ and rightly so, since no one is ideal and each offers some advantage in certain circumstances. Generally, however, the preference is to use of the B/C ratio in conjunction with a net present value measure. This provides measures of both the absolute magnitude of discounted net benefits as well as the ‘rate of return’.

6.2 COST EFFECTIVENESS ANALYSIS

Cost effective analysis [CEA] is commonly used as an alternative to CBA. CEA evaluates a potential application of Automatic vehicle Location (AVL) measuring the extent to which it may achieve a given goal within a predetermined budget or, equivalently, it compares the costs of achieving a particular goal using AVL and non-AVL technologies. Often, the goal will have been set under a separate process in which benefits and costs may have not been considered.

CEA compares, mutual exclusive, alternatives on the basis of their costs and a single qualified but not monetized effectiveness measure, such as number of lives saved, or number of minutes of travel time saved or amount of agency costs saved.³¹ Though there is no

³⁰ These two expressions, as well as internal rate of return, are discussed in detail in the section “Project Selection Criteria.”

³¹ Clearly, the development of performance measures is essential for the application of CEA to ITS.

conceptual reason why costs cannot be measured comprehensively, in practice analysts generally measure them narrowly as budgetary costs.³² CEA makes the assumption that the project should be undertaken and what is being sought is the most cost-effective way of accomplishing this. It does not provide information as to whether there are positive net social benefits associated with any of the alternatives.

6.2.1 Cost-Effectiveness Ratios

There are two basic ways to create cost-effectiveness ratios. For decision-making purposes there are two ways to impose constraints to facilitate comparison of policy alternatives involving projects of different scales. There are also adjustments that can be undertaken to make CEA closer to CBA.

Since CEA does not monetize benefits, it inevitably involves two different metrics: cost in dollars and an effectiveness measure - for example, reduced travel time, increased safety, lower transactions costs. Because non-commensurable metrics cannot be added or subtracted, it is not possible to obtain a single measure of net social benefits from the two metrics. It is only possible to compute the ratio of the two measures as a basis for ranking alternative policies. This can be accomplished in two ways.

First, cost-effectiveness can be measured in terms of cost per unit of outcome effectiveness, for example, cost per minute of travel time saved. To compute this, one takes the ratio of the budgetary cost of each alternative I , denoted by C_i to the effectiveness (or benefit) of that alternative, E_i .

$$CE_i = C_i/E_i$$

This CE ratio can be thought of as the average cost per unit of effectiveness. The most cost-effective project has the lowest average cost per unit of effectiveness. Therefore, projects should be rank ordered from the most cost-effective, those with the smallest CE ratio, to the least cost-effective.

Second, cost effectiveness can be calculated as the ratio of the outcome effectiveness units per unit of budgetary cost, or:

$$EC_i = E_i/C_i$$

This EC ratio can be thought of as the average effectiveness per unit of cost. The most cost-effective project has the highest average effectiveness per unit of cost. Thus, projects should be rank ordered from the most cost-effective (those with the largest EC values), to the least cost-effective.

³² Thus social costs are generally excluded yet some AVL impacts may have an impact on congestion or air quality.

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