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CALIFORNIA PARTNERS FOR ADVANCED TRANSIT AND HIGHWAYS

Evaluation Methodologies for ITS Applications

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Chapter 1: Need for Evaluation Methodologies for ITS

1.0 Introduction

California's Transportation Plan [CTP] was designed to set the course for the future of transportation in California.' At the heart of the plan are three comprehensive policies; promoting the economic vitality of California by assuring mobility and access for people, goods, services and information, provide safe, convenient and reliable transportation and, provide 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 but is more narrowly designating the use of advanced technologies in electronics and information to improve the performance of vehicles, highways and transit systems.

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 investments and continuing operations and management expenses while other projects will represent small capital investments. Some projects will be broadly based in urban areas while others may be specific to a link at a given location such as electronic tolling. Simply put the projects will vary in a number of dimensions from size, capital intensity, geographic coverage and user groups effected. The variety and coverage creates a challenge for investment analysis.

Investments in infrastructure and management strategies under the ITS program will generate different types, magnitudes and longevity of payoffs. They will have different levels of costs and both costs and benefits will have risks of varying size. The variability of both benefits and costs will create a degree of uncertainty regarding the evaluation of projects as well concern as to 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 through public capital markets 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. If these projects do not meet financial and economic tests in a transparent manner, including a compensation for greater risk and

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

uncertainty, the private sector is unlikely to undertake the development of new **ATS** products in the future. 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 quality of decisions will be threatened by the lack of or failure to use aids that help guide the public use of scarce resources.

Decision makers at various levels will require some means of deciding which projects should be undertaken, where and when. Funds must be allocated among competing projects. It is therefore necessary to have methods for evaluation that are transparent, accurate and able to withstand scrutiny by professionals and practitioners alike. The chance with the ITS projects is their novelty and lack of history. Relatively little information is available **as** to their impact and yet intelligent conjectures must be made if the public is to receive value for their public dollars. In some cases transportation professionals will attempt to extrapolate or transfer results fiom projects in other contexts and jurisdictions in order to obtain a better sense of the range of benefits and costs.

There are several types of evaluation methodologies and each have strengths and weaknesses, circumstances in which they are more or less appropriate and place demands for more or less data on the decision-maker. In many instances benefit-cost analysis is championed **as** the best or only evaluation methodology yet many use the term 'benefit-cost' in a generic way to mean all evaluation methods. Three approaches that encompass a range of methodologies are benefit-cost analysis, impact analysis and cost effectiveness analysis. Case studies, marginal analysis and 'intelligent conjecture' can be can be integrated into one or another of these. The three approaches will form the base of support for more informed decision-making for ITS investments.

One common feature of all three approaches is the need for quantitative information and this, at least initially, may be sparse or less reliable because of a lack of experience with ITS projects. One approach to overcome this difficulty is to use case based reasoning (CBR) in which experience in other jurisdictions or projects that affect similar outcomes is used to scope the range of potential effects.

As part of any evaluation a set of performance measures needs to be established. Benefit-cost analysis is founded on the goal of economic efficiency. It is a methodology designed to provide information on projects which yield the greatest net social economic benefit. Impact analysis on the other hand focuses entirely on benefits with no regard for the costs of the project. It is not that costs should not be of concern but rather when the impact on a community, group, location etc. is all that is of concern, costs are not part of the criteria by which this measure evaluates success. Cost effectiveness analysis is closer to benefit-cost analysis but takes a somewhat narrower perspective. Cost efficiency and not net social benefit is the basis of assessment. In our menu of project evaluation methods it is important that a menu of performance measures be considered. Those that should be examined include economic efficiency, effectiveness, mobility, accessibility and equity.

1.1 Spatial, Temporal and User Dimensions

Evaluating benefits, costs and risks requires identification of not simply how large they are but how they are distributed. The most common consideration in evaluation is the distribution over time since the discounting of future benefits and cost scan have dramatic effects on the undertaking as well as ranking of projects if there are quite different temporal distributions of benefits and costs. It has been shown, for example, that when using a criteria of internal rate of return to rank projects, the ranking is dependent upon the temporal distribution of benefits and costs. One of the significant difficulties with the temporal dimension of benefits and to some extent costs is the level of uncertainty increases as we move into the future. Future benefits and costs must be forecast and the uncertainty arises both with the forecasting variables and the relationship between the benefits and the forecast variables. It may require a risk analysis or a higher rate of discount into the future.

The spatial dimension is reflected in the ***accounting stance*** which affects what benefits and costs are included. **A** project may be quite small and seemingly affect only a given location or small area. Projects aimed at improving link performance levels may effect the link or **an** entire route or corridor and finally broadly based projects may impact an entire network, statewide. If the project is funded at a state level but the benefits accrue at a local level and a local accounting stance is taken, a large return per dollar invested at the local level will be the case because the benefits are concentrated within the small area whereas the costs are spread over the entire state. **As** a broader accounting stance is considered, there is a closer correspondence of the basis of benefits and costs and this will lower the measured return. If a local or link accounting stance is taken yet there are system effects, the measured payoffs may be understated or overstated. They would be understated if some payoffs were excluded while they would be over stated if transfers fiom other areas were counted as benefits. The broader the accounting stance the more likely will transfers be accurately considered in the evaluation. The accounting stance in most cases for **ITS** projects would, at most, be the state. Perhaps the most important feature of the spatial dimension is it defines the probability of double-counting. The narrower the accounting stance the greater the probability that double-counting will result; including transfers fiom other jurisdictions.

Changes to the transportation system affects three groups; users, infrastructure providers and the broader community and economy. The reasons for separating benefits and cots into three categories are to distinguish direct and indirect impacts, identify strategies that are applicable to one group but not another and to be able to place different valuations on changes to the system. *Users* are generally considered the direct and primary beneficiaries of any project. They can be divided into categories of movement of people and movement of fieight as well as subdivided along the lines of trip purpose (for people) and value of shipment (for freight), location and socio-economic status. *Infrastructure providers* are a separate group since depending on the nature and size of the project cost economies may be available as well as positive externalities due to network economies. The underlying cost structure and management options also differ between providers and users. In most

cases the infrastructure provider is implicitly treated on the cost side when capital and operating costs are assembled and aggregated. However, these are generally considered to occur at the beginning of the project (for capital costs) and known ongoing operating costs. There are management initiatives that may be able to effect costs that are not part of user costs and would not be included if the category of infrastructure provider were not distinguished.

The third group affected by ITS projects will be the *broader community, environment and the economy.* These will generally be considered indirect costs and benefits but in some cases, such as environmental degradation, the impacts can be direct. The benefits and costs considered in this group are taking on more importance over time. The linkages between improved transportation and the growth of the economy and competitiveness of industry are topics that are important to policy makers and that may have sizable benefits that may not generally be included. The impact of transportation on the environment is not only of broad public concern but is expressly noted in California's Transportation Plan. It is therefore necessary to know how projects impact non-users and how important these impacts are both absolutely and relatively. This group of impacts and impacted are also more difficult to measure, are more dispersed and in some cases more qualitative than quantitative.

1.2 Character of ITS Projects

ITS is designed to increase the productivity of existing capacity rather than add to capacity. This character of ITS projects means they will tend to be 'marginal' in the sense of being incremental changes to the system. Yet they can have significant impacts. A small reduction in auto trips may, for example, significantly reduce average trip time on a given route. This implies any changes are represented by moving along cost functions or demand relationships. *An* improvement in travel information, for example, will reduce travelers time costs conferring benefits on existing users, new users from other routes (transferred traffic) and induced users. However, the very nature of ITS is 'technology' and this means shifts in traditional cost and demand relationships. Returning to the traveler information example, this may not simply represent a source of saving travel time by being able to make more informed route and departure time choices but a new product, more choice and a shift in the full cost or demand function. On the supply side, infrastructure providers introducing ITS can experience lower costs because of a technological shift resulting in productivity improvements or because they have exploited the available cost economies through better management. The cost economies are available due to the ITS project but would not be realized without some new management strategies.

Does this feature of ITS that projects are aimed at enhancing productivity rather than expanding the capacity of the system result in the requirement for new models or new evaluation tools, forecasting models, and simulation models to assess benefits from ITS; these would include, for example, increased accessibility, reduced travel time, energy consumption, and air pollution (as a result of synchronized operations), smoother traffic

flow, increased use of high occupancy vehicles (shuttles, buses, etc.), and somewhat decreased reliance on private automobiles.

1.3 Purposes of the Framework

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

Information on the benefits and costs **of** ITS projects is important for planning and implementing ITS programs and setting priorities for future ITS deployments. Planners need to understand the benefits and costs in order to make strategic plans for ITS deployments. Engineers need to know the information in order to ensure that projects are appropriately designed with recognition of both positive and negative impacts. Policy makers need such information in order to decide appropriate policies to ensure that such developments achieve broader social and economic goals and objectives. Financial planners need such information for funding allocations in order to maximize the utility of public resource. Taxpayers need to know the information so that they are sure about their money is spent efficiently. Private investors also need the information in order to make investment decisions regarding deciding whether to invest in ITS projects, what projects to invest, and when and where to invest. This fiamework is developed to meet those needs.

The purpose of this fiamework is to develop a set of alternative methodologies to evaluate ITS projects and investments, and to identify methods for quantifying and valuing benefits and costs associated with different ITS projects. It will provide transportation community with a generic analytical guide for assessing and evaluating the costs and effects of ITS applications/projects and for comparing the benefits and costs of ITS alternatives for future developments.

1.4 Information Covered by this Framework

This fiamework is developed specially for evaluating ITS projects. With this specific target in mind, we try to compile and present techniques and references that may be useful for benefit-cost analysis of ITS projects. We will discuss the advantages and disadvantages of those techniques to the extent possible, so that users can select appropriate techniques according to their needs.

Since ITS applications vary fiom one to another, it is impossible to produce a fiamework that fits all. This fiamework can only provide a general guidance in identifying benefits and costs, as well as their associated values. Users may have to modify the fiamework in order to analyze a particular ITS application/project. For this reason, this is not a cookbook.

Transportation planners and engineers who engage in planning and appraising ITS projects may use this framework. Although this framework is for ITS projects, readers may find that it is useful for evaluations of other transportation projects in terms of general methodological procedures.

1.5 Generic Issues Related to Benefit-Cost Evaluations

Regardless of which methods to use for the evaluation of ITS applications, the first step is to define the point of view to be taken. Defining whose point of view is important because it essentially involves a judgment about what benefits and costs should be included, which benefits and costs should be considered as internal to an ITS application or project and which would be regarded as external. For instance, when deciding whether an ITS project investment is worthwhile, a private firm tends to make its decision in terms **of** profits (or payoff). Hence, money spending in the project and direct revenues generated from the project become internal to the firm while other impacts beyond its financial account are external. For the same situation, a city government agency may make its decision in terms of the social and economic well-being for the city in addition to financial profits. **A** state or federal government agency may extend its interests to the costs and benefits of society at large. Nonetheless, the point of view of society as a whole might be appropriate for ITS applications which involve funding from revenues of all taxpayers.

Evaluating the benefits and costs of an ITS application also involves the distinction between short-run benefits-costs and long-run benefits-costs. Distinguishing short-run benefits and costs from long-run ones is important because it affects the identification and classification of benefits and costs. For example, over the short run, capital costs of ITS applications are considered fixed because only relatively minor adjustments or additions can be made to the technology. However, in the long run, the capital costs may be considered as variable costs since the technology can be substantially altered. Similarly, some long run benefits may not be realized in the short run. Therefore, they are included when long-run benefits are considered while excluded when the evaluation only focuses on short-run benefits.

Another important issue related to the identification of benefits and costs of an ITS project is the scope of a project. When the scope of a project is not defined properly, certain costs may be overlooked or underestimated. The scope of a project can be as small as a link or a number of links of highway or arterial, or routes. It could be as large as a travel corridor, a highway network, or a comprehensive transportation system which includes various transport modes. The scope of a project can be defined in terms of the purpose of analysis (problems to be solved, objectives to be achieved, variations in the level of required investment), and geographical or jurisdictional area affected by the project.

1.6 Design of the Report

Chapter 2 of this report provides a categorization of ITS projects. The chapter describes the different applications of ITS technology, categorizes each application and how the project fit into the transportation system. In Chapter **3** the range of evaluation methods are presented. For each of benefit-cost analysis, impact analysis and cost effectiveness

analysis we describe the fundamental orientation, scope, strength and weaknesses, decision criteria, and basis of evaluation and when each should be most appropriately used. Chapter **4** presents the categories of benefits and costs for each of the **ITS** applications described in Chapter 2. The focus on this chapter is to describe the quantity of benefits and how they can be measured , calculated or forecast. Chapter **5** discusses a range of issues that arise in the application of evaluation methods. It describes in general way additional issues that must be considered when measuring benefits and costs, issues **of** discount rate and how to resolve them, issues of quantitative versus qualitative measures and how to attach some quantification to the qualitative measures, issue of risk assessment and presenting probabilities **of** outcomes rather than point estimates, issue of forecasting values into the future and pitfalls and how to include non efficiency issue such as equity/fairness, effectiveness and accessibility/mobility.

Chapter Two: Categorization of ITS Applications

This chapter defines ITS and describes its subsystems and applications. The interrelationship among ITS applications is also discussed.

2.1. Definition of ITS

ITS is a package of transportation applications which use revolutionized computer, electronic, communication, and navigation technologies to increase the performance of the entire surface transportation system. ITS also involves data and information sharing among travelers, vehicles, roadways, and transportation management. The development of ITS applications is to improve safety, increase mobility and accessibility of travelers, and enhance system productivity and environmental compatibility.

ITS applications can be defined primarily from two perspectives: deployment and user need. ITS applications defined from the deployment perspective refer to market packages. Specifically, market packages are groups of improvement strategies that are expected to be deployed together to address a transportation or air quality objective or problem. Market packages are deployment-oriented. They deal with the specific service requirements of traffic managers, transit operators, travelers, and other ITS stakeholders. The National ITS Architecture identifies fifty-three market packages. They are grouped under seven subsystems including:

- Advanced Traveler Information Systems (ATIS)
- Advanced Traffic Management Systems (ATMS)
- Emergency Management (EM)
- Advanced Vehicle Safety Systems (AVSS)
- Advanced Public Transportation Systems (APTS)
- Commercial Vehicle Operation (CVO)
- ITS Planning

ITS applications defined from the perspective of users' needs are called as user services. User services are ITS strategies and technologies that are related to specific *user needs.* User services meet the safety, mobility, environmental and other transportation needs **of** a specified user or group of users. Deployment of a user service may require several technologies that are shared with other user services.

Twenty-nine user services have been identified *so* far. Another user service, Highway-Rail Intersection, is currently being developed. The twenty-nine user services may be classified into six categories that are corresponding to the above market package subsystems except for the subset of ITS Planning.

Table 1

Relationship Between Market Packages and User Services

User Services

Column codes:
- 1.1 – Pre-Trip Traveler Information
- 1.2 – En-Route Driver Information
- 1.3 – Route Guidance
- 1.4 – Ride Matching and Reservation
- 1.5 – Traveler Services Information
- 1.6 – Traffic Control
- 1.7 – Incident Management
- 1.8 – Travel Demand Management
- 1.9 – Emissions Testing and Mitigation
- 2.1 – Public Transportation Management
- 2.2 – En-Route Transit Information
- 2.3 – Personalized Public Transit
- 2.4 – Public Travel Security
- 3.1 – Electronic Payment Services
- 4.1 – Commercial Vehicle Electronic Clearance
- 4.2 – Automated Roadside Safety Inspection
- 4.3 – On-Board Safety Monitoring
- 4.4 – Commercial Vehicle Administrative Process
- 4.5 – Hazardous Material Incident Response
- 4.6 – Commercial Fleet Management
- 4.7 – Emergency Notification and Personal Security
- 5.2 – Emergency Vehicle Management
- 6.1 – Longitudinal Collision Avoidance
- 6.2 – Lateral Collision Avoidance
- 6.3 – Intersection Collision Avoidance
- 6.4 – Vision Enhancement for Crash Avoidance
- 6.5 – Safety Readiness
- 6.6 – Pre-Crash Restraint Deployment
- 6.7 – Automated Vehicle Operation

Market Packages	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.1	2.2	2.3	2.4	3.1	4.1	4.2	4.3	4.4	4.5	4.6	4.7	5.2	6.1	6.2	6.3	6.4	6.5	6.6	6.7
ATMS																													
Network Surveillance						X																							
Probe Surveillance						X																							
Surface Street Control						X	X																						
Freeway Control						X	X	X																					
HOV and Reversible Lane Management						X		X																					
Traffic Information Dissemination						X																							
Regional Traffic Control						X																							
Incident Management System							X																						
Traffic Network Performance Evaluation						X		X																					
Dynamic Toll/Parking Fee Management								X						X															
Emissions and Environmental Hazards									X																				
Virtual TMC and Smart Probe Data		X				X	X																						
APTS																													
Transit Vehicle Tracking										X	X	X	X																
Transit Fixed-Route Operations										X	X																		
Demand Resonse Transit Operations										X	X	X																	
Transit Passenger and Fare Management											X			X															
Transit Security										X			X																
Transit Maintenance										X																			
Multi-modal Coordination						X		X		X																			

Table 1 cont'd

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
ATIS	Broadcast Traveler Information	X	X						X																
	Interactive Traveler Information	X	X						X	X	X														
	Autonomous Route Guidance		X	X																					
	Dynamic Route Guidance		X	X																					
	ISP Based Route Guidance	X	X	X							X														
	Integrated Transportation Mgmt/Route		X	X							X														
	Yellow Pages and Reservation	X	X			X					X														
	Dynamic Ridesharing	X	X		X				X	X	X														
	In Vehicle Signing		X				X																		
AVSS	Vehicle Safety Monitoring																						X	X	
	Driver Safety Monitoring																						X		
	Longitudinal Safety Warning																		X				X		
	Lateral Safety Warning																			X			X		
	Intersection Safety Warning																				X		X		
	Pre-Crash Restraint Deployment																						X	X	
	Driver Visibility Improvement																					X			
	Advanced Vehicle Longitudinal Control																		X						
	Advanced Vehicle Lateral Control																			X					
	Intersection Collision Avoidance																				X				
	Automated Highway System																								X
CVO	Fleet Administration																X								
	Freight Administration															X									
	Electronic Clearance											X			X										
	Electronic Clearance Enrollment											X	X		X										
	International Border Electronic Clearance											X	X		X										
	Weigh-in-Motion											X	X												
	Roadside CVO Safety													X											
	On-board CVO Safety														X										
	CVO Fleet Maintenance														X	X									
	HAZMAT Management																X	X							
EMS	Emergency Response																	X							
	Emergency Routing																	X							
	Mayday Support							X									X	X							
	ITS Planning								X																

Market packages and user services are not mutually exclusive, but interrelated. A market package often includes capabilities which span more than one user service. On the other hand, for each user service, various market services are necessary to complete its implementation. As a result, there is a many-to-many relationship between market packages and user services. The relationship between market packages and user services is presented in Table 1 above.

There are many similarities between market packages and user services. To avoid repetition, this frame focuses on categorization of ITS user services. For each user service, a brief description of its functions and its relationship to market packages and other user services are provided.

2.2. Advanced Travel Information Systems (ATIS)

Advanced Travel Information Systems (ATIS) is a package of user services which provide transportation users with timely travel information. Applications under the **ATIS** include:

- pre-trip travel information;
- en-route driver information;
- route guidance;
- ride matching and reservations;
- traveler service information;
- **traffic** control;
- en-route transit information;
- personalized public transit; and
- electronic payment services.

2.2.1. Pre-Trip Travel Information

Pre-Trip Travel Information service provides real-time information **on** accidents, road construction, alternative routes and modes, **traffic** speeds along given routes and modes, parking availability, event and transit schedules, fares, transfers, ride-sharing services, and weather conditions. Users can access the information before departure, select travel time, mode, and routes, and estimate arrival time. The full implementation of the Pre-Trip Travel Information requires deployments of several market packages such **as** Broadcast Traveler Information, Interactive Traveler Information, Information Service Provider Based Route Guidance, Yellow Pages and Reservation, and Dynamic Ridesharing. All types of vehicle drivers, transit passengers, and other travelers who plan to make trips are primary users. Individuals who are interested in **traffic** and weather information also benefit fiom the service.

2.2.2. En-Route Driver Information

En-Route Driver Information service conveys the above mentioned information to travelers who are on the road to their destinations through audio and visual technologies and in-vehicle signing. This service can increase the safety and convenience of vehicle drivers and

improve the efficiency of vehicle operation. En-route drivers and travelers are the primary users of this service. Information generated fiom all the ATIS market packages and "Virtual TMC and Smart Probe Data" package is required to support this user service.

2.2.3. Route Guidance

Route Guidance provides travelers with simple instructions on how to reach destinations using information provided by en-route driver information service. **A** route guidance service processes data on route traffic condition, selects an alternative route, and provides appropriate instruction. Audio technology is used **as** a main tool to convey directions to users *so* that the drivers are not distracted. A visual display will also be used in this service. En-route drivers, especially those who are not familiar with a specific geographic area, will benefit fiom this service. This user service can be linked to multi-modal traffic management for incident response and transportation demand management. This user service is supported by the market packages of Autonomous Route Guidance, Dynamic Route Guidance, Information Service Provider Based Route Guidance, and Integrated Transportation Management/Route.

2.2.4. Ride Matching and Reservations

This user service enables commuters to find a match for ridesharing using information on travel origins and destinations provided by this service. The service also allows for single-trip rideshare matching and en-route pickups. This service can be operated independently and will ease traffic congestion and maximize the utility of transportation facilities if more people carpool. A market package related to this user service is Dynamic Ridesharing. The success of the user service and market package depends on **high** concentrations of trips with the same or similar origins and destinations. Commuters and other travelers who are interested in car pooling will be the primary users of this service.

2.2.5. Traveler Service Information

This user service supplies information for planning a trip before departure or getting around while a trip is already underway. The information service is accessible fiom home and office. With some limitations, users can also use the service while traveling. Combined with pre-trip and en-route information systems, travelers can capture information on location, availability of food, lodging, parking, automotive services, hospitals, and community facilities. When fully deployed and integrated with other business and financial services, the service will collectively link users, sponsors, and providers. Furthermore, it will support financial transactions like automatic billing for purchases. **A** market package for this user service is Yellow Pages and Reservation. The primary users include both prospective trip makers and travelers who are undertaking trips.

2.2.6. Traffic Control

Traffic Control service is mainly provided by Transportation Management Centers (TMCs). Based on information on roadway conditions, TMCs manage and coordinate traffic movement on the transportation network system. The service will improve operation efficiency of transportation network and provide better transportation service to users. With

the service, users can travel faster with less stress. The implementation of this user service requires deployments of a number of market packages including Network Surveillance, Probe Surveillance, Surface Street Control, Freeway Control, HOV and Reversible Lane Management, Traffic Information Dissemination, Regional Traffic Control, Traffic Network Performance Evaluation, Virtual TMC and Smart Probe Data, Multi-Modal Coordination, and In-Vehicle Signing.

2.2.7. En-Route Transit Information

En-Route Transit Information service provides information to public transit users. The information provided by this service is similar to pre-trip travel information. It helps transit users make effective transfer decisions and itinerary modifications while a trip is underway. This user service requires a range of market packages under APTS, such as Transit Vehicle Tracking, Transit Fixed-Route Operations, Demand Response Transit Operations, and Transit Passenger and Fare Management, as well as packages of ATIS including Broadcast Traveler Information, Interactive Traveler Information, and Dynamic Ridesharing.

2.2.8. Personalized Public Transit

Using various types of vehicles, such as small buses, taxicabs, vans, or other shared-ride vehicles, this service provides convenient door-to-door service to passengers at lower cost than conventional fixed-route transit. This user service integrates flexible (demand and response) and fixed route transit operations and ride-sharing services. The service is supported by four market packages: Transit Vehicle Tracking, Demand Response Transit Operations, Interactive Traveler Information, and Yellow Pages and Reservation.

2.2.9. Electronic Payment Services

This user service allows travelers to use electronic cards or tags for payments of transportation services including tolls, transit fares, and parking. The service can reduce travel time delays and inconvenience. It has a potential to integrate all modes of transportation including road pricing options. Electronic payment services require capabilities offered by Dynamic Too/Parking Fee Management, Transit Passenger and Fare Management, Interactive Traveler Information, ISP Based Route Guidance Integrated Transportation Management/Route, Yellow Pages and Reservation, and Dynamic Ridesharing.

2.3.   Advanced Traffic Management Systems (ATMS)

Advanced Traffic Management Systems (ATMS) is a package of technologies that enable the integration of freeway and surface arterial operations. The primary intention of ATMS is to manage travel corridors and areas efficiently while retailing local community goals. Applications under the ATMS are:

- en-route driver information;
- traffic control;
- incident management;
- travel demand management;

- emissions testing and mitigation; and
- electronic payment services.

2.3.1. En-Route Driver Information

En-Route Driver Information service conveys knowledge to travelers through audio and visual technologies and in-vehicle signing. This service can increase the safety and convenience of vehicle drivers and improve the efficiency of vehicle operation as well as reduce overall trip costs. En-route drivers and travelers as well as goods movements are the primary users of this service. Information generated fiom all the **ATIS** market packages and "Virtual TMC and Smart Probe Data" package is required to support this user service.

2.3.2. Traffic Control

Based on information on roadway conditions, TMCs manage the transportation network system. With the service, average speeds are higher. The implementation of this user service requires deployments of a number of market packages including Network Surveillance, Probe Surveillance, Surface Street Control, Freeway Control, HOV and Reversible Lane Management, Traffic Information Dissemination, Regional Traffic Control, Traffic Network Performance Evaluation, Virtual TMC and Smart Probe Data, Multi-Modal Coordination, and In-Vehicle Signing.

2.3.3. Incident Management

Using advanced detection and verification technologies, this service offers to mitigate actions for traffic incidents, adverse road conditions, road construction activities, and special events. The service will shorten time for incident detection and clearance therefore reducing traffic congestion caused by incidents. Incident Management service can be integrated with many **ATIS** user services to enhance the performance of transportation system and to improve travelers' mobility. Market packages that are required to implement this user service are Surface Street Control, Freeway Control, Incident Management System, Virtual TMC and Smart Probe Data, and HAZMAT Management.

2.3.4. Travel Demand Management

Travel Demand Management (TDM) service intends to reduce traffic congestion and air pollution by promoting the use of higher occupancy vehicles (HOV), transit modes, non-motorized alternatives, or non-travel options. TDM strategies include enforcing HOV lane use, parking control and incentives, road access pricing and prioritizing schemes. Market packages for the implementation of this service include Freeway Control, HOV and Reversible Lane Management, Traffic Network Performance Evaluation, Dynamic Toll/Parking Fee Management, and Multi-Modal Coordination.

2.3.5. Emissions Testing and Mitigation

This user service has the capabilities for monitoring and managing air quality and other environment hazards such as icy condition of roads and dense fog. Sensor and communication technologies are applied in this service to collect information on vehicle emissions, air quality, or other environmental conditions and to transmit data to

management centers. Based on the collected information, strategies can be implemented **to** reduce emissions, increase air quality, and road conditions. The market package, Emissions and Environmental Hazards Sensing, is necessary for the implementation of this user service.

2.3.6. Electronic Payment Services

Electronic cards or tags are used for payments of transportation services including tolls, transit fares, and parking. The key affect is to reduce travel time delays and inconvenience through eliminating queuing. It has a potential to encompass all modes **of** transportation and to facilitate the introduction of new management initiatives such **as** including road pricing options. Electronic payment services require capabilities offered by Dynamic Too/Parking Fee Management, Transit Passenger and Fare Management, Interactive Traveler Information, ISP Based Route Guidance Integrated Transportation Management/Route, Yellow Pages and Reservation, and Dynamic Ridesharing.

2.4. Emergency Management (EM)

Emergency Management (EM) is a package of technologies that can enhance communications for emergency vehicle operations. EM services include two user services:

- emergency notification and personal security; and
- emergency vehicle management.

2.4.1. Emergency Notification and Personal Security

This service provides the capabilities of immediately notifying incidents and requesting for assistance in the case of emergency. The notification and request can be initiated both manually and automatically. Information **on** vehicle location, nature and severity of incidents will be sent to emergency personnel. Users can also receive acknowledgement signal from the message receiver. The Mayday Support market package is necessary for the implementation of this service. Information provided by this service can also be used for traffic management, transit management, and transportation information system.

2.4.2. Emergency Vehicle Management

The purpose **of** this user service is to reduce the time for responding to and clearing an incident. This service comprises three capabilities: fleet management which can quickly display the location of emergency vehicles and dispatch the vehicles to the scene; route guidance which directs emergency vehicles; and signal priority that clears traffic signals on the route of an emergency vehicle. The service is closely related to the Hazardous Material Incident Management user service in the CVO subsystem below. It requires the deployments of all the emergency management market packages. The primary users include police, fire and medical units.

2.5. Advanced Vehicle Safety Systems (AVSS)

Advanced Vehicle Safety Systems (AVSS) is a package of communication and control technologies that enhance safety and support automatic operations. Information derived

from sensor and communication equipments, along with control technologies can enhance drivers' perceptions on route conditions, speed up drivers' responses to potential collisions, augment drivers' control of vehicles and offer drivers with options of vehicle operations. The use of traffic information and control technologies can improve highway capacity and safety. User services included in this subsystem are:

- longitudinal collision avoidance;
- lateral collision avoidance;
- intersection crash warning and control;
- vision enhancement for crash avoidance;
- safety readiness;
- pre-crash restraint development; and
- automated vehicle operation.

2.5.1. Longitudinal Collision Avoidance

This user service helps reduce the number and severity of collisions by sensing potential collisions, prompting a driver's avoidance actions, and temporarily controlling accelerations and braking to minimize damage and injury. This service includes vehicles equipped with head-on and rear-end sensors, as well as dynamic control processor. The primary users of this service are vehicle drivers. The deployments of Longitudinal Safety Warning and Advanced Vehicle Longitudinal Control packages are essential for the implementation of this user service.

2.5.2. Lateral Collision Avoidance

Lateral Collision Avoidance service achieves the safety standard by rapidly providing crash warnings and assistance for lane changes, blind spots, and road departure. The service consists of crash warning and control capabilities. The crash warning system alerts drivers and elicits appropriate responses in the shortest time. The control system provides automatic control of steering and throttle in dangerous situations. The deployments of Lateral Safety Warning and Advanced Vehicle Lateral Control are needed for the implementation of this user service.

2.5.3. Intersection Crash Warning and Control

This user service aims to reduce the number and severity of collisions at intersections. It is closely related to the longitudinal and lateral collision avoidance services. This service improves situational awareness by combining information on crossing traffic and signal status. The market packages of Intersection Safety Warning, Intersection Collision Avoidance are required for realizing this user service.

2.5.4. Vision Enhancement for Crash Avoidance

The purpose of this user service is to improve drivers' ability to see objects in and around their travel ways. Hazardous conditions, such as fog, dust, and smoke, are detected,

processed, and displayed by the in-vehicle equipment to alert users. This service requires the deployment of the Driver Visibility Improvement market package.

2.5.5. Safety Readiness

This user service provides warnings regarding the condition of the driver, vehicle, and road infrastructure by detection and communication equipments both in the vehicle and on the roadside. The primary users are automobile drivers and rail operators. The user service requires capabilities supplied by six AVSS market packages including Vehicle Safety Monitoring, Driver Safety Monitoring, Longitudinal Safety Warning, Lateral Safety Warning, Intersection Safety Warning, and Pre-Crash Restraint Deployment.

2.5.6. Pre-Crash Restraint Deployment

This user service contains the capabilities of anticipating an imminent collision and activating passenger safety mechanisms prior to collision. The capabilities are supported by technologies supplied by the Vehicle Safety Monitoring and Pre-Crash Restraint Deployment market packages. The service can reduce the number and severity of accident. Vehicle drivers are the primary beneficiaries of this user service.

2.5.7. Automated Vehicle Operations

This user service has the potential to improve the safety and efficiency of existing transportation infrastructure. The service is supported by technologies in four key areas: sensors, actuators, computers, and communications. Those technologies allow automated vehicles to perform lane-keeping and to maintain a safe distance between each other. The Automated Highway System market package is needed for the implementation of this user service.

2.6.   Advanced Public Transportation Systems (APTS)

Advanced Public Transportation Systems (APTS) is a group of user services that apply various technologies to improve the efficiency and effectiveness of transit operation and user mobility. User services under this subsystem are:

- traffic control;
- travel demand management;
- public transportation management;
- en-route transit information;
- personalized public transit;
- public travel security; and
- electronic payment services.

2.6.1.   Traffic Control

Traffic Control service is provided through AVM or automated vehicle monitoring system that tracks transit vehicles against their designated route schedule. The core technology in AVM is AVL or automatic vehicle location system. Based on information on traffic

conditions, a central dispatcher manages and coordinates vehicle movement on the public transportation system. The service will improve operation efficiency of the public transportation network and provide better transportation service to users. With the service, users can reduce trip time, have greater transit service reliability and improve safety and reliability. The implementation of this user service requires deployments of a number of market packages including Network Surveillance, Probe Surveillance, Surface Street Control, Freeway Control, HOV and Reversible Lane Management, Traffic Information Dissemination, Regional Traffic Control, Traffic Network Performance Evaluation, Virtual TMC and Smart Probe Data, Multi-Modal Coordination, and In-Vehicle Signing.

2.6.2. Travel Demand Management

Travel Demand Management promotes the use of higher occupancy vehicles (HOV), transit modes, non-motorized alternatives, or non-travel options in order to effect congestion and air quality. TDM strategies include enforcing HOV lane use, parking control and incentives, road access pricing and prioritizing schemes.

2.6.7. Public Transportation Management

This service provides the capabilities of automated planning and scheduling for transit services using information on real-time vehicle and facility status, passenger loading, bus running time, and mileage accumulated. The service will improve the efficiency of transit operations and maintenance. Transit operators and paratransit providers are the primary users of this service. This service can be integrated with traffic control service to ensure transfer connections in inter-modal transportation. It is supported by the market packages of Transit Vehicle Tracking, Transit Fixed-Route Operations, Demand Response Transit Operations, Transit Security, Transit Maintenance, and Multi-Modal Coordination.

2.6.8. En-Route Transit Information

The information provided by this service assists transit users in planning and minimizing trip time, make effective transfer decisions and itinerary modifications while a trip is underway. This user service requires a range of market packages under APTS, such as Transit Vehicle Tracking, Transit Fixed-Route Operations, Demand Response Transit Operations, and Transit Passenger and Fare Management, as well as packages of ATIS including Broadcast Traveler Information, Interactive Traveler Information, and Dynamic Ridesharing.

2.6.9. Personalized Public Transit

Using various types of vehicles, such as small buses, taxicabs, vans, or other shared-ride vehicles, this service provides convenient door-to-door service to passengers at lower cost than conventional fixed-route transit. This user service integrates flexible (demand and response) and fixed route transit operations and ride-sharing services. The service is supported by four market packages: Transit Vehicle Tracking, Demand Response Transit Operations, Interactive Traveler Information, and Yellow Pages and Reservation.

2.6.10. Public Travel Security

With the capacities supported by the Transit Vehicle Tracking and Transit Security market packages, this service creates a secure environment for public transit users and operators. Transit users are protected by on-board security systems that perform surveillance and warn of potentially hazardous situations. **An** automated vehicle location system helps transit operators and police to locate vehicles quickly and take appropriate actions in the case of emergency.

2.6.11. Electronic Payment services

This allows travelers to use electronic cards or tags for payments of transportation services including tolls, transit fares, and parking. The service can reduce travel time delays and inconvenience. It **has** a potential to integrate all modes of transportation including road pricing options. Electronic payment services require capabilities offered by Dynamic Too/Parking Fee Management, Transit Passenger and Fare Management, Interactive Traveler Information, ISP Based Route Guidance Integrated Transportation Management/Route, Yellow Pages and Reservation, and Dynamic Ridesharing.

2.7. Commercial Vehicle Operations (CVO)

Commercial Vehicle Operations (CVO) consists of technologies that enhance the efficiency, productivity, and safety of goods movement. CVO applications include:
- incident management;
- commercial vehicle electronic clearance (preclearance);
- automated roadside safety inspection;
- on-board safety monitoring;
- commercial vehicle administrative process;
- hazardous material incident response; and
- commercial fleet management.

2.7.1. Incident Management

This service offers to mitigate actions for traffic incidents, adverse road conditions, road construction activities, and special events. The service will shorten time for incident detection and clearance therefore reducing traffk congestion caused by incidents. Incident Management service can be integrated with many ATIS user services to enhance the performance of transportation system and to improve travelers' mobility. Market packages that are required to implement this user service are Surface Street Control, Freeway Control, Incident Management System, Virtual TMC and **Smart** Probe Data, and HAZMAT Management.

2.7.2. Commercial Vehicle Electronic Clearance (Preclearance)

This user service allows point-to-point non-stop commercial vehicle operations while satisfying regulatory requirements, such **as** the issuance of licenses and **permits,** records keeping, **tax** collections, inspections, and weighing across multiple jurisdictions including domestic and international borders. Market packages required for the implementation of

this service are Electronic Clearance, Commercial Vehicle Administrative Processes, International Border Electronic Clearance, and Weight-in-Motion.

2.7.3. Automated Roadside Safety Inspection

This user service intends to improve safety in all commercial vehicle operations by providing safer, more efficient, more accurate inspection of commercial vehicles. The service is supported by the Roadside Commercial Vehicle Operation Safety package. Commercial vehicle operators and inspection agencies *are* the primary users of this service. The service can be integrated with the services of Commercial Vehicle Electronic Clearance (Preclearance) and On-Board Safety Monitoring.

2.7.4. On-Board Safety Monitoring

This service has the capacities for pre- and post-trip inspections, **as** well **as** warnings while underway to enhance the safety for commercial vehicles and private automobiles. Integrating this service with the Automated Roadside Safety Inspection and Commercial Vehicle Electronic Clearance (Preclearance) can achieve the most effective safety. The service is supported by the deployments of two market packages, Roadside Commercial Vehicle Operation Safety and On-Board Commercial Vehicle Operation Safety.

2.7.5. Commercial Vehicle Administrative Process

This user service provides the carriers with the capabilities to select and purchase annual or temporary credentials electronically. The use of this service could enable participating interstate carriers to electronically capture mileage, fuel purchase, trip, and vehicle data by state. It could also reduce paperwork for fuel taxes and registration. The service **has** a potential for synergy with commercial vehicle preclearance service. It is supported by Electronic Clearance, Commercial Vehicle Administrative Processes, and International Border Electronic Clearance, etc market packages.

2.7.6. Hazardous Material Incident Response

With this service, information on hazard spill notification can be transmitted to the emergency operators *so* that faster and more appropriate responses to hazard incidents can be taken. The service has the potential to reduce exposure time to potentially dangerous substances, and lessen associated traffic congestion resulting fiom road closures and cleanup operations. Freight Administration and HAZMAT Management are related to this user service.

2.7.7. Commercial Fleet Management

This service offers the same capabilities and functions **as** Public Transportation Management service. It can perform automated planning and scheduling for commercial goods movements using information on real-time vehicle and facility status, etc. The service will improve the efficiency of commercial fleet operations and maintenance. It is supported by the market packages of Fleet Administration, Commercial Vehicle Operation Fleet Maintenance, and HAZMAT Management.

CHAPTER 3: EVALUATION METHODS

3.0 Introduction

Just as individuals confront a range of attractive expenditures exceeding their budgets and firms recognize investment opportunities beyond their available funds, governments are faced with demands for ostensible socially valuable projects in excess of the resources available to them. Whether they arise from the constituents, their representatives, policymakers or the bureaucracy, there is always a long list of potential projects in a wide range of ideas – highways, mass transportation, irrigation, flood control, manpower training, education, environmental projection, parks and recreation, aid to the indigent, etc. Consequently, public decision-makers must evaluate the merits of the many alternatives and select those which they expect to make the greatest contributions to social well-being.

Caltrans is no exception and the demands for ITS projects can be viewed as competing with alternative projects within Caltrans as well as across other projects in the California government. The value of alternative projects needs to be established and a way of judging them against one another as well as against a status quo or deemed alternative. There are a variety of evaluation techniques ranging from highly quantitative to case studies. ITS projects represent enhancements to an existing system *so* do not constitute such large projects as they might result in a significant change in the nature of the system or economy.[2] Three approaches to project evaluation which can fit within the benefit - cost evaluation category are benefit-cost analysis, impact analysis and cost effectiveness analysis. After a general discussion of measurement and evaluation, each of these is described together with their strengths, weaknesses, evaluation criteria and use.

3.1 Project Evaluation

Decision-makers may weigh the choices of projects on a variety of grounds. Consideration will be given, however, to the effects upon the three areas of government functional responsibility:

- the efficient allocation of resources,
- the distribution of income, and
- the stabilization of economic activity.

Resource allocation is a major concern of the public sector because the market does not provide, or fails to provide in the appropriate amounts, certain goods which individuals desire, such as transportation facilities. Where markets fail, the public sector may intervene to correct the allocation of resources by providing social goods to complement the private goods the market sector generates. Markets may fail for a number of reasons. One reason is because of the existence of collective type goods. Collective goods

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[2] Some projects such as the Alaskan pipeline project of the 60's did have a profound impact on the Alaskan economy.

(sometimes called pure public goods) are those, like national defense, which once produced are equally available to all. Basically, it is not feasible to exclude anyone from the benefits and the consumption by one person does not detract from the consumption of another. Obviously, since consumers cannot be excluded from the benefits of the product, as with private goods, they cannot be forced to reveal their preferences by paying in order to have access to the goods, i.e., they have the incentive to free ride. Consequently, such goods are not privately provided but instead are provided by the public sector where the level of service is determined by collective choice procedures, such as rating, and contributions are compelled via the tax system.

Markets may also fail to generate the optimal level of goods and services due to the presence of externalities or spillovers of benefits or costs beyond those to the private decision-maker for which compensation is not paid. Because the private decision-maker fails to recognize the full benefits or costs of his actions, the level of output he selects will either be too small in the case of external benefits, or too large in the case of external costs. Air or water pollution by private manufacturers illustrates the case of cost spillovers which may necessitate public intervention to abate the problem if it is sufficiently severe. Similarly, noise, air pollution, and congestion from transportation facility users or environmental damage associated with new system development may necessitate preventative or corrective government action. Education, on the other hand, is widely recognized as affording benefits to society beyond those to the individual, thereby warranting public support to promote its attainment beyond the level the individual would choose if required to meet the full costs himself. Public transportation services may also provide societal benefits, such as increased economic activity, that are additional to individual user benefits.

Indivisibilities in production resulting in significant economies to larger-scale production may also lead to market failures. In some cases these economies result in one firm monopolizing the industry and exploiting consumers through low output and high prices. In other situations, scale economies may prevent a socially warranted product or service from being produced (efficiently, if at all) without a subsidy. Once again public intervention may be warranted to assure the efficient allocation of resources in the economy. Provision of ITS services may be a case in point.

Efficient resource allocation is not the only concern of the public sector. Indeed, even if private markets operate to adequately provide all goods and services, public intervention may still be sought because society is dissatisfied with the ***distribution of income*** which the market allocation generates. The public sector may see fit to modify the income distribution through any of a variety of means such as direct transfers, shifting factor endowments by education subsidies, assisting particular groups or regions through public investments like irrigation projects or subsidized industrial developments, or the protection of certain industries with tariffs and quotas. The construction of AVL facilities in the south bay area of San Francisco, for example, illustrates the manner in which such an ITS project would redistribute benefits from Californians as a whole to the South -Bay area residents. Although the appropriate means by which to achieve the public's

distributional objectives are often debatable, the role of the public sector in seeking income redistribution is legitimate.

The final area of government responsibility, and one which can influence public decision-makers' evaluations of alternative actions, is *stabilization* of the level of economic activity and *promoting economic growth* among industries. Stabilization is a necessary area of concern as private decisions need not be consistent with the full utilization of resources and a relatively stable price level. While public policy need not assure the attainment of these goals, stabilization policy has been successful in reducing the extremes of the business cycles. The stimulative nature of projects is certainly an important consideration when high unemployment is widespread or when evaluating proposals intended for a depressed region. Similarly, government expenditure on public capital, particularly, highway capital can have an impact on the competitiveness of firms and the level of economic growth in the area and state. Recent work completed for the FHWA suggests an elasticity of output with respect to public capital of approximately .18; a ten percent rise in the stock of public capital leads to a **1.8** percent rise in gross state product.

Although the criteria of allocation, distribution and stabilization are easily outlined, the public decision-makers' task of assigning resources is not **as** simple **as** that faced by the individual household or the firm. Individuals or households have only to satisfy their own preferences and, given their budget and the prices in the market, can select that combination of commodities which maximizes their welfare. Firms must contend with the preferences of consumers which are reflected in the prices they are prepared to pay for the products produced. Firms must relate these to the costs of factors in the market. Profits reward those businesses which offer valuable products and combine resources efficiently while losses penalize those which do not. Thus the market affords clear incentives to the efficient allocation of resources in the production of private goods. Because most publicly provided goods and services are not sold to consumers, the public decision-maker must cope with the difficult task of attempting to evaluate the benefits of his output to others without the aid of a market-type guide. This lack of a market where beneficiaries pay for public goods and services further complicates the problem because demands are commonly made for services beyond the point at which the recipient would be prepared to pay were he to bear the cost himself, rather than having it financed from the general find to which his contribution is minute.

Publicly provided transportation facilities are in large measure supported by general and gasoline tax revenues and in part by user license fees which may be nominal. These aggregate tax revenues are taken and spent on specific projects in specific areas. In this kind of situation it is perhaps not surprising that many people see the government as being too big and spending too much, but at the same time arguing that it does too little for them. Thus the public decision-maker confronts a multitude of possible projects whose revenues fail to meet costs and must distinguish among those that will afford net benefits to society and those that will not. Presumably it will be those projects which are considered socially worthwhile which will be included in the government's budget.

3.2 Benefit-Cost Analysis: A Brief Survey

Benefit-cost analysis [B/CA] is used to assess the viability of investment opportunities when benefits and costs are difficult to establish, often because market values are unavailable and/or the effects are diverse and widespread. The primary approach to these problems is to establish initially their suitability on allocative (efficiency) grounds. The efficiency evaluation typically reflects the major stabilization interests as resource costs frequently vary with the level of economic activity. Since the procedure for handling distributional considerations is less uniform, generally not as readily quantifiable, and subject to greater personal interpretation, distributional impacts are commonly treated separately as modifications to the efficient solution.

The first step in benefit-cost analysis is the establishment of the merits of a proposed plan or project on an efficiency basis. This is an important point to recognize in choosing among evaluation methods. B/CA evaluates strictly on the basis of economic efficiency. There are three components to the measure of economic efficiency: static allocative efficiency, dynamic [allocative] efficiency and productive efficiency. Productive efficiency addresses the question of whether an organization produces its output at a given level of quality at the least cost possible. Productive efficiency will be achieved if the best available technology is utilized and the mix of inputs used is consistent with the set of relative input prices in the market. In other words, the firm which has achieved productive efficiency is operating on the lowest cost function available. This is the measure which most people identify with the meaning of efficiency.

Static allocative efficiency refers to the issue of whether the right level and quality of output is produced which yields maximum overall benefits. This will be achieved when the price of the output reflects the marginal or incremental cost of production. If prices are less than costs, too much output is produced and scarce resources are squandered. Prices that exceed costs result in too little output or too low quality or both with the consequence that benefits are lost because a demand which would have paid all of the resource costs but are excluded from the market, has not been satisfied. A failure to price roadways therefore results in a reduction in allocative efficiency. Dynamic [allocative] efficiency deals with the issue of investment in capacity. A firm or organization has achieved dynamic efficiency in a project or firm if it is operating with no excess capacity or with as little excess capacity as the technology allows.

B/CA undertakes to compare in commensurate terms the sum total of the benefits and costs resulting from a plan or project. This is normally accomplished by deriving monetary estimates of both benefits and costs at a common point in time. Benefits are estimated as the beneficiary's willingness to pay for the publicly provided good or service and costs are valued at the inputs opportunity cost, that is, at values adequate to compensate the suppliers of the resource for foregoing its use in his best alternative allocation. One of the major tasks of B/CA is the determination of willingness to pay and opportunity cost, for often no market values exist and even where available, they need not be consistent with social value. If on this basis benefits exceed costs, the project is

considered socially justified, as the beneficiaries of the project could compensate those who lose as a result of the project. (The evaluation can also be extended to consider the benefits and costs resulting from incremental changes in the project *so* as to determine the optimal size – the optimal scale being when the change in benefits equals the change in costs.) In such a case, a Pareto improvement is possible, as everyone can be made as well or better off with the project as without – no one need suffer a loss – and that compensation could be made through a system of costless transfers on efficiency grounds, although the compensation need not in fact be paid. This is because distribution has not yet been considered and a dollar of benefits or costs is weighted equally regardless of to whom it accrues.

It must be noted that the result of the B/CA depends very much upon the perspective or the accounting stance adopted by the analyst. To this point we have spoken of social benefits and costs implying the consideration of all benefits and costs to whosoever they accrue. Not all analysts may feel it necessary to adapt such a broad stance. Local, county or state governments may ignore benefits or costs which spillover upon the residents of other municipalities, counties or states to which they are not responsible. For example, one county may decide to construct an expressway without considering the effects of increased traffic flows in the downstream county. Alternatively, one region might realize the major benefits of a highway or irrigation project while making only a modest contribution to the tax revenues required to finance the undertaking. In both instances, because of the restricted accounting stand adopted, the projects appear unduly attractive. Narrowing the accounting stance distorts the results of the evaluation because some real costs and benefits will be ignored and double counting can occur more easily. Yet considering the costs and benefits from a variety of perspectives can be useful in gaining some insight as to the local, regional and statewide impacts and the better understanding of the attitude of different areas or groups towards the project.

3.2.1 *Distributional Considerations*

As stated previously, where benefits exceed costs, the efficiency criterion supports the investment as beneficiaries could compensate the losers even though that compensation need not be paid. Since full compensation is rarely made to all losers, it can be important to identify who the gainers and losers are and the magnitude of their gains and losses. Public decision-makers are concerned with the impact of their projects on income distribution and will rate more highly those whose results are consistent with social goals. Indeed decision-makers may view with some concern a project rated highly on efficiency grounds but benefiting primarily the rich while imposing its costs upon the poor. Thus projects which have the potential of producing Pareto improvements if compensation were paid may be unsatisfactory when compensation is impossible. Even if benefits exceed costs, acceptable distributional consequences are necessary.

Desirable distributional effects may be sufficiently large in the case of some plans or projects to warrant this acceptance, despite their failure on efficiency grounds. In such cases the B/CA indicates the cost to society of accomplishing its distributional goals via

the public investment. If those costs appear unduly high, the public decision-makers may pursue alternative means of achieving the distributional objectives.

3.2.2 *Defining the Role of B/CA*

B/CA 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. The debate has, to a large extent, been fueled by overly zealous advocates of both extremes. 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 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.

To quantify benefits and costs in comparable terms typically means reducing them to dollar values, as outlined previously. Not all outcomes are amenable to such a transformation. Often the monetary values attached to certain consequences can only be crude approximations, and in other instances they may not be at all possible. For example, the establishment of a road into an isolated area may have adverse environmental consequences. This prospect may be an important effect, but it is not one to which a monetary value can be readily attached. Where monetary measures are difficult or, some would argue, impossible, the analyst should recognize the limitations of the quantitative approach, indicate the possible error in the assessments where quantification has been attempted, and outline the nature of those benefits and costs that are recognized as difficult to assess in monetary terms. This is a place in which risk analysis can play an important role. Risk analysis is described at length in a later section in this chapter.

Although attempts have been made by economic analysts to quanti@ the distributional effects of public investments and policy choices, these are to a large extent arbitrary and consequently not entirely satisfactory. Because of this the distributional impacts are best

not incorporated into *summary* statements such as benefit-cost ratios through implicit or explicit weightings. Rather, distributional impacts should be delineated and treated **as** illustrative, and then accomplished by an outline of the actual effects predicted for consideration by the government decision-makers.

Even where the outcomes of an investment choice are not subject to interpretation in monetary terms, the B/CA framework is not ruled out but must be modified generally to accept the goals (benefits) **as** given and to examine the cost minimizing means of achieving that end. Cost-effectiveness is commonly applied in defense where certain performance measures are established and the costs of meeting those standards then examined to aid in the identification of the preferred alternatives. Because of the adaptability of the benefit-cost approach and its quantitative evaluation, it is a valuable one in budgeting analysis under planning programming budgeting systems, which stress quantitative assessments in the attempt to improve public budgeting procedures by establishing objectives and relating outputs to inputs.

The role of a standard B/CA is limited, however, to examining the effects of small changes. The benefit-cost approach is based upon the assumption that things outside the immediately affected area do not change. Thus prices and incomes, other than those directly affected by the project, can be assumed constant. If this is not the case, say because the project is very large relative to the economy, then the assumptions upon which the evaluation is based are violated and the validity of the evaluation becomes questionable. When other things are not constant, a general equilibrium or system model is necessary to work through the full effects of the project upon the economy. Thus, for example, the benefits of a mass transport system cannot be evaluated simply **as** the additional costs that would result if the system were suddenly abandoned and area residents were to move by alternative modes. Instead, it must be recognized that the pattern of regional development, land prices, and transportation related prices have all been influenced by the presence of the mass transport system. If it were permanently removed or had it never existed, the structure of the area and prices within it would differ greatly. As a result, existing prices and mobility patterns do not properly reflect the situation under the postulated change. Instead the evaluation would need to compare two much different situations with that under the postulated alternative being derived fiom a general equilibrium model.

3.2.2 *Benefit Cost Analysis: Welfare Foundations and Practical Applications*

Basic Procedure. The typical problem to which B/CA is applied is to evaluate on a comparable basis the stream of social costs arising from the undertaking **of** a project or program. 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

$$C_0, C_1, C_2, \ldots, C_{t-1}, C_t$$

from the present, 0, to the termination date t or some future point such as the lifetime of the project. B_0 is 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 monetary 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 significantly. Usually the bulk of the costs occur in the early years when the project is under construction, while benefits are generated in later years once the facility 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.[3]

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. This is done by discounting future benefits and costs to their present value. The present value of one dollar available in period t and discounted at the rate i is

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

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

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

and the present value of the cost stream 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 B/CA this comparison is most commonly expressed either as a benefit-cost ratio

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[3] However, they do not, as evidenced by the fact that borrowers are willing to pay interest, a premium for the use of money today rather than waiting for the future, while 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.

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

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 efficiency grounds if the B/C is greater than one or if its net present value is **positive.**[4] 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.

This brief introduction to the basic procedures of B/CA illustrates the essential features, but ignores many complicating factors. The remainder of this section is devoted to the introduction and explanation of the more significant complications. This exercise is not intended to be an exhaustive and definitive exposition (which can be found in a variety of textbooks and manuals), but rather to indicate the complexity of the problem and the complications with which the analyst must cope. This is done in part *so* that the limitations of the analysis are appreciated, but primarily to identify the types of information, data and techniques the analyst will find useful in his attempts to surmount the difficulties encountered in applying B/CA.

3.3 Factors to be Considered in Using Benefit-Cost Analysis

<u>Defining the Objectives</u>. An important process in undertaking B/CA is for the public decision-maker and the analyst to define or have defined clearly the objectives which the project is intended to meet. Sometimes these will be clearly stated but in other instances they will be required to translate generally stated objectives, like promote regional economic development, into objective performance criteria.

One difficulty arises when project evaluation is undertaken from too narrow a perspective. Regional development may be an important objective of the project undertaken by many government departments and agencies, yet each evaluates its own projects in isolation of what others are doing, and therefore sometimes fails to achieve the degree of improvement possible had the plans and projects been coordinated.

<u>The Classification of Benefits and Costs</u>. The distinction between real and pecuniary benefits and costs is the major recognition to be made in B/CA. Real benefits are the increases in production or consumption possibilities resulting from a project, i.e., the

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[4] These two expressions, **as** well **as** internal rate **of** return, are discussed in detail in the section "Project Selection Criteria."

increase in total output made possible. Real costs, on the other hand, are the values of the resources used in the project and not available to other users. Pecuniary benefits and costs do not reflect real changes but rather are the result of changes in relative prices due to the public understanding which affords gains to some but only at the cost of offsetting losses to others. While only real benefits and costs are legitimate ingredients in the efficiency calculations, pecuniary benefits and costs are important when it comes to evaluating the distributional implications.

A second distinction common in B/CA is the separation of direct (primary) and indirect (secondary) benefits and costs. While the distribution is not precise by any means, direct or primary real benefits and costs are those most closely associated with the most important objectives, while indirect or secondary real benefits and costs are those which might be considered by-products stemming from the project. Secondary benefits are frequently seen to be gains in income to those serving the primary beneficiaries. Caution is essential in evaluating secondary benefits and costs for pecuniary benefits and costs can only too easily be inadvertently **included.**[5]

A final distinction arises between tangible and intangible benefits and costs. The tangibles are those for which market values are available, while intangibles refer to those for which market values do not exist. In the case of tangibles, the market values need not always represent the social values. In the case of intangibles, it may sometimes be possible to establish proxy values indirectly. Where not possible, the nature of the intangible benefits and costs should be identified in any case.

This brief taxonomy of benefits and costs can be illustrated in the following figure.
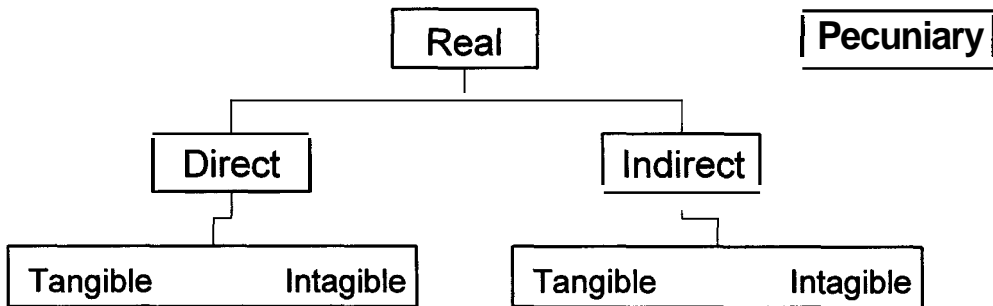
One **further** distinction also needs mention, that is external versus internal benefits and costs. The line separating these two depends upon the accounting stance adopted by the analyst. Generally, the reference of B/CA is the overall welfare change to society as a

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[5] **Since the division of benefits and costs into direct and indirect is often imprecise and frequently confusing, it seems reasonable to dispense with the largely arbitrary distinction and focus instead upon identifying benefits, all benefits, and costs, all costs, associated with an undertaking and ignore subsequent and unnecessary classifications.**

whole - i.e., is the world a better place for the project? – and this is a basic calculation that should be included in any B/CA as a reference point. Usually the national perspective is sufficiently broad to provide this view. In many instances, the decision-makers may wish to focus on a more narrowly defined group, in which case benefits and costs to others are considered external and may be valued differently. Distinctions may be made along political lines such as state or county boundaries, or along bureaucratic divisions such as energy responsibilities or clientele, or on the basis of direct versus indirect beneficiaries or some special target group. While such divisions may afford decision-makers additional information, chiefly with respect to the distribution or impact of effects upon specific groups of interest, they are in themselves an inadequate basis for project evaluation. Rather, one should accept as an initial guide the consequences upon the economy affected by the resource reallocation. Such an assessment comes from an accounting stance where there are no externalities.

3.4 The Evaluation of Benefits

<u>Theory</u>. The objective of B/CA is to determine whether the value of output is greater with the project than without the project in question. The benefits of the undertaking are treated as the beneficiaries' willingness to pay for the products from the project rather than do without them. This is the area under the beneficiaries' demand curves at the quantities provided. To illustrate, consider the case of the demand for road transportation between two points. Let the representative traveler's demand be represented by the line $D D^1$ in Figure 1, where the horizontal axis represents number of trips (or VMT or passenger miles or any other measure of output) and the vertical axis denotes value. Assuming nothing else changes (i.e., no change in tastes and preferences, income, wealth, prices of other goods, particularly closely related ones such as gasoline or airfares, etc.), the demand schedule indicates the number of trips the traveler would take at different costs (prices) to her per trip. At cost P, she will take T trips. At higher costs she will take fewer trips, until at a cost of D per trip, she will refuse to travel by road. Alternatively, as costs decline she will make more road trips up to a maximum if the cost to her was zero. If the cost to the user is P, she takes T trips, as the value of the last trip just equals the cost to him. Earlier trips, however, are valued more than P as is indicated by the DE portion of her demand schedule. The total value of the T road trips to the traveler is then equal to the area ODET, the sum of the value of each of the T trips. Thus the area under the consumer's demand curve to point E represents this willingness to pay for the privilege of taking T trips by road rather than do without road travel. The fact that the traveler pays a cost OPET (OP per trip times T trips), which is less than their willingness to pay, results in her receiving an additional benefit measured conventionally as consumer's surplus and represented by the triangular area PDE.

The economic evaluation of this project is concerned with comparing the total willingness to pay of all beneficiaries with the total costs of the project. Alternatively, the analyst may calculate the sum of the beneficiaries' consumer's surpluses and determine whether these exceed costs not directly met by charges to the user. If all costs

Figure 1
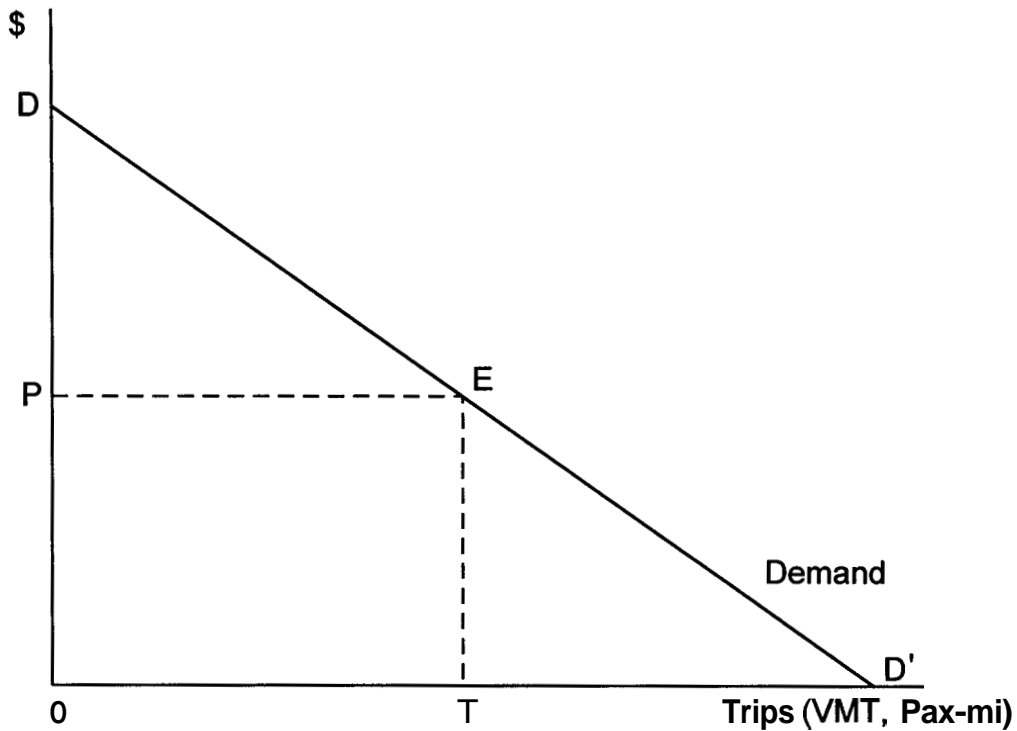
were included in the price to the traveler (total costs equal OPET times the number of travelers), the existence of consumer's surplus makes it obvious that compensation could be paid, although the social viability of the project does not depend upon it actually being paid.

Complete demand schedules are not readily available even for private goods and so are more difficult to obtain for publicly provided goods which are not normally marketed. Consequently, it may not be possible to derive a measure of willingness to pay fiom a demand schedule like DD' in Figure 1. Such a situation could arise in an effort to estimate the benefits of a road into an area to be opened for development. In most cases, however, the proposed project represents an improvement to the roadway (transportation system) so that some evidence is already available about demand. Current users now face a cost per trip of P_0 and make T_0 trips. The benefits of the improvement come fiom two sources. First, the improvement results in lower costs to the user in the current number of trips (P, rather than P_0). This amounts to a saving of $P_1 P_0 EF$ (i.e., $OP_0 ET_0 - OP_1 ET_0$). Second, there are also benefits amounting to the consumer's surpluses from additional trips which are expected to be taken because of the reduced cost to users. Some of these arise because existing users travel the road more often, part stems fiom the fact that some traffic will now find this road more attractive (less costly) than other routes and be diverted from them, and a portion is newly generated traffic which presently finds road travel too costly and so do not use any route, but with improvement will take some trips

on the improved route. The total additional number of trips expected from these sources is $T_0 T_1$. The value of those trips to the travelers is the area under the demand curve between E and G. (The demand curve in that range is often assumed to be linear in the absence of better evidence.) Their consumers' surpluses amount to the area EFG. Thus, total net benefits stemming fiom the improvement amount to the cost savings to current travelers $P_1 P_0 EF$ and the consumers' surpluses of the travelers new to this route. The total net benefits are the changes in consumers' surpluses resulting fiom the lower user cost – the area $P_1 P_0 EdG$.

It is important to note that the valuation of benefits is inseparable from the distribution issue. This is evident when one recalls that the demand curves upon which benefit estimates are derived assume that income, wealth, preferences, prices of complements, substitutes and all other goods (indeed everything that might influence consumption other than the price of the good itself) remain unchanged. Thus, willingness to pay depends upon the situation of the beneficiary, his initial endowment. If income (or wealth) were distributed differently, the demand functions would shift and the evaluation of benefits would be changed. In fact, the effects of the project itself may modify some beneficiaries' demands. Consequently, the evaluation of benefits is not independent of distribution.

Figure 2
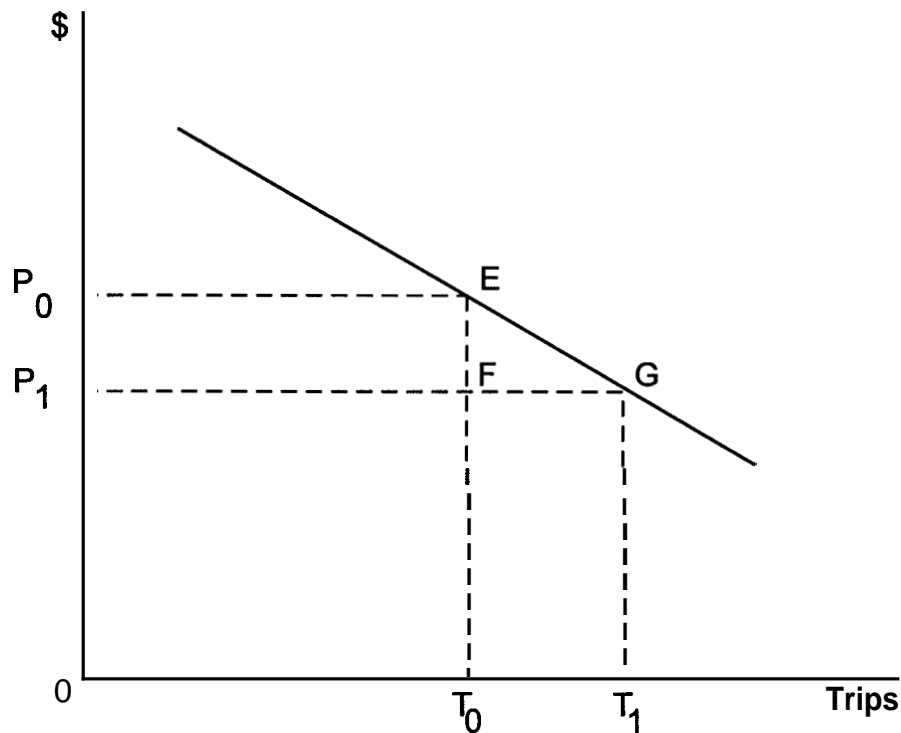
In cases in which projects have sizable effects upon the prices of commodities important in the beneficiaries' consumption bundle, the impact is an effective increase in real income contrary to the constant level of income or welfare assumed in determining the demand curve. Because of this, alternative measures of consumers' surplus have been advanced. One, compensating variation (CV), is the maximum amount the beneficiary would be prepared to pay rather than forego the privilege of acquiring the good at the new (lower) price. The maximum he would pay is the amount which would just leave him indifferent between having and not having the opportunity, an amount that would leave him with the same level of real income as welfare. For a price decline, the compensating variation estimate of consumers' surplus is less than the measure under the [Marshallian] demand curve where money, but not real income, was held constant. This **is** shown in Figure **3,** where the [Marshallian] demand curve is shown **as** DD^1 and the consumer's surplus resulting from a reduction in price from P_0 to P_1, with money income constant, is P_1P_0WY. When real income is held constant (fails to rise due to the price fall), the consumer buys a smaller amount of Q (Q, rather than Q_1) at P_1. The consumer's surplus under the constant real income demand curve WZ is P_1P_0WZ. Alternatively, one could measure the benefit to the consumer as the amount required **as** compensation for not having the good available at P,. This measure of consumer's surplus **is** called

Figure 3

Demand and Compensating Variation
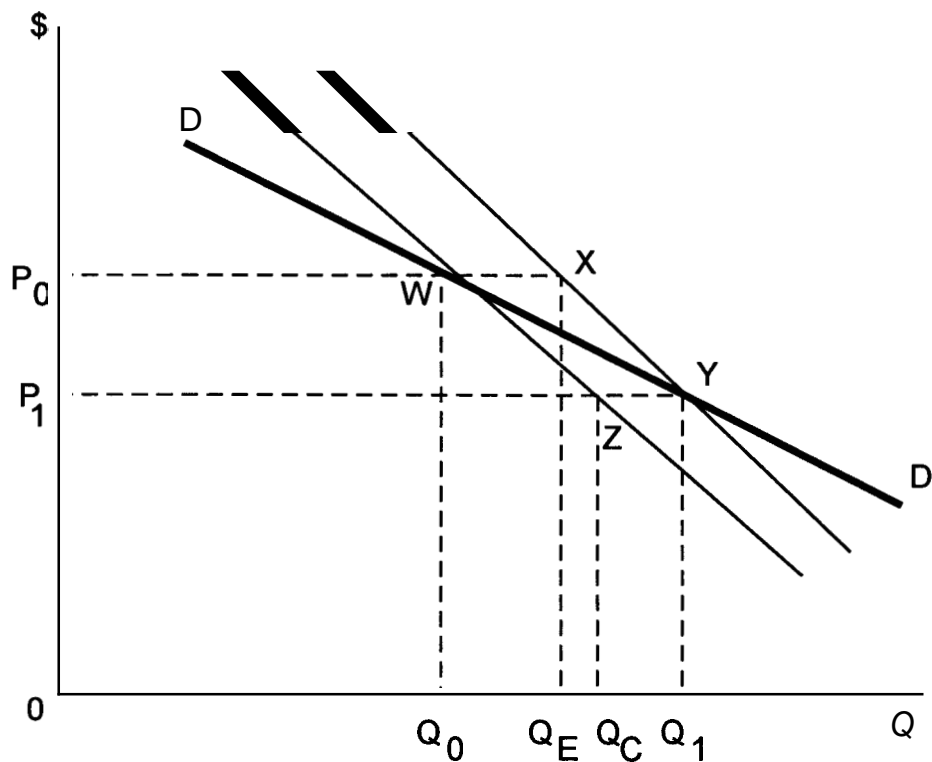
equivalent variation (EV). In this case the consumer is to be as well off as he would be at Y, rather than as well off as he was at **W,** upon which compensating variation was based. The equivalent variation surplus measure is P_1P_0XY. For price reductions CV is less than the [Marshallian] surplus measure is less than EV. *So* long as the price change results in an income effect (change in real income), these measures will differ.[6]

Generally speaking, the compensating measure (what a beneficiary is prepared to pay rather than do without the change) is the recommended measure of benefits. This however is not usually as readily derived as the [Marshallian] consumers' surplus measure. It has been common to assume this problem away by claiming that the income effects are sufficiently small, that the error resulting from using consumers' surplus rather than compensating variation too unimportant. In many cases, this is likely a suitable assumption. Whether or not this is *so* depends upon the significance of the item effected in the consumer's budget and the responsiveness of consumption to price and income changes. It has recently demonstrated that for a fairly broad and reasonable set of values, the error resulting from using the simple consumers' surplus measure is quite modest (e.g., 5 percent). This is smaller than the error associated with estimates of the demand schedule itself and so is of no concern. However, the error may be significant in some instances. In these cases, it may be important to improve upon the conventional estimate of willingness to pay. The situations in which the errors may be large and the extent of the error can now be identified for closer investigation.

The evaluation of benefits from estimates of consumers' surpluses may also be complicated by the fact that other prices need not remain unchanged. Undertaking a project results in the reshuffling of resources among uses in society. These reallocations may cause changes in prices and incomes. If the reallocations are small, to the point of being infinitesimal relative to the rest of the economy, the resulting changes are effectively negligible. But if the project results in a significant reshuffling, the price and income changes may be substantial. Where large (non-marginal) changes occur, there are gains and losses in the consumers' surpluses associated with other goods, which must also be counted in the project evaluation. Estimating the extent of price and income changes and the resulting impact on surpluses can greatly complicate the analyst's task.

3.5 The Evaluation of Costs

The estimation of project costs is typically a somewhat easier task than the estimation of benefits. The reason for this is that usually most costs are incurred early in the project life and that inputs, unlike many benefits, are acquired through market transactions where the price reflects the value of those resources in alternative uses. Thus, the market normally affords a better source of cost than benefit information. But input market prices do not always denote true social opportunity costs, i.e., what society must forego in order to shift resources to the project in question. This is because (a) market prices may not equal the cost of the increment in output, i.e., marginal cost, or (b) prices equal to

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[6] **Other consumer's surplus measures also exist but need not detain us here as the nature of the problem is evident already**

suppliers' marginal costs need not equal marginal social costs. Where prices fail to equal marginal costs, due to monopolistic situations, for example, the price will represent the true opportunity cost of the input. Similarly, market prices will under or overstate true social marginal costs if externalities are present. In undertaking cost estimation, market prices provide a first approximation of the social costs of inputs. In many cases the market prices are accurate measures but in other instances their uncritical acceptance will result in error. The problem is to distinguish those circumstances in which market information may be an imperfect indicator. A series of situations illustrating causes of divergence between market prices and marginal social costs are presented below. In such situations the analyst must estimate an accounting price or shadow price which better estimates the social value of the input than its market price.[7]

Rents. On occasion the additional demands for inputs which result from a project will push the market price of that factor up, resulting in some of the resource owners receiving more than the price at which they were prepared to offer their services. Thus, for example, to obtain L_2 workers for a project, the wage rate has to be increased from W_1 to W_2, although all but the last workers attracted would have been prepared to work for a wage rate less than W_2 (see Figure 4). In order to attract enough workers, it is necessary to pay some more than they would otherwise have accepted. This additional amount is rent in the economists' terminology, or quasi-rent if it is not expected to be permanent. In the figure, the amount of rent is the area $W_1 W_2 V$. Whereas the outlay for this labor would be $OW_2 V L_2$, the true social cost is $OW_1 V L_2$, the amounts at which they were prepared to offer their services. The difference, $W_1 W_2 V$, is a fortuitous gain, a rent or

Figure 4

Economic Rent

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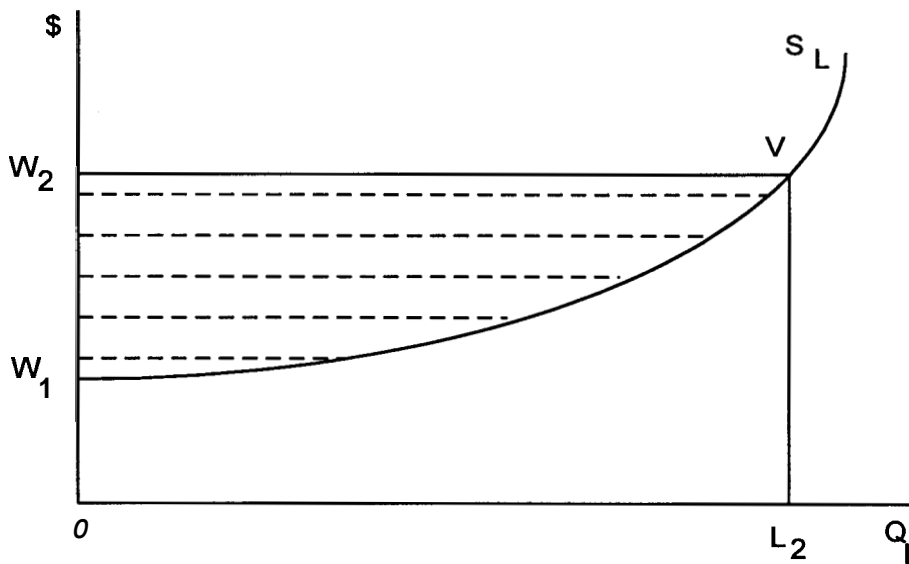
[7] A shadow price is an estimated value of a resource (natural, capital or human) based on its foregone productivity in an alternative use.

quasi-rent, to the infra-marginal worker resulting from the higher wage which must be paid all similar workers to attract enough altogether. The way to handle this type of situation in B/CA is to consider the total outlay (OW_2VL_2) as the cost of this labor, but to add the rent (or quasi-rent, W_1W_2V) to benefits. The outlay for labor does not simply represent a cost in this kind of situation, as it would if the labor supply schedule were simply a horizontal line at W_1, but also offers some benefits in terms of extra returns to the infra-marginal workers.

Rents may also accrue due to imperfect competition or strategic interdependence. A monopolist, for example, with unit costs of C may offer the amount of good **S** (Figure 5) at a price P. The difference between his total revenue and his costs (the area CMNP) is monopoly profit, a rent if permanent. How is the analyst to treat such cases in B/CA? Is the social cost **of** goods purchased from the monopolist the price paid, or its cost of production? The answer depends upon the response of the monopolist to the additional demand. If no additional output is forthcoming, then the requirements of the project must reduce the consumption of other users. Since those users value the output at P, the price they are prepared to pay, then the input should be costed to the project at its market value P. If however the additional requirements are met from new supplies *so* that existing users are not deprived of output, then the good should be priced to the project at its cost of production, C, not market price, since the resources used in its provision reflect the real costs to society.

Figure 5

Rent Under Strategic Interdependence
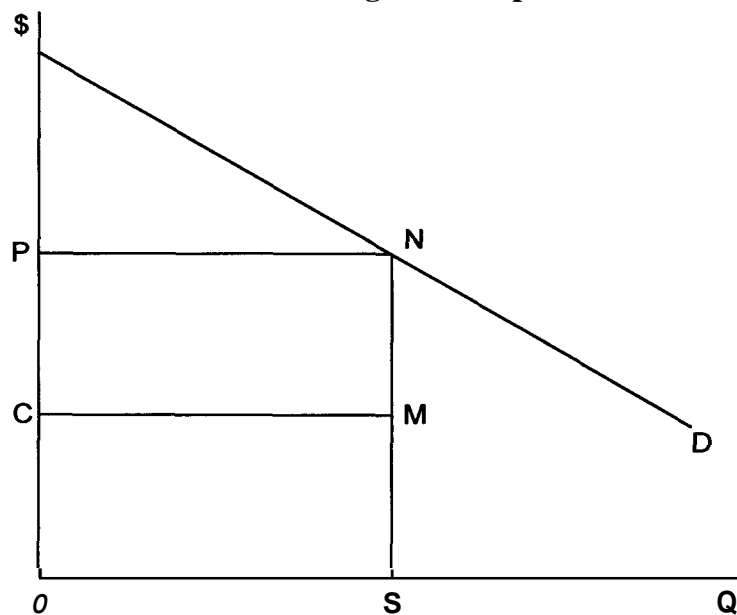
Distinguishing between market prices and costs of provision, depending upon whether project requirements deprive others or are met from new supplies, is a rule which can be applied in a variety of situations besides valuing output from imperfectly competitive

firms. Certain kinds of labor may, because of unions or professional associations, be in restricted supply and receive returns in excess of competitive rates. Even in cases where profits need not exist, prices may exceed marginal costs due to average cost pricing in decreasing cost industries, when once again the market price can overstate the cost of an increment in output. Also, if imports are employed but restricted by quantitative controls, a difference exists between their value to users and their costs of production. Finally, the same rule applies if taxes and subsidies distort input prices.

Taxes and Subsidies. Taxes and subsidies cause a divergence between market prices and costs of production or consumer and producer prices. In estimating input costs, the social cost may be either its price to the consumer or its price to the producer. This depends, as above, upon whether the additional requirements are met by reducing the supplies to others, in which case it is the price to other users (market including tax less subsidy), or from new supplies, in which case the appropriate price is the producer price (the price without tax but with subsidy. When measuring benefits, the issue is simpler. One need only consider that the user is prepared to pay. Hence, one uses the market price as influenced by taxes and subsidies.

Intergovernmental grants are an important source of funding for transportation projects. The federal government transfers monies to states to assist undertakings in which there is national interest, and state governments similarly offer grants to assist municipal and county transportation projects. It is tempting for the analyst and decision-maker to consider the grants as gifts and only determine whether state or local net benefits are adequate to justify the recipient's share of the costs. Such an approach would be acceptable if one was certain that the grants represented spillover benefits. However, grant programs are typically the result of political negotiations which may be influenced by a number of factors, and even if they reflect or approximate spillover benefits in some broad sense, the external benefits in any political case may be quite different. Therefore, despite the existence of grants, the project evaluation should initially ignore them and determine the overall merits **of** the project independent of who is to pay the cost. This approach is useful for a number of reasons. One is that it indicates whether the project would appear justified on its own merits. Second, an assessment **of** the distribution of benefits between grantor and grantee provides insight as to the suitability of the grant structure as a means of compensation for spillovers of benefits among jurisdictions, thereby affording some background for grant negotiation. **If** a project does not appear justified on its own, independent of grants, but yet attractive to the decision-making unit when the grant is included, a state or county may feel it only rational to accept the grant.

Unemployed Resources. If as a result of undertaking a project, resources are employed which otherwise would have been unemployed, the opportunity cost of those resources to society will be less than the incomes they earn. Thus, if the project hires unemployed labor, the social cost of that labor will be less than the wages paid, and similarly if unemployed capital is engaged. The opportunity cost of such resources is not, however, zero. Rather it is the minimum compensation necessary to attract their services.

The calculation of a suitable shadow price for unemployed resources can be difficult. If unemployment insurance is being paid, it is this minimum compensation less the unemployment insurance benefits, i.e., the increment added to attract them to employment. Since this increment could be negative where individuals had a strong preference for work over leisure, this measure may be difficult to attain with accuracy. Accurate estimates are also complicated by the fact that, while a project may augment the jobs in a region, it need not reduce unemployment if the unemployed lack the required skills. Instead it may simply reshuffle currently employed labor among sites. Furthermore, even if some unemployed are expected to be engaged for a time, one must estimate whether they would be unemployed over that period or whether economic conditions would improve while the project is underway and the opportunity cost of labor rise, perhaps to the wage rate.

To determine the shadow price of resource inputs is a complex task in an economy where a large project may draw resources of labor and capital from across the nation. *An* effort to trace through the effects *so as* to arrive at an estimate of the social opportunity costs of labor and capital in the United States is based upon input-output models. The results indicate that in areas of above-average unemployment, the true social cost may be **as** low **as** 70, but more typically from 85 to 95 percent of nominal costs calculated without consideration of employment effects. Thus, projects with benefit-cost ratios less than one could be efficient if their employment-inducing effects were included, but in general these effects were not large. Although results may differ widely, this evidence suggests that shadow pricing unemployed resources is not likely to result in dramatic improvements in benefit-cost ratios. Given the difficulty of estimating shadow prices, there is some question **as** to whether it is justified when the effects may be quite modest. That question can only be answered by the analyst after reviewing the particular situation and assessing the potential impact upon employment levels and the ease with which reasonable values can be defined.

Externalities (or values for unpurchased inputs). In addition to the costs of resources applied directly to such undertakings, public projects may impose costs for which compensation is not paid. A dam for flood control may prevent fish migrations, a highway may contribute to local air pollution, and an airport will inflict noise on the surrounding neighborhoods. Such costs are generally the unintended consequences of an effort to meet some other objective, an externality or spillover. The fact that there is no explicit market in which such commodities are traded often results in these effects being neglected or undervalued. Despite the lack of **an** explicit market mechanism, it is sometimes possible to estimate indirectly the values which individuals place upon the losses involved. We illustrate this for the case of airport noise.

San Diego Airport is surrounded by urban development, much of it residential. The noise from aircraft traffic disrupts neighboring residents and makes the nearby communities less attractive places to live to prospective home buyers. Consequently, one would expect to find homes with similar features, except the level of aircraft noise, to be valued

differently in the housing market. This variation in value attributable to noise can be used to estimate the cost of aircraft noise.[8]

A number of studies examining the noise impacts of airports only considered the effects upon residential property. Undoubtedly, many commercial and industries properties would also benefit fiom aircraft noise reduction, also assuming that this could be accomplished without their relocation away from the airport. The important point to make, however, is that this technique offers a means of estimating in particular situations the implicit cost of an externality for which explicit market values do not exist. Property value studies have been employed to estimate the cost of pollution and noise in a variety of cases and can also be used to estimate non-market benefits such as proximity to a park or shoreline, or presence of a scenic view. Care must be taken when undertaking benefit or cost estimates derived fiom property values to avoid double counting in that the effects are estimated both through the demand function and also via their effects on property values. The impact on property values is a means of deriving estimates when demand cannot be defined otherwise. It is not legitimate to measure both the flow and capitalized impacts of the same effect. This can readily happen in transportation studies where the benefits of improved transport may be measured as the area under the demand schedule, but those benefits are also capitalized into higher property values in the neighboring affected areas. Finally, one should note that the spillover effects of additional air pollution or noise should be treated as a negative benefit of the project and not as a cost. This parallels the treatment of positive spillover benefits, as both affect the gross benefits which stem from the investment in the project.

Concluding Comments. Although market prices may be imperfect estimates of social costs, they are easily come by. Their adjustment to account for distortion is often complex, time-consuming, and may themselves be imperfect. This leaves one wondering whether they are worth the effort. This can only be answered by the analyst's assessment of the degree of distortion, the ease of correction, and the significance to the result. In many cases, market prices may be adequate; in others one may have to choose between accounting prices or no prices at all. Other means of coping with situations in which prices are unavailable are discussed later in this chapter.

3.6 Project Selection Criteria

Having examined the various components of the B/CA, we can now consider how the composite can be applied to aid decision-makers in selecting the appropriate projects. The economic merit of any project or program can be represented by a *summary* statement, such as a benefit-cost ratio, net present value, or internal rate of return. Comparisons among alternative programs or projects can be made by comparing *summary* statements for each project. The major focus here is on selection criteria based on economic efficiency. Selection criteria are most readily discussed in the context that all social benefits and costs are accurately evaluated in monetary terms. While this is

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[8] Safety considerations also likely influence property values, but these are assumed to be closely related to aircraft noise levels.

obviously not the case, it does in fact represent a basic reference point from which further modifications in the analysis to account for real world complications can be added and to which comparison can be made.

3.6.1 Alternative Selection Criteria

The basic principle of the selection criteria has already been outlined. The central question in considering the economic efficiency of a project is whether the present value of benefits exceeds, equals, or is less than the present value of costs, i.e.,

$$\sum_{t=0}^{T} \frac{B_t}{(1+i)^t} \underset{<}{\overset{>}{=}} \sum_{t=0}^{T} \frac{C_t}{(1+i)^t}$$

From this equation one can derive the three major selection criteria - net present value, benefit-cost ratio, and internal rate of return.

1.   Net present value is the present dollar value of benefits less cost

$$NetPV = \sum_{t=0} \frac{B_t}{(1+i)^t} - \sum_{t=0} \frac{C_t}{(1+i)^t} = \sum_{t=0} \frac{B_t - C_t}{(1+i)^t} \underset{<}{\overset{>}{=}} 0$$

where the selection criterion requires a viable project to have a net present value greater than or equal to zero.

2.   Benefit-cost ratio is simply

$$\frac{B}{C} = \frac{\displaystyle\sum_{t=0}^{T} \frac{B_t}{(1+i)^t}}{\displaystyle\sum_{t=0}^{T} \frac{C_t}{(1+i)^t}} \underset{<}{\overset{>}{=}} 1$$

The criterion for an economically viable project, in this case, is that the ratio equal or exceed one. This can also be expressed as the discounted net benefit ratio [(B-C)/C], which is simply the benefit-cost ratio minus one, but has the advantage that the result appears as a rate of return on cost.

3.   The internal rate of return is derived by solving for the rate of discount which will equate the present value of benefits and costs. That is, solving the following equation for r.

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

Whether a project is economically viable or not depends upon whether the internal rate of return is greater than or equal to a predetermined minimum rate of return required of all projects.

In simple situations, the assessment of a given project by each of these techniques will lead to consistent results. That is, the project will be accepted or rejected uniformly by all three criteria. Unfortunately this need not be the case when ranking alternative projects.

3.6.2 Relative Merits of the Three Criteria

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) and the internal rate of return (IRR) 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. But more of this below.

Relative measures (B/C and IRR) are sensitive to the treatment of operating costs and future disbenefits. Such future costs may be treated in either of two ways. One is to deduct them from future benefits on the principle that they can be offset by the then current benefits and do not relate to the capital constraint in effect when the project is being initiated. The other approach is to treat all costs, initial or future, the same, arguing that it is the returns on all costs that is of interest. The effect of these alternative procedures upon the relative measures is evident from a comparison of these two formulas:

(a) $$\sum_{t=0}^{T} \frac{B_t - O_t}{(1+i)^t} \gtrless \sum_{t=0}^{T} \frac{K_t}{(1+i)^t}$$

and

(b) $$\sum_{t=0}^{T} \frac{B_t}{(1+i)^t} \gtrless \sum_{t=0}^{T} \frac{K_t + O_t}{(1+i)^t}$$

where O_t denotes operating cost and K_t capital cost. Both the B/C ratio and the IRR can be effected by the choice between (a) and (b). In a case, for example, where benefits are $6M, operating costs $2M and capital costs $2M, the B/C ratio is either (6-2)/2 = 2 by formula (a), or 6/(2+2) = 1.5 by formula (b). Although the choice between these two methods is to a large extent arbitrary, valid comparisons among B/C ratios or IRR require that one alternative or the other has been applied consistently in all the analyses. Whether a distinction is made between operating and capital costs does not affect the net present value criterion.

The internal rate of return analysis is plagued by a unique problem – more than one internal rate of return may exist. This occurs if the stream of net benefits from a project are less than zero more than once, as can occur due to periodic outlays for reconditioning or replacement of a part of the capital which exceeds the value of that period's benefits. Such results can cause some confusion as to which is the appropriate rate by which the project should be evaluated. Multiple solutions are not a difficulty with either the benefit-cost ratio or the net present value criterion. Also, the IRR cannot allow for possible variation in the discount rate over the life of the project due to expected fluctuations in the level of economic activity, which can be incorporated easily into B/C and NPV calculations. Finally, because it implicitly discounts at the highest rate of return, IRR favors projects-oriented (benefits bunched early in the project's life) as opposed to future-oriented projects.

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, economists prefer the use of the B/C ratio (or (B-C)/C ratio). This is done though, while utilizing the absolute magnitude of discounted net benefits as well. The rationale for this choice will be made more evident in the following discussion. Because of the preference of B/C, much of the discussion is oriented more in that direction.

3.6.3 Applying the Selection Criterion

The purpose of the efficiency criteria is to aid in the selection of the optimal project(s). They can be applied to the selection of the optimal scale of a specific project and to the selection of the most beneficial projects from among a set of feasible alternatives. The simplest case exists when there are no interrelationships among the projects under consideration.[9] These are examined for situations in which the scale of the project is both divisible and indivisible. Subsequently, the difficulties encountered when interdependencies exist are briefly discussed.

Divisible Projects. When projects are divisible, a major concern is the determination of the optimal scale. The objective of the analyst is not just with finding a scale of project that meets the decision criteria, but with determining the scale which offers the greatest benefits for the costs incurred. The problem is readily illustrated in Figure **6.** As the scale of the project is increased, the value of the benefits increases but at a diminishing rate, i.e., leveling off at high levels out output, Q. While the project is not perfectly divisible (witness the fixed costs associated with a zero level of output), output can be continuously varied with costs increasing uniformly for each additional unit of output. (The additional or marginal costs need not be uniform but could decrease and then increase.) The project is economically viable in that benefits exceed costs for all outputs

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[9] **Such a case seldom exists in transportation because of multi-modes and linkages. Nevertheless, it merits discussion as foundation material for the more complex interdependent projects cases.**

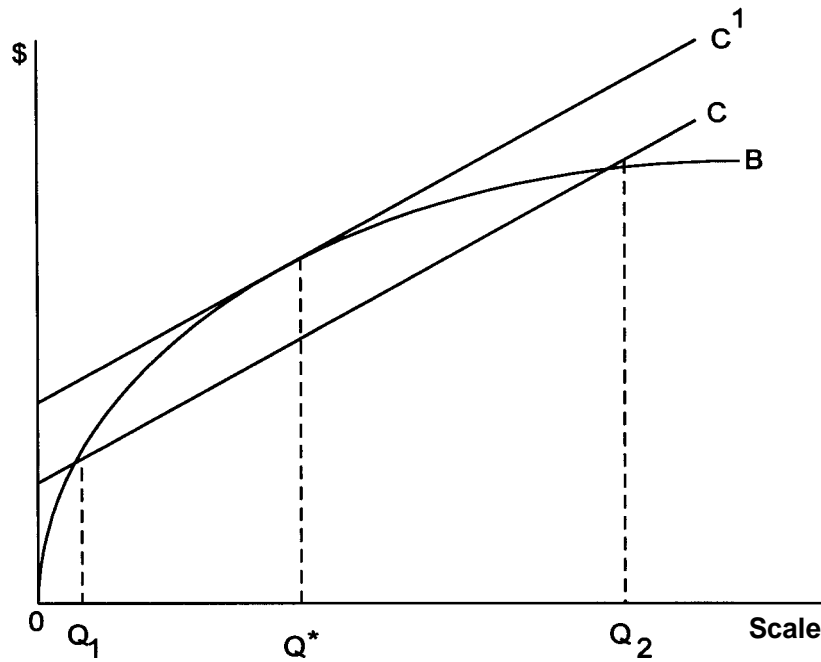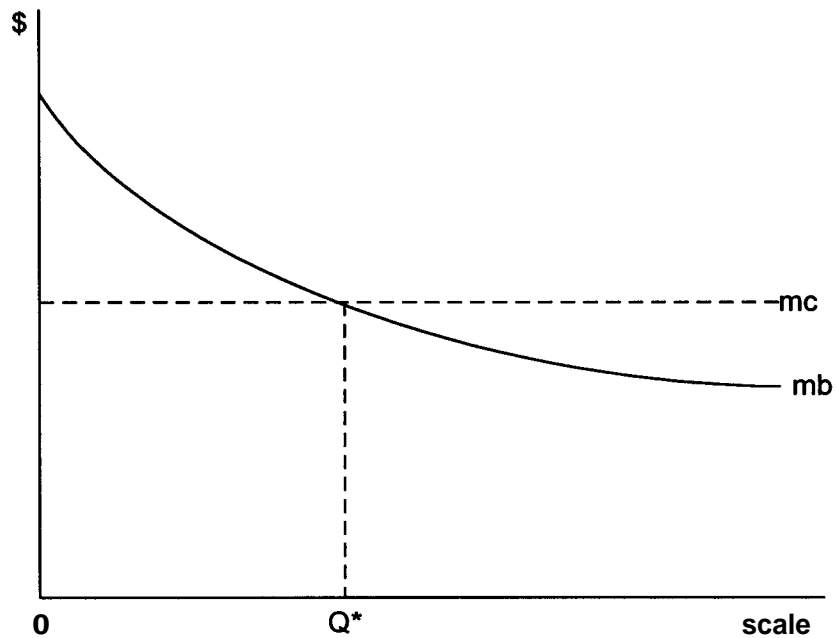## Figure 6

Benefit and Cost Functions

Figure 7

Marginal Benefit and Cost Functions

between Q_1 and Q_2. Although selection of any scale for this project generating outputs in the range would result in positive net present benefits, or a B/C ratio greater than or equal to one, there is one scale which is best. That scale generates output Q^*, the level at which

benefits relative to costs are greatest. In this particular case, net present benefits and the B/C ratio are the maximum possible for this project. This scale is that at which the value of and the cost of producing the additional output are just equal. This is the point at which marginal benefits equal marginal costs (see Figure **7**)**,** which is the scale at which the slope of the total benefit, B, function just equals the slopes **of** the total cost, C, function. (Marginal schedules equal the slopes of the total schedules). At lower levels, beneficiaries are willing to pay more for an extra unit than its cost of production, while at higher levels they are not prepared to pay the cost of producing the extra unit.

Determination of optimal capacity can illustrate this kind of **problem.**[10] Scale may be measured **as** maximum capacity per hour, for example. Given the project volumes, benefits increase as capacity is expanded because the number of travelers increases and because with additional capacity traffic flows faster, thereby reducing travel time. At sufficiently high capacities, neither volume nor the rate of flow will increase significantly, that is, total benefits increase more slowly, gradually leveling off. Assuming benefit and cost functions like those illustrated, the optimal roadway capacity can be selected as that at which marginal benefits are just equal to marginal costs. It is the analyst's task to derive these schedules, indicate the range of viable economic alternatives, and note the optimal scale.

If the proposed project as designed to produce Q_2, the B/C ratio would equal one and on an economic basis society would be indifferent between undertaking and not undertaking the project. A project of such size is too large, however, despite the fact that technically it can pass the test for economic viability. Better use of resources could be made by shifting resources elsewhere, and reducing the scale as the value of the last unit to consumers at this scale is less than its cost of production. The benefit-cost ratio also equals one at output Q_1, but this is too small a scale as net benefits can be made positive by expanding the project. A project with a B/C ratio of one is of optimal size only in the rare case that the total benefit and total cost functions are tangent to one another at that scale, **as** C, is tangent to B. It is much more likely that the benefit and cost functions will cut one another, in which case an optimal scale exists at which the B/C ratio exceeds one. Projects which are presented **as** having B/C = 1 are very likely of too large a scale to be economically optimal.

When considering several perfectly divisible projects (the C function passes through the origin), initially each should be considered at its optimal scale. If three possible projects (A, B and C) exist, the recommended scales are those producing Q_A*, Q_B• and Q_C*. At those outputs, marginal benefits equal marginal costs in each project and are equal among the projects, *so* that there can be no improvement made by allocating more or less resources to any or all projects or to reallocating given resources among the three. If the resources required to fund the three projects to their economically optimal scales, then the size of each should be reduced while maintaining the equality of benefits at the margin

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[10] **This example assumes there are no interdependencies which in reality do exist.**

among projects until the budget constraint is met. In effect, the effective price of capital (its shadow or

Figure 8

Optimal Scale of Multiple Projects
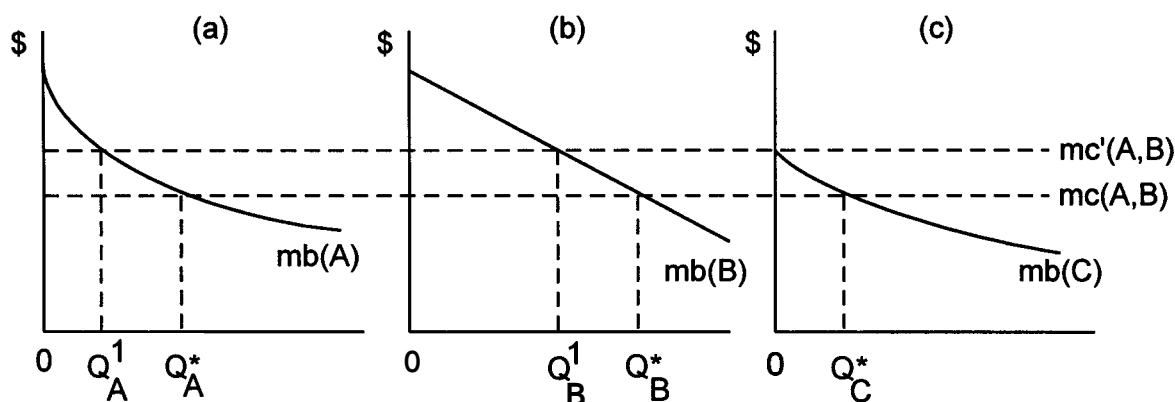
accounting price) exceeds its nominal value and pushes up the marginal cost schedule. If the budget constraint is to severe that the marginal cost of capital becomes mc,, project C is omitted entirely as the marginal benefits fiom C are less than marginal costs for all output levels, and **A** and B are cut back to $Q_A{}^1$ and $Q_B{}^1$. **A** still tighter budget could result in project B also being abandoned, but *so* long as the budget is positive, **A** will be undertaken, although at low levels of output.

When projects can vary in scale, the problem is not only to select the best order of projects, but also to select the optimal scale for each simultaneously. Both the set of acceptable projects and the scale of those depend upon the budget. When the budget is limited, all projects are cut back and if necessary, those with the lowest present net benefits to cost ratio (B/C-1) are eliminated. **As** the area between the marginal benefit schedule, mb, and the marginal cost schedule represents net benefits and the area under the mc schedule represents cost (perfectly divisible projects), the (B-C)/C ratio is represented by the shaded area relative to the cross-hatched area in Figure **9.** One can see, Figure **8,** that as scarcity of funds increases marginal costs, the (B-C)/C ratio declines for all projects reaching zero, first for project C, then B and finally **A,** when the budget allocated to this set is reduced to nothing.

Indivisible Proiects. In this section it is assumed that the scale of projects cannot be modified and the problem is to rank these projects according to their economic attractiveness. While such a degree of inflexibility may be a valid assumption in some cases, it is to a large extent simplifying here, as it allows us to focus on the ranking issue without having to consider the problem of varying scale where size variations are discontinuous and therefore more difficult than the previous case. Thus, in this discussion we ignore the possibility that the rank of projects may change as the size of the

budget increases or decreases because the optimal scale of the project changes, although in practice such situations may be encountered.

Figure 9

Benefit-Cost Ratio Representation
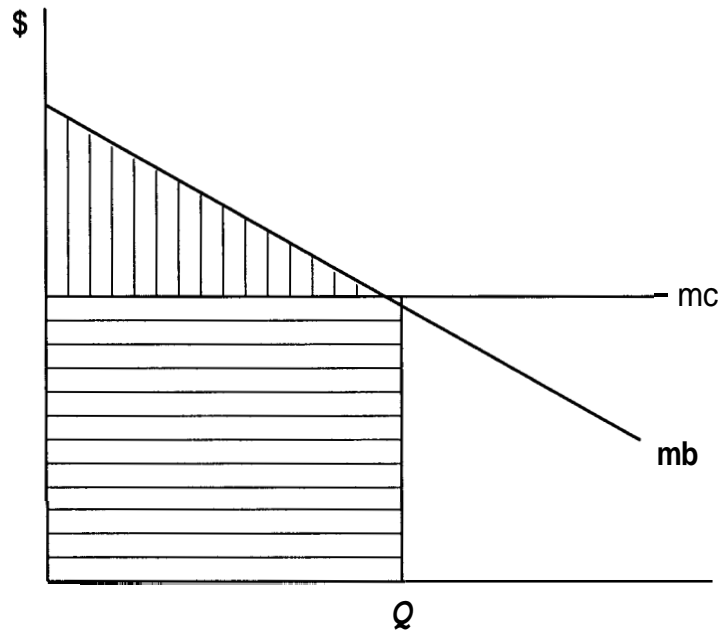
The major problem addressed in this section is to determine the basis upon which the best set of projects to undertake can be selected from a larger set of feasible projects when budget limitations prevent all from being accepted, that is, how to rank alternative projects. The reason ranking becomes an issue in the face of budget constraints is because the alternative project selection criteria may order projects differently, thereby suggesting different combinations of projects in the best set. For example, three projects **A,** B and C have net present values, benefit-cost ratios and internal rates of return as indicated below.

	B-C = NPV	B/C	IRR
A	27.5 – 20 = 7.5	1.375	.34
B	120.2 – 100 = 20.2	1.202	.17
C	39 – 377 = **-58.0**	-.15	**.46** (and **4.56)**

The NPV criterion ranks the projects B,A and C; the B/C criterion **A,** B and C; and the IRR criterion **C, A** and B. If funds are limited, which project should be undertaken (or which eliminated)? If only one project can be implemented, it could be any of **A,** B or C, depending upon the criterion used.

It is interesting to note why project **C,** which would be rejected outright by the NPV and B/C criteria, should appear not only viable but preferred under the IRR method. The

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reason for this result is because project C, unlike the others, generates a time stream of first negative, then positive, and finally negative net benefits. With a high internal rate of return, the more distant negative net benefits are discounted sufficiently heavily to make the project viable. It has been suggested that in this kind of situation (where two internal rates of return exist, **.46** and **4.56** here), the project should only be accepted if the social rate of discount lies between the alternative internal rates of return. Since in this case the **10** percent rate of discount utilized in the NPV and B/C analysis does not lie between **.46** and **4.56** percent internal rates of return, project C should be rejected. This example further illustrates the kinds of difficulties which can arise when using IRR.

Even if one discards C for the above reasons, a choice between alternatives A and B still remains. The choice is complicated by the fact that the two projects have widely differing capital requirements, **20** versus **100,** and different absolute amounts of net benefits, **7.5** versus **20.2.** Should one be concerned more with the absolute amount of present net benefits or their magnitude relative to costs? The conflict among all three criteria occurs because the projects are not, strictly speaking, put on a comparable basis. The three criteria would provide parallel rankings only if: **(1)** costs of each project are the same; **(2)** the projects have a common economic life or alternative investments are considered over the same period; and **(3)** one explicitly accounts for the reinvestment alternatives associated with each project. (None of these conditions is met in the preceding illustration.) Relating to a common outlay is sufficient to reconcile the NPV and B/C criteria. The second and third requirements are necessary to obtain agreement between the IRR criterion and the other two. Basically these requirements assure that proper account is taken of project benefits by recognizing their value in their subsequent uses over the investment period. For example, part of a project's benefits may be consumed, and part invested. It is argued that consumed benefits be evaluated at the social time preferences (i.e., the rate at which individuals are prepared to trade off present for future consumption), but that reinvested surpluses be evaluated at the opportunity cost rate. NPV and B/C apply a single rate while the IRR analysis implies that the benefits will be applied to uses where the rate of time discount equals the IRR which, of course, need not be the case.

To reconcile the three approaches, a normalization procedure has been devised. Rather than discounting to the present, this method compounds benefits and costs forward to a common terminal date, applying the rates appropriate to the eventual use of the benefits stemming fiom the project. Essentially, **this** compares what we expect to have at the end of the period (benefits) to what we might have had (costs) without the project. Normalized results for these projects analyzed previously are presented below. All projects are now consistently ranked by all three criteria with A over B over C.

	NPV_N	$(B/C)_N$	IRR_N
A	37.4	1.80	25.1
B	2.6	1.01	20.4
C	-19.0	.91	17.2

While normalization does solve the ranking problem, a simpler procedure is likely satisfactory in the majority of cases where a decision-maker is faced with selecting from a set of feasible alternatives that combination yielding the greatest present net benefits from the expenditure of his limited budget. Consider the set of possible projects listed below.

	B	C	NPV	B/C
P_1	40	20	20	2.0
P_2	31	15	16	2.2
P_3	12	10	2	1.2
P_4	12.5	5	7.5	2.5
P_5	45	30	15	1.5
P_6	12.5	12.5	0	1.0

Given his budget, the decision-maker wants to select those projects which will offer the largest present net benefits for the expenditure of that amount. This will be accomplished if he ranks the alternatives by the B/C ratio and undertakes those with the highest ratio until the budget is exhausted. In this case he would first fund P_4 then P_2 and *so* on in the order P_4, P_2, P_1, P_5, P_3, P_6. Thus, for example, with a budget of 20, the best selection is not to undertake P_1, which has the largest NPV and exhausts the budget, but rather to undertake P_4 and P_2, which for the same expenditure provide present net benefits of 23.5 as opposed to 20. If another 20 were available, then P_1 would be included. Selecting projects according to their B/C ranking assures that accepted projects are justified at the artificially high (accounting) price of capital implied by the budget constraint and therefore results in the largest net present benefits being achieved.

Where the size of the budget and the pattern of capital requirements prevents moving down the list successively, the decision-maker will want to select the combination of projects meeting the budget constraint which offers the largest net present benefits. This combination will have the highest cost weighted B/C ratio. Thus, if the budget is 25, combination P_4, P_2 does not exhaust the budget and combination P_4, P_2, P_1 exceeds it. However, either combinations P_4, P_1 or P_2, P_3 will meet the budget. Combination P_4, P_1 is preferred as the expenditure of 25 there yields present net benefits of 27.5 as opposed to 18 in the case of the P_2, P_3 alternative. This corresponds with a ranking based upon the weighted B/C ratios which in this case are (2.5 x 5/25 + 2 x 20/25 =) 2.1 and (2.2 x 15/25 + 1.2 x 10/20 =) 1.8 respectively. Where budgets are large relative to the size of projects, this is not a serious problem and even if it does arise, can be solved by following the principle of selecting projects according to their B/C ratio until funds are exhausted.

Interdependent Projects. The problem of project selection can become very complicated and simple decision rules may fail once interdependencies exist. Interrelations among projects may occur in a variety of forms. In some cases, the benefits (or costs) of one project can depend upon the existence of another project which may provide either complementary or substitute services. The potential benefits of a highway may depend

on widening a bridge or be effected by improved rail service. Alternatively, there may be interdependencies over time as, for example, when capital constraints over a number of years must be considered. Because they impose on future capital supplies, projects with future capital requirements will be viewed differently in the multi period capital constraint model than when it is constraining only today. Mutually exclusive and large lumpy projects can further complicate the selection process. When these complications are sufficiently severe, computer programmed techniques must be employed to solve for the optimal investment program. These methods are the topic of another section.

3.6.4 Adding Non-Economic Considerations

The discussion of selection criteria has thus far assumed that benefits and costs are readily measurable in economic terms and that the economic criterion accurately reflects the social merits of an undertaking. If such is the case, the analyst's and the decision-maker's problems are much reduced. The problem is then much like the private entrepreneur's, although not entirely parallel since the public project evaluation may still include benefits and costs which, though measurable in economic terms, are external to the private decision-maker and therefore not considered by him. Unfortunately, the evaluation of public projects is not usually this straightforward. Often there are costs and benefits associated with a project upon which economic values cannot be readily placed. The approach to these situations is what concerns us here.

The strictly economic assessment should be viewed as one of several basic steps in the process of gathering information for public project appraisal. In itself, it represents a fundamental ingredient which can be expected to be a significant consideration in most decisions. Secondly, it provides a building block to which more debatable economic assessments can be added or against which non-economic effects can be contrasted. Because of this role, we recommend that any project evaluation include a basic economic assessment showing the benefits and costs which can be evaluated according to generally acceptable standards and with those consequences less amenable to economic analysis enumerated and discussed, but not included in the dollar estimates of benefits and costs. This should provide a measure of the economic viability based on widely accepted values, leaving out considerations such as the value of reducing accidents or preserving wetlands, which some might argue dollar values cannot be placed upon or at least upon which their evaluations are subject to wide variation. This comes closest to the estimate of economic feasibility based on the principle that "a buck is a buck," regardless of to whom the economic benefits and economic costs accrue. All else the same, it is much easier to live with projects meeting this criterion than those which do not.

It may be desirable to supplement the purely "economic" appraisal in many cases. Sometimes the non-market benefits and costs may be large relative to the market measures or, even if not large, critical in determining the overall feasibility of the project. In some cases, although these effects do not have conventional prices associated with them, it may be possible to attach a rough estimate of this value as a proxy measure. Where these estimates are rather tenuous, it is best to add in their effects *so* as to

recognize the sensitivity of the economic criterion employed to these measures. Thus a project may have a negative net present value when evaluated in market-oriented considerations, but when one includes an estimate of amenity values or weights a dollar of benefits or costs differently depending upon the income of those to whom they accrue, this evaluation may become positive. This same result could have been indicated in a single analysis but we feel it important to distinguish the effects, particularly of what might be considered more contentious evaluation, separately to draw attention to their significance. The decision-maker should be aware of the sensitivity of the results to evaluations of this kind.

Even if no economic evaluation of certain effects is possible, the basic economic appraisal affords a benchmark against which these effects can be weighed. If, for example, a project is economically attractive but will destroy an historic site, one is able to ask whether or not the loss of the historic site is to be valued above the net benefits of the project. In this kind of situation one is at least aware of the implied benefits or costs associated with a pro or con decision.

The important point here is that the effects of alternative assumptions upon the economic feasibility measures be made as explicit as possible. Where economic measures are ad hoc and perhaps debatable, the decision-maker should be aware of their impact on the result. The analyst should display the range of feasible estimates and their effects upon the outcome. Alternatively, when economic values cannot be assigned to benefits and costs, the analyst can indicate the associated costs or benefits necessary to justify a decision one way or the other. Essentially, where non-market evaluations are necessary, as much information as possible should be provided *so* that their economic consequences can be appreciated if not measured.

When confronted by non-economic considerations, both the analyst and the decision-maker should take care that they not become *so* enamored by the B/CA that they fail to recognize its limitations. Some things are immeasurable in economic terms and one is well advised to recognize that fact. Efforts to put a price on everything only debase the goal and the field of economics in general, besides deceiving the decision-makers (and perhaps the analyst himself). Over-extension of the analysis may only generate the predetermined outcome. This is not to detract fiom efforts to establish economic values for difficult-to-measure efforts, but to emphasize that one must be continually wary of the point at which quantitative assessments fail and qualitative judgments are required.

3.7 Project Selection Criteria versus Project Choice

The selection of the projects to be undertaken is not based on economic criteria alone. Many examples exist of projects ranking high in terms of this project selection criterion being bypassed in favor of lower-ranked alternatives, even those displaying negative net benefits. In part, this is due to the fact that there are overriding non-economic considerations which are not reflected in the B/C ratio or other such summary figures. In addition, however, many of these seemingly "perverse" decisions arise because the

selection criteria reflect total benefits and total costs without focusing attention on who benefits and who loses. (This is true even of analysis which weight benefits and costs differently to individuals in different circumstances.) The criteria simply tell whether, as measured, total benefits exceed or fall short of total costs. While to a large extent the net returns are not influenced by the distribution of benefits and costs, the acceptability of the project depends on it very much. The selection criteria do not indicate how a project will be financed and whether compensation is to be made to the losers. The distribution of the cost of a project among the beneficiaries, the general taxpayers, and specifically effected parties will significantly affect its acceptability. Non-economic considerations and particularly those associated with the distribution of benefits and costs have an importance influence in determining the political pressures which emerge in favor and against a proposed undertaking.

Economically viable projects may not be implemented because of a failure to receive political support. A roadway improvement, for example, may yield benefits far in excess of its costs, but because, as proposed, the benefits accrue to a few while the costs are to be met from the municipal government's general revenues, the majority of local residents disapprove and the project is rejected. Had it been advanced in a form where the bulk of the costs were to be recovered from an improvement levy on the benefited property, very likely the issue would have been accepted. Political forces are often not as simple as the simple majority rule implies. A small interest group, well organized and motivated by substantial potential gains, may exert sufficient political pressure to secure approval of a project with social benefits less than social costs but affording net benefits to a specific group. Many irrigation and flood control projects have been accepted because of the efforts of the immediate beneficiaries to push the project through, overwhelming the unorganized interests of the average taxpayers concerned about the overall social merits. Special interests can be particularly dominating when combinations of them can organize to log-roll projects by passing a set of projects advantageous to the coalition, although without net social benefits overall.

The distribution of benefits and costs is critical in determining a project's acceptability. Alternative financing schemes imply alternative distributions and associated with each is a different set of forces directed for or against the project, which will have to work itself out in the political arena. Different alternatives establish conditions favoring different groups. That efficiency criteria will be satisfied can only be assured if beneficiaries are required to pay the costs, i.e., compensate the losers. That beneficiaries pay need not always satisfy equity objectives and instead it may be decided that the expenses be met from public funds and/or that not all losers need be compensated. This is a decision as to who benefits and who pays and by how much, but it does not affect the total benefits or costs, which remain unchanged. In cases where beneficiaries do not pay and a public agency meets the expenses of a project and compensates any losers, the budgetary costs to the agency are augmented. Such increases may result in the project becoming less appealing to the agency, as it imposes more heavily on their budget. Consequently, the bureaucratic organization itself may become resistant to proposals which, though economically and socially viable, require for distributional reasons larger amounts of

public resources. On the other hand, inefficient projects with significant uncompensated losers may appear attractive. The size and pattern of gains and losses, and whether compensation is to be paid or not, greatly effect the support a project will receive at a variety of levels of the decision-making hierarchy.

3.8 Impact Analysis as an Evaluation Method

When faced with the prospect of a major development or policy change, the question immediately arising is, "What are the consequences?" This question is important both to developers or planners and to residents of the communities or the parties effected. Each party and indeed perhaps each individual is concerned about somewhat different aspects, but all are concerned about how the project will affect the achievement of their goals and objectives. Because of the inherently fundamental nature of concern for the consequences of developments, impact analysis has in some form or another always been with us. For example, in B/CA discussed above with focus on the economic merits of alternative projects or programs, attention was also given to the incidence of benefits and costs on different individuals or groups. An examination of who benefits and who pays is in essence impact analysis. A case in point comes from the B/CA of a local highway study, where the incidence of regional benefits and costs differed markedly from the state-wide benefits and costs, that is, the economic impacts were different. This point illustrates the relationship that exists between "evaluation" and "impact analysis."

Impact analysis, however, has recently emerged as a relatively structured and popular mechanism for transportation planning. The major formal impetus for this has been the requirement, in the United States under the National Environmental Policy Act of **1969,** for environmental impact assessments of major developments. As a result of that legislation, impact statements now abound and literature on the technique and procedure for the preparation of impact statements proliferates.   More basic, however, is the underlying pressure leading to the enactment of such legislation or the acceptance of comprehensive impact analysis in the decision-making process, even in the absence of legal requirements. Whether this is due to increased affluence, changing attitudes, different conditions, greater magnitude of new developments, or other reasons, is not of vital concern here, but rather that whatever the reasons, it is now recognized that all parties should be informed of the full impacts stemming from a development and thereby be better able to participate in the decision-making process. Basically, it appears that public dissatisfaction with the results of the planning process in which the affected public often had limited information and voice has led to the development of more open and comprehensive planning procedures in which there is greater public participation. In addition to improving public participation, impact analysis is one of the tools available to assist planners and policy makers in taking positive action in directing anticipated developments rather than reacting to unexpected change.

This chapter proceeds to review and assess the techniques and application of impact analysis. What impact analysis encompasses is first outlined. Following that, the three basic areas of impact analysis are introduced and the major approaches and methods

utilized in each, the questions most applicable to transportation are outlined. **An** assessment is then made of impact analysis as it has been implemented and of its inherent limitations. Finally, an illustration of an economic impact analysis of a policy transportation issue is presented.

3.8.1 *The Definition of Impact Analysis*

Impact analysis is a structured and comprehensive effort to identify and indicate the consequences of a specific action or policy. Basically this amounts to answering

(1)	what impacts occur,
(2)	where are the impacts felt,
(3)	who is affected,
(4)	when the impacts occur
(5)	how large is the impact, and perhaps
(6)	how might the impact be mitigated?

Thus, in the case of a proposed highway, efforts would be made to determine how much traffic the road would handle, who road users are, are new employment opportunities created, are the employment impacts temporary (as in the case of construction), or of a longer-term nature, what traffk is diverted from other roads and what is the impact on businesses there, will homes or farms be displaced or subjected to noise and pollution, and a host of other possible questions.

Impact analysis can, and probably should, involve two stages – measurement of the impacts and evaluation of their significance. Measurement relates to each of the items noted above and in an attempt to specify the size, extent and timing of the outcomes, evaluation in this context is concerned with determining the significance of the specific impacts once measured, not an evaluation of the proposal based on the consideration of all impacts.

Measurement, while not always easy, can normally be accomplished in some reasonable fashion. In some cases monetary measures of the effect may be easily established; in others a physical measure such as increased traffk volume may be available, other impacts may be quantifiable but cannot be added (e.g., one historical or archaeological site destroyed), and still other impacts (modification or less of a scenic view) can only be identified or, at best, measured in qualitative terms.

In evaluation, it must be established whether the measured impacts are significant and if *so,* how significant. That is, if pollution of a particular level will occur, how serious a concern is it? **An** initial indication to the analyst of the likely importance **of** an impact may come from a comparison of projected impacts with well-established and defined standards or generally accepted or experienced norms. While this can serve as an indicator, the analysis should relate the impact to the expectations and preferences of the effected groups. For example, environmental quality may be of major importance in one

locale, while of limited importance in another. If preferences do vary, local variations have to be identified and the criteria suitably modified if the preferences of those affected are believed to matter and are to be heeded. It must be recognized, however, that many groups are affected by a project's impacts (including those, such as a government or government department, who propose the project), and their interests and preferences may vary widely. Consequently, impacts which are important for one group may not be considered important by another, yet all need to be identified and measured. Furthermore, divergent preferences can lead to conflicts among the objectives from which the project developed. The place of impact analysis is to identify and spell out all these consequences for all parties.

On an impact by impact basis, the measurement of impacts need not introduce any problem as criteria for the significance of the impact are likely defined or definable in the same units. A major difficulty in evaluation arises when one seeks to compare impacts measured in different ways when they cannot be expressed in commensurable units. Will the reduction in travel time on a new roadway, for example, compensate for the loss of a local park? While the measurement of impacts in comparable units is desirable in that it facilitates cross-category comparison and overall evaluation, this is not the prime focus of impact analysis. Impact analysis is designed to provide information on the effects of a proposal. Decision-makers may assign these impacts different weights depending on how they perceive their relative importance. Impact analysis is to identify the measure relevant impacts for decision-makers to consider, not to attempt to assess or evaluate the project on the sum of those impacts.

3.8.2 *The Scope and Technique of Impact Analysis*

This section reviews the three major areas normally encompassed by impact studies – social, environmental and economic impacts. The role of economics, the analysis of social and environmental impacts is subjected to a somewhat more cursory survey than economic impact assessment. In each of the three areas, however, the scope and purpose of the analysis is outlined and some of the major techniques identified.

Social Impact Analysis. Social impact assessments are undertaken to establish the direct and indirect effects of a project on the character and quality of a community. Although the nature of social concerns is widely understood and their significance appreciated, it is generally difficult to identify and document specifically potential social impacts. Social impact analysis is hampered by a variety of factors. One of the most basic is the ability to define with precision the community affected. Efforts to define community boundaries (even in rural areas) generally indicate a rather nebulous fiinge, confused by much merging and overlap. Communities are bonded by some sense of belonging. Even if a community is defined in some physical sense, it is difficult to establish what the ties are which make it a cohesive unit. The links are often attitudes, values and beliefs which are themselves not easily identified or measured, and only indirectly reflected in the patterns of physical interactions. Yet if social impact analysis is to be successful, it is essential to define the community and determine the ties which link it as a unit. It is only with those

insights that the effect of a particular proposal might be realized. Even then, however, it is difficult to establish how a proposed project might impact an area. While one might determine that certain ties would be severed (at least initially), the associations may be strong enough to reunite to continue through other linkages or to establish new but equally viable unions within modified boundaries. The difficulties of undertaking and predicting human relations make social impact analysis one of the more inexact but important and challenging areas of impact analysis.

The kinds of social impacts which may result from transportation developments are numerous and can be categorized in a variety of ways. Commonly included in such listings are: disruption of community aesthetics, cultural and institutional (political, religious) values and relationships disturbed, intra-community mobility and access to services affected, homes and businesses relocated, changes in accessibility modify service area and business and employment opportunities, demographic patterns shifted, and health and safety threatened. Most often, social impact assessments have focused on the effects of major highway developments in metropolitan areas, and consequently the scope and methodology is tuned to that environment. To some extent it is necessary to abstract from that situation to assess social impact analysis in a regional or state planning framework. Yet the connection is quite close, differing more in detail than concept. The major difference stems from the fact that in the regional or area-wide context, transportation developments are seen **as** chiefly affecting the linkages among communities, while in the metropolitan situation a major concern is the effect of a highway splitting a community. But after allowing for that difference (which may be no more than one of emphasis), the concerns are quite similar and can be discussed in the following framework.

(a)   Impact on immediate neighborhood and community relations. In this class of social impacts, one considers what might be called the neighborhood effects of a transportation development. Included here are its impacts on the aesthetics of the area. Can the development be blended into the local environment? Another factor is whether and what homes and businesses would need to be relocated – how many, what value, at what cost? Will the new facility change the patterns of movement through the community and what affect will this have upon community organizations, business patterns, and social relations? Existing movements can be mapped and interaction indices measured to identify communities, neighborhoods and traffic flows; different groups can be studies and negative (and positive) impact indices developed; but still it is difficult to make the connection between how these will be modified and the final social consequences. For example, what differences in social impacts occur if a major highway loops the small city or cuts through it?

(b)   Accessibility impacts. These kinds of impacts are seen **as** those which result from the transportation change modifying the accessibility among communities. **As** with the intra-community analysis, it is useful to have trip mappings by purpose for the service area and perhaps employ models of traffic flow in the more

complicated situations. From this, one may identify who is most likely to be affected (their socio-economic class and geographic location), the purpose of their trips, the means by which they travel, and the time they travel. By answering who, why, how and when, much of the basic information is available from which to predict the social effects. In many cases, improved accessibility may significantly modify the pattern of regional growth. Improved accessibility to one community can imply improved accessibility from another and, while the business and social area served by one may expand, another may contract with much different social outcomes. In either case, many of the same concerns noted in (a) will also be expressed by members of the individual communities – what will be the effects on social organizations, businesses, population structure, etc. – in regard to the impacts which the transportation change brings from outside.

(c)   Impact on lifestyle. The effects of lifestyle are to a large extent the sum of, or the consequence of, the changes at the community level. This is because those changes in large part determine the opportunities available to the individual but also exert certain social and economic pressures on him to behave in a particular way. To a large extent, the analysis of impact on lifestyle appears not so much to add new information, but rather to translate the information on community impact to the individual level. Basically, this seems a means of better extending the information to those affected so they more fully appreciate the effect which changes in public and private services, employment opportunities, environmental quality, etc., mean to them.

In order to derive the various social impacts, a number of activities must be undertaken. First, familiarity with the community is required. Since personal familiarity is not feasible for analysts in many instances, a community profile must be created to acquaint **them** with the problem area. Secondly, alternative proposals must be related to the community and potential effects identified. Thirdly, community participation is essential **in** order that the analysts become sensitive to local preferences and values, in part **from** their reaction to the alternatives before them. Finally, it is necessary to predict impacts based on known cause-and-effect relationships applied to the specific situation. If the analyst can successfully accomplish these activities, his outline of potential social impacts can play an important role in planning transportation developments and in successfully integrating that planning with public participation.

Environmental Impact Analysis. Environmental impact analysis aims to establish the effect upon an area's environmental quality of a proposed action. The environmental issues commonly examined in environmental impact studies are air, water, the ecosystem, noise, and environmental design. As the literature on these topics is extensive, this review of necessary must be cursory.

(a)   Air quality. Evidence of inferior air quality is commonly taken **as** the amount of hydrocarbons (HC), carbon monoxide (COO, nitrogen oxides (NO_x), sulfur oxides (SO,), and particulates (the primary pollutants) in the air. Also important are the

secondary photochemical pollutants such as NO_2 and ozone associated with smog. Transportation, gasoline powered motor vehicles particularly, is a major source of CO (**64** percent), HC (52 percent), and NO, (**39** percent) emissions to the air, the latter two being important contributors to photochemical smog.

The presence of these pollutants in sufficient and fairly well recognized quantities can damage human health, animal and plant life, and physical structures and equipment. Consequently, efforts have been made to limit the emission of these pollutants to the atmosphere. Efforts have also been made to predict the impact which various transportation developments might have on local air quality. While it is easier to predict the impact of stationary pollution sources, a number of models have been developed to estimate the magnitude and dispersion of emission from vehicle traffic, both at the regional and local levels.

(b)   Water. Transportation projects can have significant effects on the aquatic environment in both a quantitative and qualitative sense. Major transportation facilities often modify the amount, direction and speed of surface flows, and subsequently ground water recharge. Water quality may suffer due to wastes and residuals contaminating surface and ground water supplies. Contaminants may come from a variety of sources – solids from erosion (particularly with construction), nutrients and bacteria from waste discharges, chemicals from salt and pesticides. The impacts of alternative undertakings on surface water quality are frequently well understood and can be estimated reasonably well. The effects on ground water, however, are not as well known and subject to much cruder estimation. Often more difficult to assess are the subsequent effects of changes in water quantity and quality upon aquatic ecosystems. There the relationships are even more difficult to establish. Still, the protection of important and unique aquatic systems is a prime concern.

(c)   Ecosystems. **An** ecosystem is a biotic community and its abiotic environment. It is readily recognized that transportation and other large developments can impose substantial and rapid changes in an ecosystem, often needlessly and unintentionally. The purpose of ecosystem-oriented impact assessments is to avoid such losses by recognizing the affected ecology as a system *so* **as** to predict and evaluate the ecological consequences of a development. It is then an effort to improve planning by merging the physical aspect of the engineering effort with the possible ramifications on the surrounding ecology. **As** any activity harms the ecological system in some way, the problem is to identify those effects which are important. Endangered elements may be valuable to agriculture or other economic activity, recreation, or for scientific or aesthetic reasons. To determine the potential value, however, necessitates knowing what organisms are present, their role in the ecological system, the potential effect of a development upon them, and the subsequent impacts on man; obviously a complex task.

(d)   Noise. Noise, or unwanted sound, is one of the most generally recognized and most seriously undesired products of transportation. It is most frequently a nuisance for those in proximity of heavily trafficked roadways and airports. While high noise levels (typically in the work place) can cause loss of hearing, the effect of traffic noise on health is more subtle, through the disruption of sleep. The effect of noise depends upon its loudness, harshness and variation. Measures of noise are available which account for the nature of the sound and noise indices have been developed which account for the annoyance associated with a particular noise. Given the measurability and predictability of noise levels, standards and recommended maximum levels for exposure to noise are common. Mortgage companies sometimes will not lend money for homes to be in areas with high noise levels. Other noise sensitive land uses or activities can also be readily identified in the planning process. Assessing the impacts of traffic noise is, as a result, rather straightforward.

(e)   Environmental design. Environmental design refers to the physical form and use of the natural and manmade environment. The concern **of** environmental design includes not only the physical structure of the natural and manmade forms and spaces of an area and the effect upon them of a development, but also their quality, use and aesthetic, cultural and historical archaeological values. The purpose of studying these kinds of impacts is to identify important environmental design features and assess their compatibility with the proposed development, not only because a project may directly affect the physical features, but because it may induce further development which conflicts with significant existing uses. Environmental design features are hard to measure and assess. Their importance often depends upon individual community preferences and values, and therefore is closely linked to social considerations. Consequently, public participation often plays an essential role in identifying issues and in selecting the most pleasing or satisfactory alternatives.

Economic Impact Analysis. This aspect of impact analysis is concerned with revealing the effects of potential developments upon the economic life of an area. The major focus is the effect a development can be expected to have on the level and pattern of economic activity, i.e., employment, incomes and business opportunities. This is primarily, but not totally, concerned with the impacts upon the private sector of the economy. However, since major developments can also have substantial effects on the demand for public services and local tax bases, the fiscal impact on the affected governments is also a relevant consideration. As many impacts stem from induced developments, only evolve over time, and are often remote from the area of the initial stimulating project, impact analysis must have a broad scope. This comprehensive view is particularly important in assessments of the impacts of developments believed to significantly affect a regional transportation system. As the perspective of this study is at a regional transportation planning level, this survey primarily considers those approaches and techniques of impact analysis suited to broad, systems-oriented assessments.

This analysis concentrates on the economic impact to non-users of a facility. This is not to deny that the impacts to users are important, indeed they are likely to be of prime importance, but they are usually more obvious and generally recognized. Despite this, an impact assessment should include an analysis of the effects on users, e.g., reduced travel time, lower cost, larger numbers accommodated, etc. Recognizing this, the following focuses on the assessment of the broader impacts which are often more difficult to determine and hence more often neglected.

(a)   Level and pattern of economic activity. The impacts of major developments typically occur in two distinct phases – a short run, chiefly characterized by construction, and a long run, in which a series of induced developments or changes emerge largely attributable to the initial undertaking. Impact analysis examines both. The long run assessment is generally the more difficult to establish, as the connections leading to subsequent developments are less clearly defined and understood and *so* are less predictable. Furthermore, longer-range impacts depend on a web of interrelations which generally call for more complicated assessment techniques. In the following, short run impact analysis is briefly reviewed and then techniques for longer-term assessments are reviewed.

Short run economic impacts. The short run impacts of transportation developments on a local economy are usually closely tied to construction. Two major effects can be noted – first, the increase in area economic activity due to the extra demands for materials and labor, and second, possible losses to business due to the disruption (e.g., reduced access usually) caused by construction.

Increased business activity arises fiom direct expenditures for the labor and materials required by the project (first round effects) and also from subsequent ("second" round) expenditures made in the area (i.e., the re-spending) by those earning incomes from the direct outlays. Estimating the additional direct expenditures may be quite straightforward based on the nature of the requirements, local and alternative supplies, and experience from the similar projects. Once the share of the total outlay that **is** likely to be made in the region is established, the total regional impact may be estimated by use of a regional multiplier. Thus, for example,

$$
\boxed{\begin{array}{c}\text{Total}\\\text{Regional Impact}\end{array}} = \boxed{\begin{array}{c}\text{Total project}\\\text{direct outlays}\end{array}} \ \text{X} \ \boxed{\begin{array}{c}\text{Portion of total}\\\text{outlay accruing}\\\text{to region}\end{array}} \ \text{X} \ \boxed{\begin{array}{c}\text{Regional}\\\text{Multiplier}\end{array}}
$$

The regional multiplier is commonly estimated **as** the ratio of total to basic employment or income in the area. Basic income or employment is usually defined as that involved in the production of goods and services for export fiom the region. The non-basic

component of the total is that sector producing for local consumption. Regional impacts are then often estimated as:

$$\boxed{\begin{array}{c}100\,\text{jobs}\\ \text{on project}\end{array}} \quad \mathbf{X} \quad \boxed{\text{local } \mathbf{persons}} \quad \boxed{\dfrac{\textbf{20,000 total local employment}}{\textbf{10,00 employed in basic industry}}} \quad = \quad \boxed{\textbf{regional impact}}$$

Unfortunately each procedure often leads to an erroneous impression of the impact of the particular project. The inference often drawn and sometimes intended to be made from such calculations is that 160 area jobs are attributable to the project. In fact, such is not the case. This would only be *so* if the **80** local persons employed on the project would not be employed locally otherwise. This is unlikely to be the case. Rather, most of all of these people may have been employed on another project deferred because of the demands on local resources of this and other undertakings. The with and without comparison that should be reflected in the impact analysis is often distorted because of unrealistic assumptions. One really wants to know, "What is the net increase in local employment or incomes due to the project?" The number of construction workers resident in the area and employed locally may not change substantially, although the projects they work on may differ depending on whether this project is undertaken or not. On the other hand, the above calculation fails to consider that workers temporarily located in an area because of the project have any impact on the local economy. They usually will affect local economic activity, although much less *so* than permanent residents since they often support homes and families elsewhere.

Another problem with these estimates is that often the value of regional multiplier used is biased, typically too large. In many cases the multiplier is one used is quite aggregate and may not be appropriate to the particular area. Even if calculated from total and basic industry employment or incomes of the area, there is a good chance that the value is inappropriate, particularly for measuring the impact of construction projects. The reason for this is that multipliers reflect the re-spending of relatively stable incomes. **A** large construction project may lead to a sharp temporary increase in local income. Some may go to non-residents temporarily attracted to the area by jobs and who spend relatively little locally. Even some local residents may see the incomes generated by the project **as** a temporary windfall and therefore tend to save an abnormally large part of the increase. Both factors tend to reduce the value of the multiplier. In addition, the multiplier appropriate to smaller centers or economic areas is often two and even less, and not the commonly used values of two and one-half (or sometimes even three). This is because residents of smaller centers commonly spend a substantial portion of their income in major commercial centers often some distance from their homes.

For these reasons, the local economic impacts of large-scale construction projects are often overestimated. Care must be taken to assure estimates of economic impact are based on reasonable assumptions. For illustration, large-scale electrical generating

developments in rural areas of Wisconsin were estimated to increase local economic activity of neighboring centers by less than one percent except in the smallest and closest village." In addition, it must be remembered that the number of jobs in operation of facilities is often quite small relative to construction employment, and therefore the project can be expected to have an even smaller impact in the long run.

The second impact of construction is the disruption often caused to businesses neighboring the project to which access is impeded. Some may be temporarily inconvenienced by reduced access as a result of the construction and may suffer some loss of business because of that. Other businesses and residences may be displaced by the project, either because the site is required or because their location, while not used by the project, is left unsuitable for their purposes. The issue in those cases is if these businesses or households will relocate in the area, the suitability of the new site, and the sum of these effects on the volume of business of those and associated enterprises. While these impacts are probably greater during the construction phase, their full effects carry beyond that stage to have a continuing and sometimes permanent effect on local economic activity and therefore must also be considered in that light. The effects are often estimated as the loss in business income directly attributable to the project augmented by the multiplier now working in reverse, *so* to speak. The same reservations apply to the application of the multipliers as were noted above in discussing the determination of positive effects.

Long run economic impacts. Examination of the longer-term effects of transportation developments could be divided into three parts. One considers the long-range consequences of the relocation directly or indirectly resulting from the project being built. Another is to determine the first-round changes in the demand for the products of area businesses or residences in the area because of changes induced by the development. The third aspect to be examined is the full impact (including multiplier effects) of subsequent events on the local economy. Each of these are addressed in turn.

Construction of a facility, particularly a transportation facility, requires land. The result, especially in urban areas, is that users of the needed land are displaced or their use is disrupted and constrained. Furthermore, while some neighboring properties may find the transportation project enhances their property to them, others may find that due to noise, vibration, restricted access or rising rents that their location becomes less suitable for their purposes and they choose to vacate the site. Businesses have the options of relocating within the area, relocating outside the area, closing down, and in the neighboring properties, staying but suffering the dissatisfaction and economic setbacks arising from an unsuitable site. Households, of course, do not have the option of closing down when they are affected. The concern here is primarily for the reduction in the level of regional economic activity due to the lower profits, the closings and the relocation of businesses and relocation of households beyond the study area. These impacts are also

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[11] Melville McMillan, A Power Plant in Your Community? (Madison, WI: College of Agriculture and Life Sciences, University of Wisconsin, Report G2666), 1975.

important sociological concerns as they disturb the local social structure. In addition, they may be tied to environmental impacts as noise, etc., distract from the local amenities.

The loss in local economic activity depends to a large extent upon the number of firms displaced or relocating outside the boundaries of the economic area or, as a surprisingly large portion do (often **20** to 40 percent), closing down entirely. The option selected depends largely on the size and profitability of the operation and the age of the proprietor. Often not considered, however, in estimating the effects of these changes on employment and incomes, is the extent to which other businesses in the area expand to absorb the businesses left by those vacating. Also, the possible units that some might have closed or relocated even without being displaced. Unlike firms, households may move to another neighborhood but are less likely to relocate outside the economic area unless very narrowly defined. In both the case of households and firms, investigation of who is likely to relocate and where has the advantage of not only facilitating the determination of economic impacts, but also of revealing distributional considerations by identifying who it is that are most directly affected. In the decision-making process, relocation policy objectives (planning phase) may result in one plan being favored over others even though it is less economically efficient.

The second aspect of the analysis of the longer-term economic impacts of transportation developments is to determine the first-round impacts induced by the project. The initial effect of an improvement in a transportation system may be to reduce transport costs to current users. The immediate effect is to improve the profits or well being of the users which may be quite significant in itself. That improvement may be temporary, however, as competition may emerge to take advantage of the lower cost location. This brings up the more typical question as to the type of development that may arise. For example, if accessibility to a region is improved by new or upgraded highway links, what new manufacturing plants will locate there that would not have located there otherwise, how many persons will they employ, and at what wage level? Questions such as these might be asked about new developments and expansion of existing enterprises for a wide range of business activities – manufacturing and industry, commercial enterprises, the service sector, agriculture, and other natural resource related activities. In each case the answers are difficult to reach with a high degree of confidence. The factors affecting business location and expansion are not easily defined, ranked or measured, nor translated to specific effects. *An* indication of the most probable effects may be obtained from economic base studies. The major sectors of the area exporting goods and services to other regions are identified, their viability evaluated, and the possible impact of the development on the scale of such activities assessed. Shift-share analysis provides a somewhat more general approach based on national or state industry growth rates and assumptions about a region's ability to maintain or increase its share of the overall growth. However, even considerable study on an industry-by-industry basis of the relative location advantages may not enable an accurate estimate of the amount or timing of new or expanded business development.

Highway developments often have rather direct effects on agriculture. The path of the highway itself may divide and isolate individual operations (increasing their costs) while improving access and reducing transport costs to the agricultural area as a whole. Better accessibility may cause some modification of crops grown and livestock produced which can lead to the emergence of new processing and service industries. But in addition, improved access may also stimulate the conversion of land from rural to urban uses, as commuting to the workplace or recreational areas from a greater distance becomes feasible. Insights to such effects can, in some cases, be derived from land use simulation models. Such models are costly, complex, and generally not suited for non-metropolitan situations, although they can offer insights as to the impacts in some parts of the larger regions.

When projecting the impact of a project, attention should be paid to the possible adverse reactions of present residents. Some communities may not consider the influx of second-home developments or a manufacturing plant a blessing. In fact, if local authorities feel this way, they may take active steps (e.g., zoning, stringent by-laws and codes, etc.) to discourage "development" and *so* thwart the intentions of planners and their predictions. Either projects should be chosen with greater care to suit local preferences, or measures adopted to appease local interests.

The third aspect of economic impact analysis is to establish the total effects upon the local or regional economy of the direct and indirect first-round changes resulting from the proposed development. There are several ways to approach this problem and they vary considerably in their complexity and requirements. Input-output studies are the more detailed but most difficult to undertake. Economic base analysis is popular because of its relative simplicity and adaptability to a variety of circumstances. Regional income accounting complements the economic base approach.

Input-output analysis defines the interrelationships among the many sectors of the economy and provides the mechanism by which to trace transactions throughout the system. If output of a particular sector is projected to increase by $X, the impact which this will have upon the output of all other sectors can be established. The information available in input-output tables enables calculation of output, income and employment multipliers. Since input-output analysis takes account of all the interactions in considerable detail, the full impacts of changes can be established and the distribution of those changes throughout the economic system identified. The problems with input-output techniques, however, are several. The construction of detailed input-output tables is a huge task requiring large amounts of data, and are usually only undertaken at national and state levels. Input-output tables for smaller regions can be made for smaller areas but are usually much simpler (i.e., few sectors more broadly defined) and rely upon coefficients from state and national tables. **As** a result, these tables need not accurately describe the local economy which can deviate significantly from overall averages and fail to provide the detail desired. Therefore, input-output analysis is usually only used when major developments affecting large regions are considered. In some cases, however, the problem of developing small input-output models is bypassed as they are occasionally

developed as academic exercises and can be adapted to a specific problem without excessive effort. Even from relatively unsophisticated models, the benefit to be derived from the technique in understanding and predicting the interactions among the sectors of the economy (the multiplier effects) can be substantial. Yet the full effect of any change depends upon the initial change in the final demand for certain sectors which stimulate the subsequent changes which reverberate throughout the system as described by the input-output model. Errors made in predicting the initial impacts cannot be compensated by a more sophisticated approach to the multiplier process. Good predictions require good estimates of the initial impacts on final demand and accurate estimation of the secondary or multiplier effects. Study resources must be allocated between these two to assure comparable reliability of both steps.

Export or economic base analysis offers a less sophisticated and generally less accurate means of estimating multiplier effects. **As** already noted, export base is grounded on the notion that local economic activity depends upon the amount exported from the region. While this has a certain common sense appeal, the basis of the concept begins to collapse **as** one considers larger and larger regions. Some areas support a high level of economic activity with relatively little exporting. Yet for small areas the economic base analysis does offer a popular, if not precise, prediction tool. Regional multipliers can be calculated from the ratio of total regional employment (or income) to the employment (or income) in basic activities. The problem is to define the basic activities. There is no unambiguous distinction in most cases. Furthermore, the multiplier *so* determined is based on the current situation but the growth expected **of** the economy may modify that ratio **as** opportunities emerge for new types of business and employment.

Regional income accounting is to a large extent of descriptive value more so than useful for prediction. It shows the pattern of final outputs on one hand and the pattern of incomes earned in producing that output on the other. The two must balance. Regional accounts are valuable in that they depict the situation and that input can be useful in determining the export base of an area. Like export base analysis, regional accounts can be established with varying degrees of detail for a wide range of study areas.

3.8.3 Input-Output Methodology

I/O data is compiled at the national level for the United States every five years through a 'survey', resulting in highly disaggregated tables encompassing approximately **500** industrial sectors. There are also less disaggregated tables with **85** and **365** sectors. The data are published with a lag of some several years. The latest data, based on **1982** surveys were published in **1992** by the Bureau of Economic Analysis of the United States Department of Commerce. In addition there are non-survey updates with less detailed extrapolations published periodically by the same office, using the last complete table **as** a benchmark, and generating tables encompassing about **80** economic sectors. Data are available for **1972, 1977** and **1982.**

3.8.3.1 Description

In input-output analysis, the economy is divided into sectors or industries and the flow of goods and services among sectors is registered to indicate the systematic relations between them. Input-output models incorporate detailed information about interindustry transactions, purchases by final consumers (final use), and applied technology. Each industry sells its output to other industries and final consumers and in turn purchases goods and services from other industries and primary factors of production (such as capital and labor). This information is presented in a transactions table, which details the purchases and sales among industries. The one below provides an example. In this transactions table agriculture and manufacturing are the only industries considered and labor is the only primary input.

Industries	Inputs to Agriculture	Inputs to Manufacturing	Final Demands	Total Outputs
Agriculture	25	175	50	250
Manufacturing	40	20	60	120
Labor Services	10	40	0	50

The elements of the table are inputs for production. A row shows what inputs an industry produces for use by industries and consumers on the columns. For example, in the above table, the agriculture industry produces 175 units used by the manufacturing industry and 50 units to satisfy final demands. For now, assume that the units are the same for the elements in each row. In the agriculture row, the units could be bushels of wheat. In the manufacturing row the units could be tons of steel. The inputs produced by and used by industries constitute the bulk of the transactions table. An additional column documents the amount of production for final use (consumption). Similarly, in addition to using outputs from other industries in production, an industry also needs primary inputs such as labor. The amount of labor used by industry is indicated in a row along the bottom of the transactions table. It is assumed in the above table that no labor is used for final use.

If entries of the transactions table were expressed in dollars, the column totals would indicate the cost of production and the row totals would indicate total revenue. Only when units are consistent among row entries can columns be summed. Therefore 25 bushels of wheat cannot be readily added to 40 tons of steel and 10 man-years of labor to calculate the total inputs of agriculture. If the values are all expressed in dollar values, then column entries can be added to get a dollar amount of total input. Notice that the total inputs of an industry include purchases of inputs from other industries and primary factors such as capital and labor. Total output of an industry will therefore include output used by intermediary production (in other industries) and output used for final use.

Besides detailing interindustry transactions, the transactions table describes relationships between industries and the technology of an industry. The column of the transaction table describes precisely one point on the production function of the corresponding industry. The column indicates what combination of inputs that industry uses for its

specified output. In this way the transaction table provides an indication of the technology of production of the industry considered in aggregate. The production functions of the industries are needed to determine what production possibilities are available to society. The transactions table provides a production function for each industry since each column tells what inputs (from different industries) are needed to produce a given output of the corresponding industry. **A** change in technology will therefore result in a change in the transaction table. If technology changes, one can expect the amount and mix of inputs necessary to produce a given amount of output to change.

3.8.3.2 Assumptions of Input-Output Analysis

Use of input-output analysis is conditional on certain assumptions - one of which regards technology. Without these assumptions the coefficients in the tables cannot be thought of as requirements and as requirements of specific inputs. Input-output analysis assumes that industrial output is homogeneous, which means that an industry produces only one commodity. Not only does input-output analysis assume that an industry produces one product, but the table provides no description of the quality of the product. Therefore, looking at transaction tables for two years, such **as 1940** and **1980,** one can read off the output of the motor vehicle industry, which will be in dollars. This gives no indication that cars in **1980** are much better products than cars in **1940.** This will make estimation of productivity advances difficult. The table only relates how the amount of inputs needed to produce a car have changed and not how the quality of cars have changed.

The second assumption is that the proportion of inputs to outputs is assumed to be linear. Each input into a particular sector is assumed to vary in direct proportion with that sector's output. This implies constant returns to scale in production. It is known that such strict proportionality characterizes only certain production processes. The usual assumption in economics is that inputs are substitutable *(so* that the unit cost of an output is a strictly concave function of the price of any one input). In addition, constant returns to scale cannot be accepted **as** an empirically valid condition of production in general. It follows that the expected error in calculations made using the information given in the transaction table, will be greater the larger the changes are in the relative prices or in the production function.

The third assumption is that there are generalized diminishing returns. To meet the requirements for convexity, a production process must have the characteristic that the weighted average of two possible input combinations have a greater output than either original combination. This can be shown for production processes by demonstrating that the technical rate of substitution, which measures the slope of an isoquant, diminishes **as** one travels out along the isoquant and that the production process does not have increasing returns to scale. The first condition is true because without substitutability, the isoquants are nested right-angled curves and the technical rate of substitution is zero. **As** mentioned, there are no increasing returns to scale. Since both conditions are true for production processes in the input-output framework the assumption of convexity is also true.

3.8.3.3 The Technology Matrix

From the transaction table, one can obtain the technology matrix. This is also referred to as the direct coefficient matrix. Elements of the technology matrix, called input or technical coefficients, are referred to by a_{ij}'s. One calculates the input coefficients by dividing the input used by industry j from industry i (the entry in a cell of the transaction table) by the total output of industry **j.** The total output of an industry j is referred to as X_j. Written **as** an equation:

$$a_{ij} = x_{ij}/x_j \qquad (1)$$

where x_{ij} are the original inputs from the transaction table. As in linear algebra, the subscript i refers to a row and the subscript **j** a column. To provide an example, a technology table is calculated from the transaction table given above. In this case, the output of the industry equals the input ($X_j = Xi$), *so* we divide the x_{ij} by X_i to get the input coefficients.

	Inputs to Agriculture	Inputs to Manufacturing	Final Demand	Total Output of Industry, X_i
Agriculture	0.1=25/250	1.46=175/1 20	50	**250**
Manufacturing	0.16=40/250	0.17=20/12 0	60	120
Labor Services	0.04=10/250	0.33=40/12 0		50

This table shows us that it takes **0.33** units of labor, 1.46 units of agriculture, and 0.17 units of manufacturing to produce one unit from manufacturing. Similarly, it takes at least 0.1 units of agriculture to produce one unit of agriculture. From this description of the meaning of input coefficients, it should be apparent that for the technology to be practical, the diagonal elements of the technology matrix must be less than one. Otherwise it takes more than one unit of input fiom that industry to produce one unit of output from the same industry.[12]

3.8.3.4 Determining Possible Final Consumption

Using the following equations, one can determine the possible final consumption given the input coefficients and output of each industry. These equations are simply manipulations of initial resource constraints and the linear equations describing how industries produce goods (provided by the technology matrix). Equation two states that the amount of agricultural product produced, X_1, minus the amount of inputs needed to produce X_1 ($a_{11}X_1$ and $a_{12}X_2$) is greater than or equal to the amount of agricultural products consumed in final use, C_1. Equation three has a similar interpretation for manufactured products. In equation four, a_{01} and a_{02} are the input coefficients of labor.

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[12] **This is one of two conditions, called the Hawkins-Simon conditions, which must be true for some bill of goods to be producible.**

They relate the amount of labor needed to produce one unit of output from the industries. X_0 is the total labor available.

$$(1-a_{11}) \cdot X_1 - a_{12} \cdot X_2 \geq C_1 \qquad (2)$$

$$-a_{12} \cdot X_1 + (1-a_{22}) \cdot X_2 \geq C_2 \qquad (3)$$

$$a_{01} \cdot X_1 + a_{02} \cdot X_2 \leq X_0 \qquad (4)$$

Equation four ensures that the industries do not use more labor than is available. Using these equations, one could calculate the outputs needed from industry to support a certain level of final demand. This can be done if the second of the Hawkins-Simon conditions holds.

Just as the first Hawkins-Simon condition stipulates that it not take more than one unit of input from an industry to make one unit of output, the second condition ensures that the direct and indirect inputs be less than the output of an industry. For example, in considering the inputs to make a unit of agricultural output, one should not only consider the 0.1 units of agriculture and the 0.16 units of manufacturing necessary (the direct inputs), but also the inputs necessary to make the 0.1 units of agriculture and 0.16 units of manufacturing (the indirect inputs). The indirect inputs constitute an endless (but decreasing amount) cycle of inputs. The second Hawkins-Simon condition assures that the total indirect and direct inputs for one unit of output be of less worth than that one unit of output, otherwise production would not be feasible. In other words, all commodities should be "self sustaining" directly and indirectly. What the condition means mathematically is that the determinant of the coefficients of the industries in equations two and three must be greater than zero.

$$\begin{vmatrix} 1-a_{11} & -a_{12} \\ -a_{21} & 1-a_{22} \end{vmatrix} > 0 \qquad (5)$$

If this condition is met, equations 2 and 3 can be solved simultaneously for the total agricultural and manufacturing production (X_1 and X_2) necessary to accommodate final demands (C_1 and C_2) given the production technology (a_{ij}'s). This solution is provided in the equations below.

$$X_1 = \frac{1-a_{22}}{(1-a_{11})(1-a_{22}) - a_{12}a_{21}} C_1 + \frac{a_{12}}{(1-a_{11})(1-a_{22}) - a_{12}a_{21}} C_2 \qquad (6)$$

$$X_2 = \frac{1-a_{21}}{(1-a_{11})(1-a_{22}) - a_{12}a_{21}} C_1 + \frac{1-a_{11}}{(1-a_{11})(1-a_{22}) - a_{12}a_{21}} C_2 \qquad (7)$$

The coefficients of these equations, referred to as A_{ij}, represent the total direct and indirect gross output of industry i needed to support one unit of final consumption of

industry j. Therefore $A_{11}C_1$ is the amount of agricultural production, X_1, needed to support agricultural consumption, C_1. Similarly, $A_{12}C_2$ is the amount of agricultural production, X_1 needed to support manufacturing consumption, C_2. The total amount of X_1 required is their sum (as already expressed in equation **6).** Equations **8** and 9 can be expressed **as:**

$$X_1 = A_{11} \cdot C_1 + A_{12} \cdot C_2 \qquad (8)$$
$$X_2 = A_{21} \cdot C_1 + A_{22} \cdot C_2 \qquad (9)$$

The A_{ij} have the mathematical meaning of being the result of inverting the matrix of the identity, **I,** minus the technology matrix, **a.** Expressed as an equation, the 'Leontief' inverse is

$$[A] = [I{-}a]^{-1}$$

3.8.3.5 Using Input-Output Analysis to Predict the Impact of an Investment

As mentioned, input-output analysis can relate the technologies of production (which provide the input coefficients) and the primary factors (such **as** labor, capital) to the amount of output that can be used to fulfill final demand. This involves an interpretation of the "Leontief Inverse." Input-output can also determine the amount of final demand possible given a technology and primary factors. If an investment changes the technology of production, then there will be a change in the input coefficients of the affected industries. Therefore one could calculate an increase in the consumption possibility schedule. Alternatively, a government may use it to determine the impact of an investment on the economy by introducing the goods and services required for the investment into the open system **as** a final demand and then calculating the total output requirements. This approach involves consideration of changes in value added (wage payments, depreciation, business taxes, interest and profit), termed "induced effects", which are discussed below.

Studies described by McLeod (1987) have used input-output analysis to predict the impact of an investment in such a way. These approaches use the Regional Input-Output Modeling System (RIMS 11), an input-output model developed by the Regional Economic Analysis Division of the Bureau of Economic Analysis at the Department of Commerce. RIMS II multipliers, like multipliers from other regional input-output models, are intended to show the economic impacts of initial changes in regional economic activity. A multiplier is a number which expresses the total effect relative to the direct effect. It is a shorthand way of summarizing the magnitude of the indirect and induced effects generated by a given change in the economy. The direct effects are the sales from the first round of spending of the investment (the final demand). The later rounds of spending necessitated by the original investment comprise the indirect effects. As

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economic activity takes place, workers and owners gain money. In input-output tables this comes under value added. They in turn will spend a portion of the money, creating yet more activity. "Economic activity" can be measured as gross output, earnings, or employment. This last effect is the induced effect. Therefore, multipliers express the total effect relative to the direct effect of a change in the economy. RIMS II multipliers show the effects on regional total gross output, earnings, and employment of changes in regional final demands for imports or exports, new investments, and government expenditures. RIMS II multipliers do not show the effects of changes in regional economic structure and do not indicate the existence or magnitude of any final substitution effects occurring within the regional economy as a whole. McLeod provides a description of how input-output analysis has been used in determining the impact of aviation related projects. The following paragraphs detail the approach taken by these studies.

3.8.3.6 An example of Input-Output Analysis

The objectives of ITS investment include the reduction in the cost of transportation and facilitate movement, accessibility, trade and development. Therefore, one can expect a transportation investment to reduce the transportation input coefficients of industries. To use an input-output model developed from data for a base period prior to altering the highway network, one must estimate the changes in the input coefficients. Suppose one begins with a new ITS investment reduced the price of goods B and C because less congestion lowers production costs. This reduction in prices will in turn reduce the cost of production for industries that use these goods. A new technological matrix can be fabricated taking into account the reduction in production costs. When the Leontief inversion is performed on this matrix, one obtains new coefficients which will indicate the cost of producing previous consumption. The difference between the before and after transportation costs of meeting the same final demand provides information on the magnitude of the effects of the transportation investment.

This simple example provides another illustration of the application of input-output analysis. The input-output technique has the ability to provide estimates of the net effects in a region; other techniques do not necessarily consider simultaneous increases and decreases in economic activity resulting from an investment. Also, input-output analysis can be used to simulate investments for evaluation. The use of input-output models makes it possible to consider economic effects of any transport mode in conjunction with other modes. An adequately defined structure permits analysis of the combined effects from investment in all modes on regional economic activity.

3.8.3.7 Issues Concerning the Use of Input-Output Analysis in Transportation

One drawback to the use of input-output analysis in transportation is the fact that non-common carrier transportation does not appear explicitly in national input-output tables. Many industries besides transport produce transport services for their own use (Bennathan and Johnson, **1990).** This is especially true for road freight transport and private passenger transport. For industries using non-common carrier transportation

services, input-output analysis will underestimate the amount of transportation used in production. Therefore, a transportation improvement (resulting from investment) which lowers transportation costs, may appear to have less bearing than it actually does. A second problem is how to measure the impact of transportation which does not reveal itself in changes in rates or flows of revenues. A third problem concerns the most effective mechanism of reflecting physical transportation changes on the pattern and costs of production either: through adjustment of transportation input coefficients, through adjustment of transportation output coefficients, through changes in the coefficient for an industry's purchases from itself - as in the case of savings which are not reflected in the flow of revenues - or by some more exogenous distribution process.

3.8.3.8 Technological Change in Input-Output Analysis and in Transportation.

The transaction table describes technology as well as the flow of goods. In this way input-output is a technology map for a snapshot of time. It describes how inputs are combined to produce output. The columns detail what combination of inputs from all industries and primary inputs are needed to produce one unit of the good in the corresponding column. In this sense, to add technological change, the mix of inputs needed to produce an output should be changed to reflect the new technology and its appropriate prices. Therefore, a technology change will require a change in the mix of inputs needed to produce one unit of a good.

Technological improvements in transportation can have a dual effect. A new technology can be expected to change the nature or lower the price of the outputs produced using it. Sectors may use more transportation in substituting away from now more relatively costly inputs, or may use less transportation with the same or greater outputs. The first effect would increase the use of transportation and decrease the use of other inputs, thereby increasing the input coefficient for transportation. For instance, if there were an improvement in the speed of trains, then one might expect many industries to start shipping more by rail and less by trucking. Assuming that the table were disaggregate enough to have rail and trucking as separate industries, one would expect the inputs from rail to increase for industries and the inputs from trucking to decrease.

Besides substituting among the modes of transportation, there may also be a tradeoff between transportation and other inputs to production. There are also positive externalities to a transportation investment. One might reason that by exposing purchasers to more consumers, transportation makes markets more competitive.

3.9 Cost Effectiveness Analysis

Cost effective analysis [CEA] is commonly used as an alternative to CBA. CEA seeks to maximize the extent of achievement of a given beneficial goal within a predetermined budget or, equivalently, to minimize the expenditure required to achieve a prespecified goal. Often, the goal will have been set under a separate process in which benefits and costs may have not been considered. In marked contrast to BCA, no attempt is made to place a monetary value on the beneficial goal. CEA are potentially useful when analysts

seek efficient policies but face constraints in undertaking a **CBA.** Three common constraints are: (i) the inability or unwillingness to monetize some impacts of the project [13]; (ii) when the effectiveness measure will not capture all of the social benefits **of** each alternative., and some of these other social benefits are difficult to monetize. When **CBA** is used all impacts must be monetized. If the **CEA** measures capture 'most' of the benefits, it may be reasonable for analysts to use **CEA** to avoid the effort of undertaking a **CBA;** (iii) when the project is linked to intermediate goods where the linkages to preferences are not clear. The latter constraint would seem appropriate for some transportation projects in which their contribution to the overall California transportation network is not clear but **CEA** may give useful information concerning the relative efficiency of alternatives.

CEA compares, usually 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.**[14] Though there is no conceptual reason why costs cannot be measured comprehensively, in practice analysts generally measure them narrowly **as** budgetary costs. Thus social costs are generally excluded yet in the case of ITS should not be.

If budgetary costs happen to equal opportunity costs *and* the effectiveness measure is the only impact for which people are willing to pay, *and* the scale of the alternatives being compared is the same, then the rankings of the alternatives by **CEA** and **CBA** will be identical. However, unlike **CEA, CBA** not only produces a ranking of alternatives but also reveals whether the highest ranked alternative actually increases efficiency. In effect **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. **CBA** addresses both questions of whether to undertake the project and **how.**[15]

In many situations, the effectiveness measure selected by analysts or decision-makers fir use in **CEA** does not correspond to social benefits **as** measured under **CBA** which are based on estimated of willingness-to-pay [WTP] of individuals. One can reasonably infer in most cases that individuals would demonstrate WTP for incremental units of 'effectiveness' such **as** lives saved or increased productivity or enjoyment. For example, the number of minutes saved on a given trip may not be an approximate measure of such benefits as increased productivity, lower costs or improved life style. While decision-makers or analysts cannot avoid making estimates of WTP in doing **CBA,** even when they must rely of shadow prices, they often do not make an explicit connection between WTP and the effectiveness measure used in **CEA.** To highlight this problem some have distinguished between intermediate outputs, greater number of vehicles processed at a toll

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[13] **CEA is used quite commonly when values must be placed on life in the evaluation of a project.**

[14] **Clearly, the development of performance measures is essential for the application of CEA to ITS.**

[15] **If all alternatives are mutually exclusive and the status quo is among the alternatives, sharing similar scale and patterns of costs and benefits, then CEA does select the most efficient policy.**

facility, where the value may not be clear, and final outputs, such as greater mobility or accessibility for which people are willing to pay more. Clearly, the effectiveness measure should be as close to the final output or product as possible.

Among the applications of **CEA** the majority do not include all social costs. **CEA** studies focus on budgetary costs not other social costs . In some cases it is not clear whether budgetary cots are related to marginal costs (the appropriate measure) or average or unit costs (which may differ markedly from marginal costs). When there are non-insignificant social costs and when alternatives have different opportunity cots **CEA** will differ from **CBA** and yield different rankings.

3.9.1 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.

$$CE_i = \frac{C_i}{E_i}$$

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:

$$EC_i = \frac{E_i}{C_i}$$

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.

Both of these CEA measures involve computing for each alternative the ratio of input to output. Thus, they are a measure of <u>technical efficiency</u> and might be interpreted in some cases as measures of productivity. As described below, differences in policy alternatives in the scale of projects, as well as the fact CEA often omits important social costs and benefits, make them poor measures of <u>allocative efficiency</u>.

3.9.2 *CEA when Projects Differ in Scale*

Ratios do not take into account differences in the scale of projects. Therefore care must be exercised in selecting policy alternatives on the basis of CE ratios. If, however, all the policy alternatives have the same cost, there is no scale difference. If all social costs and benefits are included in the calculations, then CEA does rank alternatives in terms allocative efficiency. Table 2 compares three alternative projects, one of which may be the status quo, for saving travel time. The only measured costs are budgetary costs and the effectiveness criteria is the number of minutes saved. In this case the CE ratio reveals the average cost per 000's of minutes saved; alternative C is the 'best' alternative. Computing the EC ratio confirms this. It does not matter whether the CE or EC ratio is calculated because all alternatives involve the same level of expenditure. It can be thought of as different ways of spending a *fixed* budget.

Table 2

Cost Effectiveness Analysis with Fixed Costs

Cost Effectiveness	Alternatives		
	A	B	*C*
Cost Measure (budget.cost)	$10M	$10M	$10M
Effectiveness Measure	**5**	10	15
CE Ratio (cost per 000 minutes saved)	$2.0M	**$1.0M**	$0.67M
EC Ratio **(000's** minutes saved per $1million)	**0.5**	1.0	1.5

Similarly, scale is not a problem if the level of effectiveness is constant across all alternatives. Situations in which the level of effectiveness is constant across alternatives, or is treated as constant, can be thought of as different ways of achieving a fixed effectiveness.

In the case of fixed effectiveness, CEA corresponds to a simple cost-minimization problem (minimize dollars) while in the fixed-budget case CEA corresponds to a simple effectiveness maximization measure (maximize minutes saved). By holding one

dimension constant there will be *dominated alternatives,* because by holding one dimension constant, the alternative with the best cost-effectiveness ration dominates on one dimension and is exactly the same in the other dimension. It is possible one alternative can dominate another even if they have neither the same cost nor the same effectiveness, as long as it is superior on both dimensions. Clearly, dominating alternatives should always be selected.

Scale differences among projects can lead to distortions in choice. This can be illustrated in Table **3.** It shows a choice between two mutually exclusive alternatives, A and B. If a cost-effectiveness ratio is used, alternative A dominates. Yet if we look more closely at alternative B, one can see it would save a large amount of travel time at a relatively low price.. It is therefore likely that a CBA would show alternative B to have larger net benefits. Given that CEA is used, how can it be used sensibly as a decision rule without monetizing or valuing time?

Table 3

The CE Ratio and Scale Differences

Cost and Effectiveness	Alternatives	
	A	B
Cost Measure (budget cost)	$1M	$1 00M
Effectiveness Measure (minutes saved)	4	200
CE Ratio **(cost** per time unit saved)	$250,000	$500,000
EC Ratio (minutes saved per $'s)	4.0	2.0

In order to make CEA more useful for decision making, decision-makers may sometimes specify a minimum acceptable level of effectiveness, establishing a floor, denoted by $\bar{E}$. There are two common ways to impose such a constraint.

First, one could select a project that meets the constraint at the lowest cost:

Minimize C_i
Subject to $E_i > \bar{E}$

Here the decision-maker has decided on a minimum level of effectiveness and selects the least costly alternative to achieve it. The implicit decision is that additional units of effectiveness are not valued. This may apply in some circumstances but not in most. Additional units of effectiveness above the standard will have some value albeit at a diminishing rate.

Second, the most cost-effective alternative that satisfies the effectiveness constraint could be selected:

Minimize CE,

Subject to $E, > \overline{E}$

This rule generally leads to higher levels of effectiveness and higher costs than the first rule.

It is also possible to specify the rule in terms of a maximum budgetary cost, designated as $\overline{C}$. **As** above there will be two decision rules for selecting the best project subject to a constraint. First, we could select the project that yields the largest number of units of effectiveness, subject to a budget constraint:

Maximize E_i

Subject to $C_i < \overline{C}$

The problem with this approach, of course, is that it ignores incremental cost savings. In other words, cost savings beyond the constraint, $\overline{C}$, are not valued or ignored.

The second decision rule is to select the alternative project that most cost-effectively meets the imposed budget constraint:

Minimize CE,

Subject to $C_i < \overline{C}$

This rule places some weight on incremental cost savings and is more likely t result in the selection of a project with less than the minimum cost.

3.9.3 Illustration of Different CEA Rules

As an example of the different CE rules consider ten mutually exclusive and exhaustive projects illustrated in Table **4.**

Table 4

Different Versions of Cost Effectiveness Analysis[16]

Projects	Minutes Saved (million)	Budget cost ($M)	CE Ratio (Cost per million minutes saved)	Budget Cost of projects that Save at Least 5	CE Ratio of projects that Save at Least 5	Minutes Saved of Projects that Cost No more	CE Ratio of projects that Cost no more

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[16] All figures in the table are for illustrative purposes only.

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| | | | | Million Minutes | Million Minutes | than $250M | than $250M |
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A	100	250	2.5	250	2.5	100	2.5
B	20	44	2.2	-	-	20	2.2
C	100	300	3.0	300	3.0	-	-
D	50	300	6.0	300	6.0	-	-
E	10	20	2.0	-	-	10	2.0
F	100	900	9.0	900	9.0	-	-
G	60	210	3.5	210	3.5	60	3.5
H	50	200	4.0	200	4.0	50	4.0
I	40	100	2.5	-	-	40	2.5
J	45	110	2.4	-	-	45	2.4

The expected number of minutes saved for each project are given in column 2, the expected budgetary cost in millions of dollars for each project is in column 3. The 'basic' cost effectiveness ratio appears in column 4. Using the standard **CE** formula, projects can be ranked from most-effective to least effective: project **E** is most cost-effective, followed by **B,J,I,A,C,G,H,D** and F. Dominated projects can be eliminated from the choice set at the outset to simplify the analysis: project **D** is eliminated since it is dominated by project **C,** and projects **C** and F can be eliminated because they are dominated by project **A.** The most cost-effective alternative is project **E.**

However, project E saves the smallest amount of time. Project **B** saves twice **as** much time and costs only $24M more. Which project can be considered better? This illustrates the problem of differences in scale. Looking at the table what would be best is to undertake 2.2 project **E's.** This would preferable to project **B** but is not feasible since the projects are mutually exclusive and exhaustive.

If we are willing to monetize the value people place on time, **as** in **CBA,** it is possible to determine which project is most allocatively efficient. If time is valued at more than $2.40, project **B** is preferred to project E. IF time is valued at $2.00 and $2.40, project **E** is preferred to project **B.** On the other hand if time is valued at less than $2.00, no project at all is preferred to project **E** or project **B.**

No consider the situation where a decision-maker specifies that they wish to save a minimum of 5 million minutes. The cheapest alternative is project **H** but the most cost effective acceptable alternative is project **A.** Which one to choose? Which is preferable? Note that project **A** costs $50 million more than project **H** but it saves 50 million extra minutes in travel time. The cost of this extra time saved is **only** $1.00 per minute, on average. Saving these additional minutes is more cost effective than even project **E,** but it is 25 percent more expensive than project **H.** The choice depends on the decision-maker's willingness to trade additional time saved for additional budgetary cost. Thus, even though **CEA** is touted **as** a way of avoiding monetizing some benefits, decision-

makers must often make trade-offs between costs and non-monetized benefits in order to make decisions.

A similar type of problem arises if a budget constraint is imposed. Now the decision-maker should select either the project that yields the greatest benefit subject to the cost constraint or the most cost-effective project that satisfies the cost-constraint. If a maximum budgetary cost of $250 million is specified, project **A** saves the most time, but project **E** is the most cost effective. To choose between projects **A** and **E,** the decision-maker must consider the trade-offs between additional time saved and additional budgetary costs.

3.9.3 *Technical versus Allocative Efficiency: Omitted Costs and Benefits*
CEA will almost invariably omit impacts that would be included in a more comprehensive **CBA. CEA** typically considers only one measure of effectiveness despite projects often having multiple benefits. On the cost side, **CEA** studies consider in most cases only budgetary costs. Relevant non-budgetary opportunity costs may be omitted. To obtain a better measure of allocative efficiency, these costs and benefits should be taken into consideration. One method of approximating this, obtaining a happy medium, between standard **CEA** and **CBA** is to compute the following ratio:

$$C\widetilde{E} = \frac{\text{social costs} - \text{other social costs}}{\text{\textit{effectiveness}}}$$

If the numerator can be fully valued and monetized, the adjusted **CE** ratio incorporates all or most impacts that would be included in **CBA.**

Most probably, however, **CEA** will be selected because some set of social costs and benefits could not be monetized. Clearly, the omission **of** a particular category of social cost or benefit from the numerator could well alter the ranking of alternatives. The danger of obtaining arbitrary ranking rises as alternatives become less similar in terms of the inputs they require and the outputs or impacts they produce. The transparency of **CEA** is also reduced because cost no longer has a simple interpretation (budgetary dollars) and the decision-maker must rely on the judgment of someone else about what social benefits and costs to include. It is for these reason that moving to a complete **CBA** with comprehensive sensitivity and **risk** analysis is often a better analytical strategy overall than expanding the scope of measured costs in **CEA.**

When id **CEA** closest to **CBA?** These two appraisal techniques are closest when budgetary costs approximate social costs, when the effectiveness measure includes most of the social benefits and, when alternative projects are of similar scale. When there are significant non-budgetary social costs or significant other categories of benefits, **CEA** is not close to **CBA.** When they are close, **CEA** may be less expensive and more transparent than **CBA.** When they are not *so* close, there are three options. First, undertake a full **CBA.** Second, move to a more qualitative evaluation method. Third, try to incorporate

significant non-budgetary social costs and other categories of benefits into cost effectiveness measures.

Chapter Four: Benefits and Costs of ITS Applications

4.1. Introduction

This chapter discusses benefits and costs of ITS applications. It defines the basic terms related to the identification of ITS benefits and costs in this chapter, categorizes general benefits and costs of ITS applications, introduces the measurements that can be used to quantify the benefits and costs, and finally discusses methods of valuing the benefits.

4.1.1. Definition of benefits

The ITS benefits are the positive effects of an ITS project. Both total and incremental benefits may be considered in a benefit-cost analysis. Total benefits are defined as the equivalent value which travelers expect to receive from using ITS services, as measured by willingness to pay. Incremental benefits, or net benefits, are changes in total benefits or consumer surplus. They are reduction in user and social costs, as well as increase in transportation network efficiency and other improvements resulting from the introduction of ITS applications. If the goal of benefit-cost analysis is to examine the desirability of different investments when they are considered in isolation, total benefits may be more appropriate. When the major purposes of benefit-cost analysis is to determine extra benefits brought by an transportation improvement to existing conditions (baseline), incremental benefits may be used.

The benefits of any ITS applications, either total or incremental benefits, can be classified into two main categories: direct benefits and indirect benefits. Direct benefits are effects or outputs that directly result from an ITS project. They can be measured by willingness to pay for the direct outputs of the project. Indirect benefits are growth in the value of production generated indirectly by the project. They are positive externalities and can be measured by willingness to pay for the indirect effects. ITS benefits can be allocated to three major beneficiaries: users, providers, and community/society including all other non-users (individuals and businesses) within the study area.

In transportation, user benefits are primarily related to safety and time savings. Major benefits of transportation service providers are associated with the efficiency and productivity of transportation network and operation. Social and community benefits are correlated with safety and environmental improvements due to reduction in vehicle emissions, traffic congestions, and social services.

4.1.2. Definition of costs

Costs are resources required to produce a particular quantity and quality of transportation service. In general, total costs should be considered in benefit cost analysis. When the purpose of the analysis is to determine the extra costs for producing additional level of transportation services or for generating extra benefits, or when the purpose is to compare the costs of "with" and "without" ITS services, incremental costs may be used. Incremental

costs are the net/extra costs required to produce additional units of output beyond some non-zero output level or to expend facility capacity beyond the baseline or existing facility. It is determined by summing the long-run or short-run marginal costs between the "before" and "after" (or "with" and "without") output levels.

Like benefits, costs can be classified into two categories: direct costs and indirect costs. Direct costs are inputs for producing the direct outputs. In general, direct costs refer to internal costs, either for transportation service providers or transportation users. To service providers, direct costs are all the payments which must be made to obtain capital, land, labor, and other service inputs to plan, design, and implement a project. The direct costs of service providers also include resources for operating and maintaining the investment throughout its economic life. All such costs are sometimes referred as suppliers' financial costs. From transportation users' point of view, direct costs are monetary expenses for acquiring specific equipment or devices in order to use a transportation service. Users' costs also include time, effort, and payments such as fare or other service charges for using the service. It should be noted that some user costs may be benefits or transfers. For example, if an ITS service can provide transportation users with faster and more convenient service, the effort and time for users to travel from their origins to destinations will be reduced. **As** a result, these costs become benefits when the comparison is made between "with" and "without" the service. In addition, users' payments for a transportation service could be transfers when a society's point of view is taken in a benefit-cost analysis.

Indirect costs are the decreases in the value of production generated indirectly by a project. Those costs incur indirectly for suffering from or cleaning up negative externalities caused by the implementation of a project. Some common examples of negative externalities are vehicle emissions, congestion, or other types of pollution such as water pollution, noise, *etc.* Because those costs are often viewed as external to private parties and paid by governments or communities, they are also called external costs or social costs.

4.1.3. *Definitions of users, providers, and community/society*
Transportation users refer to travelers who use transportation facilities and services. They are direct beneficiaries of transportation improvements. Transportation users include both individuals and agencies. They could be commuters (either automobile drivers or users of other transportation modes), business users (including track drivers, post officers, service deliverers), leisure users, special-need travelers, trucking companies, shippers, carriers, transit agencies, police agencies, fire agencies, emergency managers and medical services, and various governmental agencies.

Transportation service providers, in this framework, refer to all public or private agencies who plan, fund, build, and operate ITS services. They could be governmental transportation departments at various levels and Metropolitan Planning Offices (MPOs). Where there is a market for ITS applications, transportation service providers could be private transportation investors, private/public partners, or other non-profit agencies. However, the benefits of

ITS applications to private providers may slightly differ from those of public transportation agencies or non-profit agencies.

Community and society, if defined narrowly, are geographic areas that are directly and/or indirectly affected by a particular ITS project or a set of ITS projects or programs. Community and society can also be defined as jurisdictional areas such as city, county, region, state, or the United States, depending on the objectives or problems that a particular project intends to achieve or address and the scale of the project.

It should be noted that transportation users, service providers, and community/society may differ across jurisdictions. Sometimes, an ITS service provider may also be an ITS service user. For example, a transit operator who provides advanced public transportation services to the public using ITS technologies may also be a user of ATIS services. Hence, one should define users, providers, and community according to needs when conducting a benefit-cost analysis.

4.2. Expected benefits and costs of ITS applications

4.2.1. Benefits

ITS is considered as a new approach for solving contemporary transportation and air quality problems. The major goals of ITS, as defined in the National ITS Architecture, are to increase operational efficiency and capacity of the transportation system, enhance personal mobility and accessibility, improve safety and productivity, and reduce energy and environmental impacts. The ITS benefits that are expected to achieve those goals can be classified into the following five categories as shown in **Error! Reference source not found.:**

- monetary cost savings;
- time savings of non-production activities;
- increase of economic productivity;
- improvements in safety and environment; and
- improvement of individual accessibility.

The monetary cost savings expected to be brought by the ITS services come from two major sources. One is direct reductions in costs for maintenance or purchases of goods by both users and providers. The other is cost savings resulting from the increase of productivity or/and time savings. In this category, the monetary cost savings refers to the former. For example, the use of ITS services may reduce the needs for labor and equipment and therefore result in savings for labor and capital costs. Users and providers of the ITS services may also reduce costs for purchasing fuel and other operational materials due to better information and transportation infrastructures. Both users and ITS service providers may be the direct beneficiaries of monetary cost savings.

Time savings is another benefit expected from the implementation of ITS services. Time savings include both time reductions related to business trips and non-business trips. In this category, time savings refers to time reductions of individual users who are not directly involved in production activities, such **as** commuters, leisure travelers, shoppers, or people who make other **types** of personal trips. The time savings of those trips have values but not necessarily cash values. The increase of personal travel speed or reduction of travel time is an indication of increasing mobility.

Economic productivity includes cost savings in manpower and other business inputs. Those cost savings are the results of time savings related to production activities and efficient use of resources. The cost savings can also be used for new production activities which may generate more jobs and revenues. Business users are the major beneficiaries of improvements in economic productivity. Transportation service providers may benefit from the ITS services by lowering their capital and operating costs of service provision through the coordination and integration of services and information. The economic productivity of society may be augmented indirectly **as** cost savings fiom one production are used for new productions which generate new jobs and extra sector outputs.

The safety and environmental benefits of ITS services include reductions in number and severity of accidents including injuries, fatalities, and property damages, **as** well **as** reductions in vehicle emissions and other pollutants. Transportation users are the direct beneficiaries of safety improvements. They may also benefit from environmental improvements if they are required to pay for the negative externalities. Transportation service providers may take advantages fiom the improvements because they may save money for repairing physical damages caused by accidents and for mitigating the level of pollution if required by government regulations. The community and society are better off because of reduction in costs for accident-related social services and for cleaning and administrating pollution. All individuals in society will also indirectly benefit from the improvements by breathing cleaner air.

Accessibility gains are reflected in the increase of personal travel opportunities and convenience at lower cost and less stress **as** a result of ITS services. Transportation users are direct beneficiaries of transportation advancements. The improvement of personal accessibility may indirectly benefit society **as** a whole in terms achieving certain social objectives such **as** equity.

4.2.2. costs

The costs of an ITS service include all the expenditures occurred during the entire life cycle of the service. As defined in section **4.1.2,** the life-cycle costs can be generally classified into two categories: direct **(primary)** costs and indirect (secondary) costs according to the correlation between costs and service outputs. The costs can also be categorized into non-recurring costs, recurring costs, and other costs based on the frequency of cost occurred. These costs can be further grouped into fixed and variable costs in terms of their relationship to the level of service outputs.

Table 5

Distribution of Expected Benefits of **ITS** Applications

Expected Benefits	Users	Providers	Community/ Society
Monetary Cost Savings			
• reduce labor cost	direct	direct	indirect
• reduce fuel cost	direct		indirect
• reduce other operational & maintenance costs	direct	direct	indirect
• reduce capital investments	direct	direct	indirect
• reduce other travel costs	direct		indirect
Time Savings of Non-Production Activities/Individual Mobility			
• reduce personal travel time	direct (individual)		
Economic Productivity			
• savings in manpower	direct (business)	direct	indirect
• savings in other business inputs	direct (business)	direct	indirect
• increase sector outputs & revenues	direct/ indirect	direct	indirect
Safety/Environment			
• reduce injuries	direct	direct	direct/ indirect
• reduce fatality	direct	direct	direct/ indirect
• reduce property damages	direct	direct	
• reduce vehicle emissions	direct/ indirect	direct/ indirect	direct
• reduce noise pollution	direct/ indirect	direct/ indirect	direct
• reduce neighborhood traffic intrusiveness		direct/ indirect	direct
Accessibility			
• increase personal travel opportunities	direct	indirect	indirect
• increase travel comfort and convenience	direct	indirect	indirect

Non-recurring costs are one-time costs required for planning, deploying, and building an ITS service. Non-recurring costs occur in planning and development phases of a project. Those costs include initial investments associated with land, construction, hardware and software acquisitions, as well as planning, designing, installing, testing, and other contingency expenses. Because those costs are for getting an service started, they are also called first or investment costs.

Recurring costs are those on-going operating and maintenance expenses over the useful life of the service. Recurring costs take place in the operational phase. Included in this cost category are labor costs of operating, maintenance, supervisory, and supporting personnel, fuel and power costs, operating and maintenance supply costs, spare and repair part costs, costs for insurance, taxes, licensing, marketing, on-going training and education, *etc.* during the operational life of the service.

Costs that don't belong to the above two categories are included in the third category. They include costs for diminishing environmental impacts such as air pollution, noise, and neighborhood disruption, as well as other intangible costs.

Fixed costs are expenditures that are relatively independent of the volume of service output. They include all the non-recurring costs and some recurring costs such as administrative expense and other overheads. In contrary, variable costs are outlays that vary in some relationship to the level of operational activity. Typical variable costs are expenditures of labor, materials, fuel and power that are proportionally related to the volume of service output, as well as costs of time, effort, and service charge associated with the level of service consumption. Table *6* displays the distribution of costs among the transportation users and providers, as well as community and society as a whole.

Nearly all the recurring and non-recurring costs are direct costs for ITS service providers. Some of the recurring and non-recurring costs are direct costs for users. For example, costs of vehicles along with certain computer and communication hardware and software are direct non-recurring costs for users. Fuel cost, vehicle maintenance cost, vehicle registration cost are examples of direct recurring costs for drivers. Typical costs for non-automobile travelers are service charges, time, and effort. The community/society may indirectly bear some of the external costs imposed by users or providers, if there is any.

4.3. Measurements of ITS benefits and costs

4.3.1. Benefit measurements

This section presents measurements that can be used for calculating, estimating or presenting the benefits of ITS applications (Table **7**). In general, benefits are measured on an annual basis. However, benefits can also be assessed on the basis of entire evaluation period, or *peak* hour periods, depending on the needs and nature of the analysis. For analyses that focus on improvements of ITS services over existing conditions, benefits of

Table *6*

Distribution of Expected Costs of **ITS** Applications

Cost Categories	Users	Providers	Community/ Society
Non-Recurring/Fixed Costs			
• research, planning, design, and installation		direct	
• R/W acquisition and relocation		direct	
• buildings and other real estates		direct	
• **road** site hardware & construction		**direct**	
• other hardware	direct	direct	
• software	direct	direct	
• other intangible costs	direct	direct	
Recurring Costs			
(1) Fixed costs			
• administrative cost	direct	direct	
• maintenance cost	direct	direct	
• potential liability & litigation	direct	direct	
• licensing, partnership, & franchising	direct	direct	
• on-going training and education	direct	direct	
• marketing costs	direct	direct	
• other overheads	direct	direct	
(2) Variable costs			
• operating labor cost	direct	direct	
• operating materials and supplies	direct	direct	
• time	direct		
• effort	direct		
• service charge	direct		
(3) Other intangible costs	direct	direct	
Others/Fixed Costs			
• environmental cost			indirect
• other intangible costs			indirect

Table 7

Some Measurements of **ITS** Benefits

Benefits	Measures

Monetary Cost Savings	‣ annual capital cost ($)
	‣ annual operating cost ($)
	  labor cost
	  material/supply cost
	  fuel cost
	  other costs
	‣ annual maintenance cost ($)
	  labor cost
	  material/supply cost
	  power cost
	  other costs

Time Savings	• minute savings per trip
	• total hour savings per year
	  % reduction in time for incident response (minutes, hours)
	  % reduction in time for incident notification (minutes, hours)
	  % reduction in time for incident clearance (minutes, hours)
	  # (or %) net increase in traffic flows (vehicles/h)
	  # (or %) net increase in travel speed (miles/h)
	  # (or %) net reduction in travel delay (minutes, hours)
	  # (or %) reduction in stops or transfer
	  queuing time reduction (minutes, hours)
	  % increase in throughput (vehicles/per lane per minute)
	  average queue length (vehicles, or miles)

Economic Productivity	• % (or #) savings in labor hours • % (or $) decrease in overhead supports • % increase in fleet utilization (fleet miles/vehicle) • % (or $) savings in other operating cost • % (or $) increase in revenue
Environmental/Safety	• % reduction in vehicle emission (tons) • % noise reduction (decibel) • # (or %) of injury reduction • # (or %) of fatality reduction • # (or %) of property damage reduction
Accessibility	• % increase in perceived stress reduction • % increase in perceived convenience • # of travel options/modes

Table 8

Some Cost Parameters of ITS Applications

cost Categories	Cost Parameters
Non-Recurring/Fixed Costs	
• Research, planning, design, and installation	% **of** total anticipated construction $
• R/W acquisition and relocation	$/mile, $/feet, $/dislocated person, $/displaced property
• Buildings & other **real** estates	$/feet2
• Road site hardware & constructions	$/mile ($/unit)
• Other hardware	$/unit
• Software	$/unit
• Other intangible costs	% **of** total anticipated construction $
Recurring Costs	
(1) Fixed costs	
• administrative cost	% **of** total operating labor $ ($/operating labor $)
• maintenance cost	$/maintenance labor hour, $/unit of maintenance material
• potential liability and litigation	$/service ($/vehicle, $/employee)
• licensing, partnership, and franchising	varies
• on-going training & education	varies
• marketing cost	varies (% **of** total operation $)
• other intangible costs	varies (% of total operation $)
(2) Variable costs	
• operating labor cost	$/direct operating labor
• Operating materials & supplies	$/unit
• **time**	**$/hour**
• **effort**	**varies**
• service charge	$/unit (each, day, month, *etc.*)
(3) other intangible costs	varies (% of total variable $)
Others/Fixed Costs	
• environmental cost	varies
• other intangible costs	varies

ITS applications can be measured in percentage, or number, or dollar increases or reductions.

The benefits of monetary cost savings can be measured by reduction in annual capital cost, annual operating cost, and annual maintenance cost. These cost savings can be further broken down to labor cost savings, material and supply cost savings, fuel and power cost savings, and other cost savings.

Travel time savings can be measured by minute savings per trip or total hour savings per year. Travel time savings can be derived from information on travel speed, travel volume, travel flows, travel delays, queuing time and length, or incident response and clearance, *etc.,* depending on data availability.

Some measurements of economic productivity include labor hour savings per year, increase of fleet miles per vehicle, revenue increase per year, savings for overheads or other business inputs per year, *etc.*

The safety benefits can be measured by reduction in numbers of injury, fatality, and property damage. The measurements of environmental impact include tons or percent of vehicle emission reduction, or percent noise reduction, *etc.*

Personal travel opportunities can be measured by number of travel options or modes. Although travel comfort and convenience cannot be measured directly, they can be assessed alternatively by percent increase in perceived comfort and convenience through surveys.

4.3.2. Cost measurements

Table 4.4 shows some cost parameters for cost calculations of ITS applications. Costs of ITS applications, in general, are measured in dollars. Costs can be calculated as the products **of** the enclosure unit cost and number of units. It should be noted that several factors, such **as** inflation, learning effect, and changes in system design, construction and operation schedules, and material prices over the life cycle of an ITS application should be taken into account when conducting an cost estimation.

Chapter 5: Implementation Issues of Evaluation techniques

5.0 Introduction

The evaluation methods were described at length in Chapter **3** and the detailed illustration of different benefits and costs for the range of ITS projects are presented in Chapter **4.** The discussion provided descriptions that ignored a number of implementation issues that can create problems for the analyst. In a number of cases decisions must be made about what values to select for inputs and outputs. How should time be valued, for example? How should life and limb be valued for safety improvements or tradeoffs? Where do distributional concerns enter? These are some of the questions that are addressed in this chapter. It opens with several illustrations of projects and the impacts that they have. These provide a context for subsequent discussion.

5.1 Illustrations of Benefit Estimation

Having outlined the theoretical basis for benefit and cost estimation for three alternative evaluation techniques, we offer below illustrations of investing in capacity to meet congestion problems and of estimating traffic demand. They are intended to demonstrate the application to transport-related problems and hopefully will serve to indicate the types of problems which can be addressed, the approach of the analyst, and the strengths and weaknesses of economic evaluation.

In the first example, consider the case of an isolated highway which is congested. It has been suggested that the highway be widened with an additional lane(s) in order to speed traffic movement. The question is whether the benefits resulting from the reduced congestion warrant the extra cost.

The nature of the problem and the measure of benefits from reduced congestion are shown in Figure 10. The demand for travel on the road is by the curve DD. The private costs to travelers in the existing situation is depicted as mpc (marginal private costs). mpc is constant at the level c for low volumes, but once the traffic exceeds V_0, congestion sets in and the traveler's costs per trip (gas, oil, wear and tear, time) increase. Marginal private costs equal marginal willingness to pay (mpc=D) at a traffic volume V_1, the number of trips per hour currently made on the road. The full cost of this volume of traffic is not, however, reflected by the mpc of the typical travelers. Individuals make their decisions to travel based on the costs to them, but ignore the fact that their presence on the highway adds to the congestion, reduces traffic speed, and adds to the costs of other drivers. This external cost imposed on others but ignored by the individual driver is reflected as the difference between msc and mpc (i.e., the difference between the marginal social cost, the incremental cost to all drivers resulting from an additional driver, and marginal private costs to the additional driver).

The deviation between social and private travel costs can be readily illustrated by a simple example. Let the speed of the traffic, S, be related to volume, V, by the function

$$S = a - bV$$

and let the value of travelers' time be H per vehicle hour. The time-cost of traveling on the road is WS per vehicle-mile, the marginal private time-cost per traveler. The time-cost of all travelers is VWS and the marginal social time-cost is the change in their time due to an additional vehicle $[\partial(VH/S)/\partial V] = aH/S^2$.

Figure 10

Transportation Demand & Supply with Congestion
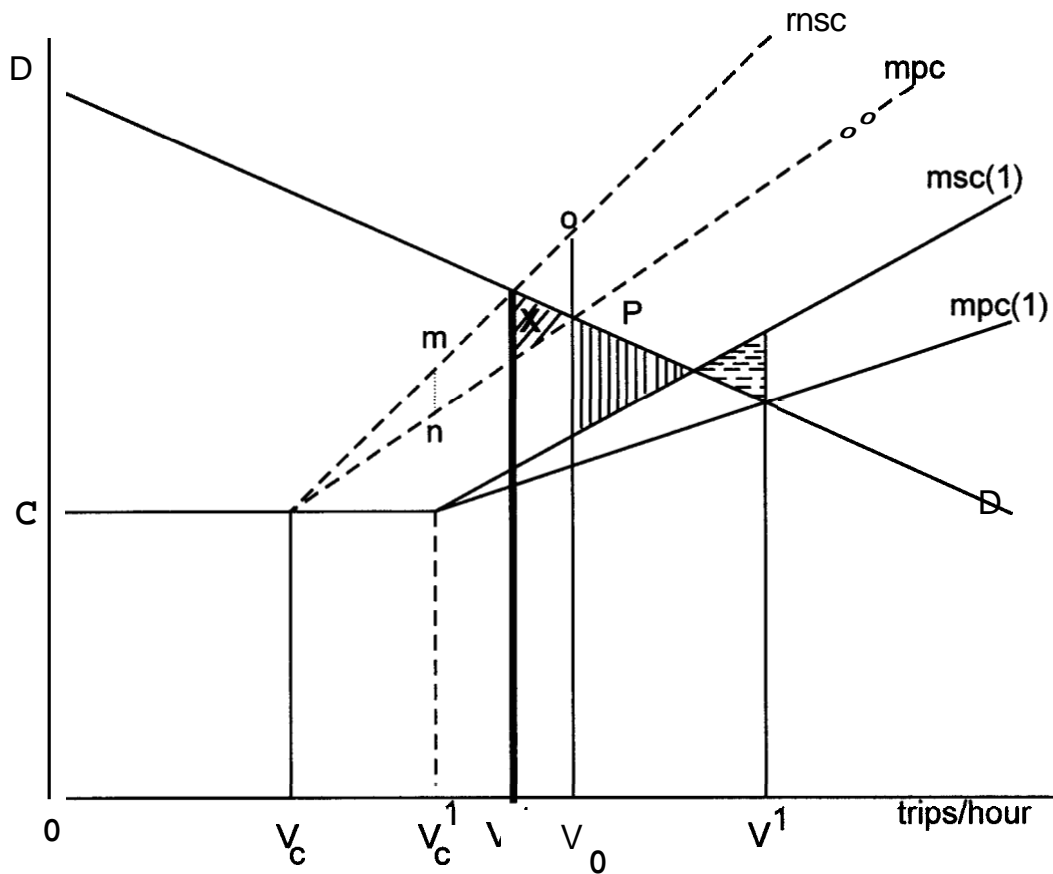
The difference between marginal social costs and marginal private costs is then

$$msc - mpc = \frac{aH}{S^2} - \frac{H}{S} = \frac{H}{S} \cdot \left(\frac{a}{S} - 1\right)$$

which is greater than zero since where congestion occurs, **a**, traffic speed "without congestion" is greater than **S.**

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Due to the failure of individual drivers to recognize the full costs of their travel decisions, there is excessive congestion on the roadway. The optimal volume of traffic on the existing highway is V^*, where marginal social cost equals demand (msc = D). To achieve the optimal volume it would be necessary to impose a tax equal to msc-mpc at V^*, *so* that each driver's private cost of travel equals the social cost (mpc + tax = msc). Generally, roadway charges to reduce congestion have not been considered feasible for political or administrative reasons. However, in some highly congested areas (Singapore, for example), a move has been made in this direction with special licenses or fees required to enter the central city area during peak traffic hours.

The proposed highway widening would shift the marginal private and marginal social cost curves to mpc' and msc' with congestion not occurring until a volume of V_c^1 trips per hour is reached. The traffic volume with this improvement is projected to be V'. Although V^1 is greater than optimal for the broader roadway, as msc exceed mpc, we will ignore that issue by assuming that it is not efficient to impose and collect a corrective tax. Part of the benefits from the highway improvement is the reduction in the costs of travel to the current volume of users. This benefit is the area between msc and msc' up to V,, the vertically hatched area. In addition, benefits also accrue because of the additional traffic, V_0V^1. Those benefits are the difference between willingness to pay for those trips and their full cost. This amounts to the diagonally hatched area where D lies above msc, less the horizontally hatched area where msc exceeds D. The deduction results from the overuse of the highway which stems from the difference between the traveler's private costs and the full costs to society.

The benefits measured here are the benefits per hour from this improvement. If traffic demand is not constant at all times, allowance must be made for the variation in benefits during the day, week, month, year, etc. when aggregating over the improvement's life. Once determined and approximately discounted, these benefits can be compared with the project's cost to determine its feasibility.

In this evaluation, it was assumed that the road was isolated, that is, that improvements in this road did not affect the volume of traffic on any other roads. If this is not the case, then account must be taken of the changes in benefits and costs to travelers on other roads. For example, if the improvement reduces the demand for trips on highway X from DD to D^1D^1, the reduction in congestion costs on that highway, due to the reduction in its volume of traffic from V_x to V_x^1, is the area abcd, and is also a benefit of the improvement originally considered (Figure 11). Alternatively, if the improvement stimulated traffic on X, an additional cost associated with greater traffic congestion on X would result.

Central to the economic evaluation of investments in new transportation facilities or improvements to existing facilities is prediction of the use, or the change in use, resulting from the expenditure. With respect to existing facilities, current users benefit by the resulting reduction in their travel costs. Where new traffic is generated on either new or

improved facilities, different types can be identified to whom the benefits differ. (Although this evaluation can be extended to account for interrelationships among transport modes, that possibility will be neglected here to focus instead upon the relation among the new alternative routes in a highway system.) Diverted traffk consists of trips that are diverted from another link in the transport system onto the proposed or improved highway, but whose purpose, origin and destination remain unchanged. The benefits per trip are equal to the savings in travel costs that result from using the proposed highway

Figure 11

Transportation Benefits from reduced Congestion
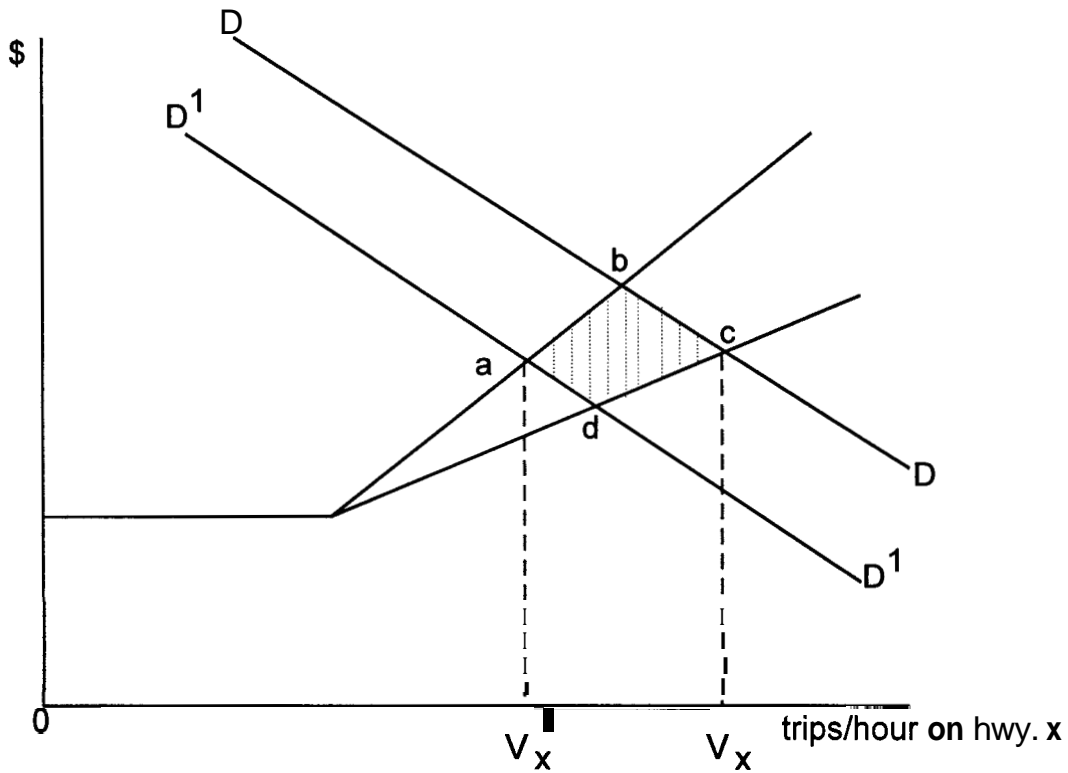
rather than the presently used route. Generated traffic consists of trips along the proposed highway that are new to the transport system. The benefits per trip are made up of savings in travel costs. However, these will be less than for a diverted trip along the same route because the trip would not be made if the proposed highway did not exist. Relocated traffic consists of trips that are diverted from another link in the transport system onto the proposed highway, because the proposed highway provides access to opportunities previously considered inaccessible for physical, economic or preference reasons. Relocated traffic differs from diverted traffic in that the destination of the trip is changed. The benefits per trip are equal to both savings in travel costs and increased well being.

The problem is to establish a model that will provide good predictions of these alternative traffic volumes resulting from proposed changes. Generally speaking, passenger and freight demands require different models or specifications. Alternative approaches to traffic demand models have been employed (economic base, gravity, intervening opportunity, revealed preference and stated preference and linear programming) with the sophistication of the model dependent on the availability of quality data.

Traffic demand studies can provide much useful information to transportation planners. Generally they indicate the responsiveness of traffic to changes in prices, income, time, and other service characteristics. Given then that incomes are expected to grow over time, one could estimate from demand studies not only the growth in, say automobiles and air passengers' travel, but observe that air travel can be expected to grow more rapidly. One might also find, **as** have some studies, that personal travel demand for rail transport is more responsive to reductions in price and travel time than are other modes. Furthermore, one may predict the effect of a change in one mode upon another, for example, rail and bus are highly competitive modes, but much less *so* with air and car. Similar evaluations can be accomplished with freight demand studies, although there the interrelationships among alternative modes (their cross-elasticities) are typically less well defined.

Finally, it is important to point out that transportation demand models as discussed above take the location and land use **as** given. In fact, improvements in the transport network are likely to modify the spatial distribution of persons and firms which will further change transport demands. To account fully for such continuing developments, complex models are required which incorporate feedback effects. Such models have been developed and found useful within urban areas for passengers' movements, but have not worked *so* successfully in inter-city evaluation (particularly for freight) as the determinants of firm location are not well known and operate with considerable lag.

A third example of evaluation is estimating the benefits of reducing accidents. When evaluating transportation projects, it is often impossible to avoid asking at some point the rather difficult question, "What are the benefits of reducing accidents?" The reason for this is because additional highways and airports, for example, promote travel which may increase the probability of our being involved in accidents. Furthermore, transportation projects, **as** well **as** other kinds, are designed, constructed and operated according to safety regulations directed towards keeping the chance of accidents within tolerable limits. Discussions to undertake projects which will result in some accidents and decisions as to the safety standard to be adapted, have implicitly, if not explicitly, placed a value on accidents. For example, if in building a new highway it was decided to forego a design which would reduce accidents from one per 10,000 trips to one per 11,000 trips, but costing one million dollars more, the benefits of avoiding an additional accident were not considered to be greater than or equal to $10,989.01.

The explicit evaluation of the benefits of accident prevention is rather sensitive. The reason is that while one can apply cold logic to determining the costs of property damage,

loss of time and medical expenses, the crucial question in the final evaluation is the value to be placed on pain and suffering and ultimately upon a human life. Despite the rather unpleasant and presumptuous nature of such an undertaking, many have sought to derive reasonable values in order to add a quantitative dimension to assessments of the merits of certain projects. Unless one is prepared to place a finite value on the value of human life, expenditures on medical research and practice and on safety should demand most of our resources. While one may not feel at ease with estimates of the value of avoiding injury or death, it does offer an alternative dimension to the evaluation of such expenditures, ie, a benefit estimate **as** opposed to the naïve, and for policy purposes, meaningless assumption of infinite value or simply a statement of the cost incurred per death (injury, accident) avoided.

Efforts to impute a value to the reduction of deaths have employed a variety of approaches which will be surveyed briefly here. One is to estimate the present value of the loss in economic output which is expected to result from an individual's death, i.e., the present value of his expected employment income times the probability that he will survive to each future period. The major problem with this approach is that it considers only the economic loss and implies that the maximization of national output, not social welfare, is the relevant objective. **A** second approach to this valuation problem is a variation of the first, which includes the employment income loss net of the individual's personal consumption expenditures, that is, the loss of income to others **as a** result of one's demise. The major criticism of this net as opposed to the previous gross measure is that it implies society is better off without those whose consumption exceeds their non-property income. Obviously this ignores the preference of retired persons who, regardless of their wealth, are regarded in such an evaluation **as** a social burden. **A** modification of these two approaches might be suggested which affects, in part, this criticism. **An** argument could be made for including in the calculation of **an** individual's life his expected future income from all sources - employment, property and even social transfers - in that this personal and public provision would include the value placed by both the individual and society upon his well-being in continued existence. This estimate would exceed both of those already noted.

A third alternative means used to assign a value to a human life is based upon the insurance principle. Here a value is imputed from the amount one is prepared to pay to reduce the probability of death a given amount. The problem with the insurance approach **(as** based on insurance data) is that insurance, because it compensates others, reflects the individual's concern for others' welfare more *so* than his own.

A final approach is to assess political decisions on projects involving varying expenditures and varying probabilities of death and impute from this the value society assigns to a life. (**A** similar assessment could also be made of private decisions of firms and individuals.) The difficulty with accepting this approach is that political choices may be directed to maximizing the political decision-makers' well being **as** opposed to social welfare. Furthermore, if the political choice is regarded **as** the appropriate criterion, the

evaluation is circular and merely confirms past choices rather than providing guidance to the political decision-maker.

The fundamental difficulty with all these approaches to imputing a value on human life is that none of them are consistent with that implied by economic theory. Since compensation for certain loss of life is likely impossible, theory can only cope with attitudes towards uncertain events. Thus the theoretical approach requires that a measure of one's willingness to pay to avoid an additional risk or the minimum amount he would accept to bear some additional risk, ie, the compensating variation measure. The difficulty with pursuing this approach is that data is not readily available on persons' willingness to pay, and indeed may demand resorting to interview studies.

In studying the benefits of risk reduction, one may recognize a variety of types of risk. Most important among these is to distinguish among those risks which persons voluntarily assume and those which are imposed upon us. Voluntary risks are those such as the risk of disease associated with smoking or the danger of accidents if we choose to travel, while involuntary risk is exemplified by the chance of disease due to higher air pollution which cannot be avoided. The distinction is important when accounting for risk reduction, for risks which are assumed voluntarily are netted out in the demand for the service, while imposed risks are not. Technically then, risk reduction in transportation projects should be accounted for by shifts in the demand function because the service is more attractive rather than by a separate accounting given a constant demand. Similarly, with respect to a project with given risks, there is no need to account separately for the risk cost, as that has already been allowed for in the demand for the service. Willingness to pay to avoid other kinds of risks cannot be ignored. Besides direct imposed risks, one may also account for one's willingness to pay for avoiding the risk of the psychic costs of bereavement and account for the effects of risk reduction upon others being financially better or worse off in the future.

Accounting for the loss of life (and similarly injury and disability) is an imperfect exercise. While improvements are necessary, they will not be easily accomplished. In spite of this, modification of the chance of death or injury is an important element of many public undertakings. Economic appraisal of such projects are still useful but the reliability of the assessment is considerably weakened. Consequently, the sensitivity of the results to the assumptions, particularly with respect to the values placed on death and injury, is important to indicate *so* as to give the decision-maker a better "feel" of the evaluation.

As a final illustration of benefit measurement, we draw attention to a technique which is sometimes employed and often abused; alternative costs as benefits. When a demand function is difficult to define, the costs of achieving a given objective by an alternative means has been offered as a measure of benefits. The problems with this approach are obvious. First, without an estimate of demand, one cannot be certain that the project is even economically feasible, even if an alternative program is more costly. Second, more

costly alternatives can easily be devised when, for reasons which some may not want to be made explicit, a particular undertaking is preferred.

A typical situation in which alternative cost procedures have been used is in the assessment of water transportation developments. Benefits are assumed to equal the difference in water transport cost and the cost of moving the expected volume of traffic by an alternative means, usually rail. **A** number of problems arise from this approach. Using railway rate schedules as an estimate of railroad costs overstates the actual cost saving, since only operating costs are reduced and railroad operating costs are low relative to their fixed costs. In part, because rail operating costs are relatively low, railroads can respond to competition by reducing their rates to maintain their traffic volume. The implication is that different benefit estimates would be associated with the new lower rates and the predicted waterway traffic may have been overstated. Finally, differences in rates or transport costs need not reflect accurately the savings to users.

5.3 Incorporating Distributional Concerns

There is considerable controversy within the profession as to the approach which should be adapted towards distributional or redistributional consequences in CBA. The efficiency-oriented evaluation simply weighs benefits and costs similarly to all persons regardless of their economic or social position. This implies that a dollar has the same value to everyone, a position with which many (including many economists) would disagree. However, there are several non-trivial arguments which can be advanced to support taking a neutral position with respect to distribution. One is that once one shifts from the arena of market determined values to the realm of merit, the economists' tools and techniques offer no special insight. The issue of what distribution should be and who is more deserving is a nebulous area and one in which no discipline or person has a unique role. Besides, the effect of any single project upon the overall income distribution is indeed very small. Most likely a specific project will only affect a small part of a disadvantaged group, therefore in the interests of horizontal equity, it is difficulty to justify that they be treated more favorably than others in similar situations, but without the potential of specific project benefits. If a particular group is deserving of special treatment, should they all not receive special considerations uniformly under a broadly based program? Finally, if distributional considerations are utilized to justify implementing an inefficient project, greater social net returns and similar distributional benefits could be achieved by alternative transfer mechanisms with an efficient allocation of resources.

For example, it may be proposed to extend road improvements in a region beyond the efficient level on the basis that the better roads will improve the real income of the region's residents. The gain to the area's population is the (shaded) area under their demand curve for road improvement between r_1 and r_2. The cost of providing this increment in service is the area under the marginal cost schedule over that same change. Obviously the additional costs fail to cover the additional benefits by the area of the triangle *ABC*. The government could make better use of its resources by only making

improvements up to r_1, using the resources necessary for the additional improvement elsewhere where benefits would exceed costs, and providing a direct subsidy or transfer to the region equivalent to the shaded area. The region would receive the same net benefits as with the greater road improvement and society would be better off, because the efficient allocation would more than compensate for the alternative subsidy.

The major difficulty with the above attitude toward the place of distribution in project evaluation is reconciling it with the manner by which redistribution is achieved in practice. Governments do not have a separate distribution branch which itself establishes the socially desired distribution of income after which only efficiency matters. Rather, some redistribution is achieved by direct taxes and transfers, but much of redistribution is achieved indirectly via the incidence of public expenditure programs. In fact, relative to incomes, government expenditures favor the poor much more than do taxes. Thus redistribution achieved via the benefits of government projects appear to be a valid component of society's distribution program and *so* deserve consideration. This is further reinforced by the fact that society may not be indifferent to the form in which transfers are made. Indeed, over-extension of the roadway may be inefficient and equivalent direct compensation appears to offer social gains, but society might consider direct transfers degrading and demoralizing and prefer to provide assistance in kind rather than as direct cash subsidy, because it prefers to see the funds used in specific ways (or not used in some ways the individual beneficiaries may choose if left to themselves). Finally, it must

Figure 12

Supply and Demand for Road Improvement
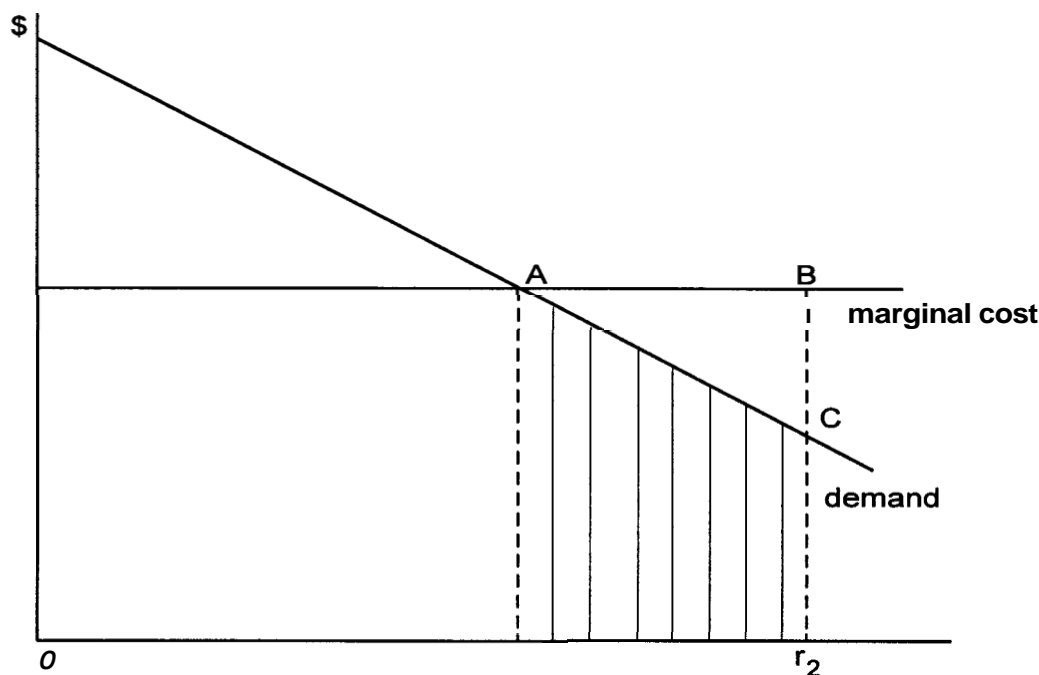
be remembered that the efficiency analysis is itself not distributionally neutral, but accepts the status quo as measures of willingness to pay depending upon one's income. Thus if a region's population had the level of income felt desirable, their demand for road improvement would be greater and *so* justify a level above r_1. **An** example of this problem lies in the building of a northern gas pipeline and the threat which many natives feel it imposes on their well-being and lifestyles. Contrast the native people's willingness to pay to prevent that change to the amount necessary to compensate them if the change occurs. The effect of the income constraint is obvious. **As** a result of these kinds of concerns, it is widely accepted that distributional issues cannot be neglected either by the analyst or the decision-maker.

5.3.1 Accounting for *Distributional* Consequences.

Income distributional effects are relevant in policy and project choices and must not be ignored. The problem is how to make the distributional issue explicit so as not to be hookwinked into accepting inefficient projects on the basis of misconceived distributional arguments or beliefs. Various approaches have been employed in efforts to include distributional considerations in a meaningful way into project evaluation. These break down into two major approaches. One aims to incorporate distributional implications directly into the estimate of net benefits and so effect the value of the B/C ratio or other project selection criterion. The other does not modify the efficiency-based estimate of net benefits, but rather supplements this with an outline of the project's distributional implications.

(a) Adding social welfare weights. This procedure weights the value of benefits and costs differently to people or groups in unequal circumstances. The weights are supposed to approximate the value that society puts on the marginal dollar to the specific parties. Thus, a dollar of benefits to a poor family may be assigned a weight of two, one for a middle income family, and one-half for a high income family. This would indicate that society values a dollar of benefits to the poor family four times **as** highly **as** a dollar of benefits to the rich family and twice **as** valuable **as** to the middle income family. Similarly, different weights may be assigned to the net benefits of native people as opposed to non-natives, or to Maritimers as opposed to other Canadians. When using such a weighting scheme, the evaluation of net benefits of a project depends upon their distribution and is summarized in the value of the benefit-cost ratio or other similar measures.

The problem with this approach is establishing the schedule of weights to employ. There is no way of knowing or comparing the marginal utility of another dollar of income among persons. One can, however, obtain some indications of the value which society puts on increments of income to different groups. In some cases, researchers have employed the marginal evaluations implied by the progressive income tax schedule. Others have sought to impute the weighting from observations of the distributional impacts of government approved economically inefficient projects of the same type. Many conceptual difficulties prevent putting much faith in weightings derived in these

ways. For example, the weights obtained will differ depending on the base used – the income tax, the total tax base, or the net incidence of government revenues and expenditures. Imputing weights fiom cases where distributional concerns are believed to have overrode efficiency considerations does not allow for other influencing factors such as environmental issues, presumes that the decisions were optimal and the weights are not subject to change, and does not recognize that similar situations should lead to similar decisions through the political process, independent of explicitly assigned weights. On the other hand, decision-makers have, and understandably so, been reluctant to explicitly specify a set of weights for the benefit of the analyst.

An alternative approach which might be employed in establishing a set of welfare weights could be adapted fiom work directed towards measuring the benefits fiom public goods and their distribution. This work is based upon an assumed function relating individual welfare to income, fiom which individuals' marginal evaluations of public goods at different income levels can be derived. Implied fiom this kind of work is a specific set of welfare weights, ie, marginal utilities of income, which could be employed by the analyst. The problem with this is that the utility function is, of course, assumed and even though there is empirical support for particular relations, there is still substantial variation in the functions which may be employed and the welfare weights implied by them. However, if one wishes to apply welfare weights by this technique, in that it is more rigorous and comprehensive, merits further consideration as an approach to the problem.

An alternative approach to the assignment of weights has been advanced, which is consistent with the Pareto-efficiency perspective of B/CA. This approach recognizes that many persons derive satisfaction fiom giving to others, thus a certain amount of redistribution may occur for the purely selfish reasons of the donor. This could be referred to as efficient redistribution and is consistent with the Pareto criterion in that everyone is left better off. In part because of the difficulty in establishing the weight schedule implied by voluntary redistribution, this method has not (we believe) been employed in project appraisal.

(b)   Display of distributional effects. Rather than specify a weighting to apply to costs and benefits, the analyst and the decision-maker may prefer to simply outline the pattern of the distributional effects. In this way, the equity and efficiency factors are less likely to become merged into a single measure but are set out separately and distinctly. The decision-maker can see clearly the efficiency consequences of alternative distributional effects (and vice-versa) and decide whether or not the gains on the one side warrant the costs on the other.

When undertaking this approach to the distribution question, it is important to establish the relevant groups for which the distributional implications are considered to be important. Decision-makers may be concerned about low-income people in general, the population of a given region, a particular ethnic group, or some combination of these. This requires close and continuing communications between the analyst and the decision-

maker to first identify the groups upon which distributional attention is to be focused; second, to draw attention to important but unanticipated consequences; and third, to facilitate the design of the project to meet both distributional and efficiency objectives.

Once the relevant groups are identified, the project must be assessed **as** to its effects upon the specific groups. This can be complicated, as both pecuniary and real effects are relevant at this stage. Furthermore, the second round effects may also be important for distributional considerations. Attempts to promote regional incomes may be hampered by low regional multipliers as the bulk of the subsequent spending goes outside the target area and perhaps to high income or other less deserving groups elsewhere. Once these effects are sorted out, tables can be set up indicating the distributional pattern of the outcomes, where important non-monetary as well as monetary effects should be outlined. These results should be presented in such a way that the figures are **as** meaningful **as** possible, for example, the change in income per family noted and its relative magnitude besides the aggregate change. When the project was intended to benefit specific groups, the degree to which it achieved these ends can be noted. One can note, for example, the benefits to the target groups relative to those to all beneficiaries, the portion of the target group aided, and the amount of aid relative to a measure of need. Furthermore, the analyst might indicate the welfare weights implied by acceptance of an inefficient project providing desirable distributional benefits. To accept a project which fails the efficiency test, for example, may imply that the decision-maker would be placing a value of $2.00 on every $1.00 of net benefits to a given group. While the format for such displays and the specific information to be provided within it will vary depending on the nature of the project assessed, the display should be designed to provide the decision-maker with as much information in as meaningful a form as possible, so as to allow him to weigh the relative merits of the outcomes. Basically it is an attempt to afford him the information necessary to make an assignment of welfare weights when it was either impossible or undesirable to predetermine such a set.

In determining the distributional consequences of a project, it is important to remember that the analysis has proceeded much beyond establishing and evaluating the basic inputs and outputs. The efficiency analysis established whether beneficiaries could compensate the losers without saying anything about whether they would or should. When distributional effects enter the picture, the issue of compensation comes to the foreground. Important here is who gains and who loses. Therefore, the method of finance and the extent of compensation enter and can be **as** important as the distribution of the actual outputs from the project. Since the distributional effects depend heavily upon the policy decisions as to pricing, taxing, charges, and compensation, it seems useful to separate these effects from the efficiency outcome and to consider the consequences of a variety of the alternative policies. Because of the significance of those choices, it is particularly important at this stage that the analyst and the decision-maker work closely with one another to define the range of policies which are to be examined. Their cooperation will enhance both the understanding and the value of the final product. The processes outlined in Volume 1 involving review, referral and feedback procedures serve, but do not guarantee, to facilitate such cooperation.

5.4 The Discount Rate

It has already been noted that it is important to discount future benefits and costs to their present value. Discounting is necessary because a dollar today is valued more highly than a dollar tomorrow. The reason for this is that, while awaiting future benefits or costs, funds could be productively utilized in alternative consumption or investment opportunities. Discounting benefits reflects the more immediate returns foregone, while awaiting future benefits and discounting costs reflects the more immediate returns available from postponing costs to the future. The discount rate is, in effect, the value put on time.

The problem is, "What is the appropriate rate of discount to utilize?" If one looks at the money markets, an extremely wide range of interest rates are observed. The spectrum includes very low rates on checkable savings accounts and Treasury Bills, modest rates on government bonds, higher rates on mortgages and private bonds, still higher rates on short-term loans and credit, and extremely high rates associated with the tax discounter. Which of these, if any, is the rate which the analyst should apply? The choice is important as the economic viability and relative attractiveness of projects may depend upon the choice.

5.4.1 The Effect of the Discount Rate

The choice of discount rate determines the present value to be associated with a dollar of benefit or cost in the future. The implications of a choice between a high and a low rate are reflected in the following diagram. The time (t) in the future at which a dollar of benefits is made available is measured along the horizontal axis and the present value (PV) of the future benefit is measured on the vertical axis (Figure **14).** The lines trace out the deterioration in present value associated with a dollar of benefits available in the more and more distant future, discounted at alternative rates. V_0L is the relation if there is a zero discount rate (ie, a dollar tomorrow is worth as much **as** a dollar today), V_0M reflects present value if a low discount rate is applied, and V_0N if a **high** rate is used. Looking at the present value of a dollar of benefits available at a given date in the future, year t_f for example, illustrates the effect of alternative discount rates. When discounting at a low rate, the present value of that dollar is V_L, but if a high rate is applied, the present value is only V_r Thus, the same absolute dollar amount of future benefits will be given a higher present value if the lower discount rate is applied, and the project will appear more attractive. Future costs are discounted similarly, but since the majority of costs are typically bunched in the early years of the project (say all before year t_n**),** variation in the discount rate does not usually effect their relative present values as greatly as it does for benefits.

Another example can serve to illustrate the impact of alternative discount rates upon a project's attractiveness. **A** particular time stream of benefits and costs are projected for the project in question. The total undiscounted value of future benefits is $15,000, while

Figure 13

Present Value of Benefit Streams
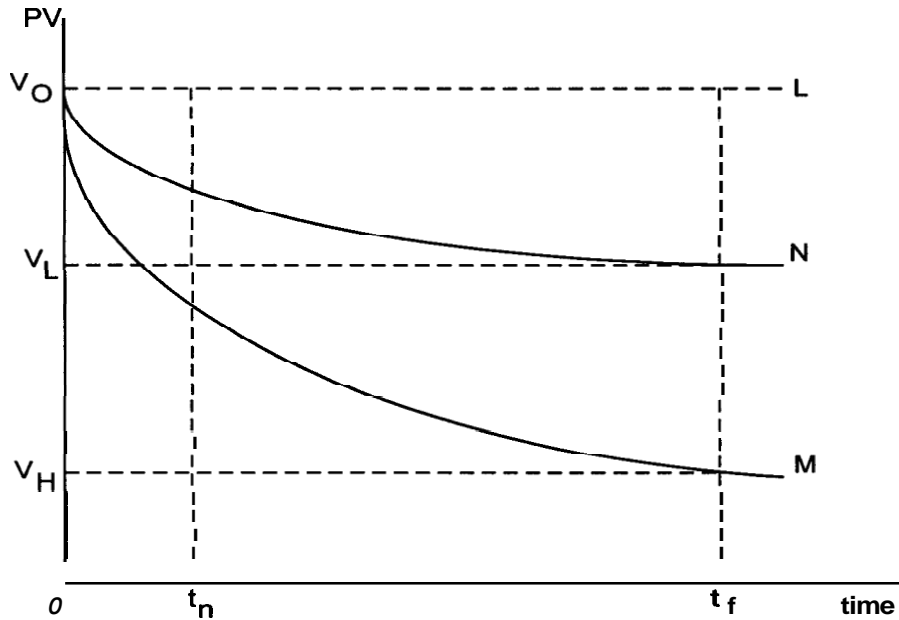
that of future costs if $7,500. If a zero discount rate is applied (no discounting), the project has a benefit to cost ratio of 2. Increasing the rate of discount, however, reduces the present value of the more distant benefits more *so* than the near costs in the following fashion.

Table 9

Rate of Discount	0%	3%	5%	10%
Present value of benefits	$15,000	$10,448	$8.456	$5,442
Present value of costs	$7,500	$6,741	$6,409	$5,906
Benefit/cost	2	1.55	1.32	.92

As the rate increases, the economic attractiveness of the project diminishes to the point that when a 10 percent rate is applied, the benefit-cost ratio is less than one and the project is no longer economically feasible. To further complicate matters, if the time pattern of benefits and costs differs between projects, one may appear to be the better investment at a low discount rate, while the other can be the preferred alternative at high rates. Thus we can see that the choice of discount rate is a critical decision and one which deserves careful consideration.

5.4.2 Suggested Alternative Rates of Discount

Two major approaches are taken toward determination of the appropriate discount rate. The social time preference approach argues for a relatively low rate on the basis that people are willing to lend funds or postpone consumption for modest rates of return. The social opportunity cost approach argues for the use of a relatively high rate of discount,

which is believed to reflect the marginal productivity (rate of return) of the resources in alternative uses, ie, if invested in the private sector of the economy. These two approaches and attempts toward their reconciliation are briefly reviewed below. A note on the problems of selecting the discount rate in an inflationary economy concludes this section.

The social time preference (STP) rate is the rate of return just necessary to have consumers forego, without risk, consumption for savings, ie, defer present for future consumption. In a capital market without imperfections, this would be the (single) market rate of interest. Since existing capital markets are replete with imperfections resulting in distortions, illiquidity and risk, different market rates are observed and the STP rate is not readily identified. Certain government securities, however, are highly certain and liquid so their rates do offer a close approximation of the STP rate.

Others argue that the rate of time preference, as expressed by individuals in their savings and consumption decisions, even with respect to relatively certain and liquid market securities, is too high a rate of discount. They feel that society suffers from myopia and overestimates the significance of the present and underestimates the importance of the future. Not only does this mean that individuals fail to provide sufficiently for their own future, but also that because they are too unconcerned about future generations, they fail to pass appropriately large capital stocks onto their descendants, and deplete natural resource stocks too rapidly. Due to these consequences of myopia, the adherents of this position call for corrective action by the government in further augmenting capital stocks to be achieved by the government's evaluation of projects using a discount rate lower than the market time preference rate.

Basically, proponents of the time preference rate argue for a low rate of discount. The moderates suggest a rate reflected by the lowest rates in the market, the extremists a rate below those observed market rates.

Advocates of the social opportunity cost (SOC) rate argue that the low STP rates do not reflect the real cost of resources devoted to public investments. Resources directed to public projects imply less private sector investment. Because of market imperfections and distortions, the rate of return available in the private sector far exceeds the STP rates suggested. The corporation income tax is seen as the major cause of the divergence of STP and *SOC* rates. Assuming a corporation income tax rate of 50 percent (and 100 percent equity financing of firms), corporations must earn a net return of 20 percent before tax in order for the stockholders to realize a net of corporation tax rate of return of 10 percent, which is assumed to be competitive in the capital market. Thus, discounting public projects at a market rate of 10 percent would be incorrect, as the social productivity (private returns plus the public tax share) of the funds displaced from the private sector is 20 percent. Consequently, a project appearing favorable at the 10 percent rate would fail to provide as great a stream of future benefits as when the resources were invested in the private sector. If public projects are to expand society's productive capacity, they must be as productive as marginal private investments. This

means that a discount rate reflecting social opportunity cost (20 percent in this illustration) should be applied.

. Only in a perfect capital market would the STP and SOC approaches rates be the same. Faced with the reality of an imperfect market, economists have attempted to reconcile the two approaches to the rate of discount. A move in this direction comes with the recognition that government investment does not reduce private corporation investment dollar for dollar. Rather, regardless of where the public sector secures its finds, arbitrage will spread the effects across the different capital markets, ie, bond, equity, corporate, non-corporate, mortgage, etc. Similarly, public projects financed by increased taxation can imply a variety of interest rates **as** the opportunity cost of funds differ among taxpayers in different circumstances. For these reasons the discount rate can be calculated as the weighted average of interest rates in different markets. The weights are the proportion of the invested funds from each source. This view holds to the social opportunity cost concept, but that cost is now a more moderate estimate based upon an average of the spectrum of market rates.

The social time preference school's position has been modified in recognition of the higher opportunity cost of funds while maintaining the low STP rate of discount **as** the appropriate determinant of inter-temporal allocations. This is accomplished by placing a shadow price on capital, that is, making capital artificially more expensive than its market cost to reflect the greater opportunity cost of capital in alternative uses. The shadow price on capital is determined by the ratio of the SOC rate to the STP rate when SOC rate is (as above) a weighted averaged based upon the sources of the funds. If, for example, the *SOC* rate is 12 percent and the STP rate is 6 percent, the shadow price applied to capital is 2(=12/6), thereby doubling the capital cost of the project for appraisal purposes. Although the cost of capital is escalated due to shadow pricing, benefits and costs are discounted at the low STP rate. The high opportunity costs are reflected in the augmented artificial cost of capital, while use of the STP rate **of** discount assures the proper inter-temporal evaluation.

These two approaches, the weighted average discount rate and the STP rate with capital shadow prices, result in the same solution if the public investment yields a perpetual stream of benefits. But if, **as** is the usual case, the investment has a finite life, the two results diverge the STP and shadow price of capital approach requiring more productive investments to be accepted. The reason for the difference stems from the implicit assumptions concerning the use of the depreciation of capital. The time preference approach assumes that depreciation is consumed (not saved) while the weighted opportunity cost approach assumes that the depreciation is saved and reinvested. Since otherwise the results of the STP-shadow price analysis imply a lower stock of capital than the weighted SOC analysis at the end of the project's life, a more productive investment is required. The choice of the appropriate discount procedure depends upon whether one believes that the depreciation resulting from a public project is saved or consumed, which in turn depends upon the degree of imperfection of the capital market. Although a full

reconciliation has not been achieved, the results of alternative discounting procedures have been narrowed considerably.

The fact that alternative approaches to the question of the discount rate tend to converge does not entirely solve the practical problem of rate selection, although this can offer some support for the rationale of the choice made. Analysts are still confronted with application of either identifying the STP rate and/or the weighted average *SOC* rate in order to undertake their appraisal. In either case the calculation of the weighted average social opportunity cost represents a formidable challenge which, even if undertaken, is not necessarily immune from criticism, **as** numerous arbitrary assumptions are involved. Because of this complexity, shortcuts are adapted. In countries with well-developed and functioning, if not perfect, capital markets, the market rate of interest on long-term securities or the rate of interest on long-term government securities are often adapted as a reasonable approximation. **As** a simplifying procedure this may be quite satisfactory, particularly if the results of discounting are shown to be relatively insensitive to the rate of discount employed.

A further important distinction that must be made is between nominal and real rates of discount; nominal being the current market rate and real being the nominal rate adjusted for inflation. The selection of a discount rate based on observed market rates of interest can err seriously in an inflationary economy. Market rates could have suggested a discount rate of 5 percent in the 1950s, but would suggest something more in the order of 10 percent today. Discounting a project offering the same stream of real benefits and costs would lead to much different evaluation today **as** compared to the 1950s, simply due to the fact that a higher discount rate is applied.

The problem is that the present high market interest rates do not reflect a greater productivity of capital, but rather only reflect the expectation of greater rates of future price change. During the 1950s and **60s** when inflation was about 2 percent, a security offering a nominal rate of interest of 5 percent provided the saver a real rate of return of **3** percent (in terms of increased purchasing power). In the 1970s when inflation averaged 7.5 percent, a security must pay 10.5 percent nominal return in order to provide the saver the same **3** percent real rate of return. In the 1990s inflation is back down to less than **2** percent. Borrowers are willing to pay the high nominal rates because they expect to repay the loan with inflated dollars. Removal of the inflationary adjustment from the market rate is essential when determining the discount rate because the future benefits and costs to be discounted are all in current dollar terms (ie, have not been estimated in inflated future dollars). Where benefits and costs are estimated on the assumption of no price change over time, the rate of discount must also be the rate that would apply if prices were to remain constant in the future. Thus, we want to discount by the real **as** opposed to the nominal rates observed in the market where

$$I_{real} = I_{nominal} - \text{inflation factor}$$

Since the market interest rates relate to the future return on money loaned today, the inflationary factor is based on the expectation of price changes over the term of the loan. Because it is based on expectations of future inflation rates, it is difficult to say exactly what the adjustment should be. On the other hand, one can observe the long-term real rates of return experienced by lenders which, over long periods of stable prices or relatively uniform inflation rates, likely reflect real returns consistent with their expectations. Estimates of real rates of return are consistently low by current standards with rates of **1.5** to **3** percent being common for short-term government securities. Such rates, however, are the absolute minimum that might be applied for discounting purposes, as they reflect the rates at which individuals would be prepared to trade present and future consumption.

A discount rate derived from an analysis of the opportunity cost of private investments incorporate a risk factor. Private investors bear some risk that the investment will fail to realize the returns expected, in which case there is a probability of the investor losing some of all of his investment. The market rates of return include a premium above the rate required to induce persons to forego consumption today for certain consumption in the future, *so* that investors will be willing to undertake investments involving some risk. The premium varies with the degree of risk investors associate with the investment. Rates of return in the private sector are high in part because of the risk attached to investment opportunities there.

Individuals are generally willing to accept lower rates of return if the return was expected with greater certainty. If there existed a perfect market for risk bearing (ie, a market in which one could, at fair premium, buy insurance against all possible future contingencies), investors would not need to bear as much risk themselves and lower rates of return on investments would be acceptable. Such a comprehensive insurance market does not exist. However, the government can act to reduce the risk borne by the individual investor in those cases where markets are imperfect. Public investment serves to reduce risk by pooling and spreading risk. Risk pooling spreads the risk over many projects. That is, the government undertakes many projects of which some, given laws of probability, will fail. The significance of the loss is relatively small to the public sector because of the scale of their investment program. Many private investors each undertaking one such project with the same chance of failure would require higher rates of return because the loss, if it did occur, would have significant consequences upon them as individuals investors without the opportunities for pooling against risk. Therefore, the public may be willing to see the government invest in projects offering lower rates of return than alternative private investments because the security of the return is greater.

Government investments also have the advantage of risk spreading. Risk spreading refers to the fact that the variable returns from a given (set **of)** project(s), if shared among many beneficiaries, have a small effect upon the well-being of each regardless of its success or lack of success, hence the risk cost individually and in aggregate is reduced relative to the situation when the variable returns risk is borne by a few. Once again, lower rates of return in the public sector may be equivalent to higher returns in the private sector. Thus,

the public sector may be justified in using a lower riskless rate of discount if the returns in its investments are not closely correlated with returns in other sectors of the economy and the returns are widely distributed.

If risk pooling and spreading opportunities are available to the public but not the private sector, either the investments of the public sector must be arbitrarily limited, or the logic exists for public investment in traditionally private activities so as to broaden the benefits of pooling and spreading and expand investment generally. Particularly where the public sector shares in private returns (corporation income tax), there is potential for government subsidization of private investment because of pooling and spreading effects. If, on the other hand, the public investment, either because of the pattern of its returns or the policy with respect to their distribution, offers none of the benefits of pooling and spreading, then the public sector should discount at the same rate as private investors undertaking projects of similar risk.

5.5 Uncertainty

Costs and benefits in the economic analysis have so far been treated as though the analyst was certain of their values. When dealing with projects which extend into the future, however, one is generally unable to predict these magnitudes with great confidence. Thus, the single values which are commonly employed in the analysis represent only the expected value of future costs and benefits. But technology, growth, tastes, relative prices, weather patterns, or a variety of other relevant variables may change in unanticipated ways to cause the actual outcome to deviate fiom what was expected. In some cases the range of possible outcomes may be quite broad, while in others narrow. The variability of outcomes is an important consideration to decision-makers averse to taking chances. For example, two potential roads may have similar benefits relative to costs based upon expected values, but the benefits of one may depend heavily upon a relatively uncertain demand (eg, the popularity of a particular type of recreational activity), while the costs and benefits of the other project are felt to be quite certain. Given the same expected net benefits, decision-makers are likely to favor the project with the lower likelihood of failure. Risk can be readily incorporated into the analysis by increasing costs (the insurance premiums) or by a reduction of benefits (if self-insured).

Since decision-makers are influenced by the variability of outcomes, they should be made aware **of** the range of possible results by the project analyst. **A** distinction need be made, however, between variability due to risk and that due to uncertainty. Risk is the chance of alternative outcomes which can be estimated accurately fiom probability functions based on past experience. Knowledge of the probability of alternative events enables prediction of the results (eg, the possibility of a given loss), and is the basis of the insurance business. Uncertainty exists when the relevant probability distribution is unknown (or at least incomplete). When constructing a dam, there is a calculable risk that a flood will destroy the project before completion, but changes in prices such as the relative increase in energy prices are uncertain.

A variety of procedures has been utilized by analysts seeking to avoid over-representing the benefits of projects with uncertain outcomes. One method is for analysts to be conservative in their estimate of benefits while liberal on the estimate of costs. Conservative and liberal estimates are subject to differences of opinion, however, and need not be related closely to the consequences of uncertainty. Another technique for analysis purposes has been to terminate the life of the project before the end of its actual time stream of benefits. Thus, a project with an expected life of 20 years may be required to show a favorable benefit-cost figure within 10 years in an attempt to account for the uncertainty associated with more distant future returns. The problem, of course, is that there is an abrupt discontinuation in service values and that the artificial length of life selected is quite arbitrary. Employing a discount rate augmented by a risk factor evaluates benefits and costs over all the project's expected life, but discounts more heavily the more distant, and presumably more speculative, outcomes. Applying a discount rate of 10 percent, for example, when the riskless rate is **7** percent implies that uncertainty grows at a constant **3** percent rate over the project's life, which may or may not represent the actual case.

A more sophisticated approach to the uncertainty problem is for the analyst to assign subjective probabilities to alternative future outcomes and then calculate the probability of particular events. In the simplest case this may be only the probabilities of the most pessimistic, most optimistic, and the best estimates of the results. In such a case, the decision-maker not only has the range of expected outcomes, but also an estimate of the possibility of their occurrence. This approach can be expanded by generating a more complete probability distribution for the range of outcomes. These tasks become more complex as the number of time periods and range of possibilities considered are expanded, but can be readily solved on computers. The problem with this approach is that the resulting probability estimates are no better than the subjective probabilities initially assigned by the analyst to alternative events in each period. If these err, the whole distribution will be wrong. However, to the extent that the subjective probabilities assigned are reasonable estimates of the chances, the decision-maker has available data giving him a better feel for the likely pattern of outcomes.

Where subjective probabilities cannot be established, it is still possible to obtain some feel for the effects of uncertainty by undertaking sensitivity analysis. In this approach one postulates possible events which might occur and determines their effect upon the viability of the project. For example, would a doubling of fuel prices reduce traffic flow along a proposed route sufficiently to make the project unattractive? Although no probability is assigned to the event, the decision-maker can see the consequences if it did occur. This approach is particularly useful in identifying assumptions to which the results are highly sensitive and which may deserve further examination. On the other hand, the analysis may reveal that the project is not sensitive to the perceived uncertainties, in which case further attempts to assess uncertainty may be unwarranted.

5.6 Approaches to Incorporation of Non-Market Values into an Evaluation

To facilitate discussion of incorporation of non-market values into an evaluation, a hypothetical situation is outlined. A region is being studied to determine future transportation needs. Two mutually exclusive plans, **A** and B, are considered attractive. The plan yielding the highest social net benefit (SNB) will be selected. For each alternative, their SNB is equal to the difference between their total benefits (B) and their total costs (C). B is the **sum** of the market **of** tangible benefits (TaB) and the non-market or intangible benefits (InB). C is the sum of the market or tangible costs (TaC) and the non-market or intangible costs (InC). However, for both alternatives, InC is zero, therefore C is equal to TaC. The subscripts **A** and B will be used to identify the use pattern to which the benefits and costs belong. For classification, a *summary* form of this hypothetical situation is presented below.

If $SNBA > SNB_B$, select use pattern **A**

If $SNBA < SNB_B$, select use pattern B

Where for use pattern **A**

$SNB_A = B_A - C_A$

and $B_A = TaB_A + InB_A$

and $C_A = TaC_A + InC_A$

but $InC_A = 0$

therefore $C_A = TaC_A$

and where for use pattern B

$SNB_B = B_B - C_B$

and $B_B = TaB_B + InB_B$

and $C_B = TaC_B + InC_B$

but $InC_B = 0$

therefore $C_B = TaC_B$

Dominance Approach. The dominance approach is applicable where more than one of the alternatives being considered involves intangibles, but the intangibles must be all either on the benefit or the cost side. The critical feature of this approach is the ranking

of intangibles. In many cases, the analyst could ascertain whether the intangibles for one alternative are larger or smaller than those for another alternative, despite the fact that absolute measures in dollar terms cannot be established. The results of this ranking are then combined with information about the level of tangible net benefits (TaNB) for each alternative.[17] Dominance occurs when an alternative is superior both in terms of tangible net benefits and in terms of the **intangibles**.[18] If an alternative is dominant over all other alternatives, then it can safely be claimed that selecting it will maximize social net benefits. Thus, if dominance is present, it will not be necessary for the decision-maker to make a value judgment about the magnitudes of the intangibles in order to select the alternative that yields the highest social net benefits.

If dominance is not present, a value judgment about the magnitude of the intangibles will be necessary. It is possible to ease the decision-maker's **task** by placing the required value judgment in context with tangible benefits and costs. To accomplish this, it is necessary to calculate a threshold value. This is done by taking the difference between tangible net benefits for a pair of alternatives. The threshold value serves **as** a focal point for determining which alternative is better. The decision-maker must decide whether or not the difference between the intangible net benefits for the two alternatives is larger or smaller than the threshold value. With this decision, the alternative yielding the highest social net benefits is simultaneously determined. If the threshold value is exceeded, then the alternative having the lower tangible net benefit is preferred. If the threshold value is not exceeded, then the alternative with the higher tangible net benefit is preferred. It is important to recognize that this approach can be used to deal with more than two alternatives by working with pairs of alternatives in sequence.

To summarize, within the context of the proposed hypothetical situation, the dominance approach is applicable where

$$InB_A > 0 \text{ and } InB_B > 0$$

The intangibles for use pattern **A** and B can be ranked so that either

$$InB_A > InB_B$$

or $\quad InB_B > InB_A$

These rankings are combined with information about TaNB for each alternative. Four possible situations could result. These are presented below.

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[17] $TaNB = TaB = TaC$

[18] **If the tangibles are considered benefits, then the alternative ranked highest would be superior in terms of intangibles. If the intangibles are considered costs, then the alternatives ranked lowest would be superior in terms of intangibles.**

	$InB_A > InB_B$	$InB_B > InB_A$
$TaNB_A > TaNB_B$	1	2
$TaNB_B > TaNB_A$	4	3

Plan **A** is dominant in Situation 1 since it is superior to Plan **B,** both in terms of **TaNB** and in terms of InB. Following a similar line of reasoning, Plan **B** is dominant in Situation **3.** Dominance is not present in either Situation 2 or Situation 4, as in both cases one of the plans is superior in terms of **TaNB** and the other is superior in terms of InB.

For Situations 1 and **3,** a value judgment about the size of InB_A and InB_B is not required to select the best alternative. In each case the dominant alternative yields the highest social net benefit.

For Situations 2 and **4,** the decision-maker must make value judgments in selecting the better alternative. Under these circumstances, the threshold value provides the focal point for the value judgment and the decision. Considering Situation 2, the threshold value is

$$TaNB_A - TaNB_B = TaNB_{A-B}$$

The decision-maker must decide if

$$InB_B - InB_A > TaNB_{A-B}$$

or $\quad InB_B - InB_A < TaNB_{A-B}$

If the first case is selected, then Plan **B** yields the highest social net benefits and will be selected. If the second case is selected, then Plan **A** yields the highest social net benefits and will be selected. An identical approach is used to handle Situation 4.[19]

The dominance approach is potentially useful in many transportation evaluations. Numerous situations may exist where intangibles are present for more than one potential project, plan or program. It is applicable, however, only if the intangibles can be ranked. Economists have done very little applied research on the ranking of alternatives where non-monetary indicators are used. However, professionals in other disciplines, particularly ecology and geography, have been very active in this **area.**[20] An examination

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[19] For an application of the dominance approach, see C. Cichetti, <u>Alaskan Oil: Alternative Routes and Markets</u> (Baltimore: Johns Hopkins Press), **1972.** This study applies the dominance approach to the problem **of** selecting alternative pipeline routes and markets for Prudhoe Bay Oil. In this case, the intangibles are on the cost side rather than on the benefit side. The intangibles are the damage to the environment caused by each alternative.

[20] For example, see **E.** Odum, <u>Optimum Pathway Matrix Analysis Approach to the Environmental Decision-Making Process</u> (Athens, Georgia: Institute of Ecology, University of Georgia), **1971.** Also see W.R.D. Sewell and **I.** Burton, <u>Perception and Attitudes in Resource Management</u> (Information Canada), **1971.** Also see T.O. O'Riordan, <u>Perspectives on Resource Management</u> (Pion Limited), 19**71.**

of contributions from other disciplines is outside of the scope of this report, but the procedure merits attention: the extent to which the dominance approach may be useful for shorelands evaluation can be ascertained only if this information is available.

Critical Value Approach. The critical value approach is more limited in its applicability than the dominance approach. It can be used only in situations where intangibles prevail for one of the alternative use patterns. The most apparent application of this approach is to situations where resource development such as a highway, airport, pipeline, railroad, etc. is being proposed for an area or site that is currently being used to protect watershed and/or wildlife habitat or for recreational purposes.

The critical value approach is somewhat similar to the approach discussed previously dealing with situations where dominance is not present. Once again, a threshold value, which is called the critical value, is calculated. The critical value is equal to the social net benefits for the plan without **intangibles**.[21] If the plan with intangibles is to have the higher social net benefits, then the sum of its tangible net benefits and the intangibles must exceed the critical value. In many cases, despite the presence of intangibles, there is no need to make a value judgment about this magnitude, provided that they are known to be beneficial. This occurs whenever the tangible net benefits exceed the critical value. Under these circumstances, the use pattern with intangibles will yield the highest social net benefits regardless of the size of the intangibles. If the critical value is larger than the tangible net benefits, then the decision-maker will be required to make a value judgment. It would be necessary to determine if the intangibles are larger or smaller than the difference between the critical value and the tangible net benefits. If it is then decided that the intangibles are larger, then the plan recognizing the intangibles yields the highest social net benefits, whereas if they are considered smaller, the use pattern not recognizing the intangibles yields the highest social net benefits.

In terms of the hypothetical situation set out earlier, the discussion can be summarized as follows. The critical value approach is applicable when either

$$InB_A > 0 \text{ and } InB_B = 0$$

or $\quad InB_A = 0 \text{ and } InB_B > 0$

Considering the case where $InB_B > 0$, then the critical value is

SNB,

where $\textbf{SNBA} = TaNB_A$, since $InB_A = 0$

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[21] If a plan has no intangibles, then its intangible net benefits are equal to the social net benefits.

Two situations may arise:

(1) $TaNB_B$ > critical value, or

(2) $TaNB_B$ < critical value.

In Situation 1, alternative Plan B yields the highest social net benefits regardless of the perceived magnitude of InB_B.[22] In Situation 2, a value judgment must be made about the magnitude of InB_B. The decision-maker must decide if:

InB_B > critical value - $TaNB_B$

or InB_B < critical value - $TaNB_B$

If the former case is selected, then Plan B will have the highest social net benefits. In the latter case, Plan A will have the highest social net benefits.

Implementation of the critical value approach is much easier than implementation of the dominance approach. In some cases, all that is required to implement the critical value approach are estimates of tangible net benefits for each use. In other cases, qualitative information about the intangibles will also be required. This is in contrast to the dominance approach where all the above information is required in all cases, along with a procedure for ranking the intangibles. On the other hand, the critical value approach cannot be applied in situations where intangibles are present for more than one use, whereas this is possible using the dominance approach. The critical value approach is essentially less complex as it deals with simpler situations.

Safe Minimum Standard Approach. The safe minimum standard approach was developed to deal with situations where a proposed plan could have irreversible consequences on an existing or prospective resource use pattern.[23] It was recognized that these situations needed to be handled with special caution as not only present but also future generations could be adversely affected. The extent of this adverse effect depends a great deal on the needs of future generations. With some possible patterns of future needs, there is very little damage to future generations, while with others the damages are inordinately large. B/CA is not equipped to deal with the interests of future generations and therefore an alternative approach for public policy is proposed. This approach seeks to minimize the possibility of high losses by incurring reasonable safeguard costs. It is likened to an

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[22] Since $SNB_B = TaNB_B + InB_B$, and $TaNB_B > SNB_A$, and $InB_A > 0$, then $TaNB_B + InB_A > SNB_A$, regardless of the size of InB_A substituting $SNB_B > SNB_A$.

[23] S.V. Ciriacy-Wantrup, Resource Conservation: Economics and Policies, 4th ed. (Berkeley, CA: Division of Agricultural Sciences, University of California), 1968, 251-268.

insurance policy where a relatively small premium is paid to avoid a possible very large loss.

In applying the safe minimum standard approach, information is sought about the cost of avoiding the irreversible action and about the damages that would result from carrying it out. The costs of avoiding the action are of two types: (a) the cost of providing the protected use, and **(2)** the opportunity cost of foregone uses. The latter costs would be equal to the social net benefits of the plan that would have led to the irreversible result. The damages that would result **from** permitting the irreversible action can be viewed as the benefits of avoiding such an action. This makes for an easier comparison with the cost of avoiding the action. Some of these benefits will be measurable but some obviously will not be, including most notably costs to future generations. The application of the safe minimum standard approach creates no difficulties as long **as** the costs of avoiding the irreversible action exceed the tangible benefits from doing so by a small to moderate amount. Under these circumstances, the irreversible action should be avoided. **A** problem does arise, however, when avoiding the irreversible action costs a great deal more than the tangible benefits. The safe minimum standard approach can no longer be considered applicable under these circumstances. Within the analogy of the insurance policy, the premium is no longer relatively small. It is not clear which is more important; large, highly certain losses to present generations, or possibly larger, but less certain losses to future generations. It will be necessary in such instances for the decision-maker to make a value judgment. The irreversible action will be avoided if it is felt that the claims of future generations are stronger while the opposite will occur if it is felt that the claims of present generations are stronger.

Turning to the hypothetical example, the present discussion is summarized. The safe minimum standard approach is applicable if development of Plan **A** (or B) precludes the possibility of reproducing the resources necessary for resource use pattern B (or **A)** for an extremely long time, possibly forever. Consider the case where Plan **A** can cause irreparable damage to use pattern B and

$$InB_A = 0 \text{ and } InB_B > 0$$

The costs of avoiding the irreversible action are

$$^{24}C_B + SNB_A{}^1$$

while the benefits are

$$TaB_B + InB_B$$

Three situations could arise:

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[24] **Recall that** $TC_B = Ta_B$ **since** $InC_B = 0$

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$$(1) \qquad C_B + SNB_A < TaB_B$$

$$(2) \qquad C_B + \textbf{SNBA} \text{ slightly to moderately larger than } TaB_B$$

$$(3) \qquad C_B + \textbf{SNBA} \text{ considerably larger than } TaB_B$$

In Situation 1, Plan A should clearly be rejected, thus avoiding the irreversible action.[25] The same holds true for Situation 2, when the safe minimum standard approach is applied. Situation 2 requires a value judgment of the decision-maker about the magnitude of InB. It must be decided if

$$TC + SNB_A - TaB_B < InB_B$$

or $\qquad TC_B + \textbf{SNBA} - TaB_B > InB_B$

If the first case is chosen, then Plan **A** is rejected and the opportunity to have use pattern B is retained. If the latter case is chosen, then use pattern **B** is adapted, and the opportunity to have use pattern **B** is lost for an extremely long time.

Application of the safe minimum standard approach is best suited to situations where the use pattern that is being damaged irreparably is the only use pattern with intangibles. In these situations, this approach requires exactly the same information as the critical valure approach would if it was being applied. These observations give the impression that the safe minimum standard approach may be nothing more than an application **of** the critical value approach to irreversible situations. This is deceiving **as** there is **an** important difference between the two approaches. The safe minimum standard approach is applied where there are fewer cases where a value judgment about intangibles would be required from the decision-maker. The critical value approach, on the other hand, assumes that such value judgment about intangibles would be required whenever the cost of avoiding an irreversible action exceeded the tangible benefits. The safe minimum standard approach requires that a value judgment is necessary if the cost of avoiding the irreversible action significantly exceeds the tangible benefits.

Sensitivity Analysis Approach. The sensitivity analysis approach is applicable to all situations where intangibles are present. It can be applied in conjunction with the three approaches discussed previously or it may be applied independently where more than one plan involved intangibles and the dominance approach could not be implemented. The intent of the approach is to give the decision-makers an explicit perspective of the importance of the intangibles. While the analyst may not be able to ascertain the precise value of intangibles, frequently he has sufficient information available to him to place

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[25] This situation is exactly the same as Situation 1 that was presented in the critical value approach, only with the symbols arranged and presented in a slightly different manner. $TaC_B + SNB_A < TaB_B$ rearranging $SNB, < TaB_B - TaC_B$ and substituting critical value $< TaNB,$. This last statement can be written as $TaBN_B$ critical value. This is the same statement that was used for Situation 1 of the critical value approach.

bounds on the value. **A** reasonable minimum and maximum value for the intangibles can be established. These values can be combined with the tangible net benefits to arrive at a range for the social net benefits. In some cases, it will be apparent which use patterns are superior from examination of the ranges. In other cases, this may not occur but an indication **of** the necessary value judgment will be available.

In terms of the hypothetical example, consider the case where

$$InB_A > 0 \text{ and } InB_B > 0$$

A minimum and maximum value is established for each of these. For use pattern **A** it is

$$InB_{Amin} \text{ and } InB_{Amax}$$

and for use pattern **B** it is

$$InB_{Bmin} \text{ and } InB_{Bmax}$$

These values are combined with tangible net benefits to obtain a range for social net benefits.

For use pattern **A**

$$TaBN_A + InB_{Amin} = SNB_{Amin}$$

$$TaNB_A + InB_{Amax} = SNB_{Amax}$$

For use pattern **B**

$$TaNB_B + InB_{Bmin} = SNB_{Bmin}$$

$$TaNB_B + InB_{Bmin} = SNB_{Bmax}$$

Four situations can arise:

(1) $$SNB_{Amin} > SNB_{Bmax}$$

(2) $$SNB_{Amax} < SNB_{Bmin}$$

(3) $$SNB_{Amin} < SNB_{Bmax}$$

(4) $$SNB_{Amax} > SNB_{Bmin}$$

In Situation 1, Plan **A** is clearly superior, as the social net benefits of Plan **B** never exceed those of use pattern **A**. In Situation 2, the reverse is true and Plan **B** is clearly superior.

For Situations **3** and **4,** it is not clear which plan is superior. The decision-maker will have to choose, taking into account the information about the range of social net benefits for each use pattern.

The principle limitation to applying the sensitivity analysis approach is the requirement that the analyst establish reasonable bounds on the values of intangibles. Whether **an** analyst will be able to do this or not will depend on a number of factors, including overall knowledge and understanding of this or similar situations, and the kind of non-monetary information available.

5.7 Risk Analysis

Sensitivity analysis is an acceptable method of dealing with some irregularity in a variable in the calculation of benefits and costs and used in any of the three evaluation techniques discussed in Chapter **3.** However, by using a plus or minus **8** percent, for example, the implicit assumption is that the variability is symmetric and that the chances of having an increase are the same **as** having a decrease. This is not likely to be the case. Furthermore, it is also probable to be more than one variable that is uncertain or subject to some degree of variation and the variability will differ across variables. How is the best way of handling this type of problem?

Risk analysis is a technique that allows the analyst to explore not only the consequences of variation in the values of the variables that enter the calculations of costs and benefits but also to report the results in the form of a probability distribution. Traditionally, when CBA, impact analysis or CEA are used there are few numbers reported to decision-makers and those that are reported are implied to occur with certainty; a NPV calculation of $7 million is reported **as** if this was 'the' number and had a 100 percent chance of occurring. The decision-maker is really not provided with much information and in fact is placed at risk. It would be better for the decision-maker, and for public policy generally, if they were provided with information regarding the chances of this number occurring and of course the chances of it not occurring. Risk analysis is a method that permits the analyst to do exactly that, provide a probability distribution to decision-makers that indicates the chance that a value in a range of outcomes will occur.

The principal advantage of the risk analysis approach is that it allows for a range of input assumptions to be used to generate model outputs, rather than point estimates which are often used in evaluation models of this type. This approach is particularly well suited for the study of ITS projects because results from secondary research will frequently be used to enumerate the model until data from project experience is available. Model input assumptions are therefore developed such that the analysis does not rely on the results or methods from one particular study, but reflect the knowledge and experience from a variety of sources and experts.

The results of a risk analysis simulation offers an estimate of the central results, but they also offer the added benefit of accounting for the uncertainty in the selected inputs. The

expected values for the results will tend to be lower if the inputs stipulate more downside risk or higher if the inputs imply more optimism than pessimism. The limitation of model results without risk analysis is the failure to model the full range of possible input values.

Our proposed approach to cost-benefit evaluation using any of the techniques described in Chapter 3 involves incorporating risk analysis as a foundation by which the planner can evaluate alternative options under a variety of scenarios. The result of a risk analysis is a forecast of future events and the probability, or odds, of their occurrence. Risk analysis provides a sense of perspective on the likelihood of future events. This is illustrated in Figure 14 where the elasticity with respect to travel time, used perhaps to measure the gains from introducing a link specific ITS project, has taken on a number of values instead of just one. Some of these values are more sensible than others and this should be integrated into the analysis and the results rather than ignored.

Figure 14

Risk Analysis Process Probability Density Function

80%
Confidence
Interval

0.05   0.10   0.20

Elasticity w.r.t. Travel Time
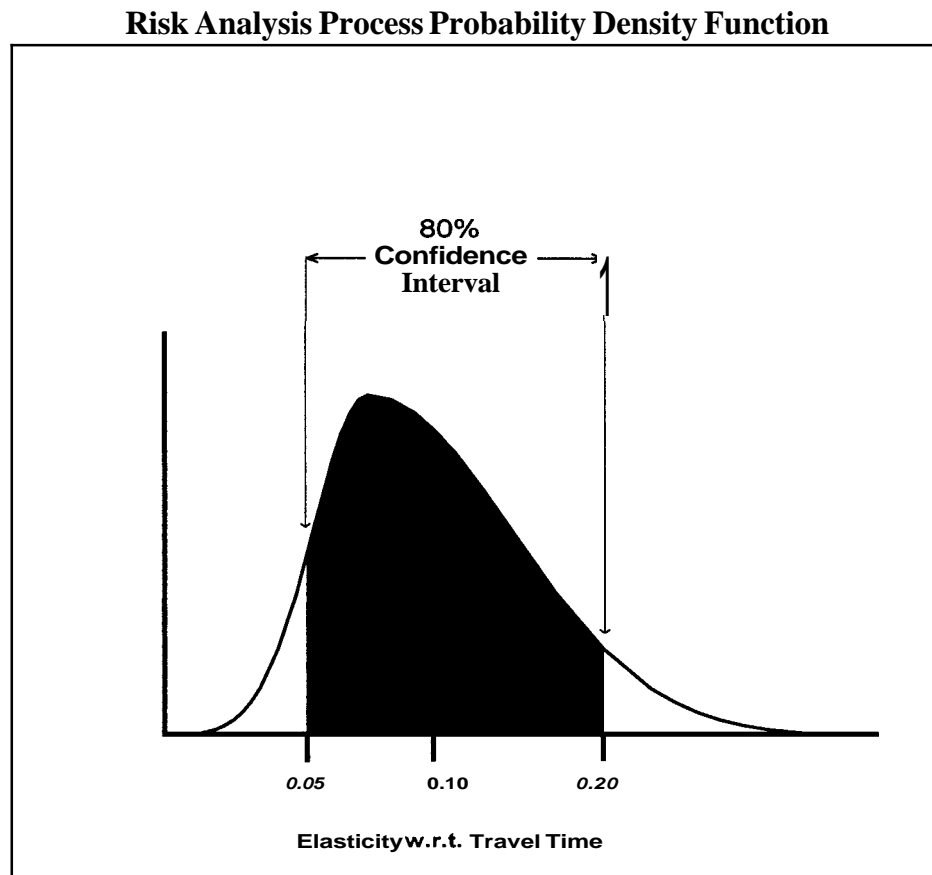
Risk analysis is an easily understandable, but technically robust method that allows planners and decision-makers to select the level of risk within which they are willing to

plan and make commitments. This process is illustrated in Figure 15. The different values of the inputs in the evaluation are integrated using a Monte Carlo method. The final 'generated' probability distribution is created by sampling from each variable's individual probability density function. Using this approach the integration of the individual variables probabilities are combined and are reflected in the set **of** probabilities of outcomes.

Figure 15

Monte Carlo Simulation ⁻ A Way to Combine Probabilities
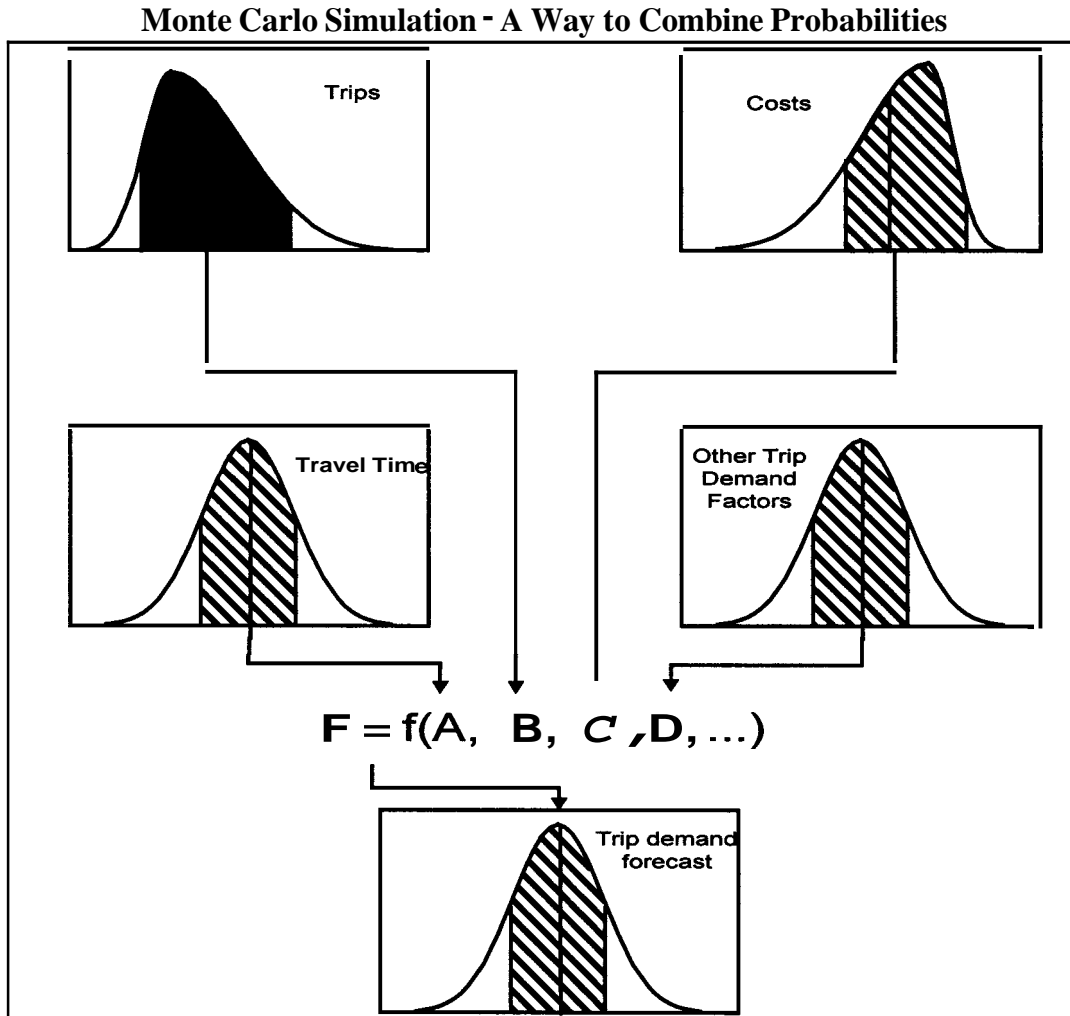
5.8 Placing Values on Benefits and Costs

As described in chapter 3, the valuation of benefits and costs are based on market values and opportunity cost principles. The purpose of evaluation methods is to place a value on the outcomes of projects and assess, on the basis of different criteria, whether the value to society exceeds the resource cost. Values are a product of quantities and prices. Chapter 4 provides a listing of the quantities of benefits and resources used on the variety of ITS projects. Prices are generally taken as market prices since in competitive markets they provide a measure of the valuation that society places on different goods and services.[26] In some cases shadow prices may need to be used since markets may be imperfect or not provide accurate measures of valuation. There are three areas of particular interest for ITS project valuation which require more detailed discussion; valuing time, valuing life and placing values on pollution and other externalities.

5.8.1 Valuing Life, Safety and Accidents

There are a number of sources recording highway accidents. The National Highway Traffic Safety Administration has two databases: NASS - the National Accident Sampling System and FARS, the Fatal Accident Reporting System. In addition, each state keeps records, as does the insurance industry, the National Council on Compensation Insurance DCI (Detailed Claims Information) database. Injuries are typically classified according the following scheme, along with the percentage of crashes associated with each category. Only a small proportion of accidents result in death or incapacitating injury:

Table 10

Accidents by Classification[27]

	Classification	Percent of Crashes	Percent of People
K	Killed/Fatal Injury	**0.3**	0.1
A	Incapacitating Injury	2.9	1.5
B	Non incapacitating/ Evident Injury	5.6	3.0
C	Possible Injury	7.6	4.8
O	Property Damage	31.2	36.2
	Unreported	52.4	54.4

source: Miller 1991

note: the number of unreported accidents was estimated from surveys.

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[26] Including consumer surplus in the welfare calculation is important in the final evaluation. Again this is described in Chapter 3.

[27] The total number of crashes was computed for the years 1982-85 and was 14,800,000 affecting 38,146,000 people.

The actual rates of accidents are also not immediately apparent. Many crashes, particularly minor accidents without **loss** of life or major injury, are not reported to the police or insurance industry for obvious reasons. However, we proceed with reported accidents.

Table 11

Number of Accidents on California Freeways, 1993

	Road Miles	Travel (MVM)	Accidents Total	Property Damage Only	Injury	Fatal	Killed
Rural Freeway	1935	19592	8901	4942	3692	267	338
Urban Freeway	2190	92315	79459	53493	25463	503	562

source: Caltrans **1993**

Using the following equations to compute accident and fatality rates, California-specific rates can be computed:

Accident Rate $(AR) = (\#$ Accidents $\mathbf{x}$ 1,000,000) / VMT

Fatality Rate (FR) = (# Victims $\mathbf{x}$ 100,000,000) / VMT

The following table shows accident rates by automobile on rural and urban highways in California. There is a general trend toward a reduction in the rate of accidents, and in their fatality. Safety features such **as** seat belt usage, air bags, anti-lock brakes, and better design, as well **as** lower speeds due to congestion in urban areas may be a factor. On the other hand, higher speed limits in rural areas may have a safety cost. To what extent technology continues to improve safety in the future remains an unsettled question.

Table 12

Accident Rates in California

Year	Rural			Urban		
	Accidents Total /MVM	(Injured + Fatal) /MVM	Fatal /100MVM	Accidents Total /MVM	(Injured + Fatal) /MVM	Fatal /100MVM
1989	.50	.20	2.08	.92	.34	.87
1990	.47	.23	1.85	.91	.33	.80
1991	.45	.22	1.60	.90	.32	.74
1992	.43	.20	1.35	.88	.31	.62
1993	.45	.20	1.73	.86	.28	.61

source: Caltrans **1993**

It should be noted that while there are more accidents proportionately in urban areas, the share of fatal accidents is much less than in rural areas, as urban accidents tend to be at lower speed.

Placing a value on injury requires measuring its severity. Miller (1993) describes a year of functional capacity (365 days/year, 24 hours/day) as consisting of several dimensions: Mobility, Cognitive, Self Care, Sensory, Cosmetic, Pain, Ability to perform household responsibilities, and Ability to perform wage work. The following tables show the percent of hours lost by degree of injury, and the functional years lost by degree of injury.

Table 13

Percentage of Hours Lost to Injuries by Degree of Injury

	Modest MAIS 1,2	Major MAIS3-5	Fatal	Total
Functioning	18.0	40.7	41.3	100.0
HH Production	25.2	22.1	52.7	100.0
Work	21.7	19.1	59.2	100.0

source Miller (1991) p.26

Table 14

Functional Years lost by Degree of Injury

MAIS	Per Injury	Percent of Lifespan	Per Year	Percent of Annual Total
1. Minor	0.07	0.15	316,600	10.7
2. Moderate	1.1	2.3	587,700	20.0
3. Serious	6.5	13.8	1,176,700	40.0
4. Severe	16.5	35.0	446,700	15.2
5. Critical	33.1	70.0	413,800	14.1
Avg. Nonfatal	0.7	1.5	2,941,500	100.0
Fatal	42.7	100.0	2.007,000	

note: expected lifespan for nonfatally injured averages 47.2 years
source Miller (1991) p29

5.8.1.1 Estimates of Value of Life

Central to the estimation of costs is an estimate of the value of life. Numerous studies have approached this question from various angles. Jones-Lee (1988) provides one summary, with an emphasis on British values from revealed and stated preference studies. He finds the range of value of life to vary by up to two orders of magnitude (a factor of 100). Miller's (1991) summary is reproduced below.

Table 15

Estimated Value of Life by Type of Study

Average of 49 studies	$2.2 M
Average of 11 auto safety studies	2.1 M
Study Type	
Extra wages for risky jobs (30 studies)	1.9-3.4 M
Market demand vs. price	
safer cars	2.6 M
smoke detectors	1.2 M
houses in less polluted areas	2.6 M
life insurance	3.0 M
wages	2.1 M
Safety behavior	
pedestrian tunnel use	2.1 M
safety belt use (2 studies)	2.0 - 3.1 M
speed choice (2 studies)	1.3-2.2 M
smoking	1.0 M
Surveys	
Auto safety (5 studies)	1.2-2.8 M
Cancer	2.6 M
Safer Job	2.2 M
Fire Safety	3.6 M

Source: Miller (1990), in millions (M) of 1988 after-tax dollars.

5.8.1.2 Comprehensive Costs

After converting injuries to functional years lost, combining with fatality rates, and value of life, a substantial portion of accident costs have been captured. But this data must be supplemented by other costs, including hospitalization, rehabilitation, emergency services, etc. By taking the comprehensive costs listed in Table 16, it is possible to allocate them to the various accident categories where categories are constructed on the basis of severity. These are listed in Table 17.

Costs also vary by location. Rural crashes, (at $85,614/crash) which occur more often on freeways and at higher speeds, are more expensive than urban crashes (at $32,324/crash) (Miller, 1991). Furthermore, rural interstates are ($92,436/crash) which are more expensive than urban interstates ($53,579/crash).

5.8.1.3 The Full Cost of Accidents

While without any estimates of highway demand, it is not possible to estimate the total cost of accidents on a hypothetical facility, the cost per passenger mile can be estimated by multiplying the comprehensive cost and the accident rate, after adjusting injuries to fractions of life.

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Table 16

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
Human Capital Subtotal	5517
Pain and Suffering	11788
Comprehensive Subtotal	17305
Direct Costs	3021
Years Lost	0.13

Source: Miller (1991) p 42

Table 17

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
0-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)**[28]

Taking Miller's (1991) value of $92,436 for crashes on rural inter-states and $53,579 for urban inter-states, (1988 dollars) and California accident rates for 1993, we have the

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[28] These costs are in general higher than estimates previously used by **NHTSA** (1983), Miller discusses the differences in depth.

following estimated cost per million vehicle miles (top row) and per million vehicle kilometers.

Table 18

Cost of Highway Accidents, Rural and Urban Interstates

English Units 1993	Rural Rate /MVM	Rural cost	Rural Cost NMT	Urban Rate /MVM	Urban cost	Urban Cost /VMT
1993	.45	$92,436	0.042	.86	$53,579	0.046
Metric	Rural Rate /MVK	Rural cost	Rural Cost NKT	Urban Rate /MVK	Urban cost	Urban Cost /VKT
1993	.27	$92,436	0.025	.52	$53,579	0.028

These results are consistent with, though not identical to other studies, which give the following costs of accidents by mode (Canadian cents per Pkm or Tkm)

Table 19

Cost of Accidents by Surface Transportation Mode, International Data

Country	Year	Car pkm	Bus pkm	Pass. Rail pkm	Truck tkm	Freight Rail tkm	Inland Water tkm
Germany	1990	2.83	0.51	0.44	1.62	0.01	0.01
France	1985				1.04	0.004	
Belgium	1985				0.48	0.19	
Switzerland	1991	4.20	1.02	0.57	4.96	0.04	
Sweden urban	1987	7.06	1.77	0.18	1.77		
Sweden interurban	1987	12.36	0.18		0.18		
USA	1990	2.83	0.60	0.51			

source: **IBI** Group **(1995)**
note: in **1994** Canadian cents

Australian data (ABTC 1992) shows an average cost per accident of $AU **10,378.** This result is significantly lower than American figures, principally due to a lower value **of** life in the Australian method, which is not **as** comprehensive as in the United States.

5.8.1.4 Incidence, Cost Allocation, and Recovery

Obviously, some costs of crashes fall on involved individuals, some on their insurance companies, and some on society at large. Therefore some of the costs are internal to the driver, some are external to the driver, but internal to transportation, and some are external to transportation. For the purposes of this analysis, insurance costs should not be counted simply in addition to accident costs to estimate "full costs" because insurance costs are a transfer of accident costs (and some overhead to cover risk and profit) from

the traveler to a third party. However, it is interesting to analyze who bears which costs of accidents.   Miller (1991) estimates the following incidence matrix using national data, associating cost category with the organization which bears the cost.

Table 20

Costs by Incidence

cost Category	Fed.	State	Auto Ins.	Health Ins.	Work. Comp	Life Ins.	Disab. Ins.	Other &Sick	Self	TOTAL
Medical	0.7	0.4	2.2	6.1	0.4			0.8	2.0	12.6
Emergency Services		0.9								0.9
Productivity	1.6	0.2	21.0		0.85	1.2	0.8	0.9	24.5	51.1
Income Tax	*5.8*	1.2								7.0
Workplace								2.4		2.4
Legal/Court			7.9		0.02					7.9
Admin	0.07	0.04	6.83	0.51	0.17	0.17	0.11	0.07		7.8
Travel Delay									2.0	2.0
Prop Damage			24.9						13.4	38.3
TOTAL	8.17	2.74	62.83	6.61	1.44	1.31	0.81	6.1	39.9	130.0

source Miller 1991 (p. 105)

note: 2.5% discount rate, 1988 dollars (Billions), excludes pain & suffering

5.8.2 *Valuing the Environment and Damages*

Perhaps the external costs with the greatest uncertainty are those relating to environmental damage. Damage to human health, agriculture, and buildings is one aspect of environmental externality. Damages resulting in acid rain, ozone depletion, and global warming are a second class.

The environment can be sectioned into air, land, and water components, which will need to be addressed in some fashion. Also the environment includes the more abstract notion of an ecosystem. Any new right of way will to some extent disturb the patterns of ecological interaction. Water pollution, including damage to wetlands, are a serious issue with highways, however these costs are quite site specific, and damages will probably need to be fully mitigated in construction. Therefore, these costs are included with infrastructure construction costs. Similarly, the taking of land for a new facility, and the creation of construction waste products which need to be land-filled are also infrastructure construction costs. This leaves air pollution, which will be the principal focus of this section.

Air pollution is in part an outcome of current fossil fuel based transportation vehicle technology. The switch to zero-emission vehicles or electrified rail moves the generation pollution from the transportation sector to the electricity generating sector, thereby reducing and changing but not eliminating air pollution. The following section describes

each of the air pollution damage issues. This is followed by estimating their production from the highway system. An estimate of damages per unit pollutant is provided.

5.8.2.1 The Nature of Air Pollution

Probably the most difficult cost to establish in any project assessment is that of air pollution. Determining the quantity of pollutants emitted from an automobile, truck or bus is in concept a relatively straight-forward engineering task, though it depends on vehicle type, model year, vehicle deterioration, fuel type, speed, acceleration and deceleration, and other factors. However, emission rates are determined by tests in laboratory, rather than actual conditions. *So* to some extent, these rates probably underestimate the amount of actual emissions (Small and Kazimi **1995).**

Determining the damage done is more difficult still. For a variety **of** reasons, pollution is generally considered a negative externality, the polluter involuntarily imposes a cost on the recipient. Studies have looked at various aspects of air pollution and its costs. This chapter will attempt a synthesis to provide useful information.

As used here, the costs of air pollution fall into four main categories: Photo-chemical Smog, Acid Deposition, Ozone Depletion, and Global Warming; though it is only the first and last for which significant research into transportation costs have been undertaken. There is considerable scientific controversy surrounding all of these categories, and there is no direct translation from pollutant emitted to damage. The amount of damage depends on a number of environmental factors including the place and time of emission.

5.8.2.2 How are the costs of pollution calculated?

First are damages: Calculations of the health effects of pollution have been attempted, though **as** with many numbers in this study, its accuracy is open to question. To some extent, the damage cost of pollution is capitalized in real estate values, but it is likely difficult to extract this information. Environmental economic studies have attempted to calculate damage losses due to global warming, and from that estimate an appropriate carbon tax, or price which would be charged on an activity based on the amount of carbon produced.

Second are protection measures, which include defense, abatement, and mitigation approaches to preventing or counter-acting a decision creating pollution. Some analyses use **100%** cost of mitigation. An example of a mitigation measure is the cost of the number of trees planted to *soak* up the C02 pollution generated. However, in some cases there may be no abatement measures, and the only prevention measure would be to avoid production.

Third, stated preference methods have been used, to estimate how much would people pay to avoid (or in be compensated) for a certain level of air pollution. Similarly, the implied cost due to preventative regulations may be a way to cost pollution. However,

these methods are suspect for a variety of reasons, including their hypothetical nature, which allows individuals to answer unrealistically, or perhaps even "strategically game" to influence the outcome of the study and thus influence policy.

The science of emissions estimation is an extremely complicated subject to which full justice cannot be provided in this research. Sophisticated models (e.g. EMFAC, MOBILE) have been developed which characterize emissions generation by a number of factors including fleet mix (size and age of vehicles), fuel usage, the environment (temperature) and travel characteristics.

Table 21

Summary of Exhaust Emission Rates from MOBILE 4 and EMFAC Models

Light Duty Autos (gasoline)(w/Cat Converter)	HC (TOG, VOC)	CO	NOx
Zero Mileage Level **Running** Emissions (g/mi)(MOBILE 4)	0.27810.305113.38 19921198211972	2.91513.376140.94	0.635/0.633/4.35
0-50 K Mile Deterioration Rate (g/mi/10K miles)	0.05610.07410.16	0.74811.07912.35	0.03410.07110.0
50+ K Miles Deterioration Rate (g/mi/10K miles)	0.07610.108110.160	0.93911.61612.35	0.034/0.071/0.0
Incremental Cold Start (g/trip)	4.84	48.47	2.85
Incremental Hot **Start** (g/trip)	0.60	9.80	1.59
Hot *Soak* (g/trip)	0.77	N/A	NIA
Diurnal Emissions (g/Hour)	0.75	NIA	N/A
Summertime, 1993, 75 **F**, running (EMFAC) 55 MPH	0.26	4.33	0.98

source: EMFAC, MOBILE

It should be noted from the table that light duty truck pollute about 20% more than autos, that medium duty trucks (with catalytic converters) pollute about two times as much as autos on HC and NOx and the same on CO, and that heavy duty trucks are also about two times for HC and CO, and five times for NOx.

It has been reported from studies of pollution in more realistic situations outside of the laboratory, that the rates proposed above may err on the low side. Small and Kazimi (1995) provide corrected emission factors. These factors should be considered in developing the measures of environmental damages.

5.8.2.3 Damages
Just as there is a divide in the sources for estimates of the quantity of emissions produced, there are also various sources of estimates of pollution costs. The first divide is between

the cost of accepting the damage as opposed to the cost of mitigating or offsetting the pollution. A second divide within damage estimates is between health and environmental damages, different pollutants are associated with each. These are dealt with in turn.

Table 22

Corrected Emission Factors, 1992 Fleet Averages

Pollutant	Gasoline Car	Light duty diesel truck	Heavy duty diesel truck
CO	13.000	1.607	9.326
VOC	3.757	0.362	2.356
NOx	1.260	1.492	15.683
SOX	0.038	0.122	**0.576**
PMlO	0.011	0.395	2.359

note: 1992 Fleet Average, (gm/mile) from EMFAC7F, updated for VOC underestimate **by** 2.1, Small and Kazimi, 1995

Lave and Seskin (1977) reported a regression **to** estimate mortality rate of various SMSA in 1969 as a result of a variety of factors, including sulfate readings and suspended particulates.

Table 23

Mortality Rate Regression Analysis

Variable	**Coefficient**	**T-Statistic**
Minimum Sulfate Reading	0.774	2.11
Annual Arithmetic Mean Suspended Particulate Reading	0.818	3.39
Population Density	0.131	2.54
Percentage of SMSA Population 65+	6.568	18.09
Percentage of the SMSA Population that is non-white	0.204	2.27
Precentage of the SMSA Population with incomes below the poverty level	0.557	2.29
the logarithm of the SMSA Population	-0.365	-1.94
Constant	330.647	

R-Square = **0.805**
source: Lave and Seskin (1977)

This provides an elasticity (with respect to mortality rate) of sulfates and particulates of 0.0297 and 0.0866 respectively (0.1163 in total). This assumes a linear relationship between pollutants and mortality, which is not in consonance with dose-response literature, but may be acceptable in a small range. Fuller et al(1983) apply this along with data from Cooper and Rice to estimate total health damage due to pollution **as**

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$21,982 million in 1977 $21,982 = 0.1163 * $258,920 * 73% (where 73% reflects percent of US population in SMSA).

Table 24

Cost of Illness (in millions of 1977 dollars)

Category	1972	1977
Direct	$75,231	$114,918
Morbidity	$45,323	$61,127
Mortality	$57,380	$82,874
Total	$174,934	$258,920

souce: Cooper and Rice **(1976),** Fuller et al **(1983)**

Using the methodology in the following table, they provide an estimate for damage costs from the various pollutants. Taking a tolerance factor based on health estimates at the time, this is converted to a severity factor relative to CO. Total tons are converted to CO equivalents, and then the costs are allocated to each pollutant based on their relative severity. This is multiplied by total costs to estimate total cost per pollutant, and thus cost per unit of emissions.

Table 25

Macroscopic Estimates of Cost of Pollution

	CO	**HC**	**NOx**	**SOX**	**PMIO**
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)**

Ottinger (1990) provides separate estimates of environmental and health damages per pollutant from a variety of synthesized methods. The results are reproduced in Table 26.

Some recent work on the costs of air pollution from cars comes from Small and Kazimi analyzing the Los Angeles region. They update factors from EMFAC and MOBILE 4 to correct for reported underestimation of pollution,. They also review recent evidence on mortality and morbidity and its association with pollutants (VOC, PM10, SOx, NOx). Using work from Hall et al(1992) and Krupnik and Portney (1991), they combine

various exposure models of the Los Angeles region with health costs   Their finding suggest that particulate matter is a primary cause of mortality and morbidity costs,

Table 26

Starting Point Costs of Environmental Damages by Pollutant (1989$CAN/kg)

Damage	Effect	SO_2	NOx and Ozone	Acid Deposit	PMlO	CO_2
Health	Mortality	$4.48	$0.89	na	$0.86	na
	Morbidity	$0.13	$0.76	na	**$0.08**	na
	Total	$4.61	$1.64	$0.00	$0.94	na
Materials	Corrosion/ Soiling	$0.31	$0.03	na	$0.00	na
Vegetation	Crops Ornamental Forests	$0.00	$0.03	na	$0.00	na
Visibility		$0.36	$0.44	na	$0.00	na
Ecosystems		na	na	na	$0.00	na
Historical Monuments		na	na	na	$0.00	na
	TOTAL	$5.29	$2.14	$0.00	$3.10	$0.018

source: Ottinger et al 1990

followed by morbidity due to ozone. Of course, costs in densely populated areas, such as the Los Angeles basin, should be higher than in rural areas as the exposure rate is far higher. They also assume a value of life of $4.87 million in their baseline assumptions, though they test other scenarios, we report their estimate using a $2.1 million value of life (VoL) for consistent comparison with other studies.

The health cost estimates from Fuller et al(1983) differ from the more recent effects estimated by Ottinger et al (1990), and even more so from Small and Kazimi (1995) estimates for the Los Angeles basin. The estimates are most similar on the ozone producing NOx and HC, and vary widest for the particulate problems due to PMlO and SOx . These are reported in Table 27.

Fuller et al(1983) also apply methods developed by Salmon (1970), Small (1977) and Schwing et al(1980) to estimate materials damage, again the numbers vary, this time Fuller's estimates are significantly higher. They are reported in Table 28.

Finally, Fuller et al update the results from a 1964 study (Benedict et al 1971) to estimate vegetation damage from air pollution. Both Fuller and Ottinger agree in general that

NOx is the primary source of vegetation damage, and their estimates $0.02 - $0.03/kg are close.

Table 27

A Comparison of Estimates of Health Effects ($/kg)

	Fuller et al	Ottinger	Small (1995) @4.87M VoL	Small (1995) @2.1 M VoL
SOX	$0.84	$4.61	$24.97	$10.76
NOx + HC	$1.22	$1.64	$3.09	$1.33
PMlO	$1.20	$0.94	$23.19	$10.00

note: Fuller et al. (1983) updated to 1995 U.S. dollars using medical care inflation rates
Ottinger (1990) updated from 1990 Can to 1995 U.S. dollars
Small and Kazimi (1995) in 1995 U.S. dollars, Los Angeles region

Table 28

Estimates of Materials Damage **($/kg)**

	Fuller et al	Ottinger
CO	$0.0063	na
HC	$0.19	
NOx	$1.00	$0.03
SOx	$1.60	$0.31
Particulates	$1.03	$0.00

note: Converted to 1995 U.S. dollars

Table 29

Vegetation Damage ($/kg)

	Fuller et al	Ottinger
CO	na	na
HC	$0.0019	na
NOx	$0.023	$0.03
SOX	$0.0019	$0.00
Particulates	na	$0.00

note: Converted to 1995 U.S. dollars

5.8.2.4 Full Cost of Pollution: Highway

Combining the information from the collection of tables above, it is possible to obtain an integrated cost of automobile travel. These figures, as for safety in the previous section, can be used in the calculation of benefits of alternative ITS projects. They are listed in Table 30.

Table 30

Air Pollution Costs of Automobile Travel

Pollutant	Emissions gm/pkm	Health Damage $/kg	Control Costs $/kg	costs $/km
PMlO	0.0066	$0.94 - $10.00	$0.36 - $9.46	$0.0000062 - $0.0000066
s o x	0.0228	$0.84 - $10.76	$0.91 - $13.75	$0.00001915 - $0.0002453
HC	2.254	$1.22 - $1.33	$3.96 - $5.83	$0.0027498 - $0.00299
CO	7.8	$0.0063	$0.96	$0.00004914
NOx	0.756	$1.22 - $1.33	$4.35	$0.000922232 - $0.00100548
Carbon	46	$0.0058	$0.0029 - $0.132	$0.000266
TOTAL				$0.0046

source: **Emissions:** Small **1995;** Damage **and** Control Costs: **Various.**

For cars, there is a cost of $0.0046 per passenger kilometer, $4.60 for the 1000 km trip. Rates for trucks are higher based on higher emission rates. The estimate of 0.43 cents per pkm by automobile (excluding the cost of carbon emissions and greenhouse effects) compares favorable with the low end of the range of estimates provided by IBI (1995).

5.8.3 Valuing Travel Time

The value of travel time savings are a major component of any project evaluation. It is used to establish a value of the aggregate of time resources saved **as** a result of any investment or change in management strategy. Despite much empirical investigation consensus as to what is the appropriate value to use in evaluations remains unsettled. This is not surprising since the valuation of time is a composite of value of time in use and value of time in exchange. It will vary from place to place, time to time and modal context. The variation in values is illustrated from the listing of empirical studies contained in Table **31.** Despite this agencies will have to select a value or range of values to be used in evaluations to ensure consistency in evaluations.

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Table 31

Values of Travel Time Savings

Author	Country	VTTS as % of Wage	Trip Purpose	Mode
Dawson and Smith (1959)	UK	86%	interurban	auto
Mohring (1960)	USA	22-43%	commuting	auto, transit
Claeson (1961)	SWEDEN	64%	commuting	auto
Claffey et al. (1961)	USA	65%	interurban	auto
Becker (1965)	USA	42%	commuting	auto
Beesley (1965)	UK	33-50%	commuting	auto
Lisco (1967)	USA	40-50%	commuting	auto
Thomas (1967)	USA	72%	commuting	auto
Quarmby (1967)	UK	20-25%	commuting	auto
Lave (1968)	USA	42%	commuting	auto
Stopher (1968)	UK	21-32%	commuting	auto
Oort (1969)	USA	33%	commuting	auto
Lee & Dalvi (1969)	UK	30%	commuting	auto
Hansen (1970)	NORWAY	36%	commuting	auto
Thomas & Thompson (1970)	USA	40-85%	interurban	auto
Howe (1971)	KENYA	102%	commuting	auto
Lee & Dalvi (1971)	UK	40%	commuting	auto
Wabe, J. (1971)	UK	43%	commuting	auto
Charles River Associates (1972)	USA	32%	commuting	auto
Dawsen and Eerall (1972)	ITALY	60-89%	interurban	auto
Talvittie (1972)	USA	12-14%	commuting	auto
Kentner (1973)	GERMANY	91%	commuting	auto
Kenter (1973)	GERMANY	40%	commuting	auto
Algers &=et al. (1974)	SWEDEN	21%	commuting	auto
Hensher & Hotchkiss (1974)	AUSTRALIA	27%	commuting	auto
Hensher & Delofski (1974)	AUSTRALIA	39%	interurban	auto
Kraft & Kraft (1974)	USA	38%	interurban	auto
O'Farrell & Markham (1975)	IRELAND	86%	commuting	auto
McFadden (1975)	USA	28%	commuting	auto
Ghosh, Lees & Seal (1975)	UK	73-89%	commuting	auto
McDonald (1975)	USA	45-78%	interurban	auto
Ghosh et al. (1975)	UK	73%	interurban	auto
Guttman (1975)	USA	63%	commuting	auto
Hensher (1977)	AUSTRALIA	145%	commuting	auto
Hensher & McLeod (1977)	AUSTRALIA	35%	interurban	auto
Nelson (1977)	USA	20%	commuting	auto
Hensher (1982)	AUSTRALIA	23-45%	commuting	auto
Hauer & Greenough (1982)	CANADA	46%	commuting	auto
Edmonds (1983)	JAPAN	67-101%	commuting	auto
Thomas (1983)	MALAYSIA	42-49%	commuting	auto
Algers & Wildert (1985)	SWEDEN	53%	commuting	auto
Chui & McFarland (1985)	USA	20-30%	commuting	auto
Deacon & Sonsteille (1985)	USA	82%	interurban	auto
Hensher & Troung (1985)	AUSTRALIA	52-254%	leisure	auto
Guttman & Memashe (1986)	ISRAEL	105%	commuting	auto
Fowkes (1986)	UK	59%	commuting	auto
Hau (1986)	USA	27-59%	commuting	auto
Winston et al. (1987)	USA	46%	commuting	auto
Horowitz (1987)	AUSTRALIA	75%	interurban	auto
Bates et al. (1987)	UK	68%	interurban	auto
Bates et al. (1987b)	UK	62%	commuting	auto
Chui & McFarland (1987)	USA	82%	commuting	auto
Mohring et al. (1987)	SINGAPORE	60-120%	commuting	auto
Hensher (1989)	AUSTRALIA	36%	commuting	auto
Hensher (1990)	AUSTRALIA	34%	commuting	auto
Cole Sherman (1990)	CANADA	93%	commuting	auto

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In selecting values of time to be used in different ITS projects the important factors to consider is the modal context and the type of time being saved. This goes to the issue that time is not simply a scarce resource but also has utility attached to it in use. Saving **30** minutes of driving on a relatively quiet rural roadway is not valued in the same way a saving the equivalent amount of time on a crowded urban expressway.

Another issue that requires attention is using information from projects in other jurisdictions in assessing your projects. The paucity of ITS projects has led some to argue that information from areas in the **U.S. as** well **as** abroad. However, different agencies use different values of time in evaluating projects. In **North** America, for example, 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, 7-80 percent of the wage rate. Clearly an identical project could be ranked quite differently indifferent jurisdictions. 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.

5.9 Summary

In this chapter a number of difficulties that arise when using evaluation methods have been examined. The purpose of the chapter was to identify pitfalls and to provide some guidance in overcoming them. In addition the valuation of benefits and costs was described in detail. The point has been made that benefits are a composite of quantities and prices and problems can arise in the calculation of either or both. In most cases the valuation and quantity measures are quite straightforward but in other cases there can be significant difficulties. We identified three areas requiring considerable care; valuing safety, valuing the environmental impacts and selecting a value for time savings.

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