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16. Abstract

Every entity, whether public or private, is confronted with the economic problem: it wishes to accomplish more than its resources will permit. This problem requires that two fundamental economic questions be answered: (1) what objectives should be pursued, and (2) how should these objectives be accomplished. In general, the answer to the first question is that an objective should be undertaken only when the value to be derived from undertaking it equals or exceeds what must be foregone to achieve it--its cost. The general answer to the second question is that each objective undertaken should be accomplished for the least amount of resources possible--or for the lowest cost.

Economic analysis provides a systematic approach to answering the economic questions. This Guide presents methodology for applying economic analysis to investment, regulatory, and certain grant award decisions commonly encountered by the Federal Aviation Administration. Techniques are developed for measuring such benefits as improved safety, delay reductions, cost savings as well as others. Cost estimation methodology and a discussion of distributional impacts are also presented.

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Economic Analysis of Investment and Regulatory Decisions--Revised Guide

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PREFACE

This document is intended to provide basic guidance for use in the conduct of economic analysis of investments, including certain Airport Improvement Program (AIP) grants, and regulations subject to Federal Aviation Administration decisionmaking.

It is the third edition of material originally issued in 1976 and subsequently revised and expanded by the Office of Aviation Policy and Plans in 1982. This edition provides a basic update to the 1982 guide. Updated material includes current Executive Branch policy, requirements, and procedures for the conduct of benefit-cost and associated analyses and references to current models and data sources. New material is also provided on subjects such as probabilistic assessment of the variability of benefit-cost estimates and the assessment of distributional impacts.

This edition represents an ongoing effort by the Office of Aviation Policy and Plans to provide up-to-date information together with workable, contemporary techniques for undertaking the required analysis. Further improvements are currently in progress or are planned, particularly with respect to benefit estimation techniques. Comments are invited on this edition as well as requests for inclusion of additional materials targeted at specific benefit-cost problems currently facing the Agency. Comments and requests should be addressed to the Economic Program Officer, APO-3, Office of Aviation Policy and Plans.

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INTRODUCTION

I. Purpose of Economic Analysis

Three major Federal Aviation Administration (FAA) programs are: (1) provision of air traffic communication, navigation, surveillance and management services--collectively known as air traffic control (ATC)--to the flying public, (2) establishment and enforcement of regulations to ensure safe and efficient operation of the national aviation system (NAS), and (3) administration of the Airport Improvement Program (AIP). Programs under the first category involve the construction, maintenance, and operation of the NAS. These programs require the FAA to make major decisions regarding the allocation of public and private resources. Such decisions involve system acquisitions to provide new services, extend already provided services to new locations, and improve internal operating efficiency. Efficiently making these decisions is a major task of FAA management.

Programs under the second category encompass the making and enforcement of rules, regulations, and minimum standards pertaining to the manufacture, operation, and maintenance of civil aircraft and to safety and operating standards for airports. These activities include the certification of new aircraft, oversight of the existing fleet regarding maintenance and operating problems, certification of pilots, mechanics, and others with respect to proficiency and medical fitness, and certification of certain airports. Many of these regulatory activities impose substantial costs in that they mandate the allocation of private resources to specific uses. Efficient regulations require that these costs be carefully weighed against the benefits they are expected to achieve.

The third program provides grants to airports for undertaking capital improvements. These may be made for a number of purposes including safety improvements, noise mitigation, and capacity expansion. Grants vary widely in scope and amount. Some involve major investments by the Federal Government in the nation's airport infrastructure.

The problem of resource allocation confronts agency managers, grant administrators, and regulators. The purpose of economic analysis is to provide such decisionmakers with a systematic approach to making resource allocation decisions leading to the undertaking of appropriate objectives in a least cost manner. Such analysis is specifically mandated with respect to Federal investments, regulatory actions, and certain AIP grants by Executive Orders, Office of Management and Budget Circulars, DOT Orders, FAA Orders, and other official guidance. (See Appendix A for an annotated list of relevant documents.) This handbook provides a guide to this process.

II. The Economic Questions

Every entity is confronted with the economic problem: it wishes to accomplish more objectives than its resources will permit. How entities may maximize the attainment of their objectives subject to the limited resources available to be utilized in pursuing these objectives involves the simultaneous answering of two fundamental questions:

1) Which objectives should be pursued?
2) How should these objectives be accomplished?

In general, the answer to the first question is that an objective should be undertaken only when the value to be derived from achieving it equals or exceeds what must be foregone to achieve it--its cost. The general answer to the second question is that each objective undertaken should be accomplished for the least amount of resources possible--or for the lowest cost. This will assure that the greatest number of objectives can be achieved for the available resources.

In the market economy, analysis can help provide answers to these questions. Market research can make decisionmakers aware of what goods and services consumers wish produced. Operations research and cost accounting methods can help assure that production is achieved at the lowest cost possible. Market forces will also aid decisionmakers in answering these questions before goods and services are produced. By producing only those goods and services which consumers are expected to buy, the question of what to produce is answered. In the quest to expand sales and increase profits, the lowest cost methods of production will be sought out. Market forces will also come to bear after production has occurred. Those who answered the economic questions correctly will be rewarded. Those who answered them incorrectly will be penalized. And those who answered them incorrectly and who continue to answer them incorrectly will not remain in business. The market economy optimizes the production and consumption of services.[1]

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[1] This, of course, assumes that the private sector markets are approximately competitive and that externalities--impacts on parties other than buyers or sellers--are not a significant consideration. Where the actual situation does not approximate competition and/or

In the public sector, the situation is somewhat different. Few goods and services which are governmentally produced, required by regulation to be produced, or partially or totally funded by governments are sold in the marketplace. Of those that are sold, the price is often arbitrary and may not recover the cost of providing the good or service. Accordingly, in the absence of market forces, there is no assurance that production is efficient. As a result of the lack of market direction in answering the economic questions, these answers must be obtained by analysis. Such analysis will indicate what goods are worth producing and how they can be produced as cheaply as possible.

A second difference between the private and public sector is that consumers of privately produced goods and services usually pay for them directly, whereas consumers of publicly produced goods and services usually do not. This factor does not eliminate the need to answer the economic questions correctly. Regardless of who pays for a good or service, it should be produced only if the value placed upon it by its consumers equals or exceeds the cost of producing it. Where value exceeds production cost, the aggregate value of all production increases because more value is generated by producing the good or service than is used up to produce it.[2] Similarly, instances where direct payment is not provided for a governmentally produced good or service do not change the requirement that production be accomplished at the lowest possible cost. The more efficiently inputs are transformed into outputs, the more outputs that can be produced.

Also, differences between the recipient and payer for governmentally produced goods and services raises distributional issues. Accordingly, analyses should be performed to identify which groups benefit from these goods and services and which groups bear their production costs. Where significant, analyses should measure the extent of such redistributions and to what degree, if any, those who benefit actually compensate those who initially incur the costs.

III. Handbook Organization

The remainder of the handbook contains seven chapters and two appendices. An overview of economic analysis and the procedures required to evaluate investments and regulations is contained in Chapter 2. Chapters 3 and 4 provide the conceptual framework for measuring and valuing benefits and costs. They also present practical

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externalities exist, the correct answer to the economic questions will not necessarily occur.

2 Such cases will have the characteristic that consumers of the good or service which was paid for by someone else could, if required, reimburse completely those who paid for it and still be better off than before.

guidance for estimating benefits and costs in situations which are typical of FAA investments, regulations, and grant programs. Multi-period economic decision criteria are developed in Chapter 5. Topics include why discounting must be used to compare benefits or costs occurring in different future time periods, how to use discounting, and how to make decisions between alternatives which extend over a number of time periods. Chapter 6 deals with variability in benefit-cost estimates. It presents techniques to aid decisionmakers in selecting between alternatives under conditions of risk and uncertainty. Techniques for measuring price level changes for specific goods or services, as well as for the general price level are contained in Chapter 7. This chapter also sets out the appropriate treatment for inflation in benefit-cost analyses. Chapter 8 addresses analysis of distributional issues

Appendix A contains a listing, accompanied by a brief explanation, of the Executive Orders, Office of Management and Budget Circulars, DOT Orders, FAA Orders, and other guidance which documents the requirement for economic analysis. Appendix B contains tables of factors useful in making the present value calculations detailed in Chapter 5.

CHAPTER 2

ECONOMIC ANALYSIS--AN OVERVIEW

I. General Types of Economic Analysis

The term economic analysis is a broad one. It encompasses a spectrum of topics including economy-wide analysis, regional studies, market structure investigations, and analysis of specific decisions. It is this last topic, as applied to FAA investment, regulatory, and certain grant award decisions, that is the topic of this handbook. Such applications usually concern the addition or subtraction of a particular investment or regulation to the existing system or body of regulations--denoted as marginal or incremental analysis. For the most part, the methodology outlined is also applicable to the evaluation of a system in total or a body of regulations.

Economic analysis of investment and regulatory decisions seeks to provide answers to two economic questions: (1) is a particular objective worth achieving, and (2) which of several alternative methods of achieving an objective is best? Two general procedures are employed to answer the questions. The first, cost effectiveness analysis, assumes that the first economic question has been answered in the affirmative and concentrates on providing an answer to the second question of which alternative is best. The second, benefit-cost analysis, seeks to answer both questions. While benefit-cost analysis is more complete than cost-effectiveness analysis, studies are often limited to the latter because of an inability to measure benefits in dollars.

A. Cost Effectiveness

There are two types of cost-effectiveness analysis: (1) least cost studies, and (2) constant cost studies. Least cost studies are appropriate where the level of effort is undetermined and relatively unconstrained but the level of output/benefits is fixed. The procedure concentrates on identifying the least expensive way of producing a given amount of a certain output. The analysis typically begins with a statement of a required objective. Alternative methods of achieving the requirements are then defined. Costs are estimated for each alternative and the least cost alternative identified.

Least cost studies are frequently undertaken when the decision has already been made to produce a given amount of the output in question. Examples of such situations are when a requirement for the output is established by administrative or legislative direction, when the output is required to support another program which is required, or when deciding whether or not to replace existing equipment with new, cheaper-to-operate equipment which produces the same output. In all such situations, the analysis is confined to answering the question of how to produce.

Constant-cost studies are appropriate in situations where the level of output/benefits is undefined but the budget/resources available are fixed. The purpose of the analysis is to identify the outputs of each of a number of equal cost options and then decide which of the alternatives is best for producing the determined level of outputs/benefits. Such a situation typically arises where an agency is allocated a given amount of funds and directed to pursue a particular objective. The analysis permits the agency to determine how to produce the maximum amount of desired output/benefits with the given funds.

Analyses of this type require that outputs be measured in some way. If only one output is involved, the measurement can be in any convenient albeit arbitrary unit. If more than one output is involved, a unit of measurement applicable to all units is required. If no such unit can be found, the study must of necessity be confined to a description of the outputs of the various alternatives. Judgments as to the relative importance of each separate output are then left to the policymaker.

B. Benefit-Cost Analysis

Benefit-cost analysis seeks to determine whether or not a certain output shall be produced and, if so, how best to produce it. It thus goes beyond the limited objective of cost-effectiveness analysis of determining how best to produce. Benefit-cost analysis calls for the examination of all costs related to the production and consumption of an output, whether the costs are borne by the producer, the consumer, or a third party. Similarly, the method requires an examination of all benefits resulting from the production and consumption of the output, regardless of who realizes the benefits. Because the ultimate objective of benefit-cost analysis is the comparison of benefits and costs, they both must be evaluated in the same unit of measurement. It is rare that anything other than dollars (or another monetary unit) proves to be satisfactory.

The benefit-cost procedure requires that alternative methods of producing the output be identified. The benefits of each alternative are then valued in dollars and compared to their expected costs. That alternative for which benefits exceed costs by the greatest amount is identified as the project alternative to be undertaken. The action is worth taking because benefits exceed costs. It is best because benefits exceed costs by the greatest amount. Unfortunately, such studies often experience difficulty in the identification and valuation of benefits. Governmentally produced outputs (or outputs required to be produced by regulation) are usually not sold under market conditions making it difficult to determine their value to consumers and the benefits they may provide to the rest of society.

II. Economic Analysis Process

The economic analysis process consists of nine steps:

1. Define the Objective
2. Specify Assumptions
3. Identify Alternatives
4. Estimate Benefits and Costs
5. Describe Intangibles
6. Compare Benefits and Costs and Rank Alternatives
7. Evaluate Variability of Benefit-Cost Estimates
8. Evaluate Distributional Impacts
9. Make Recommendations

The analytical considerations involved in each of these steps are described as follows.

STEP 1 - DEFINE THE OBJECTIVE

The analysis cannot proceed until the exact objectives of the project or regulation under consideration are precisely stated. Moreover, any project or regulation actually undertaken without a clear understanding of the desired outcome is likely to be inefficient and, perhaps, unnecessary. The objective should be stated in terms of desired outputs of the project or regulation. It is a common failing to describe an action in terms of the inputs required to accomplish it. For example, the objective of providing airspace surveillance should be stated in terms of the expected improvement in benefits--enhanced safety, increased system capacity, reduced costs, better weather detection, etc.--rather than as a need to procure a new radar system.

In some situations the objective will be specified by external authority. For example, either the executive or legislature may mandate that a particular objective be pursued. The analyst's role in such a case is limited to formulating a succinct statement of the mandated objective and clarifying ambiguities that may be present in it.

At times, several projects or regulations may be combined for administrative purposes. For analytical purposes, they should be separated and independently evaluated to the extent that their objectives are functionally separate. Functionally separate objectives are those which are independent of each other and do not depend upon common investments or regulations. For example, regulations pertaining to design requirements of different types of aircraft should be considered separately. But regulations concerning flight time and duty time restrictions should be considered together because one interacts with the other. As to common investments, the separate objectives of safety and delay reduction should be considered together when they arise from a common investment such as an ASR and separately when they arise from separate investments such as an LLWAS (safety oriented) and PRM (delay reduction oriented).

STEP 2 - SPECIFY ASSUMPTIONS

Analysis of projects and regulations which will have most of their impact in future years involves a substantial amount uncertainty. In order to proceed, assumptions must frequently be made. For aviation investment and regulatory analyses, assumptions generally include aircraft fleet characteristics, levels of aircraft activity, equipment life, the number of passengers and/or shipment revenues, the cost of fatalities and injuries, and the value of passenger time. These should be explicitly identified and their basis--judgment, econometric forecast, etc.--clearly elaborated. Assumption specification often cannot be done exhaustively as a second step. Frequently, some assumptions cannot be specified at the beginning of a project. Others must be changed as the project proceeds and more information is obtained or information gaps appear that can be filled only by assumption.

STEP 3 - IDENTIFY ALTERNATIVES

There are normally several ways to achieve an end. It is important to identify all reasonable ways to achieve the desired objectives. This step is critical because only those alternatives that are identified will be evaluated. Any alternatives that exist but are not identified cannot be selected as the most efficient method to achieve the objective. In the absence of a sufficiently low cost alternative, the analysis that follows may determine that the objective is not worth undertaking since its costs exceed its benefits.

This step should not be interpreted to require that every conceivable alternative way of doing something needs to be included in the analysis. Many technically possible alternatives may be ruled out from the beginning as inferior to others which are being considered. This may occur in several situations. First, it may be well known that a particular approach is more costly than others, at least for the scale of activity under consideration. Second, it must be recognized that most investments or regulations build upon existing ones. Because new investments or regulations must mesh with existing ones, many potential alternatives which do not mesh can be ruled out. Note that this exclusion criterion is not applicable when considering the adoption of a new system or a functionally separate set of regulations or a replacement for existing ones. Finally, other cases may arise where it can be determined that one or more alternatives are inferior to the others before a formal analysis is undertaken. The analyst is cautioned that such determinations should be well founded and supportable. Moreover, while such exclusions will save analytical resources, care must be taken that viable alternatives--perhaps the best one--are not excluded at this point. In particular, the analyst must not exclude alternatives merely because a predisposition exists in favor of others arising out of causes such as past practice or external constraints such as budget or personnel ceilings.

Successful alternative identification requires extensive knowledge of the production process or processes which can be utilized to achieve the objective. Such information is often highly technical and not confined to any single area of expertise. As a result, it is often necessary to enlist the aid of one or more technical experts at this stage of the analysis.

STEP 4 - ESTIMATE BENEFITS AND COSTS

This step requires that the value in dollars of all quantifiable benefits and costs be estimated. With respect to benefits, it is first necessary to determine the goods and services which the project or regulation can be expected to yield. Then, the value of these goods and services must be determined. For costs, the physical resources which the project or regulation will consume must be determined and their costs estimated. Guidelines for formulating benefit estimates are presented in Chapter 3. Procedures for cost estimation are contained in Chapter 4.

STEP 5 - DESCRIBE INTANGIBLES

A natural follow-on to quantification of benefits and costs is the identification and description of intangibles--those things which cannot be evaluated in dollar terms. Intangible considerations should be listed and described for the decisionmaker. If possible, a range in which a dollar value could be reasonably expected to fall should be reported.[1] Intangibles should not be neglected; it is very likely that they will be extremely important to the outcome of the analysis.

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[1] Note that to the extent that a benefit or cost initially thought to be an intangible can be described with a minimum and maximum value and characterized by a probability distribution, it may be possible to treat it as a quantifiable item in the variability analysis described in Step 7 and Chapter 6 below.

STEP 6 - COMPARE BENEFITS AND COSTS AND RANK ALTERNATIVES

It is this step that provides answers to the economic questions of what objectives to pursue and how most efficiently to obtain them. It establishes whether or not benefits exceed costs for any or all of the alternatives, thus indicating whether or not the objectives should be undertaken. In addition, by providing a ranking of the alternatives it identifies which is the most efficient in achieving the objective. Criteria for making this comparison are enumerated in Chapter 5.

STEP 7 - EVALUATE VARIABILITY OF BENEFIT AND COST ESTIMATES

Because uncertainties are always present in the benefit and cost estimates used in the comparison of alternatives in STEP 6, a complete picture of the situation can best be presented only if this uncertainty is explicitly considered.[2] Techniques for doing so include sensitivity analysis, monte carlo simulation, and decision analysis. By utilizing these and other methods, it is possible to examine how the ranking of the alternatives under consideration holds up to changes in relevant assumptions and, given uncertainty, how likely it is that the project is or is not worth doing. Selected methodologies are presented in Chapter 6.

In addition to helping deal with uncertainty, such analysis also provides feedback within the economic analysis process. At this stage of the analysis, it is often necessary to change key assumptions, formulate additional alternatives, and/or revise methodology. The analysis is then repeated under these new conditions. Thus, the economic analysis process becomes an iterative one.

STEP 8 - CONSIDER DISTRIBUTIONAL IMPACTS

For many Governmental investments and regulations, the recipients of the benefits are not those who bear the costs. From an overall perspective, society's welfare is improved as long as all accepted projects and regulations have benefits in excess of costs. This is true because those who benefit could fully compensate those who bear the costs and still be better off. However, while the potential for compensation may exist, it may not occur, or it may require further initiatives to implement. If costs are imposed on parties who neither benefit nor are compensated, the impact will be inequitable. Benefit-cost analysis should identify gainers and losers of Governmental investments and regulations and whether gainers actually compensate losers. When benefits and costs have significant

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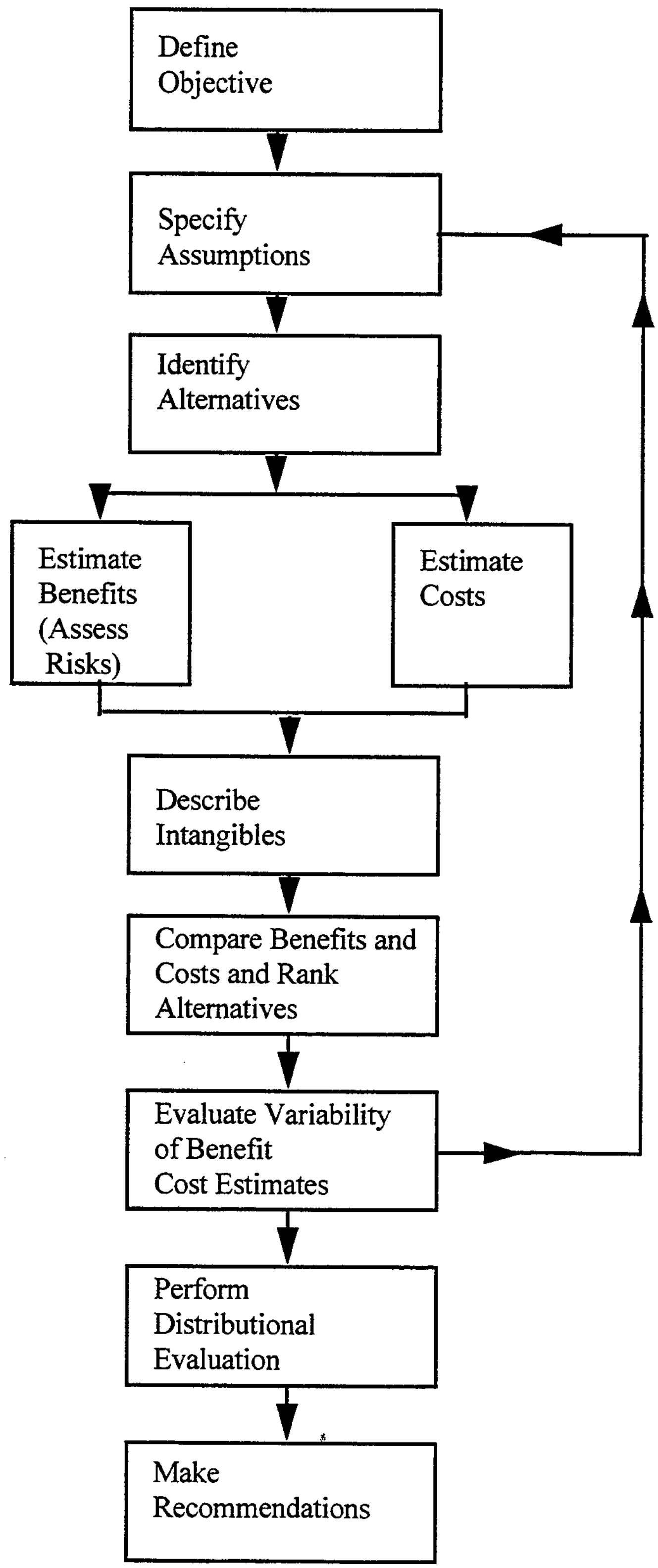
2 Such techniques are sometimes referred to risk analysis. It should be noted that techniques to evaluate the variability of benefit and cost estimates maybe separate and distinct from risk analysis conducted to assess problems the solution of which is the objective of the project or regulation.

distributional effects, these should be analyzed and discussed. Procedures for undertaking this analysis are contained in Chapter 8.

STEP 9 - MAKE RECOMMENDATIONS

The final outcome of the economic analysis process is a recommendation concerning the proposed objective. Under a benefit-cost analysis there are two parts to this recommendation: should the activity be undertaken, and if so, which alternative should be selected to achieve it. For a cost-effectiveness analysis, one of two answers is provided: which alternative should be selected to achieve the objective or on what activities should a fixed amount of resources (e.g., budget) be expended so as to best achieve the stated objectives. Note that this step goes beyond STEP 6 in that it incorporates not only a comparison of alternatives but also information gained by the risk analysis and the iterative process. The entire economic analysis process is summarized in Figure 2-1.

FIGURE 2-1
ECONOMIC ANALYSIS PROCESS



CHAPTER 3

BENEFIT ESTIMATION

I. General

Benefits are the outputs of goods or services that are produced by the investments, operations and regulations of a government agency. Most frequently they are provided to the public but may on occasion be furnished to other governmental agencies. When valued in dollars, benefits are analogous to (but not identical with) private sector revenues. However, unlike the private sector where products are sold and their value established in the market place, most governmental outputs frequently are provided free or at arbitrary prices. As a consequence, measurement of benefits can be a formidable task.

A related outcome of government operations or regulations are cost savings. While savings benefits do not represent products or services delivered to the consumer, they are reductions in the cost of delivering these items. The savings provide resources which may be used in other activities to produce new goods and services. Thus, savings should be treated as benefits because they represent value to the government and/or private parties which arises as the result of undertaking a project or regulation and incurring its life cycle cost.

The benefit estimation procedure is a three step process. The first step is to identify what effects will occur and who will be affected as a consequence of undertaking an activity. This can be difficult in itself if the proposed activity is large and/or complex. The second step is to measure these effects in physical units. Finally, the physical units must be valued in dollars. Suggested procedures for accomplishing these tasks are detailed in Section III. A theoretical basis for valuation is considered in Section II.

II. Benefit Valuation

A. A Concept of Value

Before beginning a discussion of how to value specific benefits, it is important to know what is meant by value and how it can be measured. In this discussion a principal distinction lies between the value of a product to consumers and the amount of money they must spend to acquire the product. When a consumer voluntarily exchanges money for a specific commodity, the consumer indicates that the value placed on the specific commodity equals or exceeds the value placed on what that amount of money could buy in its next most valued use. If it did not, the consumer would not voluntarily make such an exchange. Thus, the amount of money expended on a commodity is a minimum measure of the value of a commodity to a consumer. The total value of a commodity is measured by the maximum amount of money a consumer would be willing to give up and still be willing to voluntarily engage in the exchange. The concept of value measurement may be clarified with reference to the economist's concept of the demand curve.

Figure 3-1 presents a typical demand curve for a particular commodity. The curve indicates the quantity of the commodity that consumers as a whole will purchase at any particular price. It slopes downward to the right because consumers can be expected to purchase larger quantities at lower prices than at higher ones. A useful property of the demand curve is that it traces out the prices which consumers are just willing to pay for an additional unit of a commodity for all different quantities actually purchased. This price represents the marginal value placed by consumers on an additional unit of the commodity. In Figure 3-1, the demand curve shows that consumers can be expected to buy quantity Q_1 at price P_1. To induce consumers to increase purchases by one unit to Q_2, price must fall to P_2. Thus, the maximum price that will be paid for one more unit, provided that Q_1 units are currently being purchased, is P_2. Or in other words, P_2 is the marginal valuation which consumers place on this unit of the commodity. To determine the marginal value of each successive unit, it is necessary to repeat the process. The total value to the consumers of a number of units is obtained by summing the marginal valuations.[1]

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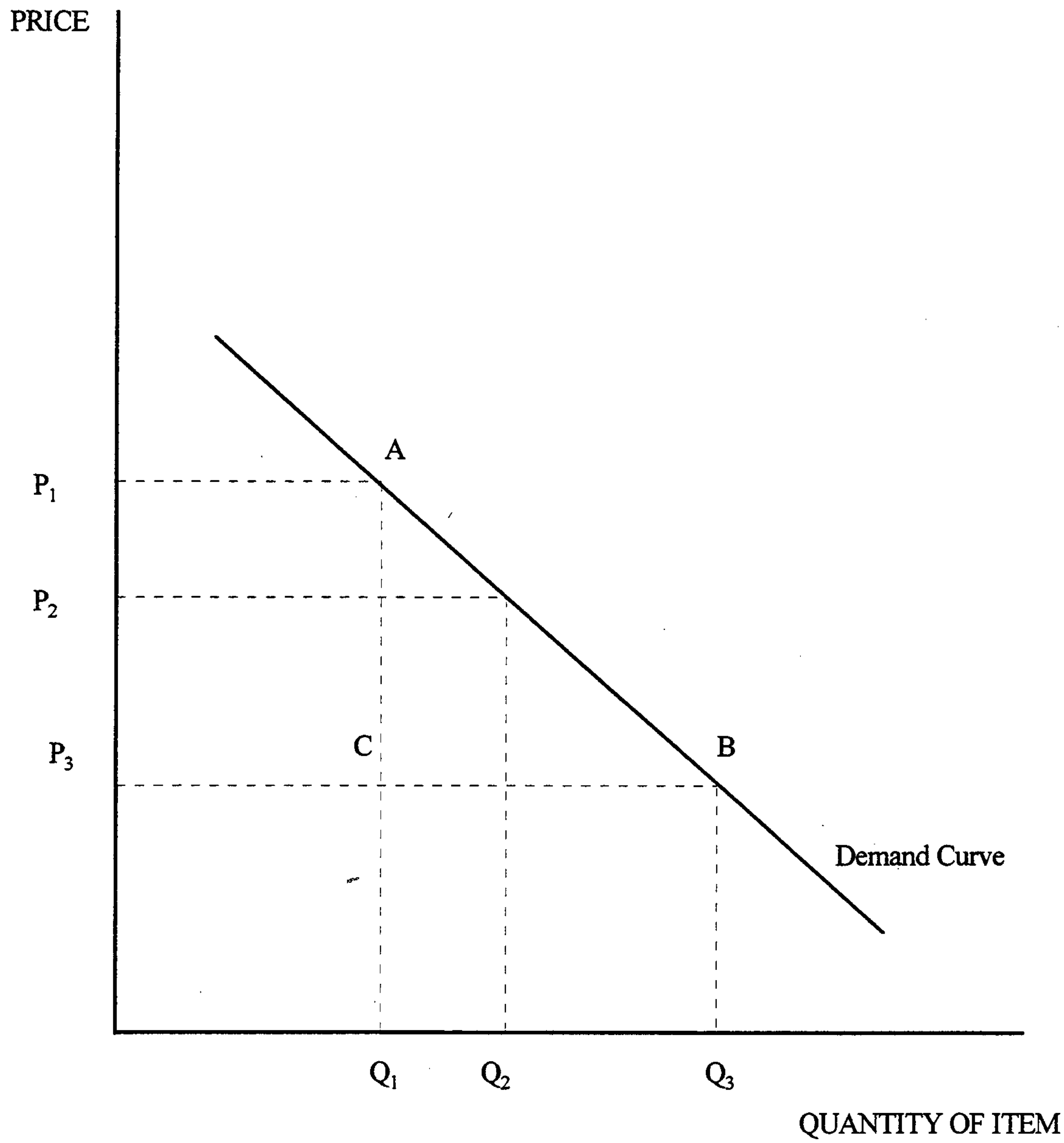
[1] The demand curve described here is known as a "compensated" demand curve along which real income is held constant. It is different from the commonly observed empirical demand curve along which real income changes. However, in most situations including those faced by FAA, empirically observed demand curves will closely approximate "compensated" ones and can be used directly in benefit-cost analysis without adjustment. For an introductory discussion of this issue, see Mark Blaug, *Economic Theory in Retrospect*, Richard D. Irwin, Inc., Homewood, Illinois, 1968, pp. 359-373.

FIGURE 3-1

TYPICAL DEMAND CURVE



In Figure 3-1, the sum of the marginal valuations of units Q_3 - Q_1 is represented by the area Q_1ABQ_3. This area represents the maximum amount consumers would be willing to pay for units Q_3 - Q_1. It consists of rectangle Q_1CBQ_3 plus triangle ACB. Rectangle Q_1CBQ_3, equal to P_3 x (Q_3 - Q_1), equals the total amount consumers would be required to pay for Q_3 - Q_1 at P_3. Triangle ACB represents additional value of the units Q_3 - Q_1 overand above this payment which consumers would be willing to pay rather than go without these units of the commodity.

B. Benefits of FAA Actions

Most FAA investment projects, AIP grants, and regulatory actions are intended to reduce the costs of air transportation. Cost reductions accrue to the flying public through reduced accident costs, reduced delay costs, and in other ways. To the extent that FAA activities result in relatively small cost reductions, the benefits of such activities may be valued based on current system use without taking into account any increase in system usage resulting from cost reductions. With reference to Figure 3-1, assume that an FAA action causes the per unit cost of using some segment of the system to fall from P_1 to P_2. The value of this to the current users of the service may be approximated by (P_1 - P_2) x Q_1. Although this procedure understates the true increase in value by ignoring the value of unit Q_2 - Q_1, the amount of error is small enough that it can be ignored for practical purposes.

For activities that result in larger cost reductions to the public, the value of additional units which will be demanded must be considered or the total increase in value will be substantially understated. In terms of Figure 3-1, if costs are reduced from P_1 to P_3, consumers of Q_1 units will be benefited by (P_1 - P_3) x Q_1. But the reduction of P_1 - P_3 will also induce the additional units of Q_3 - Q_1 to be demanded, both by current and new consumers. The value of these units is equal to the sum of the their marginal valuations as indicated by area Q_1ABQ_3. The magnitude of the cost reduction makes this amount large enough that it can no longer be ignored.

Frequently, the value of additional units such as Q_3 - Q_1 are measured net of the costs which consumers must bear to consume them. The resulting net benefit is then compared to other public and private costs in the benefit-cost analysis. In Figure 3-1, the net benefit would be represented by triangle ACB under this procedure. This is equal to the sum of the marginal valuations, Q_1ABQ_3, less the amount consumers are required to pay, as shown by rectangle Q_1CBQ_3. (Note, this procedure is strictly a convention. The same result would occur if total benefits of units Q_3 - Q_1, Q_1ABQ_3, were counted under benefits and consumer borne costs, Q_1CBQ_3, considered under costs in Chapter 4.)The total net benefit of a project is equal to the sum of the benefits to current consumers plus that associated with the additional units demanded because of lower costs. In Figure 3-1, this amount is indicated by area P_1ABP_3.

For commodities traded in markets, value may be determined with reference to observed market behavior of consumers. For many items produced by government or brought about by government investments, grants, or regulation, value cannot be determined by reference to market behavior because the items are not traded in markets. Rather, they are provided free or at arbitrary prices. Nonetheless, they may be valued by determining the maximum amount consumers would be willing to pay for them. The following section outlines methodology for estimating the value of benefits provided by FAA investments, AIP grants, and regulatory activities.

III. Benefit Categories

There are three primary areas in which FAA investments, AIP grants, and regulations generate benefits. These are safety improvement, capacity increases including congestion related delay reductions and avoided flight disruptions, and cost savings. Other benefits outside of these three areas also frequently occur and should be included in any particular analysis using appropriate methodology for the particular circumstance. Each of these benefit areas is now considered.

A. Safety

Safety may be defined in terms of the risk of death, personal injury, and property damage which results from air transportation accidents. A major responsibility of FAA is to reduce the incidence of such outcomes. FAA carries out this function through its capital investment, operations, and regulatory functions. The evaluation of the benefits of such activities requires determination of the extent to which deaths, injuries, and property damage resulting from preventable accidents will be reduced, and that these reductions be valued in dollars. This subsection presents methodology for determining deaths, injuries, and damages prevented by risk reduction. Once known, these can be valued in dollars by applying standardized DOT and FAA economic values.[2]

[2] See "Treatment of Value of Life and Injuries in Preparing Economic Evaluations," Office of the Secretary of Transportation Memorandum, January 6, 1993 and subsequent annual updates; and *Economic Values for Evaluation of Federal Aviation Administration Investment and Regulatory Programs*, Federal Aviation Administration, Report FAA-APO-89-10, October 1989.

1. Unit of Exposure

Meaningful accident measurement requires that accidents be stated as a rate per some unit of exposure. Such a unit should have the characteristic that each time it occurs an accident of a particular type either can or cannot result. The appropriate unit of exposure will differ depending on the type of accident under consideration. Every aircraft movement from one point to another consists of several components: departure taxi, take off, climb out, enroute cruise, descent, approach, landing, and arrival taxi. All components other that the enroute cruise will have approximately the same duration each time they occur and will be approximately independent of the duration of the enroute component. Moreover, each component other that the enroute one constitutes a self contained phase of flight which is approximately the same from one flight to another and which must be undertaken each and every time an aircraft is flown from one place to another. Accordingly, because the risk of an accident can be considered to be approximately independent of the duration of a flight for all but the enroute component, the appropriate measure of exposure for other than enroute accidents should not vary with the duration of a flight.

For the enroute component of a flight, the opportunity for an accident to occur is present throughout its duration. The longer the enroute component lasts, the greater the exposure to the risk. Consequently, appropriate exposure measures for the enroute component should vary with the duration of the flight. In the case of enroute turbulence accidents, the exposure measure should also vary with the number of passengers transported. This is because the chance that at least one passenger's seat belt will be unfastened at the same time an aircraft encounters turbulence, thus creating an opportunity for a turbulence accident, varies with the number of passengers, as well as with the duration of the flight.

For the most part, all flight segments except the enroute one occur primarily in the terminal area. Acceptable exposure measures are operations and instrument operations.[3] An operation occurs each time an aircraft either takes off or lands. An instrument operation occurs each time an aircraft on an instrument flight plan takes off or lands. A third measure, instrument approaches (as distinct from instrument operations), occurs each time an aircraft on an instrument flight plan makes an instrument approach under instrument weather conditions. Although conceptually acceptable and used in many previous analyses, instrument approach counts are subject to errors. Moreover, in many applications it is necessary to estimate the number of instrument approaches that would be expected to occur if an instrument approach should be installed where one does not now exist. Accordingly, it is not recommended that this measure be used. Rather, instrument approaches should be estimated directly from operations and weather data.

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[3] Data may be found on Office of Aviation Policy and Plans Home Page, http://api.hq.faa.gov/apo_home.htm.

Acceptable techniques for and applications of such estimation may be found in "Preliminary Analysis of the Correlation Between Annual Instrument Approaches, Operations and Weather," Federal Aviation Administration, Report No. DOT-FAA-78WA-4175, December 1980, *Establishment and Discontinuance Criteria for Precision Landing Systems*, Federal Aviation Administration, Report No. FAA-APO-83-10, September 1983, Appendix C, and *Establishment Criteria for LORAN-C Approach Procedures*, Federal Aviation Administration, Report No. FAA-APO-90-5, pp. 7-8.

For accidents which occur enroute such as those resulting from engine failure or flight system failure, exposure measures related to flight duration are appropriate. Acceptable measures are hours flown or miles flown. Measures which also reflect the number of passengers carried such as passenger miles, the product of miles flown and passengers carried, should not be used because the risk of these types of enroute accidents is not dependent on the number of passengers being carried. (For enroute turbulence accidents, measures such as passenger miles are acceptable.)[4]

2. Models

One method of determining prevented deaths, injuries and property damage is to construct a model which relates these items to a unit of exposure. Such a model typically computes the number of accidents that can be expected to occur per unit of exposure both with and without a particular system in place. The difference is the number of prevented accidents. The actual estimating procedure can be as simple as calculating accidents as a fraction of the exposure unit. Or it can be complex, allowing the probability of an accident to vary with a host of other factors such as weather, aircraft types, length of runway, etc.[5]

Prevented deaths, injuries, and property damage can then be ascribed to the prevented accidents using historical averages for these types of accidents for fatalities, minor and serious injuries, and damage per accident. Because there is wide variation in fatalities, injuries and property damage by type and size of aircraft, as well as by passenger loads, it is important that the averages used reflect the aircraft types and passenger loads likely to have been involved in the prevented accidents. This can be accomplished by using different averages for different airports or air routes.

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4 *Air Carrier Traffic Statistics*, Bureau of Transportation Statistics, U.S. Department of Transportation, published monthly.

5 A simple model that relates terminal area mid-air collisions, both with and without an airport traffic control tower, to traffic levels is developed in *Establishment and Discontinuance Criteria For Airport Traffic Control Towers*, FAA Report FAA-APO-90-7, August 1990.

3. Judgmental Accident Evaluation

A second method for determining prevented accidents is to examine a large number of accidents of a particular type and make a judgmental determination of which ones could have been prevented by the investment or regulation in question and which ones could not have been. To add validity to the work, it is often desirable to have the analysis of accidents undertaken by a group of knowledgeable individuals so as to avoid the biases of any one particular person. In those cases where a decision between classifying an accident as preventable or not preventable is a toss-up, it should be classified as preventable by convention. This is done to let the benefits of any doubt favor making the investment or implementing the regulation.

The judgmental method has the advantage of simplicity and ease. Moreover, it does not have the large data requirements typically associated with model estimation. It has the disadvantage of almost always overstating the benefits of any proposed activity. This occurs because some accidents judged preventable would still have occurred. A given safety program will be successful in preventing only a certain percentage of all potentially preventable accidents. This percentage is generally unknown. Note, however, that a proposed activity which fails to muster benefits in excess of costs when the judgmental method is used is probably not worth undertaking.

4. Estimating Accident Risks Absent Historical Data

Often it is necessary to determine accident risks when there are not historical data. This situation can arise under a number of circumstances. These include cases where common sense tells us that the probability of an accident is not zero yet no accident has ever occurred. (This could occur either because the probability of a accident is very small and one has just not happened yet despite numerous opportunities--such as an aircraft crashing into a nuclear power plant--or because a new technology is involved and there has been limited opportunities for accidents to happen--such as with high intensity radiated fields interference with aircraft systems.) Another would be when it is necessary to make estimates outside of the range of previously observed data, as is the case with issues involving aging aircraft.

In all such cases, it should be recognized that an accident risk estimate is a forecast which should be based on a logical extrapolation of all currently available information and data. In fact, the choice of an estimating approach will often be driven by the amount and quality of data available. There are several ways to proceed, including:

- Analytical deduction: Although there may be no direct observations of accidents themselves, frequently information and data will exist concerning the processes which produce the accidents of interest. In such cases, it may be possible to construct models of the accident process, assign values to model parameters using data which is available, and analytically calculate accident risk estimates. Examples of this approach include fault tree analysis (FTA) and failure modes and effects analysis (FMEA).[6]

- Analogies: Despite the lack of historical data specific to the problem at hand, there may exist similar but not identical situations from which accident risk estimates can by made by analogy, with appropriate adjustment--either judgmental or analytical--to reflect the differences between the analogous situation and the one of interest. Such an approach essentially involves an extrapolation beyond the range of available data. It can be expected to be progressively less representative the greater the range of extrapolation.

- Statistical estimation: Often limited but incomplete information or data may exist. In such cases it may be possible to develop estimates of accident risk using certain statistical techniques including selected Bayesian methods. Such procedures combine existing or prior information--developed either empirically or from expert opinion--with situation-specific information (often of a limited nature) in a systematic fashion to yield the desired estimates.[7]

5. National Aviation Safety Data Analysis Center

Numerous data bases suitable for safety benefit development are maintained by FAA in the National Aviation Safety Data Analysis Center (NASDAC). These include both data on accidents, incidents, and near misses as well as selected exposure data such as hours and miles flown by air carriers. A detailed listing of data maintained by NASDAC is contained in Table 3-1 .

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6 A discussion of these and other techniques may be found in *Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment*, Society of Automotive Engineers Aerospace Recommended Practice (ARP) 4761, Warrendale PA, 1996 and in K. G. Vohra, "Statistical Methods of Risk Assessment for Energy Technology," in *Low-Probability High-Consequence Risk Analysis: Issues, Methods, and Case Studies*, edited by Ray A. Waller and Vincent T. Colvello, Plenum Press, New York, 1984.

7 For a discussion of such techniques see H. F. Martz and M. C. Bryson, "Predicting Low-Probability/High-Consequence Events," in *Low-Probability High-Consequence Risk Analysis: Issues, Methods, and Case Studies*, edited by Ray A. Waller and Vincent T. Colvello, Plenum Press, New York, 1984.

TABLE 3-1

DATA BASES AVAILABLE in NASDAC

Source	Data Range
National Transportation Safety Board Aviation Accident Database	1983 - Current
NTSB Safety Recommendations/FAA Responses	1963 - Current
NAIMS -Pilot Deviations(PDS)	1987-Current
NAIMS-Operational Errors & Deviations (OEDS)	1985 - Current
NAIMS-Near Midair Collisions (NMACS)	1987 - Current
NAIMS-Vehicle/Pedestrian Deviations (VPDS)	1988 - Current
NAIMS - Runway Incursions (RI)	1988 - Current
FAA Accident/Incident System (AIDS)	1978 - Current
Service Difficulty Reporting System (SDRS)	1986 - Current
Aviation safety Reports	1988 - Current
Airclaims Database (AC)	1952 - Current
General Aviation activity (GA) Survey	1992 & 1993
NFDC - Landing Facilities (LF)/Airports (APT)	Current
NFDC - Air Route Traffic Control Center(ARTCC)	Current
NFDC - Radio Fix(FX)	Current
NFDC - Location Identifier	Current
NFDC - Navigational aids(NA)	Current
Aircraft Registry(AR)	Current
Aviation System Indicators(SI)	1983 - Current
Aircraft Operations Data - tower counts	1987 - Current
BTS - Form 41 Activity (T1) for large carriers	1974 -Current
BTS - Form 41 Activity (T2) by carrier/aircraft. type	1968 - Current
BTS - Form 41 Activity(T3) by carrier/airport	1990 - Current
BTS Bulletin Board System (Form 41 financial data)	1992 - Current
BTS - Form 41, 298-C, etc.	Current
FAA Aviation Safety Analysis Systems(ASAS)	Current
FAA Flight Standards Info. systems (FSIS)	Current
Aviation Data CD-ROM(Pilots, Aircraft, Owners, Mechanics, Medical Examiners, Airports, SDRS, Air taxis, Schools)	Current
ATP Navigator(Airworthiness Directives, Associated Service Information, Type Certificates, Supplemental Type Certificates, Advisory Circulars, Federal aviation Regulations, and Orders)	Current
Aviation Publications (FARS, AIM, Advisory Circulars, and Airworthiness Directives)	Current
Jane's	Current

Selected NASDAC databases and exposure data--including the National Transportation Safety Board Aviation Accident Database, Near Midair Collisions, FAA Accident/Incident System, and selected Bureau of Transportation Statistics Form-41 data--are also available on the internet at http://nasdac.faa.gov/internet.

B. Capacity Increases which Reduce Congestion Related Delay[8]

The major reason for operating the air traffic control system is to allow many aircraft to use the same airspace simultaneously without colliding with one another. The capacity of the ATC system to handle aircraft safely is a given for any particular weather situation. As this level is approached, some aircraft must wait to use the system or various parts of it until they can be accommodated. This waiting imposes costs both in terms of aircraft operating expenses and the value of wasted passengers' time. Estimation of the delay benefits of a new project or regulation requires measurement of the aggregate annual aircraft operating time and passenger time which the new proposal will save. This saving is the difference between the delays currently experienced and those which would be experienced with the proposed new project or regulation. Once determined, the value of this saved time can be valued in dollars using standardized values.[9]

The estimation of delay reductions that a particular proposed project or regulation can be expected to produce requires that the relationship between average delay, capacity, and system demand for the segment of the ATC system of interest be determined for both the existing system and the proposed new one. Although such relationships will differ from situation to situation, their general form is depicted in Figure 3-2. As indicated, two definitions of capacity are relevant in defining this relationship. One is the "through put" measure. It defines the absolute number of system users that can be served in a given period of time, provided that a user is always present waiting to use the system. The second measure is that of "practical" capacity. It provides a measure of the ability of a given system to accommodate users subject to some maximum acceptable level of delay. As shown, average delay is low at low levels of demand and increases as demand approaches capacity, as defined under either definition. As demand exceeds "practical"

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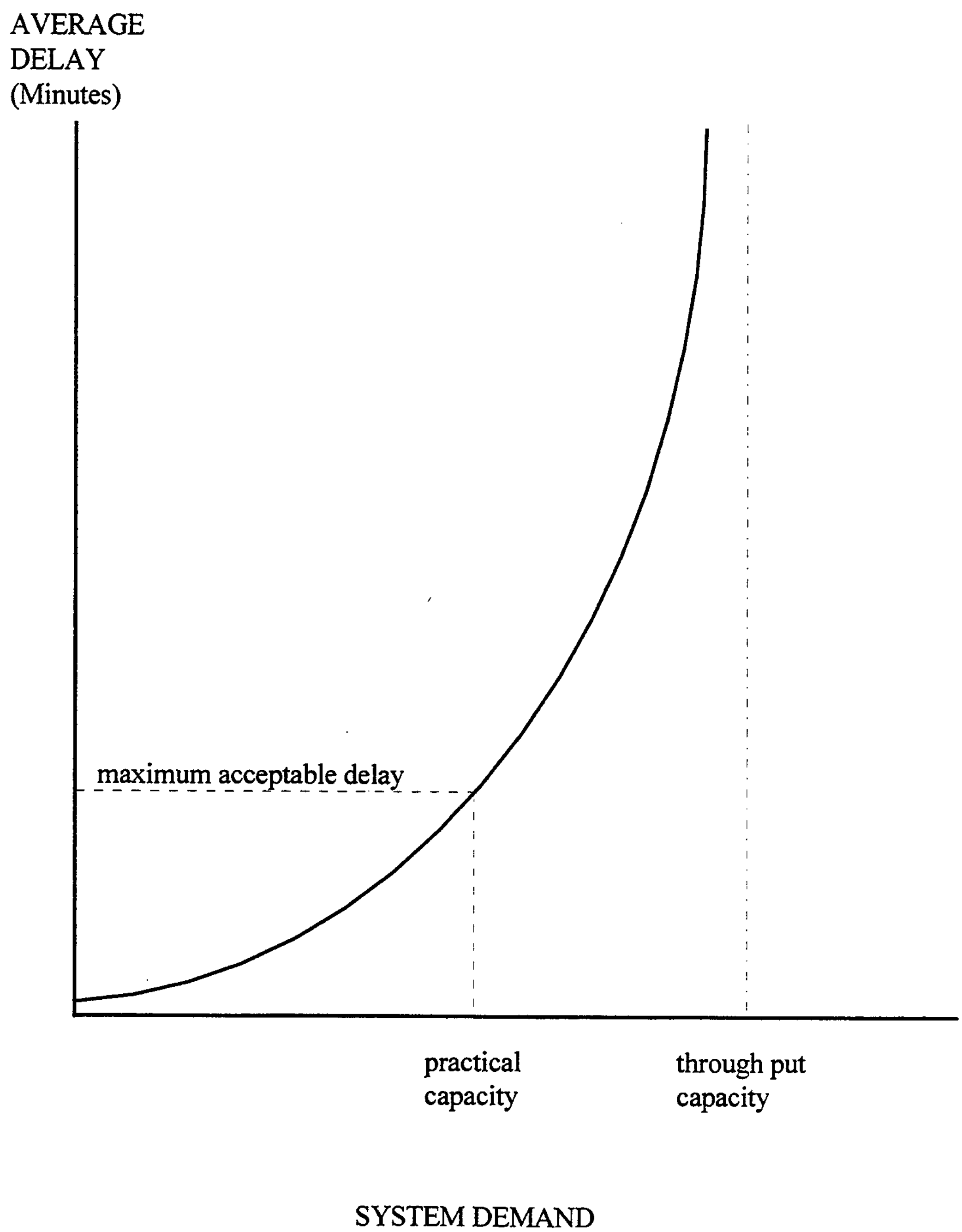
8 Another type of capacity increase is the provision of facilities where none now exist. See section III.E.5 of this chapter for a discussion of the benefits associated with the construction of a new airport where there currently is none.

9 Values for passenger time are provided in "The Value of Saving Travel Time: Departmental Guidance for Conducting Economic Evaluations," Office of the Secretary of Transportation, April 9, 1997. Values for aircraft operating cost are provided in *Economic Values for Evaluation of Federal Aviation Administrative Investment and Regulatory Programs*, FAA Report FAA-APO-89-10, October 1989.

FIGURE 3-2

RELATIONSHIP BETWEEN CAPACITY AND AVERAGE DELAY



capacity, delay exceeds the acceptable level. And as demand pushes up against "through put" capacity, delays begin to become infinite. This occurs because the number of users demanding service, per time period, begins to become greater than the ability of the system to serve them, resulting in an ever growing line of users waiting for service.

It is important to note that delays began to occur before capacity, under either definition, is reached. This happens because of the random nature in which system users demand services. If all users of a system consistently arrived at evenly spaced intervals, the system could provide service hourly to a number of users equal to the "through put" capacity rate. No delay would occur until "through put" capacity was actually exceeded. In actuality, system users do not arrive consistently at evenly spaced intervals. Sometimes several users arrive at one time and sometimes no one arrives. As a consequence, some of those who arrive at the same time as do others must be delayed.

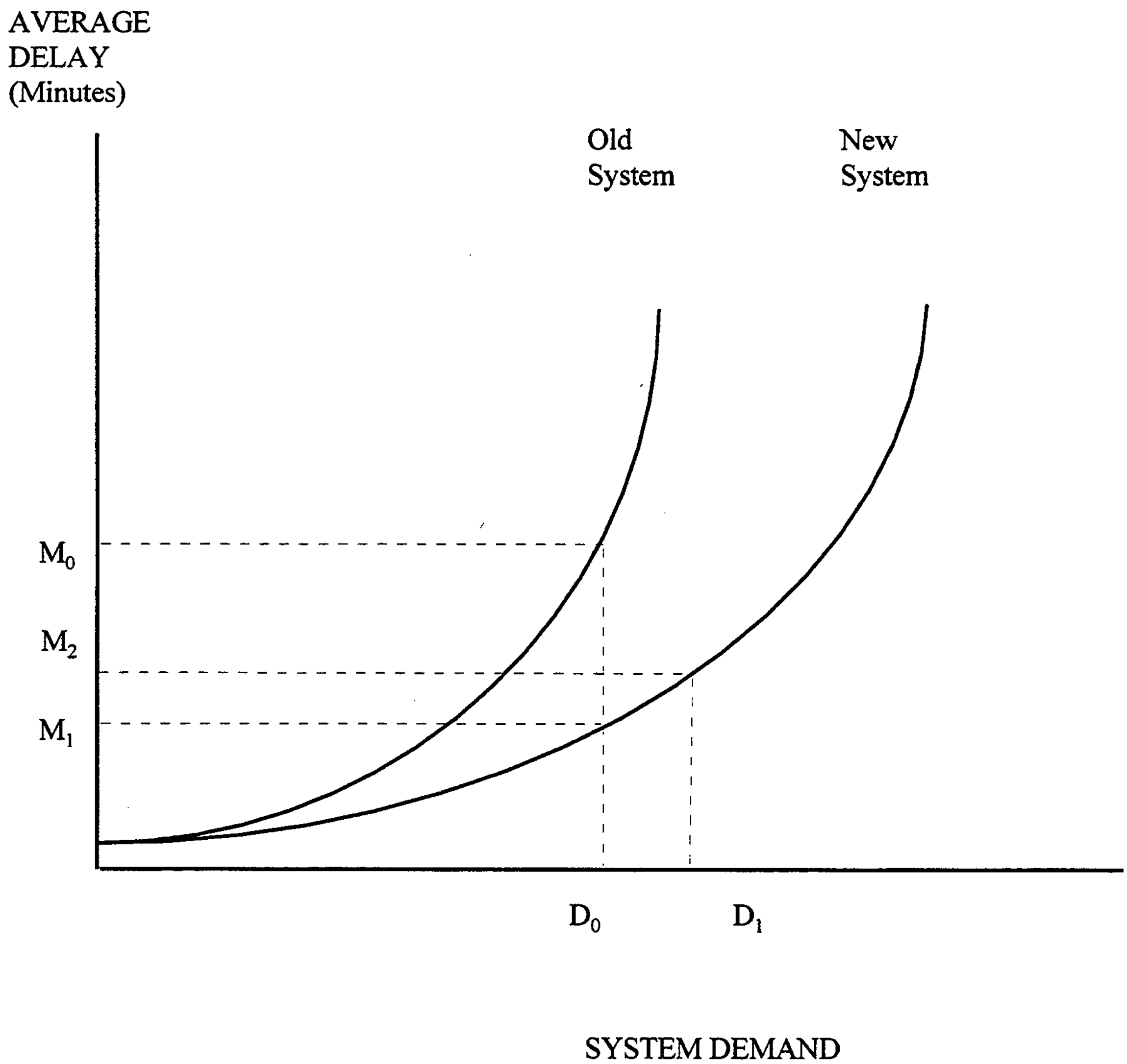
Measurement of capacity and delay benefits requires that the relationship depicted in Figure 3-2 be determined for both the existing system and the proposed new one. The general form of such relationships is shown in Figure 3-3. Each has the same general form as that of Figure 3-2, but with the proposed new system having greater capacity and lower average delays than the old one at each level of demand.

The average delay reduction per system user at the current level of demand, D_0, is M_0 - M_1 minutes. This is not the delay reduction that will occur if the indicated capacity increase is provided at demand level D_1 after system users have adjusted to the increase, however. Capacity improvements will reduce the costs of using the system both in terms of passenger time and aircraft operating expense. As indicated in Figure 3-1, cost reductions will generally lead to an increase in the quantity of any good or service demanded. In this case, assume system demand increases from D_0 to D_1 resulting in delay of M_2 per user. This level of delay is above M_1 and represents that level which will result from the indicated increase in capacity once demand has adjusted to the lower costs brought about by the capacity increase.

Having determined the average delay per system user after demand adjustments, it is now necessary to value these delay reductions. For users of the system before the capacity improvement, valuation is given by total cost savings per user. Because most delay reduction activities are air terminal area related, it is convenient to define user as an operation for the remainder of this discussion. The value of delay reduction for that level of operations that was occurring before the capacity improvement is equal to M_0 - M_2 minutes multiplied by the operating cost of the aircraft plus M_0 - M_2 minutes multiplied by the average number of passengers per aircraft and the value of passenger time. The average number of passengers per aircraft must be determined by the analyst in each specific case.

FIGURE 3-3

DELAY REDUCTION MEASUREMENT



For operations induced by the lower costs per user brought about by the capacity increase, value will be less because each additional unit of a commodity is valued less by consumers, as explained in Section II of this chapter. Value is given by the change in benefits accruing to passengers and air transportation service providers less the additional costs required to produce these benefits. Under conditions of competition in the air transportation industry, it can be shown that these net benefits can be approximated by one half of the number of additional operations, D_1 - D_0 in Figure 3-3, multiplied by M_0 - M_2 minutes multiplied by the operating cost of the aircraft plus one half of the number of operations, D_1 - D_0, multiplied by M_0 - M_2 minutes multiplied by the average number of passengers per aircraft multiplied by the value of passenger time.[10] Total delay benefits are equal to this amount plus the benefits for those operations already being conducted before the capacity increase. Finally, it should be noted that this procedure must be applied to each time period over the life of the capacity improvement. This requires that values for system demand be estimated for each year assuming both that the capacity improvement is and is not put in place.

The actual estimation of delay reduction usually requires the use of a model, although simpler analyses may be based on published relationships derived from models and/or empirical observation.[11] A host of different such models exist. Depending on the particular situation and proposed project or regulation, the analyst must choose (or develop) an appropriate model. Important factors in selecting a suitable model are the segment of the National Airspace System (NAS) which is to be analyzed and the level of detail required. A recent survey of available models classifies them by NAS segment of coverage and level of detail.[12] Segment of coverage differs across models, which may be

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[10] The procedure is an approximation for several reasons. First, it assumes, correctly or not, that demand curves can be represented as straight lines over the relevant range of interest. Second, it assumes that all passengers can be represented by a single "representative passenger." Finally, implicit in the procedure is the assumption that passengers of various types at various airports increase their system usage in response to a reduction in delay by the same proportion. A detailed discussion of the limitations of this procedure, as well as attempts to improve upon it are contained in Robert A. Rogers, John L. Moore, and Vincent J. Drago, *Impacts of UG3RD Implementation on Runway System Delay and Passenger Capacity*, Final Technical Report, Department of Transportation, March 31, 1976.

[11] A number of relevant capacity, delay, and airport design relationships suitable for simpler analyses that must be completed quickly may be found in *Airport Capacity and Delay*, FAA Advisory Circular 150/5060-5, September 9, 1983, Change 2 to *Airport Capacity and Delay*, December 1, 1995, and *Airport Design*, FAA Advisory Circular 150/5300-13, September 29, 1989.

[12] A.R. Odoni *et al*, *Existing and Required Modeling Capabilities for Evaluating ATM Systems and Concepts*, International Center for Air Transportation, Massachusetts Institute of Technology, March 1997,

divided into enroute airspace models and terminal areas models. Terminal area models may be further sub-divided into terminal airspace, runway and final approach, and apron and taxi way models.

High detail models typically recognize specific aircraft on an individual basis and simulate their movement through a segment of the NAS. Their use is highly resource intensive--often requiring several months or more of effort. They are frequently employed in pre-design engineering studies and for benefit-cost analyses of large, high cost projects and regulations with substantial impact. Intermediate detail models are detailed macro models of one or more parts of the NAS. Although they lack the aircraft specific detail of the high detail models, they can be resource intensive and are suitable only for major benefit-cost analyses. Finally, there are the low detail models. These are relatively easy to utilize and are suitable for most policy and benefit-cost analyses where the objective is to quickly obtain appropriate answers and assess the relative performance of a wide range of alternatives. Some available models are summarized in Table 3-2.

Chapter 2. This report may be downloaded from http://web.mit.edu/aeroastro/www/labs/AATT/aatt.html

TABLE 3-2

SELECTED CAPACITY and DELAY MODELS

Model	Developer (Availability)	Coverage	Level of Detail
FAA Airfield and Capacity Model	FAA/Mitre (CAASD) (NTIS: AD-A104 154/0)	Runway and Final Approach	Low
DELAYS	MIT (MIT Operations Research Center)	Runway and Final Approach	Low
NASPAC	FAA/Mitre (ASD-130)	Runway and Final Approach Terminal Area Airspace Enroute Airspace	Intermed iate
SIMMOD	FAA (ASD-400)	Aprons and Taxiways Runway and Final Approach Terminal Area Airspace Enroute Airspace	High
ADSIM	FAA (Technical Center) (NTIS: PB84-171560, PB84-171552)	Aprons and Taxiways Runway and Final Approach Terminal Area Airspace	High
RDSIM	FAA (Same as ADSIM)	Runway and Final Approach	High
The Airport Machine	Airport Simulation International Inc.	Aprons and Taxiways Runway and Final Approach	High

C. Avoided Flight Disruptions

One particular class of FAA investments--establishment of non-precision or precision instrument approaches--gives rise to particular type of benefit know as an avoided flight disruption. Instrument approaches have the characteristic of allowing operators to land aircraft in weather conditions under which they could not land without establishment of the approach. Because such approaches permit landings at weather minimums below what would be possible without the approach, they permit flights to land that would otherwise be disrupted. (Flight disruptions are a form of delay, albeit one that is not caused by congestion.)

Weather caused flight disruptions impose economic penalties on both aircraft operators and users. When the weather is below landing minimums at the destination airport, the operator can take one of four actions:

1. fly to the intended airport and hold until the weather improves.
2. fly to the intended airport and divert to another airport if the weather does not improve.
3. on a multi-leg flight, operate the flight and overfly the below minimums airport.
4. cancel the flight.

Estimation of the benefit of avoiding a flight disruption requires that the relative occurrence of each of these four possible outcomes be determined. It is also necessary to estimate the costs associated with each of these possible outcomes. This is done by constructing a scenario of events associated with each and then measuring costs, including aircraft operating cost, passenger time lost, passenger handling cost, and aircraft repositioning cost, for each scenario. The relative occurrence of each outcome is then used as a weight to calculate the average cost of a flight disruption.

The final step in estimating the benefits of an investment in an instrument approach is to determine the number of such disruptions that can be avoided if the approach is established. This can be done by estimating from weather data the percent of the time that the weather at the airport will be below the minimum existing before the approach is established and above the minimum that will be achievable after the approach is established. This percentage is then used together with a measure of annual operations at the airport to determine the number of landings that will be possible with the establishment of the approach that would not be possible without it. Multiplying these landings which are no longer disrupted by the cost of a flight disruption yields the annual benefit of establishing the approach.[13]

D. Cost Savings

Investment and regulatory decisions may result in cost savings to both the private sector, the FAA, and other governmental agencies. These savings may come in the form of direct cost savings where actual dollar outlays are reduced, or they may be reflected in efficiency gains. In the second case, output levels achievable with existing resources go up, but actual costs remain constant. Given enough time, it is usually possible to shift such resources from one use to another if it is not desired to increase output by the full amount made possible by the increased efficiency.

Examples of direct cost savings are investments and/or regulations which reduce utility costs or fuel consumption. Included would be investments in more efficient heating and cooling equipment, aircraft engines, and solid state electronics. Also under this category would be regulations or procedures to minimize aircraft fuel consumption such as direct routings and free flight. Direct cost savings of an investment or regulation should be measured as the actual value of the savings expected to occur.

An example of efficiency gains is agency investments to increase employee productivity. Included would be the continued automation of the air traffic control system which has relieved controllers of many record keeping functions and the near universal acquisition and continuous upgrading of personal computers and applications software for most FAA employees. In the case of ATC automation, additional productivity has been reflected in greater output. For personal computers, it has been possible to shift employee resources away from document and graphics preparation to other tasks. These gains should be measured by the value of the additional benefits which the more productive workers can now provide. For ATC automation this would be the value of the additional output. For personal computers, it would be the value of the other tasks which employees may now perform in the time saved by the use of the computers.

E. Other

The above categories constitute most of the benefits that can typically be expected to flow from FAA investment and regulatory activities. Any analysis, of course, should include

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[13] A detailed algorithm for estimating the benefits of avoided flight disruptions for various user classes operating to and from hub and non-hub airports has been developed by the Office of Aviation Policy and Plans. It is published in *Establishment Criteria for Loran-C Approach Procedures*, FAA Report FAA-APO-90-5, June 1990, Appendix A.

all known benefits whether or not they can be classified in the major categories. The following presents selected examples of other such benefits that have been identified in previous studies.

1. Noise Reduction

The provision of air transportation services generates noise which imposes costs or dis-benefits on those who are subjected to this noise. Government investments which promote aviation may have the accompanying effect of increasing aircraft noise. Other Governmental activities have been undertaken to reduce aircraft-generated noise. The benefits of noise mitigation activities are the reductions in noise-produced costs which these activities achieve. These noise related costs and benefits should be addressed in economic analyses of activities which result in increases or decreases in aircraft noise.

Although it is possible to establish a conceptual framework which correctly measures the social cost of aircraft noise, deriving empirical estimates for such a framework is a difficult undertaking requiring numerous assumptions and estimation compromises.[14] As a consequence, benefits of noise abatement undertakings (or costs associated with increased noise levels accompanying a project) are most frequently developed in terms of physical units such as area, area size in square miles, number of dwelling units, or number of persons removed from (or added to) areas experiencing specified levels of noise.[15]

The first step to measure these physical units is to identify the area around an airport which is impacted by noise. This area, designated as the noise footprint, may be mapped by use of a model. The FAA Integrated Noise Model (INM) is one such model which is widely used by the aviation community for mapping and evaluating aircraft noise impacts in the vicinity of airports.[16] This model is typically used in the U.S. for FAR Part 150

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[14] For a discussion of such issues, see E. J. Mishan, *Cost-Benefit Analysis*, Geroge Allen and Unwin, London, 1982, pp. 346-362, and D.W. Pearce and A. Markandya, *Environmental Policy Benefits: Monetary Valuation*, OECD 1989.

[15] This approach is illustrated by two recent studies. *A Study of the High Density Rule,* DOT Report to Congress, May 1995, evaluated a possible regulation revision, one result of which would have been a change in noise impacts. *Final Report of the Economic Analysis Subgroup*, ICAO Committee on Aviation and Environmental Protection, Bonn, June 1995, analyzed alternative environmental policies and their expected outcomes.

[16] *FAA Integrated Noise Model(INM) Version 5.1 User's Guide*, FAA-AEE-96-02, December 1996.

noise compatibility planning and FAA Order 1050 environmental assessments and environmental impact statements. It permits the noise of different aircraft types on specified flight paths to be measured by one of several common noise measures. It is thus possible to measure the noise which currently exists and that which will exist after a change in aircraft type mix, flight path, number of operations, or other variables.[17]

The measures of noise provided by the model deal with two characteristics of noise: single event noise intensity and the cumulative number of occurrences of the noise events. Single event noise intensity measures are useful for such purposes as measuring the noise generated by a particular engine or in determining the amount soundproofing required to achieve desired indoor noise levels. The general annoyance associated with noise is usually best assessed by a cumulative measure. One such measure is the Day-Night Average Sound Level (DNL). Scaled in decibels, it represents the cumulative impact of aircraft noise over a 24-hour period in which aircraft operations during the nighttime (between 10 p.m. and 7 a.m.) are assessed a 10 dB penalty to account for the increased annoyance in the community.

FAA has also developed a simpler noise model--the Area Equivalent Method (AEM). It is a screening tool that provides an estimate of the size of the land mass enclosed within a level of noise, not a noise footprint, as produced by a given set of aircraft operations. The AEM produces contour areas (in square miles) for the DNL 65dB noise level and any other whole DNL value between 45 and 90dB. The AEM assists users in determining whether a change in aircraft mix or number of operations warrants additional analysis using the INM.[18] Once the noise footprint is determined, the physical impacts of the increase or decrease in noise may be determined by tabulating the change in dewelling units and population subject to each level of noise intensity.

2. Missed Approach Benefit

In making an instrument or visual approach to a landing, the pilot almost always has the option of aborting the approach if it is judged to be unsatisfactory by executing what is known as a missed approach. This requires the pilot to fly around and try again. This maneuver, called a go-around, results in both aircraft operating expenses and wasted time. The missed approach benefit arises when certain approach aids which help reduce missed approaches and avoid go-around costs are installed. It may be estimated for a single

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17 FAA has also developed a model for evaluating noise at Heliports. See *HNM-Heliport Noise Model Version 2.2 User's Guide,* DOT/FAA/EE/94-01, February 1994.

18 *Area Equivalent Method Version 3 Users Guide,* DOT/FAA/EE-96-04, September 1996.

approach by calculating the probability of a missed approach being averted by a landing aid and multiplying this probability by the cost of a go around. Summing this per approach benefit across all approaches occurring in a particular year will yield the total annual benefit in that year.[19]

3. Avoided Accident Investigation Costs

Another cost of aviation accidents, in addition to fatalities, injuries, and property damage, is the cost of investigating them. The National Transportation Safety Board (NTSB) is responsible for the investigation of all aircraft accidents. NTSB is typically assisted by others in its investigations. NTSB conducts two types of investigations: major investigations which are directed by NTSB headquarters in Washington and field office investigations which are conducted by NTSB field offices. Major investigations are conducted primarily for major air carrier disasters involving numerous fatalities and substantial property damage. They are characterized by the dispatch of an investigative party--go team--to the accident site and usually involve substantial support by the FAA and involved private parties such as the airline, airframe and engine manufacturers, avionics manufactures, component and sub-component suppliers, etc.

Field investigations may be further divided into regular investigations and limited investigations. Field office regular investigations are much smaller in scope than major investigations. They are conducted for air carrier accidents involving limited loss of human life and for most fatal general aviation accidents. Limited field office investigations are conducted for most other accidents. FAA provides significant support to NTSB in the conduct of field office investigations.

Costs for each type of investigation and average investigation costs for air carrier and general aviation accidents may be obtained from the Office of Aviation Policy and Plans.

4. Regulatory Changes in Capacity at Access Capped Airports

In order to avoid excessive congestion at several of the nation's airports, access is capped through regulations which establish a fixed number of landing and takeoff rights ("slots"). Any change to the number of such slots can be expected to generate both benefits and costs for airport users. The primary benefit resulting from an increase in slots is the value to consumers of the additional trips made possible by the increase. Referring to Figure 3-1, and assuming that the number of slots is increased from a current

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19 Specific methodology, which may be adapted to calculate such benefits is contained in "Missed Approach Probability Computations of the FAA/SCI (vt) Approach Aid Model," Interim Draft Report, Contract DOT-FA78WA-4173, October 1980.

level of Q_1 to a new level of Q_3, the value or benefit of Q_3-Q_1 slots is indicated by the area Q_1ABQ_3. This represents the maximum amount that consumers would be willing to pay for the trips that these slots could support. To determine if a proposed increase in slots would yield a *net* benefit, it is necessary to offset the costs generated by the additional slots against the their value. Such costs include the costs to operate the additional flights which would use the additional slots, the additional aircraft operating cost to current airport users associated with increased delays that might arise because of the increase in slots, the value of passenger time associated with the delay experienced by the passengers flying in the new slots, and the value of passenger time to current passengers associated with increased delays that might arise because of the increase in slots.[20]

5. Construction of New Airport where None Currently Exists

From time to time it is necessary to evaluate the construction of a new airport where one does not currently exist. Several benefits including those identified here are associated with such a project.

First, is the reduction of transportation costs currently incurred by travelers and shippers to and from the region to be served by the new airport. Current land and/or water transportation systems into and out of the region have both dollar and time costs associated with them. An airport will support air transportation into the region. This substitute to existing modes of transport will reduce time costs of traveling to the region and may either reduce or increase the dollar cost of such transportation. The net reduction in time and dollar costs to existing travelers or shippers constitutes a benefit. Second, to the extent that costs of transportation are reduced, additional transportation will be induced. The maximum amount that travelers and shippers are willing to pay for this induced transportation will be another benefit.

These two benefits may be illustrated graphically by reference to Figure 3-1. For purposes of this illustration, quantity refers to the volume of trips by all modes into and out of the region. Price represents the "full price of travel" which is defined as the dollar cost of a trip plus the time cost where time cost is the amount of time consumed by a trip multiplied by the dollar value of time. Prior to the introduction of air transportation, the cost of a trip is equal to P_1 and Q_1 trips are consumed. Introduction of air transportation has the effect of reducing the full price of travel from P_1 to P_3. The benefit to all current travelers is indicated by P_1ACP_3, that is the travel cost savings per trip times the number

[20] For an example of the estimation of the benefits and costs associated with a change in capacity controls at certain major airports, see "Appendix G to Technical Supplement No. 3--Analytical Concepts and Methods, A Study of the High Density Rule," Report to Congress, Department of Transportation, May 1995.

of trips. The value of the induced demand for additional trips is given by the triangle ABC which is equal to half the decline in trip price, P_1-P_3, times the increase in trips, Q_3-Q_1.

Additional benefits associated with economic development may also occur depending on the particular situation. If the region is particularly suited to producing--can produce at lower cost than others can--a particular good or service which must be shipped quickly to a distant market, building of an airport may allow the regional economy to produce and export this good more cheaply than it can be produced elsewhere thus improving the welfare of those who consume it. The reduction in the delivered cost of this good or service together with the value of additional consumption of it because of its now lower cost are benefits of constructing the new airport. An example would be fresh flowers that can be more cheaply grown on a distant tropical island than closer to their consumers in a greenhouse. Construction of an airport on the island makes possible the cheaper production of the flowers. Another example would be where the central location of the new airport would make it a low cost location to warehouse inventory intended to be shipped on a just-in-time basis. Distribution cost saving associated with the particular regional location would be a benefit of the new airport.

Depending on the particular case, additional economic development benefits may be present. Such benefits will posses the common characteristic that they arise because the new airport lowers transportation costs and thus facilitates the development of a new industry or the expansion of an existing one. It should be noted that job creation from airport construction is not a benefit. While jobs are created at the site of the construction, absent significant unemployment the workers who fill them must be hired away from other jobs where they would have contributed to the economy. Also, industry attracted from another location should not be considered a benefit of the new airport. Although this site may gain from the migrated industry, another location loses. Any reduction in production cost resulting from the industry relocating, however, should be captured as a benefit of the new airport.

CHAPTER 4

COST ESTIMATION

I. General

Cost is defined as the resources that will be consumed if an objective is undertaken. The value of consumed resources is measured by the yardstick of dollars. This makes different cost elements comparable with themselves, as well as with benefits. In addition, because resource value indicates what resources are required for a particular proposed objective, it is a measure of the cost of other objectives that cannot be pursued. Each alternative method of accomplishing the objective will have its own associated cost. Costs include all capital, labor, and natural resources required to undertake each alternative whether they are explicitly paid out of pocket, involve an opportunity cost, or constitute an external cost which is involuntarily imposed on third parties (such as engine emissions, noise, or contaminated water runoff from airports). Costs may be borne by FAA,[1] other governmental units, various components of the flying public, the general public, or some other particular group. Inclusion of all costs borne by all groups is required in order to measure the total value of what must be forgone to undertake each alternative and to avoid errors in answering the economic questions.

An example of the need to consider total cost is that associated with the adoption of a new navigation system. Such systems generally require expenditure by both the signal provider (generally the Government) and the signal user (aircraft operators). Whether or not the system is worth undertaking depends on whether total benefits exceed or equal total costs. Total costs consist of all governmental costs to provide the system and private costs to users to purchase the new avionics. Undertaking the project where benefits exceed only the private or the governmental costs but not total costs would be improper. It would result in the value of resources consumed exceeding the benefits of the system for an overall net loss of value.

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[1] FAA costs are frequently characterized by their budget appropriation, including research, engineering and development, facilities and equipment, operations and maintenance, and AIP. While such categorization is useful for various management purposes, it is not necessary for purposes of economic analysis. A cost is a cost irrespective of which appropriation provides for it.

II. Concepts

A. Opportunity Cost

This is the value foregone when resources are shifted from satisfying one objective to satisfying another. An all inclusive "measure," it represents what society as a whole--government and all private groups--must give up to obtain the desired objective. It is the theoretically correct measure of cost for use in economic analyses. As an example, consider an entity with a fixed budget which presently produces benefits from its activities. To undertake a new activity, it must limit or stop completely one or more of its current activities. The opportunity cost of shifting resources to the new activity is the value of the benefits generated by the activity(ies) which must be either limited or terminated.

B. Sunk Costs

These are costs which have already been incurred. The resources represented by these costs have already been consumed and cannot be recovered. As a consequence, they are not relevant for current decisionmaking simply because nothing can be done about them. For example, the decision to add a glide slope to a localizer should be based strictly on the additional benefits and costs associated with the glide slope. The costs of installing the existing localizer and the benefits derived therefrom are irrelevant because they have already been incurred.

C. Out-of-Pocket Costs

These are actual cash outlays. Frequently, they represent only a part of the total cost of a project. Other costs can arise if resources required by a project are already owned by the government. When they are consumed by this project there is an opportunity cost in that they cannot be used in another use, but there is no cash outlay. Care must be taken in the exercise of economic analysis that all costs, and not just out-of-pocket costs, are included.

D. External Costs

These are costs which third parties are involuntarily forced to bear as a consequence of the undertaking of an action by others. Even though these costs impose no cash outlays, they are nonetheless a cost because they consume valuable resources. Noise, engine emissions, and contaminated water runoff from airports are examples.

E. Average Incremental Cost

This measure is an attempt to implement the economist's concept of marginal cost--the increase in total cost associated with a small increase in the production of any particular service or product. Small increases are defined with respect to the infinitesimal changes of the differential calculus or unit of the discrete calculus. In the real world, feasible changes in the size of a project are usually much larger. Average incremental cost is defined as the change is total cost divided by the change in total output over a range that is feasible to achieve.

As an example, the ultimate constraint on airport capacity is the number of runways. When existing runways are operating as efficiently as possible, additional capacity can be obtained only by adding a new runway. An increase of one runway is the feasible change in service level in this case, and average incremental cost is the cost of this runway divided by the total operations that it can handle.

F. Depreciation

Depreciation is a concept used in financial and cost accounting. For accountants, it denotes the periodic allocation of the cost of tangible capital assets over their estimated useful lives. It is a process of allocation, not valuation. While depreciation is important in matching capital costs to the annual revenue stems they generate in order to fairly determine reasonable annual accounting net benefits or income, its use in economic analysis is limited.

Economic analysis is concerned with when resources are consumed and when their benefits occur. Depreciation does not provide such information. Depreciation methodology, however, may have applications in estimating salvage values. To yield reasonable results, such depreciation must relate the asset's age to its actual value. Essentially arbitrary depreciation schemes designed for tax or other purposes must not be used for calculating salvage values.

G. Inflation

The cost of resources consumed and benefits provided are measured by the yardstick of the dollar. This yardstick itself often changes from year to year. The process of a decreasing (increasing) value of the dollar is known as inflation (deflation). For cost or benefit estimates to be comparable from period to period requires that a constant yardstick of value be used. This may be achieved by measuring everything in the dollars of any particular year.

Such estimates are said to be in the constant dollars of a particular year. Estimates where the benefits or costs of any particular year are measured in the dollars of that particular year are said to be current dollar estimates. The process of converting current dollar values to constant dollar values is explained in detail in Chapter 7.

III. Life Cycle Cost Model

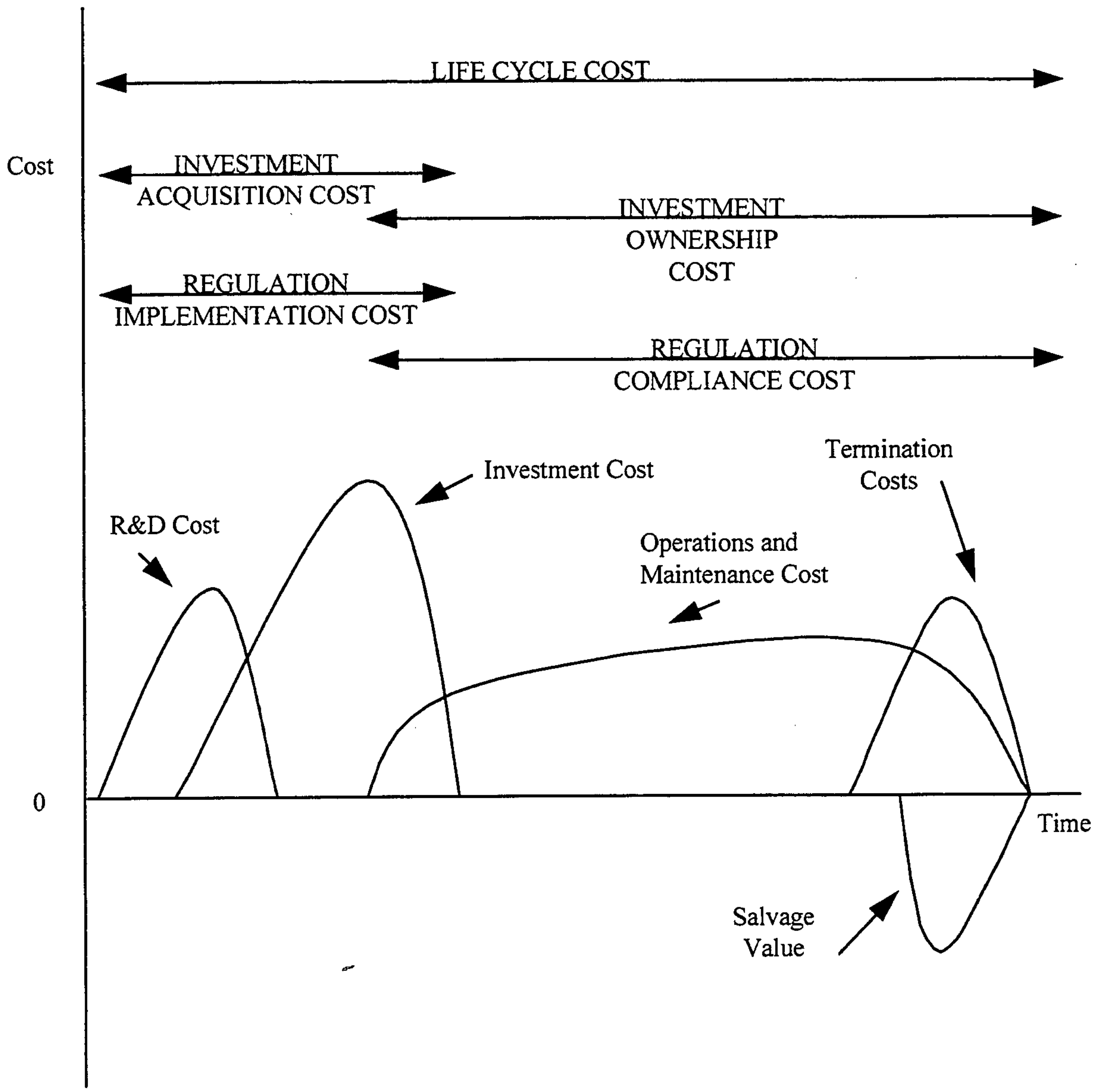
The fundamental cost problem is to determine the total economic costs of proposed governmental actions. Such information is required as input to the decision criteria described in Chapter 5. The life cycle cost model--applicable to both capital investments and regulations--is designed to address this problem by capturing all relevant costs.[2] It organizes costs by when during an activity's life they occur. Costs are classified under four life cycle phases: Research and Development, Investment, Operations and Maintenance, and Termination. Typically, there is an overlap of life cycle phases, but specific costs can be identified with a certain phase based upon the effort they reflect. Figure 4-1 presents an "idealized" summary of major life cycle cost components. Significant variation from this pattern can be expected depending on the characteristics of the specific activity being costed.

As indicated, research and development costs occur first and generally increase every year from project inception up until the beginning of the investment phase, after which they rapidly diminish. Investment costs occur next. They need follow no particular pattern except that they occur over a relatively short period. Operating and maintenance costs rise rapidly following initial investment as facilities and equipment of the project are brought on-line or a regulation is fully implemented. After the investment phase is completed, operating and maintenance costs may continue to rise slowly as a result of increasing equipment age. Near the end of the project life, operating and maintenance costs decline as equipment is retired. Retirement also gives rise to termination costs and salvage value.

[2] The life cycle cost model presented here does not explicitly address external costs. These are often difficult to measure in dollars although they may often be quantified in non-dollar terms. The most significant external cost associated with aviation activities is noise. Techniques for addressing noise reduction (a benefit) are presented in Chapter 3.III.E.1. above. These techniques are equally applicable to addressing noise increases (a cost).

<u>FIGURE 4-1</u>

LIFE CYCLE COST ELEMENTS



Within each phase, particular types of costs typically occur. Recognizing that for organizations which have a large volume of investment programs there is an advantage to having a standard approach to classifying costs, formal cost classification schemes have evolved. Known as work breakdown structures (WBS), the Department of Defense (DOD) pioneered their use with respect to equipment acquisitions. DOD has documented its approach in MIL-STD 881B.[3] Although originally developed with respect to government investment projects, WBS concepts are also applicable, with appropriate modifications, to regulations as well as airport construction projects. Moreover, while their original focus was on the development and investment phases of life cycle cost, the WBS concept may be expanded to include the operations and maintenance and termination phases as well.

The cost categories identified below are deliberately general, being intended to cover many potential situations. For the research and development and investment phases, they are defined with respect to outputs--products to be acquired, constructed, or produced. Costs in the operations and maintenance and termination phases are categorized by function, or input to the production process. Not all cost components identified are relevant to the evaluation of any particular proposed investment or regulation. Moreover, very detailed cost sub-classifications may be appropriate for particular actions, depending on their particular characteristics, which are not specifically identified here.

A. Research and Development Costs

Research and development costs are associated with products requiring development, regulations requiring planning or analysis or mandating purchase of products requiring development, and the planning and design of construction projects including airport projects. They include all costs incurred prior to actually making an investment under evaluation or incurring construction costs, equipment costs, other investment costs, or on-going expenses of complying with a regulation, except those costs that have already been incurred at the time the analysis is undertaken. Incurred costs are sunk costs and are not relevant for decisionmaking purposes. Typical research and development phase costs are:

- Feasibility Analysis
- Environmental Assessment
- Prototype Hardware
- Test Facilities
- Technical Experiments

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[3] *Military Standard--Work Breakdown Structures for Defense Material Items, MIL-STD 881-B,* Department of Defense, 25 March 1993.

- Operational Tests
- Construction Project Design and Engineering Plans
- Coordination with Regional Development and Transportation Plans
- System Design and Engineering
- R&D Oriented Software
- Modeling and Simulation
- Regulatory Analysis (prior to issuance of a final regulation)
- Arrangement of Project Financing
- Public Outreach

B. Investment Cost

These are the costs of associated with making a governmental investment, undertaking the cooperating private sector investment associated with a governmental investment, implementing a regulation, or undertaking an airport construction project. They typically include of one or more of the following: land, facilities, equipment, other regulatory implementation costs, and transition costs.

1. Land

Included here are all interests in land that must be acquired: purchases, leaseholds, easements, air rights, mineral rights, etc. Interests in land can be a significant cost for airport projects. Land can also be important for FAA investments. Not only must building sites be acquired to construct new facilities such as the Southern California TRACON, but frequently small parcels must be obtained on which to locate field facilities such as VOR's, marker beacons, or communication facilities. Land that is already owned should not be treated as a sunk cost. Rather it should be valued according to its opportunity cost or market value.

2. Facilities

Facilities consist primarily of buildings and other real property improvements. They may encompass new construction, modifications to modernize or refurbish existing facilities, and leasehold interests. Construction cost should also include any costs to expand, modernize, or refurbish any other part of the facility necessitated by the implementation of the project. Such costs can be significant, particularly with respect to airport construction. When similar facilities are being established in numerous locations, standardized costs may be developed and applied at all specific locations with appropriate modification to reflect the conditions. For projects with significant unique characteristics, including most airport projects, cost estimates are generally site-specific.

3. Equipment

Equipment consists of items--either developed during the research and development phase or non-developmental commercial off the shelf--required to accomplish an activity other than facilities. Equipment acquisition is characteristic of almost all FAA activities, many regulatory actions, and all airport projects. Moreover, many FAA activities are characterized by not only government purchases of equipment but also require private sector acquisitions of complementary equipment, most notably avionics. Examples of FAA equipment are the non-facility components of VSCS, TDWR, and the agency's aircraft. For private parties, examples are avionics, aircraft equipment, and aircraft instrumentation. And for airport projects, equipment can comprise a wide variety of items ranging from vehicles to security systems. Other items such as furniture or tools would also be classified as equipment.

4. Other Regulatory Implementation Costs

Although regulations can potentially impose any type of investment cost, most regulatory actions will require investments of equipment--described under III. B. 3. above--and/or labor costs. For example, the requirement that all new commercial pilots be instrument rated required candidates to invest in instrument training. And, at the very least a new regulation will require an investment of employee time for affected parties to familiarize themselves with the regulation and establish a system for complying with it. (Such costs may occur when the regulation is initially implemented or be spread out over its life. They are properly classified as investment costs in that for each instance they occur once and then a stream of benefits flow from them. This is in contrast to an expense like refresher training that must be incurred periodically to maintain a particular skill level.)

5. Transition Costs

Transition costs reflect the expense of the impact on ongoing activities caused by building and/or transitioning to a new facility, new equipment, or new procedures (as might be prescribed by regulation). This impact can be very small as in the case of a minor regulation-driven change requiring a few hours of employee time to accommodate. Or it can be very large such as with a construction project at a major airport that leads to the temporary closure of major facilities of an airport. For example, a runway reconstruction project could lead to the total or partial closure of the runway itself, and may cause the temporary closure of any runway intersecting it. Disruption and delay associated with the project might result in millions of dollars of additional costs to airlines, general aviation users, passengers, and others using the airport.

Frequently, FAA investment projects incur significant transition costs. This occurs because service cannot be disrupted requiring that new equipment and sometimes facilities must be put in place and be made operational before changing over to the new system. Moreover, because many FAA investments require cooperating investment from the private sector, such as the purchase of new avionics, two otherwise redundant systems must be operated while the private sector has time to make the required new investment.

C. Operations and Maintenance Costs (O&M)

These are the ongoing costs required to operate and maintain a proposed investment project or remain in compliance with the proposed regulation. These costs may occur continuously, annually, or periodically every so many years. These costs are typically grouped into functional or input based categories. The following list includes most of these costs.

- Personnel Costs: These must be incurred to both operate and maintain any investment or comply with many regulations. A major component of ongoing costs, they include all compensation paid to employees, including benefits and paid absences, as well as compensation paid to employees during recurring training and during travel time.

- Consumables: These are the costs of all materials consumed in the operation or support of equipment. Examples of some typical materials are oil and lubricants, copier paper, toner, paper rolls and tapes, magnetic recording tape, and photographic supplies.

- Energy and Utilities: Included here are the costs of electricity, gasoline, diesel fuel, natural gas, water, etc.

- Facilities: Consists of the ongoing costs to provide facilities and equipment such as real property lease payments and equipment lease payments.

- Telecommunications: Consists of the cost of communications services procured from another organization. Examples are commercial and FTS telephone service or satellite communications. Not included within this category are telecommunications services produced within the system being costed; these are captured through equipment acquisition and rental costs, personnel costs, utilities cost, etc.

- Computer Service Costs: Consists of the costs of computer services purchased from others. As with telecommunications costs, this category does not include computer services produced within the system being costed; these enter through equipment acquisition and rental costs, personnel costs, utilities cost, etc.

- Spares and Support Equipment: Replenishment spares indicate the recurring costs of inventory replacement. (Inventory already purchased as initial spares and repair parts is not included.) Replacement support equipment represents the ongoing cost associated with maintaining sufficient quantities of peculiar and common support equipment.

- Packaging, Handling, and Transportation: Represents the cost of packaging, handling, transportation of spares, repair parts, and other material between supply points and equipment to be maintained.

- Recurring Training: This indicates training costs to maintain operations and support employees' skills and to train new employees needed to replace departing employees. For current employees, this category includes training, specific travel costs, and FAA Academy cost. For replacement employees, it also includes compensation during training.

- Recurring Travel: This item represents the direct costs of travel and transportation necessary to operate and support a project. It consists of such items as airfares, subsistence payments, lodging, and depreciation and operating costs of vehicles. It does not include wages or salaries paid to employees while in travel status; these are defined to be included in personnel costs above.

D. Termination Costs

- Dismantling Costs: These are the costs, if any, required to dismantle, disassemble, remove, and dispose of old buildings, equipment, spare parts, etc. at the end of an investments lifetime.

- Transportation and Packaging: These are the costs, if any, required to package and ship old equipment, spare parts, etc. after dismantling.

- Site Restoration: This is the cost, if any, to restore the site on which the old equipment was located to its original or near original condition. It may involve grading of earth, reforestation, or landscaping.

- Storage of Material Management: This is the cost to store, maintain, and manage equipment, spares, etc. which are removed from a site but not yet disposed of.

E. Salvage Value

Salvage value is the value, if any, of the investment equipment at the end of its expected life. It is treated as an offset to termination costs.

IV. Selected Cost Estimation Topics

Cost estimation is a diverse discipline in and of itself and apart from benefit-cost analysis. A systematic treatment of it is beyond the scope of this guide. [4] However, certain topics of particular use to FAA analysts are treated in this section.

A. Work Breakdown Structures

For organizations like FAA which have a large number of facilities and equipment acquisition programs, there is a distinct advantage to having a standard approach for describing those acquisitions. A work breakdown structure (WBS) provides such a structure upon which to build the management information system necessary to support technical and financial needs of acquisition programs. Historically, WBS's have been utilized with respect to the research and development and investment phases of acquisitions. Conceptually, the WBS approach can be expanded to include airport investment costs and regulatory implementation costs as well as other elements of life cycle cost. By providing all parties with a common reference in describing the system, it serves as a framework against which a project's costs may be estimated, budgeted, and reported. It can be a primary reference in identifying project elements and of insuring that all portions of the project are captured in the cost estimate.

The Department of Defense (DOD) pioneered the use of the WBS for equipment acquisitions (including research and development and investment costs). The WBS is a

[4] A useful treatment of life cycle cost estimation with respect to FAA acquisitions is presented in *FAA Cost Estimating Handbook*, ASU-305, 1997.

method of diagramming the way work is to be accomplished. The diagram separates the work content into "elements". These elements reflect the prime mission product (PMP) together with other elements such as support equipment, data, training, and spares that constitute the total system. It is important to realize that the WBS is product or output oriented, as opposed to having a functional or input orientation. Product orientation allows managers to better focus on management problems that are impacting the product, the deliverable system.

Military Standard 881B contains WBS outlines for various types of systems, such as aircraft, missiles, electronics, tanks, ships, and recently, simulators. The Military Standard breaks these systems down into three summary levels, defining elements of detail at each level. It does not define level 4 elements, recognizing that these need to be constructed to reflect the specific characteristic of particular acquisitions. Electronics systems are of primary applicability to the FAA. An example of the WBS for an electronic/automated software system is shown in Table 4-1. Appropriately adapted, this structure may be useful in building frameworks against which to estimate research and development and investment costs for many FAA facility and equipment acquisitions, certain regulatory actions, and certain airport equipment investments.

TABLE 4-1

SAMPLE WBS for an ELECTRONICS SYSTEM

Level 1: Electronic/Automated Software System	
Level 2	**Level 3**
Prime Mission Product (PMP)	Subsystem 1...n (Specify Name) PMP Applications Software PMP System Software Integration, Assembly, Test and Checkout
Platform Integration	
Systems Engineering/Program Management	
System Test and Evaluation	Development Test and Evaluation Operational Test and Evaluation Mock-ups Test and Evaluation Support Test Facilities
Training	Equipment Services Facilities
Data	Technical Publications Engineering Data Management Data Support Data Data Depository
Peculiar Support Equipment	Test and Measurement Equipment Support and Handling Equipment
Common Support Equipment	Test and Measurement Equipment Support and Handling Equipment
Operational/Site Activation	System Assembly, Installation and Checkout on Site Contractor Technical Support Site Construction Site/Ship/Vehicle Conversion
Industrial Facilities	Construction/ Conversion/ Expansion Equipment Acquisition or Modernization Maintenance (Industrial Facilities)
Initial Spares and Repair Parts	

The following provides summary definitions for the Level 2 items in Table 4-1. Detailed definitions may be found in Appendixes B and H of MIL-STD 881B.

- Prime Mission Product (Hardware and Software): This element identifies the cost of those subsystems--hardware and software--designed to accomplish program mission (as opposed to supporting the program's mission). Any system engineering, program management, data, or testing such as factory acceptance testing, which can be specifically identified with a subsystem (as opposed to the system as a whole) is included in the cost of the subsystem in this element of cost. Also included as separate subelements of this item of cost are system integration and assembly, hardware/software integration and test, and first destination transportation.

- Platform Integration: This element includes the cost of all engineering and technical efforts provided to the platform manufacturer or integrator directly associated with installing the product into a host vehicle (if any).

- Systems Engineering/Program Management: This item indicates the systems engineering and technical control as well as the business management of particular projects. (Note that, if system/program management can be associated with a specific subsystem or piece of hardware/software, it is typically included in the subsystem cost as part of Prime Mission Product.)

- System Test and Evaluation: This element indicates the detailed planning, conduct, support, data reduction, and reporting on the use of prototype or production hardware/software to obtain or validate engineering data on the performance of the system. (Note that, if the test can be associated with a specific subsystem or piece of hardware/software, the test is not systems test but is a subsystem test and should be included in Prime Mission Product as part of the subsystem cost. Moreover, acceptance testing during production and/or installation is not part of this element but rather is included as part of Prime Mission Product.)

- Training: This element identifies the cost of training services, devices, accessories, aids, equipment, and parts used to facilitate instruction through which personnel acquire concepts and skills to operate and maintain the system. It encompasses all costs of designing, developing, and producing training programs, and training the initial instructors as well as the first generation of personnel who will maintain and operate the system.

- Data: This cost element indicates the effort required to record and preserve information concerning the new system. It includes technical publications, engineering data, management data, and support data.

- Peculiar Support Equipment: This element identifies those items required to support and maintain the system but not directly engaged in the performance of its mission. The term "peculiar" indicates that the item is not stock listed or maintained within an accessible inventory.

- Common Support Equipment: This element identifies those items required to support and maintain the system but not directly engaged in the performance of its mission. The term "common" indicates that these items are stock listed or maintained within an accessible inventory.

- Operational/Site Activation: This element refers to the real estate, construction, conversion, utilities, and equipment to provide all facilities required to house and serve prime mission product at the organizational and intermediate level, except for turnkey operations. It includes contractor technical support, site construction, site conversion, and on site system assembly, installation, and checkout.

- Industrial Facilities: this element refers to the construction, conversion, or expansion of industrial facilities for production, inventory, and contractor depot maintenance required when that service is for the specific system.

- Initial Spares and Initial Repair Parts: This element consists of the spare components, assemblies, subassemblies, and materials to be used for replacement purposes in major end items of prime mission product. This element excludes test spares (included in systems test element of cost) and spares provided specifically for use during system installation, assembly, and checkout on site (included in operational site activation).

B. Cost Estimation Techniques

There are several general approaches to actually making cost estimates. The three most widely recognized are: the parametric method, the analogy method, and the grass roots method. In addition, two other approaches can be identified: the component part method and the vendor bid method. When choosing an estimating methodology, the estimator must keep in mind that cost estimating is a forecast of future costs based on a logical extrapolation of currently available data. Selection of a method to estimate any particular cost element is influenced by a number of factors including the type of investment or program (hardware, software, regulation, etc.), life cycle cost element (research and development, investment, operations and maintenance, etc.) to be estimated, the life cycle phase a program has actually reached, and data availability.

- The parametric method estimates costs based on various characteristics or attributes, called parameters, of the system being costed. It depends on the establishment of a functional relationship between system costs and these parameters. Such relationships, known as cost estimating relationships (CER's), are typically estimated from historical data using statistical techniques. Examples would be estimating costs as a function of such parameters as equipment weight, vehicle payload or maximum speed, number of units to be produced, or the number of lines of software code to be written. This method is applicable to all types of investments and programs, to all elements of life cycle cost, and at any point in a programs life cycle.

- The analogy method estimates the cost of a new system by taking the cost of a similar existing one and adjusting it to reflect the differences between the two systems. This adjustment can be made either analytically or judgmentally. The analogy method is applicable to all elements of life cycle cost at any point in a program's life cycle. Because it depends on a comparison with an existing system or program, its application with respect to radically new systems or programs, particularly those embodying significant technological advances, is limited because relevant analogies do not exist.

- The grass roots method, also known as the piece part or industrial engineering method, estimates cost by developing a detailed list of parts. The cost of each of these parts is then determined and the costs of the parts are summed to determine total parts cost. Assembly and/or manufacturing costs and overhead costs are added to total parts cost to yield total cost. The grass roots method is primarily applicable only to hardware production. Moreover, because it requires detailed specifications for the items to be procured, it is not suitable for use early in the research and development phase of a program. Properly executed once detailed specifications for the items to be procured are developed, it can yield more precise estimates than either the parametric or analogy methods.

- The component part method is similar to the grass-roots method but proceeds at a more aggregate level of detail. It determines cost by summing the costs of all components (as opposed to the parts which comprise components) which are known. Components for which costs are unknown are estimated by one of the other cost estimating methods and added to the sum of known costs. Finally, assembly and overhead costs are added to obtain total cost. Like the grass roots method, the component part method is primarily applicable only to hardware production once specifications have been developed.

- The vendor bid method utilizes the cost proposals or bids submitted by vendors in response to a request for production proposals. Use of this method is limited because cost estimates are usually required prior to receipt of bids. However, previously developed contractor estimates may be utilized at times, provided they are judged and found to be reasonable.

C. FAA Cost Estimation Factors

A common technique for estimating certain elements of development and investment phase costs is to calculate them as a percentage of prime mission product hardware and software costs. This approach requires that estimates for prime mission product first be developed and that appropriate percentages be available. The Office of Aviation Policy and Plans has developed such percentages, calibrated to FAA experience, by which development and acquisition cost estimates can be developed once the cost of the prime mission product hardware and/or software components is known.[5] Table 4-2 presents a summary of FAA cost factors by work breakdown structure element.

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[5] The results are documented in APO Bulletin, APO-88-2, "Federal Aviation Administration (FAA) Cost Factor Study," May 1988.

TABLE 4-2

FAA COST FACTORS SUMMARY

All Factors Are Presented As A Percentage of Prime Mission Product Cost (Less Integration and Assembly Cost)

WBS		Communications FAA Factors		Radars FAA Factors		Electronics FAA Factors		Systems Composite FAA Factors	
Level	Element	R&D	ACQ	R&D	ACQ	R&D	ACQ	R&D	ACQ
3	Integration & Assembly	23.7	27.9	12.3	10.0	10.2	-	15.5	15.1
2	Training	0.5	2.8	0.7	-	-	0.7	0.6	1.8
2	Peculiar Support Equipment	33.6	5.8	1.2	9.6	12.0	7.0	10.4	5.4
2	Installation & Test	-	18.0	-	-	-	-	-	18.0
2	Systems Engineering/ Program Management	55.0	31.9	30.8	13.3	32.0	11.7	40.1	18.0
2	Data	9.0	4.4	22.8	4.6	24.0	6.4	20.9	4.5
2	Site & Facilities	2.2	7.2	46.0	21.4	47.0	15.3	24.3	12.7
2	Common Support Equipment	8.0	3.0	-	-	-	0.8	0.8	2.5
2	Initial Stock	0.8	37.0	16.5	7.0	38.5	22.0	18.6	15.2
2	Test & Evaluation	21.5	9.5	18.6	8.3	14.8	5.2	17.1	6.6
2	Industrial Facilities	-	-	-	2.0	14.0	-	14.0	2.0

D. Utilities

Utilities expenses include the costs of electricity, natural gas, water, etc. These costs are typically computed by multiplying a cost per unit by the units to be consumed. Energy consumption needs of new equipment for the initial year of implementation should be based on current experience for existing or analogous systems and engineering estimates for new systems. Future estimates should be made by adjusting initial year estimates for anticipated future experience. Other regular utility costs related to general facilities and not specific equipment are more of an overhead nature and typically have an established pattern of usage. Tables 4-3 and 4-4 provide a recent history of the average retail prices of electricity and natural gas, respectively. Additional information can be obtained on the Internet at http://www.eia.doe.gov/price.html.

TABLE 4-3

AVERAGE RETAIL PRICES of ELECTRICITY SOLD by ELECTRIC UTILITIES
(Cents per kilowatt-hour)

	1991	1992	1993	1994	1995	1996
Residential	8.05	8.23	8.34	8.41	8.42	8.39
Commercial	7.51	7.63	7.72	7.75	7.70	7.63
Industrial	4.85	4.84	4.86	4.72	4.69	4.60
Other	6.43	6.66	6.86	6.79	6.70	6.72
Total	6.75	6.83	6.92	6.92	6.90	6.87

Source: Energy Information Administration, U.S. Department of Energy

TABLE 4-4

AVERAGE RETAIL PRICES for NATURAL GAS
(Dollars per thousand cubic feet)

	1991	1992	1993	1994	1995
Residential	5.82	5.89	6.16	6.41	6.06
Commercial	4.81	4.88	5.22	5.44	5.05
Industrial	2.69	2.84	3.07	3.05	2.71
Vehicle Fuel	3.96	4.05	4.27	4.11	3.98
Electric Utilities	2.18	2.36	2.61	2.28	2.02

Source: *Natural Gas Annual 1995*, Energy Information Administration, U.S. Department of Energy, Nov. 1996, p. 5

E. Personnel Cost

Personnel costs can be a major component of the ongoing costs of an investment or of complying with a regulation. They may be estimated as the product of the quantity of labor required and the total compensation paid per unit of labor. Labor requirements are typically measured in full time equivalent work (FTE) years and compensation as total annual compensation per FTE per year.

1. Hourly Labor Requirement

The first step in computing personnel costs is to determine the annual labor hours required by type of skill and by pay level. This should be done separately for government employees and private sector employees. For government employees, a further distinction should be made between permanent, temporary, and intermittent employees. (These distinctions are necessary because different fringe benefit and annualization factors apply for different groups). Hours requirements should include not only direct labor, but such other items as recurring training, travel time, break time, supervisor time, staff support time, other overhead staff time, etc.

Labor requirement estimates for new systems or regulations can be developed based on engineering data or previous experience with similar types of undertakings. For existing ones, estimates can be based on actual experience. A potential data source for many existing FAA systems is the FAA's staffing standards.[6] The staffing standards are detailed models relating required staffing to the volume of work required to be done. Each contains information on the staff required to provide specific services or maintain specific equipment. While potentially very useful, the analyst is cautioned to carefully screen staffing standard data for suitability for the analysis at hand. At times, it may contain assumptions or procedures which are inappropriate for benefit-cost analysis.

2. Conversion to Full Time Equivalents (FTE's)

The next step is to express hourly labor requirements on an FTE basis. For hours to be worked by permanent and temporary government employees, this requires that the required labor hours by each skill and pay level be divided by the actual number of hours *worked* per year by a full time employee. Dividing by hours actually *worked* rather than by *hours paid* for a full time work year adjusts for all leave usage and holidays. For FAA employees, a precise estimate of this number of hours may be obtained from the Office of Financial services (ABA) and the Office of Human Resource Management (AHR).

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6 *Air Traffic Staffing Standards Systems*, FAA Order 1380.33B, March 10, 1980; *Airways Facilities Sector Level Staffing Standard System*, FAA Order 1380.40C, December, 21, 1992; *Staffing Standards--Flight Standards Field Regulatory Programs*, FAA Order 1380.28A, November 1975; *Regional Logistics Division Staffing Standards*, FAA Order 1380.42A; *Staffing Guide--Aviation Safety Inspectors (Manufacturing)*, FAA Order 1380.49A, May 1995.

Information may also be found in the various staffing standards. For most estimates involving government employees, however, a government-wide representative value may be used.[7] For hours to be worked for all classes of government employees other than intermittent workers (also known as paid when actually employed or WAE employees), a value of 1776 hours may be used.[8] For private sector employees--including government contractors--actual data should be used where available. Where unavailable, annual hours required should be divided through by 1902 hours assuming utilization of full time employees, 2017 hours assuming utilization of part time employees, or 1916 hours if the breakdown between full time and part time employees is unknown.[9]

3. Total Compensation per FTE

Third step is to determine total compensation per FTE. It is estimated as the sum of four components: the annual stated compensation, other compensation subject to fringe benefits, fringe benefits, and other pay.

- Annual Stated Compensation: FAA employees are paid with respect to either the FG (General Schedule or GS before personnel reform) or FW (Federal Wage Scale or WG before personnel reform) pay scales. Stated compensation for FW employees is expressed directly in hourly rates which must be annualized by multiplying by 2087--the number of paid hours in a full time work year. FG compensation is expressed in annual salaries. Private sector employee stated compensation rates can be determined based on FG or FW compensation rates for equivalent skills or other data which may be available on a case by case basis. For project or regulation evaluation purposes, compensation levels associated with FG step 5 and FW step 3 should be used.

- Other Compensation Subject to Fringe Benefits: If the project or regulation involves labor requirements that will generate compensation subject to fringe benefits, discussed below, such as premium pay for air traffic controllers, location pay, or night differential and weekend pay for certain employees, this should be identified and added to the stated compensation rate to the extent it is expected to occur.

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7 *Performance of Commercial Activities*, Revised Handbook to OMB Circular No. A-76, March 1996, p. 20.

8 FAA employees relatively few WAE workers. Should it be necessary to compute FTE's for these workers, guidance should be sought from AHR. Before personnel reform, required hours could be annualized by dividing by 2007--reflecting that WAE workers accrued no leave but were paid for official Federal holidays. This could change under personnel reform.

9 *Statistical Abstract of the United States*: 1996, Table 669.

- Fringe Benefits: Fringe benefits are additional compensation provided to employees. They may be computed as the product of an appropriate factor and the sum of annual compensation and other compensation subject to fringe benefits. Fringe benefits are grouped into four categories: retirement and disability, health and life insurance, Medicare, and other benefits. Current government-wide factors for each are indicated in Table 4-5 for permanent employees under the Civil Service Retirement System (CSRS) or Federal Employees Retirement System (FERS), temporary and intermittent Federal employees, and for private sector employees. The factors given for private sector employees are an average for the overall private sector. Because benefits vary widely in the private sector, more specific data should be used when estimating effective compensation levels for specific private sector employees when such data is available.

TABLE 4-5

FRINGE BENEFIT FACTORS

Category	Permanent Government	Temporary and Intermittent Government	Private Sector
Retirement and Disability:			
General	23.7%	6.20%	10.3%
Air Traffic Controllers	32.3%		
Law Enforcement/ Fire Protection	37.7%		
Health and Life Insurance	5.6%		7.1%
Medicare	1.45%	1.45%	1.45%
Miscellaneous	1.7%		4.6%

Source: *Performance of Commercial Activities*, Revised Supplemental Handbook to OMB Circular No. A-76, March 1996, p. 20. Employee Benefit Research Institute (EBRI) 1994 data.

The standard retirement cost factor represents the federal government's complete share of the weighted CSRS/FERS retirement cost to the government, based upon the full dynamic normal cost of the retirement systems; the normal cost of accruing retiree health benefits based on average participation rates; Social Security, and Thrift Savings Plan (TSP) contributions. Miscellaneous fringe benefits include workmen's compensation, bonuses and awards, and unemployment programs.

For federal civilian employees not covered by either CSRS or FERS (normally intermittent and temporary employees), the Federal Insurance Contribution Act (FICA or Social Security) employer cost factor of 6.2 percent for retirement and disability and 1.45 percent for Medicare (or the current rate established by law) should be applied. For retirement and disability, the rate is applicable for each employee only up to a maximum salary. Where such estimates must be made, care should be exercised that current tax rates are used and that the rates are applied only to wages below the maximum applicable salary.

The reader should note that the fringe benefit factors given for permanent Government employees are not comparable with those given for the private sector. The Government work force does not mirror the private work force but tends to consist of higher than average skill level employees. In the private sector, such employees tend to receive higher than average benefits and paid absences.

- Other Pay: This includes other compensation that does not earn fringe benefits. Some examples are night differential pay for FG employees, overtime, holiday pay, awards, and bonuses.

4. Total Personnel Costs

The fourth step is to translate annual labor requirements for each required skill into dollars. This is accomplished by multiplying the annual FTE's required (from step 2) by the appropriate total annual compensation per FTE (as determined in step 3) for each labor category and summing across all categories.

F. Airport Development Cost

Characteristics peculiar to the research and development and investment phases of airport investment projects require certain modifications/extensions to the life cycle cost model presented in Section III. above. The FAA has published draft guidance for the conduct of benefit-cost analysis of certain airport construction projects which addresses these considerations.[10] Portions of that guidance that relate to the specific characteristics of airport construction cost estimation are summarized here.

1. Planning and Research and Development Cost

Airport projects typically do not involve the development of new technology. They do involve long term land use commitments, require complicated financing packages, impact many peoples lives, and may have significant environmental impacts. Accordingly, their

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[10] *FAA Airport Benefit-Cost Analysis Guidance*, Office of Aviation Policy and Plans, Federal Aviation Administration, Draft-June 2, 1997.

development phase costs tend to involve more planning and consultation and less research than equipment acquisitions or regulations. Typical costs in this phase of airport projects are indicated below. They include all costs to be incurred prior to beginning construction of the project under evaluation, except those costs that have already been incurred at the time of benefit-cost analysis or which must be developed in order to complete the analysis. Incurred costs are sunk costs and are not relevant for decisionmaking purposes.

- Any necessary research and development expenses associated with the project
- Project environmental assessment
- Detailed project design and engineering plans
- Coordination with regional development and transportation plans
- Arrangement of project financing
- Public outreach

2. Investment Cost

Airport investment phase costs typically involve much more land acquisition/development and specialized facilities construction than FAA acquisitions or regulations. Moreover, they may require cooperating investments by FAA, such as air traffic control facilities or instrument approach systems and other landing aids, and may involve purchase of specialized equipment. Airport investments may also entail significant transition costs which must be captured in the cost estimate. Airport investment phase costs requiring special consideration are:

- Land Cost: Land cost includes all interests in land that are acquired for the project, such as purchases, leaseholds, easements, air rights, mineral rights, etc.

- Construction Cost: Construction cost includes all expenses associated with the building of a new facility or the expansion, modernization, or refurbishment of an existing facility. Construction cost should also include any costs to expand, modernize, or refurbish any other portion of the airport or its infrastructure necessitated by the implementation of the project. Construction cost estimates are generally site-specific and should be developed based on engineering estimates. Table 4-6 summarizes airport construction costs. FAA should be consulted for cost estimates of facilities (e.g., air traffic control towers or precision landing systems) to be built by or in coordination with FAA.

- Equipment, Vehicle, and Provisioning Costs: Equipment, vehicle, and provisioning costs consist of items in addition to physical facilities that are required including the non-facility components of Airport Terminal Buildings. Vehicles include emergency and maintenance vehicles required to service an expansion of airfield infrastructure. Provisioning costs are incurred for initial spare parts, special tools, and technical documents. Other items such as furniture would also be classified as equipment. All cost estimates should include any charges for transportation to the airport site.

- Transition Cost: Transition cost reflects the impact on airport operations of building and/or transitioning to the new project. This impact can be very large, particularly if the construction of the project leads to the temporary closure of major facilities of the airport. A runway reconstruction project will lead to the total or partial closure of the runway itself, and may cause the temporary closure of any runway intersecting it. Disruption and delay associated with the project may result in millions of dollars of additional costs to airlines, general aviation users, passengers, and others using the airport, and must be measured and included as an important cost element of the project.

TABLE 4-6

AIRPORT CONSTRUCTION COST ELEMENTS
Relocation of existing buildings and utilities at site
Site development
Clearing
Runway and taxiway facilities
Subgrade preparation
Paving and lighting
Shoulders and blast pads
Runway safety areas and other conformance to FAA design standards
Environmental mitigation costs (sound insulation, residence acquisition)
Precision landing system
Supplemental grading
Obstacle removal
Installation of precision system
Approach lights and MALSR
PAPI, NDB, and beacon
Air traffic control facility
ARFF facility
Air Terminal Building (ATB) access
ATB access taxiways
ATB access taxiway shoulders
ATB/cargo apron
ATB
Passenger terminal
Cargo terminal
Jetways
ATB Parking
Entry roadway and transit system
Water supply system (on- and off-site)
Sanitary sewer system (on- and off-site)
Storm water system (including water treatment)
Electric, gas, and telephone
Perimeter and security fencing
Fuel facilities
Airport maintenance facility

CHAPTER 5

MULTI-PERIOD ECONOMIC DECISION CRITERIA

I. Requirement to Discount

This chapter presents methodology with which to make the comparison of investment or regulatory alternatives required by step 6 of the economic analysis process. The methodology accounts for the characteristic that benefits and costs occur over a number of years. It explicitly recognizes that otherwise equal benefits or costs which occur at different points in time will not be equal when viewed from a common point in time. Generally, a benefit will be worth more the sooner it is received, and a cost will be less the longer it is deferred. This economic phenomena is the result of two factors: the productivity of capital and the time preference of economic decision makers.

An observed characteristic of economic life is that production processes which employ capital--buildings, machines, organized methods such as assembly lines, etc.--are frequently more productive than other production methods. Such methods are not only able to recover the costs of the resources to build the capital, but return something in addition to this. This additional return, known as the net productivity of capital, provides an incentive to undertake every activity for which it exists. Unfortunately, there are insufficient resources to carry out all such projects.

At any particular time, the quantity of resources in an economic system is fixed. As a consequence, only some of the many activities capable of returning more than their cost can be undertaken. Rational decision making requires that those activities with greater returns over cost be undertaken before those with smaller returns until all investable resources are exhausted. The last activity undertaken before exhausting the investable resources should have a return less than or equal to all activities actually undertaken and greater than or equal to all activities not undertaken. This level of return, commonly expressed as an annual rate, is known as the marginal rate of return to capital. It represents the prevailing level of capital productivity that can be achieved at any particular time by investing resources.

Limited resources may be divided between current consumption and capital investment, which implies future consumption. However, there is a general predisposition for people to prefer current consumption over future consumption, or to have a positive time preference. In very poor subsistence level economic systems, immediate consumption of everything, or almost everything, may be necessary for survival. But even in wealthier systems, either because of general impatience, or the ever present probability of death, or some other reason, people are willing to forgo current consumption to invest in the future only to a limited degree. The extent to which a person discounts future consumption is referred to as the rate of time preference. The rate at which society discounts future consumption is known as the social rate of discount.

Any investment requires that resources either be diverted from another investment or obtained by deferment of consumption. This gives rise to a cost, either in terms of the return that could be earned on capital in its next best alternative use--the marginal rate of return to capital--or the compensation that must be paid to induce people to defer an additional increment of current consumption--equivalent to their marginal rate of time preference. This cost is captured in benefit-cost analysis through discounting. Before proceeding, it is emphasized that the requirement to discount does not depend upon the existence of inflation. Rather it arises from the productivity of capital, peoples preferences for current over future consumption, and the scarcity of investable resources. Even in an inflationless world, discounting is required. (The appropriate treatment for inflation in investment analysis will be discussed in Chapter 7.)

II. Discounting Methodology

A. Mechanics

For a period of one year, an investment can be expected to grow at some rate, as shown by equation (5-1):

$$O_1 = I + rI = I(1+r) \tag{5-1}$$

where: I = the investment's initial value,

O_1 = the investment's value in one year, and

r = the growth rate.

For a period of two years, investment growth is given by:

$$O_2 = I(1+r)(1+r) = (1+r)^2 \tag{5-2}$$

Here the growth rate is applied, in succession, twice because the investment is allowed to grow for two years. Similarly, for a period of n years the growth rate is applied n times:

$$O_n = I(1+r)^n \tag{5-3}$$

The significance of equation (5-3) is that it indicates the extent to which resources invested today (*I*) can be transformed into outputs in the future (O_n) any growth rate *r*. In many instances, the amount that will be received in the future is known. The value today of an amount to be received in the future can be determined by dividing (5-3) through by $(1+r)^n$ to yield (5-4). It is equation (5-4) that is relevant to discounting.

$$I = \frac{O_n}{(1+r)^n} \tag{5-4}$$

It indicates that *I* is the present value of O_n after being discounted over *n* years at rate *r*.

Equation (5-4) can be extended to situations where outputs are generated and resources consumed in more than one period. This requires that several equations--one for each year--of the form of (5-4) be added together, as in (5-5):

$$I^1 + I^2 + \ldots I^n = \frac{O_1}{(1+r)^1} + \frac{O_2}{(1+r)^2} + \ldots + \frac{O_n}{(1+r)^n} \tag{5-5}$$

where: I^i = the initial investment associated with outputs in year *i*.

By defining O_t as the difference between benefits (B_t) and costs (C_t) in year *t* and their discounted value as their net present value, equation (5-5) may be rewritten in its usual form:

$$NPV = \sum_{t=0}^{k} \frac{(B-C)_t}{(1+r)^t} = \sum_{t=0}^{k} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{k} \frac{C_t}{(1+r)^t} \tag{5-6}$$

where: NPV = the discounted net present value of a series of outputs and resource inputs, and

k = the total number of periods in the evaluation period of the project or regulation.

B. Discount Rate

As noted above, the discount rate represents the cost associated with diverting investment resources from alternative investments or from consumption. There is no general consensus, either conceptually or empirically, as to what this rate should be. A principal reason for this lack of consensus is that the rate of time preference of those who postpone consumption--savers--is typically significantly lower than estimates of the marginal rate of return to capital. This occurs in large part because of the impact of corporate and personal income taxes. The marginal rate of return to capital is appropriately measured on a before tax basis whereas returns actually received by savers are net of taxes. Because people adjust their saving until they are indifferent between a dollar of current consumption and a dollar of future consumption plus the return they actually receive after taxation for deferring consumption, their time preference is equal to the after tax return to saving.

Four conceptual alternatives for the discount rate have been proposed. These are:

- the marginal social discount rate
- the marginal opportunity cost of capital
- a weighted average of the marginal social discount rate and the opportunity cost of capital
- the shadow price of capital

For most Federal investments and regulations, the Office of Management and Budget (OMB) requires use of the marginal cost of capital approach as a base case. OMB further recognizes the merit of the marginal social discount rate approach through a requirement to conduct sensitivity analysis with respect to the discount rate. The shadow price of capital approach is also permitted with prior OMB concurrence.

1. Marginal Social Rate of Discount

This rate indicates the compensation required by society to substitute future consumption for current consumption. Discounting a stream of benefits and costs at this rate produces the present value of this stream as viewed by society. It is often measured empirically as the after tax, after inflation riskless rate of interest, such as could be earned on U.S. Treasury debt less taxes. There are fundamental conceptual problems with this approach, however.

First, use of the rate of time preference will represent the opportunity cost of investment resources only if these resources are in fact diverted from consumption. If they actually come from another source, such as other investments or foreign borrowing, other rate(s) representing the cost of these resources is relevant.

Second, an observed interest rate net of taxes will measure the willingness of people to substitute future for current consumption only if they in fact do make such substitutions in response to the prevailing rate of interest. But many observers believe that consumers do not vary consumption in response to interest rates over the range of rates which typically prevail. Thus, observed rates measure only the rent earned on those resources available for investment, not peoples' rate of time preference.

Third, observed rates reflect the preferences of individual members of society who have finite lives and are currently living. Because society presumably has an indefinite life, it may well discount future consumption by less than its individual members. The issue is one of intergenerational equity--do current members of society have any more rights to consume existing resources than future members? It is most relevant when evaluating potential actions with very long lives where a significant portion or all of the benefits will accrue to those yet to be born. Evaluation of environmental policies and regulations are examples.

2. Marginal Opportunity Cost of Capital

This approach presumes that resources used for the investment under evaluation will in fact be diverted from private investment. The appropriate opportunity cost under these circumstances is what actually will be foregone in the private sector. It is measured by the return on additional investment in the private sector of the economy before taxes and net of inflation.

3. Weighted Average of the Marginal Opportunity Cost of Capital and the Social Rate of Discount.

This approach recognizes that resources required to undertake investments may actually come from both other investments and consumption. Accordingly, a weighted average is constructed where the weights represent the respective shares coming from consumption and other investment. Because it is an average of two other methods, this approach avoids the problem that funds may come from more than one source; most other problems remain.

4. Shadow Price of Capital Approach

The shadow price of capital approach explicitly recognizes that the marginal rate of return and the rate of time preference typically have different values and provides a conceptual solution to the discounting problem which incorporates both rates. Proceeding from the premise that consumption is the purpose of all economic activity, it expresses all benefit and cost flows of the decision under evaluation in terms of their consumption equivalents in the year in which they occur and then discounts them back to the present at the rate of time preference.

For benefits (which by definition are consumed in the current time period) and costs which affect outputs only in the current time period--operations costs for example--this is straight forward. These quantities are valued at their prevailing values in each time period. For capital investments which give rise to benefit flows in the future, the valuation process to express these amounts in current consumption equivalents is more involved. First, it is necessary to divide the amount invested in each period into that which is diverted from current consumption and that which is obtained by forgoing other investments. Because that which is diverted from consumption represents foregone consumption, it is already valued in consumption units and its value can be used directly in the computation of present value. The challenge comes in expressing in its current consumption equivalent value the investment which is diverted from some other competing investment use.

In its next best use investment resources can be expected to give rise to a future stream of outputs, some of which will be invested and some of which will be consumed. Those which are reinvested will in turn give rise to their own future stream of outputs, some of which will be in turn invested and some of which will be consumed. This process will continue into the future, perhaps indefinitely. Under a wide range of reasonable circumstances, it is possible to calculate the present value of the stream of future output available for consumption that the initial investment will make possible. The present value of the future consumption yielded by one dollar of capital is known as the shadow price of capital.

If this approach were used, equation (5-6) would be restated as:

$$NPV = \sum_{t=0}^{k} \frac{B_t - [(1-c)S + c]C_t}{(1+i)^t} \tag{5-7}$$

where: c = the fraction of project costs coming from saving,

i = the rate of time preference, and

S = the shadow price of capital.

The term S--the shadow price of capital--effectively adjusts that investment cost drawn from alternative investment projects to account for the higher marginal return to capital, and the ultimate reduction in future consumption, that must be forgone to undertake this project. Randolph Lyon has derived the following expression for S assuming that geometric depreciation adequately represents economic depreciation of the capital stock:[1]

$$S = \frac{r - sr}{i + d - sr} \tag{5-8}$$

[1] Randolph M. Lyon, "Federal Discount Rate Policy, the Shadow Price of Capital, and Challenges for Reforms," *Journal of Environmental Economics and Management*, 18, no. 2, part 2 (March 1990), S29-S50.

where: r = the marginal return to capital before depreciation,

s = the rate of savings from the gross return,

i = the rate of time preference, and

d = the rate of depreciation.

Use of this approach effectively solves the problem of which rate to use at the conceptual level. It is the analytically preferred means of capturing the effects of Governmental projects on resource allocation. Unfortunately, its actual application is far from straight forward. The difficulty is that S can vary significantly as its determinants are varied over their plausible ranges.

C. Executive Branch Discount Rate Policy

The OMB establishes discount rate policy for most Executive Branch evaluations of investment and regulatory decisions. Its policy is outlined in OMB Circular A-94, "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs," (Revised--October 29, 1992).[2] OMB permits analyses to be conducted in either nominal or current year dollars or in constant dollars of a particular year, although nominal and constant dollars cannot be mixed-up in the same analysis. There is a preference for the use of constant dollars unless most of the underlying values are initially available in nominal dollars. Although some conversion from nominal to constant or vice-versa may be necessary to get all values into one form or another, the choice of nominal or constant dollars should be made so as to minimize the conversions required. If the analysis is conducted in nominal dollars, the discount rate selected should be a nominal one; if the analysis is conducted in constant dollars, the discount rate should be a real one. Real rates can be approximated by subtracting expected inflation from a nominal rate.

OMB effectively divides potential Government investments and regulations into four categories: (1) public investment and regulatory analyses, (2) lease-purchase and asset sale analyses, (3) cost-effectiveness and internal Government investments, and (4) combined projects. Discounting concepts and rates vary across categories.

1. Public Investment and Regulatory Analyses

OMB specifies that a base case analysis be conducted for potential actions using a real discount rate of 7 percent. Circular A-94 states that "this rate approximates the marginal pretax rate of return on an average investment in the private sector...." Selection of this rate implies OMB acceptance of the marginal opportunity cost of capital approach to

[2] A summary of applicability of the Circular A-94 is contained in Appendix A.

discounting discussed above. However, Circular A-94 also states that "public investments and regulations displace both private investment and consumption," thus acknowledging the marginal social discount rate approach.[3] Rather than suggesting a weighted discount rate approach, OMB recognizes that investment resources may come from multiple sources with different opportunity costs by requiring that sensitivity analyses be conducted at discount rates both higher and lower than 7 percent. The Office of Aviation Policy and Plans recommends that sensitivities be carried out at both 10 percent and 4 percent.

Alternatively, OMB recognizes that "using the shadow price of capital to value benefits and costs is the analytically preferred means of capturing the effects of Government projects on resource allocation in the private sector." Because of the practical problems involved with using this approach, it may be used only with OMB concurrence.[4]

2. Lease-Purchase and Asset Sale Analysis

These types of analyses do not address diversion of resources to a Government investment project. (For lease-purchase the decision to undertake the investment has presumably already been made under the public investment approach noted above. For Asset Sales the investments have already been made and are owned by the Government.) Rather, they concern asset ownership. In the case of lease-purchase, the question is should a particular asset which will be used by the Government be owned by the Government or by the private sector. The issue is viewed strictly as one of minimizing the Government's cost. Accordingly, OMB requires that the stream of lease payments and the stream of ownership costs--purchase plus operation--each be discounted by the Treasury's borrowing rate on marketable securities of comparable maturity to the period of analysis, expressed in real or nominal terms, depending on how the cost streams are measured.[5, 6]

In the case of asset sales, the question is whether an asset owned by the Government should be sold to the private sector.[7] Gains in social efficiency may be possible under

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3 "OMB Circular A-94" (Revised--October 29, 1992) p. 9.

4 "OMB Circular A-94" (Revised--October 29, 1992) p. 9.

5 Real and nominal Treasury borrowing rates for alternative maturities are published by OMB in Appendix C to Circular A-94. This appendix is updated each February.

6 For the reasons indicated above in Section II.B., it should be noted that the Treasury borrowing rate does not *conceptually* correspond to any of the four discount rate alternatives. It is strictly the government's cost of borrowing.

7 Governmental assets which are typically candidates for divestiture to the public are those associated with the sale (as opposed to free provision) of goods and services to the public by the government, often in competition with the private sector. Examples would include Federal

private ownership which subjects an asset to market discipline and private incentives. If so, presumably the private sector will be willing to pay more for it than it is worth to the Government. To determine if the asset is worth more under private sector ownership, it is necessary to determine its value under Government ownership and then ascertain if private parties are willing to pay more for it. Circular A-94 requires that the assets present value be determined by discounting its future earnings stream--after adjustment for expected defaults or delays, Government administrative costs, and expected increases or decreases in asset value--using the Treasury borrowing rate for a term equivalent to the life of the asset, either real or nominal, depending on how the earnings are measured. Further, because the private sector will tend to discount earnings streams at a higher rate than the Government borrowing rate to account for risk, when there is evidence that Government assets can be used more effectively in the private sector, valuation analyses for these assets should include sensitivity comparisons that discount the returns from such assets with the rate of interest earned by assets of similar riskiness in the private sector.

3. Cost-Effectiveness Analyses and Internal Government Investment

Cost-effectiveness analyses are undertaken in a situation where the decision has been made to produce a particular output and it is necessary to determine the lowest cost method to produce it. Analyses of Government investments address the viability of proposed projects where the benefits take the form of increased Federal revenues or decreased Federal costs. For both these cases, Circular A-94 indicates that the comparable-maturity Treasury borrowing rate, either real or nominal depending on how benefits and costs are measured, be used as the discount rate. Specifying this rate will have the effect of selecting projects which minimize the present value of costs or maximize the present value of benefits to the Government.[8]

4. Combined Projects

Many investment projects yield both cost savings to the Government and external social benefits. Circular A-94 specifies that these be discounted at the base case rate of 7 percent, as required for public investment and regulatory analyses, unless it is possible to

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credit programs and the loan portfolios which they generate and the Postal Service. Governmental assets which are used to provide benefits to the public which generate little or no revenues are not candidates for sale in that they would attract no buyers.

[8] It should be noted that these analyses, unlike lease-purchase decisions or asset sales, involve decisions as to the amount of investment resources to be diverted from the private sector and/or the time distribution of these investments. As such there is an opportunity cost of these resources. The OMB policy, in effect, permits the Federal Government to consider its borrowing cost as the opportunity cost of capital rather than the marginal pre-tax return to capital which is required for investments which provide benefits to the private sector. While this procedure will lead to projects that minimize costs to the Government, it may divert resources away from more productive uses in the private sector.

"*allocate* the investment's costs between provision of Federal cost savings and external social benefits." Where such an allocation is possible, the project can be treated as two separate projects with the part yielding benefits to the Federal Government discounted at the Treasury rate and the part yielding external social benefits discounted at the 7 percent real discount rate.[9]

Although many FAA investment projects yield both benefits to the Federal Government and external social benefits, the costs are frequently difficult to allocate between these two. The following guidance is offered:

- The total project should first be evaluated with the 7 percent base case real discount rate. If it has positive net present value, it is probably unnecessary to go further.

- Should a project not have a positive net present value at the 7 percent real rate, the following steps may be taken:

  * If Governmental cost savings are a large component of the benefits, evaluate the project at the Treasury borrowing rate considering only the Governmental benefits. (So doing will ensure that a relatively small amount of external social benefits associated with what is fundamentally a cost saving project would not *taint* the outcome of the analysis by requiring the higher 7 percent be used.)

  * Where there are significant benefits in both categories and a positive net present value does not result from the above procedures, costs may be allocated between the two categories. The amount of project cost allocated to Governmental cost saving should be at least as large as the costs that could be avoided if the project were redesigned so as not to yield Governmental benefits (avoidable costs of the Governmental cost savings) but no larger than the cost of producing the Governmental benefits independently of the external social benefits (stand alone costs). Should avoidable costs exceed stand alone costs, the allocation should be set at the level of stand alone costs. Within these two extremes, a reasonable allocation based on accepted cost accounting procedures may be employed. In addition, the allocation at which the project would have a zero net present value should be identified with sensitivity analysis.

D. Evaluation Period

The number of years over which the benefits and costs of an investment or regulation should be considered may be designated as the evaluation period. Three time periods are

9 "OMB Circular A-94" (Revised--October 29, 1992) p. 11.

of concern in determining the evaluation period: requirement life, physical life, and economic life. The requirement life is that period over which the benefits of the good or service to be provided or mandated by regulation will be greater than the costs of producing it. It can be for a very short period of time such as a requirement to provide special air traffic control services to an air show held at an otherwise uncontrolled airport. Or it may be for a very long period of time such as the provision of en route surveillance coverage.

The physical life is that period for which facilities and equipment can be expected to last. It is to a considerable degree under the control of the decisionmaker. Not only can alternative facilities and equipment with different physical lives resulting from inherent quality differences be procured, but maintenance policies can be varied to alter an asset's physical life after it has been put in service.

The economic life is that period over which an asset can be expected to meet the requirements for which it was acquired at the lowest achievable cost. Thus, by definition, economic life is less than or equal to requirement life. Economic life may be equal to physical life but it is frequently less. If less, this indicates that it is not efficient to operate the asset as long as possible. Rather, it is cheaper to replace it. The need to replace often occurs as the consequence of ever rising maintenance costs, particularly for relatively old items. Estimates of economic lives should be based on actual information where possible. In the absence of such information, the guidelines in Table 5-4 may be used. These guidelines have been synthesized from a number of sources and are intended to represent actual practice with respect to broad classes of assets. As such they may be regarded as approximations to economic lives.

The evaluation period may be defined with respect to either the length of time over which the good or service to be produced will be required or the economic life of the investment required to produce it. Because either method will yield the same results, the choice is dependent on the circumstances of the analysis and can be made based on considerations of practicality. Although the evaluation period may be defined with respect to either requirement life or economic life, investment projects or regulations requiring specified investments--design regulations--are usually best evaluated over their economic lives.[10] Use of the requirement life method would require the assumption that the facilities and equipment would be replaced at the end of each economic life period forever. Such assumption, while not improper, would add little to the analysis. Moreover, it might obscure the fact that equipment performance is likely to improve with time and that better performance, lower cost replacements are likely to be available in the future.

[10] In practice, physical life is often used. To the extent this diverges from economic life, costs will be overstated which may result in otherwise potentially viable projects failing the benefit-cost test.

TABLE 5-1
ASSET LIFE GUIDELINES

Item:	Asset Life in Years
Aircraft: (a) (c) (d) (e) (f)	
Airframes	20-40
Avionics	10-20
Flight Instruments	10-20
Airports: (a) (g)	
Lighting Systems	15-25
Pavements	20-40
Terminals (Permanent Structures)	45+
Automation: (c) (d) (f)	
FAA Developed Hardware	15-20
FAA Developed Software	10-15
Mainframe Computers	10-15
High-End Work Stations	5-7
PC Workstations	5-7
PC Workstation Application Software	3
Communications: (c) (d) (f)	
Radios	8-15
Telephone/Telegraph/Teletype	10-20
Miscellaneous	10-20
Tower/TRACON Voice Switches	10
Enroute Voice Switches	10-15
Operating Equipment: (c) (d) (e)	10-20
Navigation/Landing Equipment: (c) (d)	20-25
Structures: (b) (c) (d) (f)	
Permanent	45+
Semi-Permanent	25-45
Temporary	15-25
Surveillance Radars: (a) (c) (d)	20-25
Weather: (c) (d)	
General-Purpose Weather Sensors	10-20
Weather Radars	20-25
Vehicles: (c) (d) (f) (h) (i)	
Passenger Cars and Station Wagons	3-6
Light Trucks	4-6
Heavy Trucks and Truck Tractors	5-9
Off Road Heavy Equipment	6-10

Derived from:

[a] *Capital Stock Measures for Transportation: A Study in Five Volumes*, US Department of Transportation, December 1974.

(b) *Performance of Commercial Activities: Circular A-76 Revised Supplemental Handbook*, OMB March 1996, p.22.
(c) *Performance of Commercial Activities: Circular A-76 Revised Supplemental Handbook*, OMB March 1996, Appendix 3.
(d) *Long Range resource Allocation Plan*, FAA, October 1995.
(e) "A History of Federal Tax Depreciation Policy," Office of Tax Analysis, US Treasury Department, May 1989, Appendix.
(f) *Publication 534*, Internal Revenue Service, November 1995.
(g) *Airport Pavement Design and Evaluation*, FAA Advisory Circular 150/5320-6D, July 7, 1995, p.23.
(h) *Report to the Congress on the Depreciation of Business-Use Passenger Cars*, Department of the Treasury, April 1991.
(i) *Report to the Congress on the Depreciation of Business-Use Light Trucks*, Department of the Treasury, September 1991.

Analysis of regulations which mandate provision of a good or service but which do not specify the method of production are known as performance regulations. They cannot be evaluated over the economic life of the required investments because the equipment has not been specified and its life is, thus, unknown. Performance regulations should be evaluated over the requirement life. The length of time for which a regulation is required must be determined on a case by case basis. In those cases where it is anticipated that the mandated new good or service will become a permanent part of the NAS, the requirement life may be treated as infinite.

Regardless of the evaluation period selected, it should extend over the same number of years for each alternative. This is necessary because benefits and costs are flows and must be measured with respect to time. In certain situations, it will not be possible to compare alternatives with the same number of time periods. This situation frequently arises when an existing facility is being compared with replacements. The existing facility will continue to be functional for sometime; however, its physical life probably will not extend beyond the economic life of the new replacement alternatives. Techniques for dealing with this type of situation are presented in Section III. C.

E. Calculation Issues

1. Basic Procedure

To compute *NPV*, each element of the summation of (5-6) must be evaluated. The first step is to estimate the value of activity benefits each year for each alternative. Next, the cost for each alternative must be estimated and subtracted from the benefit estimates. (Procedures for estimating benefits and costs are developed in Chapters 3 and 4, respectively.) The resulting net benefit in each period *t* must then be discounted--divided by $(1 + r)^t$ --and the resulting values added up to obtain the net present value of the alternative. Such calculations are readily accomplished using a financial calculator or a personal computer. Many calculators and most spreadsheet software, including Excel© and Lotus 1-2-3©, have functions that make this calculation automatically. Should a financial calculator or computer not be available, the computation can be done manually with the aid of discount factors found in published tables. (Relevant portions of such tables are reproduced in Appendix B.) Table 5-2 presents an example the calculation of these factors for benefits or costs flowing at the end of each period.

TABLE 5-2

REPRESENTATIVE END of PERIOD DISCOUNT FACTORS for 7 PERCENT DISCOUNT RATE

Years from Present	Factor
0	$1/(1+.07)^0 = 1.000$
1	$1/(1+.07)^1 = .935$
2	$1/(1+.07)^2 = .873$
3	$1/(1+.07)^3 = .816$
4	$1/(1+.07)^4 = .763$
5	$1/(1+.07)^5 = .713$

2. Timing of Benefits and Costs

Using the factors in Table 5-2 to discount both benefits and costs occurring in each period would implicitly assume that all benefits and costs occur at the end of a period and are discounted for this period to reflect receipt at the period's end. Actually, several more realistic assumptions are commonly employed with respect to when benefits or costs occur within each period. The most conservative assumption--yielding the lowest NPV for given streams of benefits and costs--is to assume that all costs occur at the beginning of a period and all benefits at the end. The assumption involves discounting the stream of benefits by one more time period than the stream of costs. That is, costs, incurred in the first time period are not discounted at all while benefits in this period are discounted by one period; in the second period, costs are discounted by one period and benefits by two periods, and so on. This assumption is commonly used with financial calculations where money is advanced at the beginning of a period and paid back at the end of the period with interest.

Another common assumption is to assume that all benefits and costs occur at the mid-point of a period. Such a procedure attempts to approximate the reality that benefits and costs occur throughout each period for most investment activities. The discounting procedure involves applying the discount factor for half a period in the first period, one and a half periods in the second period, and so on. Table 5-3 presents an example of such factors. In practice such factors need not be used. All that is necessary is to discount using end of year factors and then multiply the results by 1.034408. Multiplication by this factor, equal to $(1+.07)^{1/2}$, has the effect of moving all the end of year discounted values closer to the present by a half a year.

TABLE 5-3

REPRESENTATIVE MID-PERIOD DISCOUNT FACTORS for 7 PERCENT DISCOUNT RATE

Years from Present	Factor
0	$1/(1+.07)^{0} = 1.000$
1	$1/(1+.07)^{1/2} = .967$
2	$1/(1+.07)^{1\ 1/2} = .903$
3	$1/(1+.07)^{2\ 1/2} = .844$
4	$1/(1+.07)^{3\ 1/2} = .789$
5	$1/(1+.07)^{4\ 1/2} = .738$

The final assumption commonly employed is that benefits and costs occur continuously over the period and are discounted continuously over the period. This procedure explicitly recognizes that benefits and recurring costs very likely occur throughout a period, rather than at its beginning or end. Moreover, one-time costs projected to occur in the more distant years of an activity's life, such as major overhauls or modifications, are unlikely to occur only on anniversary dates. The continuous procedure assumes an equal probability of the occurrence of such one-time costs throughout the year. Representative discount factors are presented in Table 5-4; complete tables are contained in Appendix B. The computation of these factors is beyond the scope of this guide. The interested reader is referred to any standard engineering economics text.[11]

[11] For example: E. Paul DeGarno and John R. Canada, *Engineering Economy*, Fifth Edition, MacMillan Company, New York, 1973, pp. 143-146.

TABLE 5-4

REPRESENTATIVE CONTINUOUS DISCOUNT FACTORS for 7 PERCENT DISCOUNT RATE

Flow Period	Factor
0 to 1	.967
1 to 2	.904
2 to 3	.845
3 to 4	.789
4 to 5	.738
5 to 6	.689

From a practical point of view, the mid-point and continuous procedures are about the same. Either can be used to approximate the continuous characteristic of benefit and cost streams. Also, there is not a large difference between the end of period discounting and either mid-period or continuous discounting--slightly less than 3.5 percent at a 7 percent discount rate. And assuming costs to occur at the beginning of the period and benefits at the end has the effect of increasing costs relative to benefits by 7 percent. The relatively small changes produced by changing discounting procedures suggests that, with respect to project and regulation evaluation, any of the methods is acceptable. However, the mid-point or continuous procedures have conceptual appeal because they explicitly recognize the continuous nature of benefits and costs. It is recommended that one of these methods be utilized.

3. Special Cases

The computation procedures for determining *NPV* can be simplified substantially in two special situations. The first is where the flow of benefits and costs each period are equal and occur for a finite number of periods. In such cases, the present value of the streams is given by:

$$NPV = \sum_{t=0}^{k} F_t (B - C) \tag{5-7}$$

where: F_t = the appropriate discount factor at a given interest rate for the period t periods from today, as discussed above in Section III. E. 1. and given in Tables B-1 and B-2 of Appendix B.

Because *(B-C)* is constant across all periods, it may be removed from the summation to yield (5-8):

$$NPV = (B - C)\sum_{t=0}^{k} F_t \qquad (5\text{-}8)$$

Values for $\sum_{t=0}^{k} F_t$ for various discount rates and values of *k* are tabulated in Tables B-3 and B-4 in Appendix B. Given the evaluation period of an activity, *k*, and the discount rate, the analyst need only determine the appropriate value from the table and multiply it by the annual net benefit amount to determine *NPV*.

A second special case occurs when the flow of benefits and costs each period are equal and occur forever. Such a situation is known as a perpetuity. The present value of such a stream can be calculated very easily by dividing the flow per period by the discount rate, as indicated by equation (5-9).

$$NPV = (B\text{-}C)/r \qquad (5\text{-}9)$$

III. Alternative Decision Criteria

In order to answer the economic questions of (1) which objectives should be pursued and (2) how these objectives should be accomplished, it is necessary to adopt a decision criteria which takes the time distribution of benefits and costs into account. Several proposed criteria may be found in the capital budgeting literature. Four discussed here are net present value, the benefit-cost ratio, uniform annual value, and the internal rate of return. Note that OMB has specified that net present value shall be the standard criteria for deciding whether Government programs can be justified on economic principles. However, OMB encourages presentation of other summary measures as supplementary information to net present value.[12]

A. Net Present Value

The present value (NPV) criterion requires that equation (5-6) be evaluated for all investment or regulatory alternatives. The criterion provides that the alternative to be undertaken (1) have a positive NPV and (2) be that one which has the highest NPV of all alternatives. Condition (1) insures that the activity is worth undertaking; that is, it contributes more in benefits than it absorbs in costs. Condition (2) results in the optimum

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[12] "OMB Circular A-94" (Revised--October 29,1992) pp. 3-4.

amount of benefits being efficiently produced. The NPV criterion, then, answers both of the economic questions--what to produce and how to produce it.

As an illustration of the application of NPV, consider the following hypothetical example. An airport is being evaluated for the establishment of a windshear detection system. Three alternatives are being considered: Alternative A--Low Level Windshear Avoidance System (LLWAS), Alternative B--Terminal Doppler Weather Radar (TDWR), and Alternative C--an integrated combination of the two systems (TDWR+LLWAS). Table 5-5 presents the present value of benefits, the present value of costs, the net present value, and the benefit-cost ratio (discussed in section III. B below) for each alternative. Present values are computed using the OMB prescribed 7 percent discount rate and a 20 year project life.

TABLE 5-5

ALTERNATIVE WINDSHEAR AVOIDANCE SYSTEMS
PRESENT VALUES of BENEFITS and COSTS
and BENEFIT-COST RATIOS[a/]
(millions of constant dollars)

Alternative	Benefits	Costs	Benefits Minus Costs	Benefits ÷ Costs
A--LLWAS	\$5.2925	\$1.0	\$4.292	5.29
B--TDWR	\$8.820	\$4.410	\$4.410	2.0
C--TDWR+LLWAS	\$9.526	\$5.540	\$3.986	1.72

[a/]Adapted from "Integrated Wind Shear Systems Cost-Benefit and Deployment Study," Martin Marietta Air Traffic Systems, March 1994, and "Establishment Criteria For Integrated Wind Shear Detection Systems," Report FAA-APO-90-13, December 1990. I should be noted that this is strictly an example, developed to illustrate problems involved in selecting between alternatives. Based on benefit-cost analysis, FAA has in practice installed LLWAS, TDWR, or both at selected airports depending on such factors as airport activity, weather, and technological effectiveness of each system at the time it was installed.

In the hypothetical example of Table 5-5, the LLWAS is substantially cheaper than the TDWR but provides a lower level of benefits than does the TDWR. The combined system has the highest level of benefits and also the highest level of costs. The NPV decision criteria--present value of benefits minus present value of costs--indicates that Alternative B is the best to undertake because it provides the greatest surplus of benefits over costs of the three alternatives.

B. Benefit-Cost Ratio

Another investment criterion is the benefit-cost ratio. It is defined as the present value of benefits divided by costs, and is given by equation (5-10).[13]

$$B / C = \frac{\sum_{t=0}^{k} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{k} \frac{C_t}{(1+r)^t}} \tag{5-10}$$

The ratio indicates the present value of the dollar benefits that will result per present value dollar invested. A proposed activity with a ratio of at least one will return at least as much in benefits as it costs to undertake. This corresponds to having a positive or zero net present value and indicates that an objective is worth undertaking.

For activities which are independent of each other, the benefit-cost ratio criterion provides a correct answer to the first economic question of which objectives should be undertaken. This is indicated by a benefit-cost ratio greater than or equal to one. FAA has routinely employed benefit-cost ratios in its Facility Establishment Criteria to summarize the benefit-cost relationship for establishing or discontinuing such items as airport traffic control towers, precision approach landing systems, airport surveillance radars, etc. at airports. This procedure has been correct because each proposed installation of a particular facility type is independent of the others. In addition, benefit-cost ratios can be used correctly to rank independent projects as to which are most cost-beneficial. Given the usual constraint of a limited budget, projects can be pursued from highest to lowest benefit-cost ratio until the budget is exhausted.

However, when a selection must be made between competing alternatives, it often fails to completely answer the first economic question as well as correctly answer the second question of how to accomplish the desired objectives most effectively. The difficulty arises in choosing between competing alternatives to accomplish a particular objective which are interdependent. Interdependence occurs when the benefits or costs of one alternative depend on whether or not certain other alternatives are also selected. Interdependence will result in mutual exclusivity--when selection of one alternative precludes selection of any of the others. In some cases the mutually exclusive alternatives relate to the scale of the proposed activity. Selecting one size precludes selecting another. In other cases the mutually exclusive alternatives relate to different

[13] Equation (5-10) is written using discrete, end of period discounting. It could also be stated in terms of any of the other discounting conventions discussed above in Section II. E. of this chapter.

methods of achieving the desired objectives. When competing sizes are involved, the benefit-cost ratio cannot fully answer the first economic question because it does not permit selection between alternative projects. When competing methodologies are involved, it cannot identify the best technique and thus cannot answer the second economic question.

The hypothetical example presented in Table 5-5 demonstrates the interdependence/mutual exclusivity problem. LLWAS and TDWR are both targeted at preventing the same set of windshear accidents. The benefits of implementing one will depend on whether or not the other is already installed. This interdependence is why the benefits of Alternative C (TDWR+LLWAS) are less than the sum of the benefits of the two installed alone. The Alternatives are mutually exclusive because picking Alternative C changes the benefits of Alternatives A and B thus logically precluding them. (Note, in some cases mutual exclusivity will be both logical and physical. For example, building a 100 story building on a particular lot physically precludes building a 200 story building on the same lot.)

From the benefit-cost ratios of the hypothetical example it is not clear which alternative should be selected. All have ratios greater than one indicating that all are cost-beneficial. But, Alternative A has the highest ratio suggesting that it produces the most benefits for the dollars invested and that it should be undertaken. Nonetheless, selecting either Alternative A because it has the highest ratio or Alternative C because it has a positive ratio would be incorrect. To demonstrate that Alternative C is inferior to Alternative B, it is necessary to restructure the data in Table 5-5 to show the incremental benefits and costs of adding TDWR assuming LLWAS is already installed and to show the incremental benefits and costs of adding LLWAS assuming that TDWR is already installed. This information is presented in Table 5-6. As can be seen, adding the second system to the first one has a negative net present value and a benefit-cost ratio less than 1.0 indicating that the incremental addition of the second system is not cost-beneficial.

Having eliminated Alternative C, it remains to choose between Alternative A and Alternative B, which remain mutually exclusive. If the alternative with the highest benefit-cost ratio is selected, it will provide an opportunity to earn the greatest return on the resources actually invested. But, selecting it will preclude earning a positive, albeit smaller return, on additional resources that might be invested under Alternative B. Accordingly, Alternative B--the one with the greatest net present value--is the correct choice. (With mutually exclusive alternatives, only if all the alternatives have the same present value of costs will selecting the benefit-cost ratio with the highest value produce the economically correct result.)

TABLE 5-6

ALTERNATE WINDSHEAR AVOIDANCE SYSTEMS
INCREMENTAL PRESENT VALUES of BENEFITS and COSTS
and INCREMENTAL BENEFIT-COST RATIOS
(millions of constant dollars)

Alternative	Benefits	Costs	Benefits Minus Costs	Benefits ÷ Costs
A--LLWAS	$5.2925	$1.0	$4.292	5.29
C--LLWAS+TDWR	$4.300	$4.5400	-$.24	.95
B--TDWR	$8.820	$4.410	$4.410	2.0
C--TDWR+LLWAS	$.71	$4.5400	-$3.8300	.16

C. Uniform Annual Value

As an alternative to net present value, benefit or cost values may be expressed as annual uniform values (UAV). This involves dividing the present value of a stream of benefits or costs by the same factor that was multiplied by a constant valued stream in equation (5-8) to obtain a present value:

$$UAV = \frac{NPV}{\sum_{t=0}^{k} F_t} \qquad (5\text{-}11)$$

The factors denoted by $\frac{1}{\sum_{t=0}^{k} F_t}$ are known as capital recovery factors. They may be computed by taking the reciprocal of the values contained in Tables B-3 and B-4 of Appendix B.

The uniform annual method will produce answers to the economic questions which are identical to those produced by the NPV method. This follows by virtue of the fact that all the present values computed under the NPV method need be only divided by the same constant to convert the results to a uniform annual basis. Table 5-7 presents the example of windshear detection systems expressed on a uniform annual cost basis. Also reported are ratios of annual uniform benefits and costs; note that the ratios are identical to those produced by taking the corresponding ratios of present values as reported in Table 5-6.

TABLE 5-7

ALTERNATIVE WINDSHEAR AVOIDANCE SYSTEMS
INCREMENTAL UNIFORM ANNUAL VALUES of BENEFITS and COSTS
and INCREMENTAL BENEFIT-COST RATIOS
(millions of constant dollars)

Alternative	Uniform Annual Benefits	Uniform Annual Costs	Uniform Annual Benefits Minus Costs	Uniform Annual Benefits ÷ Costs
A--LLWAS	$.4995	$.0943	$.4051	5.29
C--LLWAS+TDWR	$.4059	$.4285	-$.0226	.95
B--TDWR	$.8325	$.4162	$.4162	2.0
C--TDWR+LLWAS	$.0670	$.4285	-$.3615	.16

Historically, the UAV method was widely used for many years, particularly by civil engineers. Its widespread use probably had its origin in Wellington's classic work, *The Economic Theory of Railway Location* (1887). Wellington published during a time when most engineers worked for railways during at least part of their career, and he influenced the thinking of the entire engineering profession. Grant, whose well known book on engineering economy was first published in 1930,[14] prefers to use the UAV method when making comparisons. However, contemporary practice is to use NPV instead of uniform annual values. Not only does the NPV method focus attention on the total net benefits to flow from an activity, it also explicitly identifies the present value of all costs of an undertaking. Comprehensive recognition of costs, discussed in Chapter 4, is known as life cycle costing. Although other summary measures are encouraged to be presented, OMB requires reporting of net present value.[15]

A special UAV application is an exception to the general preference for NPV. In those situations where the alternative methods of accomplishing the objective have unequal

[14] Eugene L. Grant and W. Grant Ireson, *Principles of Engineering Economy*, The Ronald Press Company, New York 1964.

[15] "OMB Circular A-94" (Revised--October 29, 1992).

lives and (1) the cost estimates associated with the lifetime of any particular alternative may be repeated in the future for as many lifetimes as required and (2) the period of required services is either indefinitely long or of a length of time equal to a common multiple of the various alternatives, the UAV method can be used to determine which alternative is best. This requires that the difference between uniform annual benefits and costs be computed as indicated in equation (5-11). Where benefits are identical for alternatives, the same result may be obtained by computing only uniform annual costs and selecting the lowest. It should be noted that where the objective requires provision of a service to a specific future date, the UAV method should not be used. Rather, the NPV method should be computed for each alternative over the required time period.

D. Internal Rate of Return

The internal rate of return (IRR) is defined as that discount rate which equates the present value of the stream of expected benefits in excess of cost to zero. In other words, it is the highest discount rate at which the project will not have a negative NPV. To apply the criterion, it is necessary to compute the IRR and then compare it with the OMB prescribed 7 percent discount rate. If the IRR is greater than or equal to 7 percent the project should be undertaken for its NPV is non-negative. If the IRR is less than 7 percent, the project has a negative NPV and should not be undertaken.

While the IRR method is effective in deciding whether or not a project is worth undertaking, it is difficult to utilize in ranking projects and in deciding between competing mutually exclusive alternatives. It is not unusual for rankings established by the IRR method to be inconsistent with those of the NPV criterion. Moreover, it is possible for a project to have more than one IRR. Although the literature on capital budgeting contains solutions to these problems, these are often complicated or difficult to employ in practice and present opportunities for error.[16] As a consequence, although OMB permits reporting of IRR as supplemental information to NPV, it is not recommended that the IRR method be employed in FAA benefit-cost analyses.

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[16] See G. David Quirin, *The Capital Expenditure Decision*, Richard D. Irwin, Inc., Homewood Illinois 1967, pp. 46-55, and Jack Hirshleifer, *Investment, Interest, and Capital*, Prentice-Hall, Inc., Englewood Cliffs, N.J., pp. 71-80.

CHAPTER 6

VARIABILITY OF BENEFIT-COST ESTIMATES

I. Risk and Uncertainty

Previous chapters discuss various aspects of economic analysis. Such analysis is almost always characterized by uncertainty in that it involves the use of estimates, forecasts and assumptions related to key variables. For example, the benefits or costs of a given undertaking are typically not known with certainty but must be estimated. In addition, it is often the case that some benefit or cost value is estimated for a single year or other relevant unit of time and then is projected to grow at some rate (which itself may change overtime) out into the future. Or, as discussed in Chapter 5, the relevant evaluation period may also be subject to uncertainty.

This chapter considers how various types of uncertainty can be characterized and how they impact cost-benefit analysis. First, it is important to differentiate between "uncertainty" and "risk." In those cases when it is possible to characterize the uncertainty numerically or mathematically, one can analyze the potential variation in benefit-cost analysis results. Such analysis, sometimes termed "risk analysis," is the focus of this chapter. It is important to emphasize that such analysis requires one to be able to characterize uncertainty to the maximum degree of mathematical specificity possible.[1] The type of analysis of the variability of benefit-cost estimates (as discussed below) is influenced by the degree of mathematical specificity.

In order to fully inform decision-makers of the consequences that may, but are not guaranteed to follow from their actions as a result of uncertainty, analysis of the risk of variability of estimates should be conducted as part of every benefit-cost analysis. This analysis should, at a minimum, report expected value estimates for benefits, costs, and net present values; identify the key sources of uncertainty; and estimate the impact of these uncertainty sources on outcomes. This may be accomplished by undertaking a sensitivity analysis. Where relevant, probability distributions of benefits, costs, and net present value should also be presented. Stochastic simulation and other methods can be used to derive these results. This chapter presents methods for accomplishing these requirements as well as other techniques useful for analyzing risk.

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[1] The term "risk analysis" as used in this chapter pertains to the evaluation of the variability associated with benefit-cost estimates. The term "risk analysis" or " risk assessment" is also used to refer to various techniques used to estimate accident risks when historical data are absent or limited. A summary of some of these techniques is provided in Chapter 3, Section III.A.4.

II. Certainty Equivalents

An understanding of the concept of certainty equivalents is important to any risk analysis. A certainty equivalent refers to the net benefits of a *certain* (i.e., non-risky) return that has the same value to individuals as the expected value of an uncertain (i.e., risky) return. For example, suppose the expected present value of an undertaking that entails risk is $1000. If individuals would be willing to trade these risky net benefits for a certain lump sum of $800, then $800 is the value of the "certainty equivalent" of the risky activity. When the certainty equivalent is less than the risky expected value of an activity, risk aversion is implied (i.e., there is a preference to avoid risk). The difference between the expected value and the certainty equivalent value is called the "risk premium." When the certainty equivalent is equal to the expected value of the undertaking, risk neutrality is implied.

For most FAA benefit-cost analyses, expected values should be treated as identical to certainty equivalent values. This is because, to the extent that costs and benefits accrue to the Federal government, the government is large enough to be considered risk neutral with respect to FAA projects.[2] For private parties, the incremental impacts of FAA investments and regulations associated with uncertainty typically alter gains or losses over a fairly small range causing analysts to frequently treat private parties subject to FAA regulation as if they are risk neutral over this range.[3] Moreover, benefits and costs of FAA investments and regulations actually realized can be expected to approximate expected values. FAA investments and regulations are diversified over a large number of activities such that variations in benefits and costs can be expected to actually average out. Also, their impact tends to vary independently across numerous individual parties such that variations should also average out.[4]

In general, risk should be captured through the use of certainty equivalent values. For most FAA benefit-cost analyses, expected values should be used as certainty equivalents. In those rare cases where risk neutrality is not an appropriate assumption, any allowance for uncertainty should be made by adjusting the corresponding benefit or cost expected values so that they

[2] Office of Management and Budget (OMB) Memorandum, "Economic Analysis of Federal Regulations Under Executive Order 12866," p. 21.

[3] There is a body of opinion and experience that argues that the general public is risk adverse with respect to aviation safety. However, the difference between "certainty equivalent" value and "expected" value of events has not be adequately quantified.

[4] Boardman, et. al, *Cost-Benefit Analysis: Concepts and Practice*. Prentice Hall: Upper Saddle River, NJ., 1996, pp. 225-228.

represent certainty equivalents.[5] It should be noted that variations in the discount rate are not an appropriate method of adjusting expected values for the risks of a particular undertaking.[6]

The remainder of this chapter focuses on risk assessment (identification of different types of risk and characterizing them mathematically) and two conventional methods of conducting risk analysis (sensitivity tests and Monte Carlo analysis). A somewhat less popular but also useful tool — decision analysis — is also discussed.

III. Risk Assessment of Benefit-Cost Results

This section describes the components of a risk assessment and discusses how the information from such an assessment can be collected. This information is then used as input to the risk analysis methodologies described in later sections. There will be focus on the following topics:

- Identification of types of risk relevant for FAA
- Discrete risky events vs. risk continuums
- Evaluating and characterizing risk probabilities
- Identifying and evaluating risk severity and impacts for discrete events
- Interdependencies among risks

Ideally, the consideration of all of these topics together would be completed in order to conduct a complete risk assessment; such an assessment would strive to identify and quantify all relevant risks for the project under evaluation. In practice, it may be difficult to explicitly consider all possible sources of uncertainty; in the simplest case, one might want to focus on just one or a few aspects of uncertainty that can be treated through sensitivity tests. This approach is considered in Section IV below. More formal risk analysis approaches that require a more complete risk assessment involving some or all of the topics listed above are considered in Sections V and VI.

In presenting the topics, it will be useful to use a simplified example as a common theme where all of the different aspects of a risk assessment can be presented. The example is that of a promising ground traffic management safety technology for aircraft. To keep the analysis straightforward, we will assume the following:

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[5] For a discussion of the problems associated with developing such adjustments, see Boardman, et. al, *Cost-Benefit Analysis: Concepts and Practice*. Prentice Hall: Upper Saddle River, NJ., 1996, pp. 213-225.

[6] "OMB Circular A-94" (Revised--October 29, 1992) p. 13, and Edward M. Gramlich, *A Guide to Benefit-Cost Analysis--Second Edition*, Prentice Hall, Englewood Cliffs, NJ, 1990, pp. 90-100.

- Basic research begins in Year 1 (today) and is expected to take one year. (The research is assumed to be successful. This assumption will be relaxed in Section V.)

- Development and testing begins in Year 2 and is expected to take one additional year. (Development and testing is assumed to be successful. This assumption is also relaxed in Section V.)

- The technology will then be installed at the rate of one machine per 100,000 operations at each of two airports in Year 3. Each machine costs $250,000. Airport operations are assumed to grow at 3% annually from current levels for the foreseeable future.

- The technology is expected to reduce the likelihood of an accident (or collision) on the ground between two aircraft by 50 percent.

- Once installed, the technology is expected to have a useful economic life of 5 years, and to cost $100,000 per year to operate.

A sample benefit-cost flow analysis based on this information is shown in Table 6-1; the analysis is presented using constant dollars.[7]

A. Risk Types

There are a variety of different types of risk that may affect FAA investment projects. Although the following discussion may not be exhaustive, it should give some guidance to the analyst attempting to identify risk characteristics that may need to be included in a risk assessment.

For many FAA projects, an obvious area of uncertainty is the degree to which a project or expenditure may affect safety or accident rates. Using the above example, suppose the current probability of an accident is 1 per 10,000,000 operations; the new technology is expected to reduce this by 50 percent. It is the uncertainty associated with this latter number that may need to be addressed in a risk analysis. One must be able to characterize this uncertainty mathematically in order to complete a standard risk analysis.

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[7] For ease of explanation, the analysis covers only seven years, which covers the life cycle of the first set of installed equipment. Note, however, that the analysis should be extended beyond this period if the technology would still potentially produce benefits.

TABLE 6-1

BENEFIT-COST FLOW ANALYSIS for GROUND TRAFFIC MANAGEMENT TECHNOLOGY ($000)

	Year 1	2	3	4	5	6	7
Research Cost	(1,000)						
Development and Testing Cost		(500)					
Airport 1							
Operations @3% annual growth	370,000	381,100	392,533	404,309	416,438	428,931	441,799
Number of Machines Required			3	4	4	4	4
Incremental Units Required			3	1	0	0	0
Airport 2							
Operations @3% annual growth	180,000	185,400	190,962	196,691	202,592	208,669	214,929
Number of Machines Required			1	1	2	2	2
Incremental Units Required			1	0	1	0	0
Total Incremental Machines Required			4	1	1	0	0
Cost per Machine (F&E)			(250)	(250)	(250)	(250)	(250)
Total Annual Investment			(1,000)	(250)	(250)	0	0
Total Machines Operating			4	5	6	6	6
O&M Cost per machine-year			(100)	(100)	(100)	(100)	(100)
Total O&M Costs			(400)	(500)	(600)	(600)	(600)
Total Cost	(1,000)	(500)	(1,400)	(750)	(850)	(600)	(600)
Discounted Cost Flow @7%	(1,000)	(467)	(1,223)	(612)	(648)	(428)	(400)
Accident Rate per 10,000,000 Operations without Technology			1	1	1	1	1
Reduction in Accident Rate with Technology			50%	50%	50%	50%	50%
Expected Number of Accidents							
Without Technology			.058	.060	.062	.064	.066
With Technology			.029	.030	.031	.032	.033
Cost per Accident			(70,000)	(70,000)	(70,000)	(70,000)	(70,000)
Accident Benefit with Technology			2,042	2,103	2,167	2,232	2,299
Discounted Benefit Flow @7%			1,784	1,717	1,653	1,591	1,532
Net Disc. Benefit-Cost Flow @7%	(1,000)	(467)	561	1,105	1,004	1,163	1,132
Net Present Value	3,498						
Benefit/Cost Ratio	1.73						

A second source of uncertainty relates to technical or R&D risk; this is likely to be relevant in situations where a project is being evaluated before some or all of the required research and development is completed. Thus, there may be uncertainty as to what level of effort is required and/or the operational characteristics of the technology once it is developed. In our example, any benefits from the project depend entirely on a successful research phase, so one must be able to characterize the likelihood or degree of success of the research phase if a risk analysis on this aspect of uncertainty is to be carried out.

A related uncertainty is schedule risk — the uncertainty associated with when a project may be completed or deployed. In practice, there may be a number of so-called "decision points" in the project undertaking when key decisions about whether or how to proceed can be made. In the above example, one such decision point (not reflected in the benefit-cost flow analysis) might occur at the end of Year 1 when a decision about whether to continue on with development and testing work can be made. Accurate identification of decision points can be a key part of risk analysis because the decision today to proceed on a project may well depend on outcomes that are not known today but will become known in the future.

Uncertainty with respect to implementation or compliance may also be important in the context of certain types of FAA investment projects. In our example, the technology is assumed to be installed in Year 4. But due to financial, political or other constraints, there may well be uncertainty with regard to how fast the technology can be deployed. In any event, it may be worth assessing the risk arising from departures from expected deployment of the technology. In practice, such risks may take the form of changes to the expected time path of various cost or benefits flows.

Finally, there may be risk due to uncertain estimates of future external activities or measures that affect future costs or benefits. For example, the overall dollar benefits of the ground traffic management technology will depend not only on accident rates, but also the overall number of operations at the airports in question. As noted earlier, suppose it is assumed that over the life of the technology, airport operations are assumed to grow at 3% annually. Uncertainty in this estimate may affect the overall cost-benefit calculations, and the analyst may want to attempt to address this during the risk analysis.

This discussion highlights the general point that, in principle, *any* of the elements of the cost or benefit streams in a project evaluation may be subject to uncertainty, and a good risk analysis should attempt to identify those likely to have an important impact on the results of the evaluation.

B. Characterizing Risk: Discrete Events vs. Risk Continuums

In creating a net present value benefit-cost flow analysis as described in Chapter 5, the underpinnings of the analysis will be made up of certain variables whose values affect the benefit-cost flow; in the ground traffic management technology example, one of these variables would be the projected growth rate of airport operations. An important practical aspect of risk analysis is whether the uncertainty of relevant variables can be characterized in terms of well-defined alternative discrete events; if so, and if the analyst can also assign probabilities and explicit outcomes to each possible event, then the risk analysis can be cast in a so-called "decision analysis" framework. For example, suppose the analyst can assume that the operations growth rate will be 3% with probability 0.50, and 2% or 4% each with probability 0.25. If this discrete assignment of outcomes were possible for all such variables of interest (along with their associated impacts on costs and benefits), then a decision analysis could be undertaken as described in Section VII below.

This process of identifying all possible outcomes and their likelihood of occurrence is equivalent to specifying the "probability distribution" for each variable. Of course, the probabilities across all outcomes for a given variable must add up to one. When all possible outcomes are explicitly identified as in the above example, one is essentially employing a "multinomial" distribution to characterize the uncertainty in the variable of interest.

In practice, certain types of risk identified above are more likely to be amenable to the discrete sort of analysis described above than others. For example, the uncertainty associated with accident risks often can be characterized by just a few discrete possibilities, e.g., either the technology will work as projected, leading to a 50% reduction in accidents, or it will not work at all, leaving the accident rate unchanged. In addition, if an accident does occur, the cost will be some known amount.

Also, it is often useful to characterize uncertainty associated with schedule and/or implementation risks by identifying critical decision points where Yes/No decisions are posited at some point in the future; the key here is to structure the analysis so that the decision points come immediately *after* some new piece of information comes to be known. Our example from above is set up so that a decision about development and testing can be made after one knows the outcome from the research phase. In this way, the impact of uncertainty about the research schedule itself (e.g., it may take more than one year) is mitigated because a decision to continue the project is delayed until after the outcome from the research is known, at which point a reassessment of future benefit and cost flows can be made. It is important to understand that allowance for a post-research decision point helps to decide *today* whether to undertake the project at all. How this plays itself out in a decision analysis framework is discussed in Section VI below.

Technical and other risks may or may not be adequately captured by identification of discrete outcomes. As noted earlier, there may be uncertainty as to what level of effort is required and/or the operational characteristics of a technology once it is developed. In some instances, it may be reasonable to confine the analysis to just a few possible discrete outcomes (e.g., the level of effort will be either 10 man-years, 50 man-years or 100 man-years), but in other cases it may not (e.g., the 10 and 100 man-year estimates represent low and high estimates, but anything in between — or even outside the likely range — is also possible). In the latter case, the analyst still may be able to formalize the uncertainty without explicitly identifying all possible outcomes.

A common way to formalize uncertainty is to employ a probability distribution that requires the analyst to specify only a small number of parameters, even though a whole range of outcomes is possible. For example, it is very common to use the normal distribution, which is defined by its mean (the average outcome) and variance (the spread of outcomes away from the mean). The normal distribution is a reasonable choice when the uncertainty can be characterized as a bell-shaped curve, with the most likely outcome in the middle of other outcomes (e.g., 50 man-years might be the mean outcome in the above example) and with the uncertainty spread symmetrically around the mean (e.g., if 50 is the mean (most likely) level of effort, then the probability that the level of effort might in fact turn out to be 70 is equal to the probability that it might in fact turn out to be 30).

Again, the analyst need not specify each and every possible outcome; rather, there are just two parameters that must be specified in order to completely define the normal distribution — the mean and the variance; the square root of the variance is known as the "standard deviation". As should be clear from above, the mean should be assigned the most likely (or "expected") value for the variable in question. Estimates of the appropriate variance to specify can be aided by knowing that about 95% of the probability for any normal distribution lies within 2 standard deviations of the mean. Thus, for a variable assigned a normal distribution of, say, mean 50 and variance 25 (implying a standard deviation of 5), the most likely outcome is 50, and this implies a 95 percent chance that the variable value will fall between 50±10, i.e., between 40 and 60, and only a 5 percent chance that the variable will fall outside this range.

Of course, there are circumstances when the normal distribution may not be a reasonable representation of the uncertainty associated with a variable; many other probability distributions can be specified, including the Poisson (often appropriate for characterizing accident or other events that occur infrequently), uniform (appropriate when a range of values are equally likely) and the exponential (appropriate when there is uncertainty over the length of time between certain events occurring). For practical purposes, the triangular distribution is commonly used; this distribution is characterized by a single most likely value and minimum and maximum values, with the probabilities declining linearly from the most likely to the minimum and maximum values. Details on these and other distribution types can be found in most business statistics textbooks. As described in Section V below, there is also commercial software available that helps lead the analyst through the process of selecting distributions and calculating results.

In practice, the analyst's judgment will have to be used in assessing whether it is reasonable to specify a small set of outcomes to represent all possibilities for the variables identified for consideration in the risk analysis; as noted earlier, a complete listing of explicit outcomes and associated probabilities would be required in order to employ the decision analysis approach described in Section VI below. If it is more reasonable to employ probability distributions that statistically account for uncertainty without having to explicitly identify each possible outcome, then the Monte Carlo approach to risk analysis can be used. This approach is discussed in Section V below.

C. Qualitative and Quantitative Risk Estimates: Prior and Posterior Probabilities

As hinted at above, the risk analyst may be required to make many judgments about how to characterize the uncertainty inherent in any project evaluation. In practice, much information may have to be gathered from decision makers, technical personnel, and others who have specialized knowledge about the likely risks and uncertainties. Yet it is to be expected that these sources may not be able to provide the needed information in the strict form of probability distributions or a complete set of discrete event probabilities. Instead, much of the information may be qualitative in nature (e.g., "we expect the level of effort to be 50 man-years, but it could go much higher if we have to use Approach B instead of Approach A; the chances that A will not work are fairly low, however"). Obviously, this sort of information does not by itself yield a probability distribution; rather, it is the job of the risk analyst, in concert with the personnel supplying the information and others, to make reasonable judgments in order to translate the qualitative information into quantitative information that can be used in a formal risk analysis.

Another possibility when gathering information is that the experts involved may provide data or estimates that are to be used as "second opinions." In other words, the analyst may already have a "prior" estimate of the value of some variable (based on current information), but another opinion from an expert is acquired. The expert's estimate of the value of the relevant variable may well differ from the prior estimate. If the analyst also has some information about the likely reliability of the expert's opinion, then the new "sample" information from the expert can be used to form a so-called "posterior" estimate; such estimates refer to probabilities or variable values that are determined after sample information has been obtained. Posterior estimates essentially involve revising the prior estimates based on new sample information. These topics are beyond the scope of coverage of this chapter, but the interested reader may consult standard statistical textbooks for further information.[8]

D. Interdependencies Among Different Risks

A well thought out risk analysis will consider not only the effects of uncertainty regarding various individual variables, but also how the variables may be interrelated. For example, Table 6-1 indicates an expected research cost of $1 million in Year 1 and an expected development cost of $0.5 million in Year 2. Now suppose these are the only uncertainties that will be investigated. Of course, *actual* costs may be more or less than expected. For the research phase, the actual research cost will be related to the expected cost in the following way:

$$\text{Research Cost} = \text{Expected Research Cost} \times (1 + \text{Forecast Error})$$

[8] See, for example, J. McClane and P. Benson, *Statistics for Business and Economics* Dellen Publishing: San Francisco, 1991.

(The specific relationship would presumably be defined by specifying a probability distribution.) But it is likely that if research costs are higher than expected, then development costs may be also. Thus, modeling the uncertainty in development costs should attempt to account for the impact of uncertain research costs as well as uncertain development costs. For example, if it were estimated that a 10 percent increase in research costs would lead to an expected 5 percent increase in development costs, then the development cost could be modeled as:

$$\text{Development Cost} = \text{Expected Development Cost} \times (1 + \text{Development Forecast Error} + 0.5 \times \text{Research Forecast Error})$$

It would be relatively easy to incorporate an equation like this into a spreadsheet model, and in fact this is one way Monte Carlo models can be used to specify interdependencies.

In theory, interdependencies among variables can be modeled in a decision analysis framework by explicitly specifying all possible relationships among all variables; of course, this may result in a very complex set of equations even if the underlying benefit-cost flow model is quite small. In practice, the analyst must limit the scope of the analysis by making decisions about which interdependencies to focus on. When using the Monte Carlo approach by employing distributions which allow a range of uncertainty without the need to explicitly specify all possible outcomes, interdependencies can be specified via a "correlation coefficient", which is a number varying between -1 and 1 that indicates the existence or lack thereof of a linear relationship between two variables. A correlation of 1 implies a perfect positive linear relationship. A correlation of 0 implies no linear relationship. A correlation of -1 implies a perfect negative linear relationship.

The reader is referred to standard statistical textbooks for treatment of various probability distributions.[9] In addition, the Monte Carlo simulation software packages discussed below in Section V have certain features to help the user specify interrelationships in a straightforward way.

IV. Sensitivity Testing

In the previous section, it was demonstrated that the outcome of an analysis will depend on numerous factors including estimates of specific variables, forecasts of their future values, assumptions regarding how they vary with each other, and the inherent uncertainties in forecasting future events. Each of these factors has the potential to introduce error into the

9 See, for example, W. Mendenhall, *Introduction to Probability and Statistics*, Duxbury: Boston, 1987; J. McClane and P. Benson, ibid.; A. Caniglia, *Statistics for Economics*, New York: HarperCollins, 1992.

results. Decision-makers will want to have information on potential errors in order to make informed decisions. In many cases, the degree of uncertainty associated with a particular project may be a decisive factor in determining whether to go forward, either now or in the future, or to cancel the project entirely. This section will demonstrate how to use sensitivity analysis as a way to determine which variables are most likely to have a dramatic effect on a particular project. Thereafter, some of the more sophisticated methods described briefly above will be reviewed.

The basic approach to sensitivity analysis is to vary key assumptions regarding variables systematically over appropriate ranges and then observe the impact on the net present value of the project. In some cases, the impact may be insignificant, or at least have no affect on the sign of the net present value. For example, in some cases certain variables over a wide range may not alter whether a project has a positive or negative net present value. In such cases, one might conclude that the project itself is insensitive to a particular variable. In other cases, relatively small changes in a particular variable may have dramatic effects on results. Having such information available helps the analyst determine which variables warrant further study. Sensitivity analysis may also be important for a decision-maker in gauging the appropriateness of a project given the willingness of the FAA to accept risk.

Although, as noted above, variations in risk cannot be adequately captured by varying the discount rate, uncertainty as to what is the appropriate discount rate to use in the first place should be captured by evaluating benefit-cost flows at different discount rates. OMB guidance recommends a discount rate of 7 percent.[10] The Office of Aviation Policy and Plans suggests conducting sensitivity estimates at 4 and 10 percent to show the impact of varying the discount rate.

A. One Variable Uncertainty Tests

One useful sensitivity test is to vary one variable at a time, holding all others constant so as to determine the independent, or partial, effect on the outcome. This procedure is known as the one variable uncertainty test. Its primary purpose is to identify the sensitivity of the net present value of each alternative to changes in the value of each component individually.

To carry out the one variable test, the NPV of each alternative must be recalculated for different values of a particular component while all others are held constant. The range of values should extend over those that can reasonably be expected to prevail. Where a probability distribution for a component of interest is known, the relevant range may be established over values corresponding to most of the probability (usually 90 to 95 percent). Where distributions are unknown, the range should extend from the smallest to largest value that could reasonably be expected to occur.

[10] "OMB Circular A-94" (Revised—October 29, 1992) p. 9.

One may then display the results in either tabular or graphic form. In Table 6-1, it was shown that a standard net present value analysis for the ground traffic management technology example showed an expected net present value of $3.5 million. Shown in Table 6-2 are the results of one variable uncertainty tests for the same project. Five variables are varied over appropriate ranges. The five variables are: discount rate, F&E or purchase price of the equipment, operations and maintenance costs (O&M), accident rate, and traffic growth. A quick perusal of the table illustrates that even with relatively wide variations in F&E costs, O&M costs or traffic growth, the ground traffic management technology is estimated to have significant positive net present value. The sole exception relates to changes in the accident rates. In Table 6-1, the technology was assumed to reduce accidents by 50 percent. If this rate is overestimated and in fact there is only a 25 percent reduction, then the one variable uncertainty test suggests that the net present value of the program would be -$640,000. On the other hand, if the accident reduction rate had been underestimated, the net benefits of the technology would be substantially higher than in the base case in Table 6-1. Such an outcome might suggest that the analyst spend additional time assessing the reliability of the accident reduction rate estimates. For example, the analyst might investigate whether the data used to make the estimates were representative of the type of accident that might be prevented using the ground traffic management technology.

TABLE 6-2

ONE VARIABLE TESTS: NPV ($000)

Range	Discount Rate	F&E	O&M	Accident Reduction Rate	Traffic Growth Rate
Lower Value	4,125 (4%)	3,815 (187.5)	4,009 (75)	-640 (25%)	3,503 (0%)
Mean Value	3,498 (7%)	3,498 (250)	3,498 (100)	3,498 (50%)	3,498 (3%)
Upper Value	2,964 (10%)	2,230 (500)	1,455 (200)	7,636 (75%)	3,961 (6%)

B. Two Variable Uncertainty Tests

The one variable test permits examination of one factor holding all others constant. At times it may be useful to let two factors change at the same time. For example, the analyst may be concerned not only about effectiveness of the system, but also about the potential of cost overruns in producing the ground traffic management technology. Concern might focus on what would happen if the accident reduction benefits are overestimated in the base case and the costs of F&E are underestimated. To examine the sensitivity of the project in such an eventuality, the analyst would conduct a two variable test. The results of such a test are illustrated in Table 6-3. The horizontal axis relates to variations in accident reduction effectiveness while the vertical axis relates to variations in F&E costs. The results in the table are the net present values if two variables vary at the levels illustrated on the two axes. All other variables are held constant. For example, the top entry on the left hand side of the table would be a case where F&E costs are actually 25 percent less than the base case (i.e., F&E is $187,500 instead of $250,000 per unit), and where accident reduction effectiveness is 25 percent rather than 50 percent. The result is a net present value of -$323,000. The results from the table also make it clear that the benefits of the project depend much more on the accident reduction estimate than on the F&E estimate.

TABLE 6-3

TWO VARIABLE TESTS: NPV ($000)

F&E ($000)	Accident Reduction Effectiveness		
	25%	50%(Base)	75%
187.5 (-25%)	-323	3,815	7,953
250 (Base)	-640	3,498	7,636
500 (+100%)	-1,908	2,230	6,368

C. Limitations of Sensitivity Analysis

In principle, it would be possible to vary all the variables in an analysis, each over their likely range. One could begin by varying just one variable at a time, then two variables together, then three variables at a time, etc. In this way, sensitivity tests could be conducted on any of the different risk types that typically impact FAA investment projects or regulations. In the context of our example, technological risk could be examined by varying expected accident rate reductions with and without the technology and/or the expected research and development and testing costs; schedule risk could be investigated by changing the year in which different events occur, e.g., the first machine installations at airports might be delayed until Year 4; finally, the impact of external uncertainty could be examined by changing the assumed growth rate of airport operations.

While the potential ramifications of all sorts of changes could be investigated in this way, such an approach would quickly yield an overload of information. A practical goal of risk analysis is to present a range of likely results in a compact, straightforward manner, and presenting a large number of sensitivity results is not likely to be a satisfactory way to achieve this goal.

Moreover, sensitivity testing does not require one to assess how likely it is that specific values of the parameters at issue will actually occur. In the above one-variable tests for accident reduction effectiveness, one cannot adequately assess how uncertainty affects net present values without some knowledge about the likelihood that accident reduction effectiveness will actually be 50% or 100% above or below the base expected value.

Sensitivity testing also does not encourage the analyst to consider relationships *between* parameters and the probabilities that certain values will occur together. In the two-variable tests discussed above, for example, it may well be that higher-than-expected F&E expenditures may result in higher-than-expected accident reduction effectiveness, and vice versa. In such a situation, NPV results in Table 6-3 from the lower right corner and upper left corner are more relevant than those in the lower left corner or upper right corner, yet this is not reflected in the table itself.

These criticisms of sensitivity testing can, in many cases, be overcome by the careful structuring of a set of sensitivity scenarios that accounts for the distribution of parameter probabilities and interrelationships among the variables being tested. In such an analysis, interdependent restrictions would be placed on the variables and they would be varied as a group with the restrictions in place; each such set of restrictions would constitute a scenario. With such an approach, it is important to ensure that each scenario is internally consistent (i.e., that the implied or explicit interdependencies make sense). In this way it is possible to create a set of scenarios which are representative of the universe of possible outcomes.

A more formal approach to risk analysis which forces the analyst to directly consider both the probability distribution of specific parameters (i.e., how likely is a given value of a parameter), as well as the interrelationship between values of different parameters, is offered by Monte Carlo analysis.

V. MONTE CARLO ANALYSIS

In the preceding sections, it has been shown that sensitivity analysis can be useful in considering the effects of uncertainty regarding critical variables in a capital budgeting exercise. By looking at a project under alternative scenarios, one can consider the effect of a limited number of plausible combinations of variables. Monte Carlo simulation is a tool for considering many more possible combinations. It uses simulation techniques to calculate the entire range of all possible project outcomes *and* the likelihood of each actually occurring. When collected in a probability or frequency distribution, this information presents decisionmakers with a concise summary of a project's benefit-cost status.

To under take a Monte Carlo analysis, the analyst must be able to specify the determinants of each of the variables under consideration, and their range as expressed in probability distributions, and the interrelationships between them. For most real world applications, it is impossible to fully specify every variable, all of their determinants and/or their interrelationships. But, using computer modeling packages designed for the purpose, an analyst can select the distribution of a particular variable. This process allows the analyst to skip the formal specification of the determinants of each variable in exact detail, and instead rely upon generalized distribution forms which are likely to be representative. For example, accident rates might be best represented by Poisson distributions, while certain other technical variables like installation costs might vary according to the normal distribution. Simulation packages are designed to help the analyst select both the shape of the distribution and the size of the variation in each distribution. The packages can also account for interdependencies between variables as specified by the analyst. The computer then models the results by randomly selecting values for each variable from the applicable distribution and then computing NPV's for the project.

Under the Monte Carlo approach, hundreds or thousands of simulations of the model are performed. For each simulation, the computer randomly samples from the probability distribution for each variable (accounting for interdependence if necessary), and computes and stores the results. In the present context, the final result is a distribution of net present values for the project. Some software packages can provide additional information regarding which variables have the most influence on the present value distribution, the likelihood of achieving a target net present value, etc.

A. Conducting a Monte Carlo Simulation

As mentioned earlier, the Monte Carlo method is particularly well-suited for conducting risk analysis when it is not feasible to explicitly identify and list all possible discrete outcomes and their likelihood of occurrence. This is most often the case when trying to assess uncertainty in safety or accident rates, cost uncertainty with respect to technical, R&D, or operations costs, or the risk associated with uncertain estimates of recurring future activities such as growth rates in airport operations, inflation rates, etc. In these types of situations, it is most often reasonable to specify uncertainty via a probability distribution which can be specified with only a few parameters (e.g., the mean and variance), yet that adequately captures the range and likelihood of uncertain outcomes. Monte Carlo analysis is designed specifically for such situations.

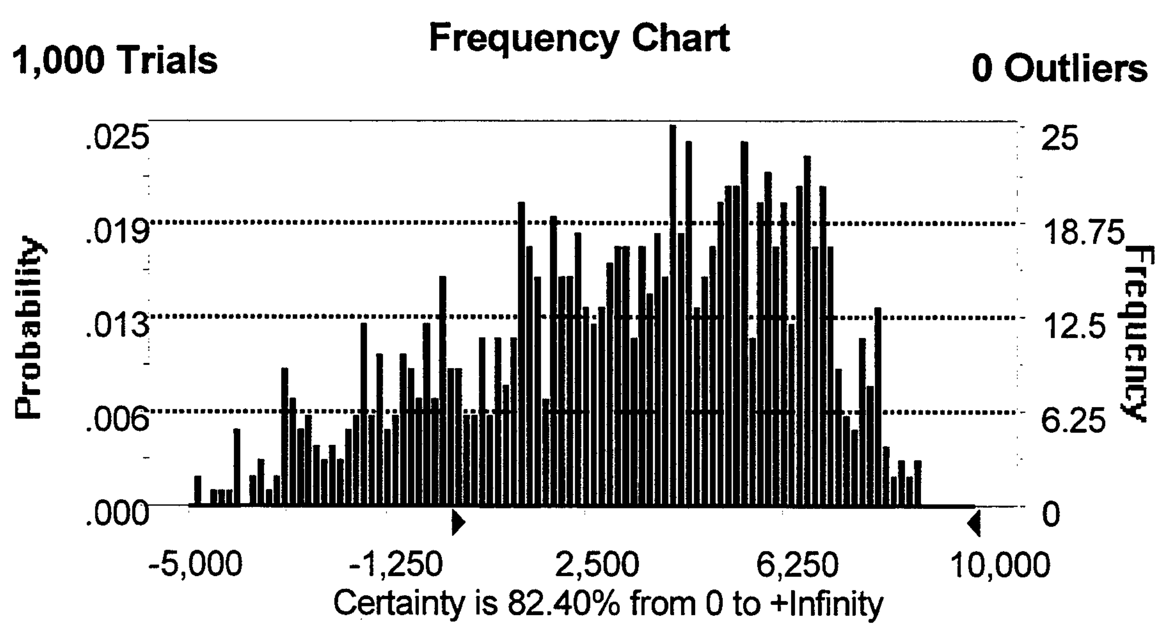
Consider again the ground traffic management technology analysis from Table 6-1. Suppose we are interested in assessing how the results are affected by uncertainty with respect to the cost of F&E (currently estimated at $250,000 per machine) and the accident rate reduction actually achievable by the technology (currently estimated at 50 percent). Note that the associated NPV results are affected by uncertainty on both the cost side (due to F&E) and the benefit side (due to the reduced accident probability).

To illustrate how a simple Monte Carlo exercise could be undertaken, assume that the F&E estimate is subject to some uncertainty; in particular, we believe that this uncertainty can be adequately captured by specifying the F&E cost per machine as a normal random variable with a mean of $250,000 and a standard deviation of $50,000. Remembering that about 95 percent of the probability distribution lies within two standard deviations of the mean, this implies a 95 percent chance that the true cost will lie in the range of $150,000 to $350,000. In turn, this means that when the computer is randomly drawing values for the F&E cost, about 95 percent of them will be within this range.

At the same time, let us assume that the accident reduction rate, currently set at 50 percent, involves uncertainty that can be adequately characterized by a triangular distribution, with a most likely value of 70 percent, a minimum of zero percent (implying no impact on the accident rate), and a maximum of 80 percent. Such a distribution implies a *mean* value of 50%, consistent with the base expected value used in Table 6-1. Finally, let us allow for interdependence between these two variables. Recalling the earlier discussion that higher-than-expected F&E costs are likely to lead to higher-than-expected accident rate reductions, this implies a *positive* correlation between the two variables; assume that we estimate this correlation to be 0.5. With this specification, the computer is being instructed to ensure that the majority of the simulations involve either a high F&E coupled with a high accident reduction rate, or a low F&E coupled with a low accident reduction rate; there will be relatively few simulations where a high F&E occurs along with a low accident reduction rate, or vice versa.

FIGURE 6-1

MONTE CARLO SIMULATION RESULTS for F&E and ACCIDENT RATE REDUCTION VARIATIONS PRESENT VALUE of NET BENEFIT ($ 000)



The NPV results of a Monte Carlo analysis with these specifications, running 1,000 simulations, are shown in Figure 6-1. Note that the majority of the distribution represents positive values, implying a net return of 7 percent or greater. In fact, the simulation results indicated that 82.4 percent of the distribution of the present value of net benefit was in the positive range. Thus, the analyst could conclude, based on this set of simulations, that there is about a 4 in 5 chance that the project would generate a positive net present value using a discount rate of 7 percent. To assess whether enough simulations have been run to ensure accurate results, one can compare the "observed" mean NPV that occurred when both the F&E cost and the accident rate were set to their mean values ($3,498,000 from Table 6-1) with the mean NPV from the simulations ($3,352,000). This indicates that the simulation results are consistent with the mean results from the initial spreadsheet analysis. Other useful outputs can be obtained from a Monte Carlo analysis, but the NPV distribution is the single most key result to be utilized by the analyst.

B. Using Commercially Available Monte Carlo Software

At the time of this writing, there are at least two commercially available computer packages that work in conjunction with either Lotus 1-2-3© or Microsoft Excel© spreadsheets and produce Monte Carlo results.[11] Both of these programs start with a spreadsheet representation of a project to be analyzed such as those shown in the previous tables. The Monte Carlo programs then work directly in conjunction with the spreadsheets to produce the simulation results.

The process is relatively straightforward. The analyst identifies the variables within the spreadsheet that are subject to uncertainty. The distribution that best characterizes the range of possible values is then selected for each variable. For example, the analyst might select a normal distribution for certain variables or Poisson distribution for others. The model would then prompt the analyst for additional information that would allow it to apply the distribution to that variable. As was shown above, the analyst can also make one variable depend on another. For example, one might calculate Variable B based upon the value of Variable A. In effect this would mean that values selected by the computer from the distribution for Value A would determine (in part) the value of Variable B.

The simulation packages are designed to accommodate virtually any type of statistical distribution for any type of variable. They then use random number generators to select values from the distributions for each variable and assign them for a particular simulation. Because oftentimes more than one variable is subject to uncertainty, the possible combinations of outputs becomes very large. One advantage of the software packages is that they take advantage of the capability of a computer to make hundreds or thousands or iterations of the model in a relatively short period of time. The packages then produce all of the tabular and graphical representations

[11] The two software products are *@Risk*© (Palisade Corporation, 31 Decker Road, Newfield, NY 14867, www.palisade.com) and *Crystal Ball*© (Decisioneering, Inc., 1515 Arapahoe Street, Suite 1311, Denver, CO 80202, www.decisioneering.com)

of risk presented in this chapter, as well as many more. For example, the packages quickly produce a rank ordering of the sensitivity of models to each individual variable. Or, one can quickly identify which variables account for relatively high or low project outcomes.

Another key advantage of these risk analysis packages is that they are self documenting. That is, one can quickly access a list of assumptions made in the risk analysis model, and alter them as appropriate as new information becomes available. It is therefore recommended that an analyst take advantage of commercially available software, especially when complicated investment decisions are to be considered.

C. Limitations of Monte Carlo Analysis

Monte Carlo simulation forces decision-makers to explicitly consider uncertainty and interdependencies among different inputs, and can be a useful tool in assessing risk. On the other hand, it is often difficult to examine certain types of risks associated with schedule uncertainty in a Monte Carlo framework. On a theoretical level, this is because one may not have any reasonable basis on which to ascribe a parameterized probability distribution to the schedule of relevant events, e.g., R&D may be expected to take two years, but it may be difficult to assess, say, the variance of this estimate. Even if one could make such an assessment, however, the standard spreadsheet framework for designing Monte Carlo experiments does not lend itself to incorporating schedule risk except in a very simple way. As our earlier example shows, a typical spreadsheet analysis "hard-wires" the schedule for when events are expected to occur, e.g., development and testing begins in Year 2. One way to account for uncertainty in this estimate would be to create a second testing phase that begins in, say, Year 3, and set up the model so that the Monte Carlo technique randomly select only one of the two possible testing phases for each simulation. Of course, another alternative would be to carry out sensitivity tests and scenario analyses out by manually adjusting the schedule between successive analyses.[12]

A second drawback of Monte Carlo simulation comes when attempting to interpret its primary output, i.e., a probability distribution of net present values. The amount of risk is presumably reflected in the dispersion of the NPV distribution. But it is sensitive to the definition of the project being analyzed. For example, if two unrelated projects were combined and analyzed as one, the "risk" of the NPV of the combined project would be less than the average "risk" of the NPV's of the two separate projects. Moreover, it is difficult to interpret a distribution of NPV's.

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12 If one were not tied to a spreadsheet format, it is possible that one could handle schedule uncertainty via Monte Carlo methods. A simulation technique known as VERT (Venture Evaluation and Review Technique) has been designed which allows one to analyze schedule and time-based risks. This technique has been used in previous FAA-sponsored analyses of advanced automated air traffic control systems. See *Quantitative Assessment of Risks on the Attainment of the Benefits and Costs of Advanced Automated Air Traffic Control System Alternatives, Volume VI*, prepared by Mitre Corporation, 1987.

There is no single rule arising out of such a distribution that can guide decision-makers concerning the acceptable balance between expected return and the variance of that return.

VI. Decision Analysis

Another way that an analyst can help improve decision-making regarding investment projects is to recognize that many investment evaluations involve not one decision but rather several sequential decisions. If subsequent investment decisions depend on those made today, then today's decision may depend on what happens tomorrow. By recognizing that decisionmakers may be able to stop projects after one or two steps in the process without committing the full measure of resources, the analyst may provide options for decision-making that would otherwise go unrecognized. These concepts are best illustrated using decision trees.[13]

To illustrate the value of decision trees, Figure 6-2 illustrates many of the important features of the example for the ground traffic management technology first summarized in Table 6-1. For purposes of this example, the earlier assumptions that the initial research and subsequent development and testing will necessarily be successful are changed to allow for the possibility of failure. Specifically identified are decision points (designated by squares) and chance nodes (designated by solid dots). In Figure 6-2, there are three distinct decision points that have been identified by the analyst (although there could easily be many more depending on which outcomes in the process of researching, testing and implementing the ground traffic management technology are actually uncertain). The three key decision points are:

1. Initiate research on the ground traffic management technology: This is followed by a chance node which can result in success or failure. Based on information collected from technical personnel, the analyst assigns a probability of success of 50 percent and a probability of failure of 50 percent.

2. Develop and test the equipment: This is followed by a chance node which can result in success or failure. The analyst estimates the probability of success at 75 percent and a probability of failure at 25 percent.

3. Implement equipment: The analyst assumes implementation will result in the full measure of benefits assumed in Table 6-1. (This is, the chance node has a probability of success of 100 percent.)

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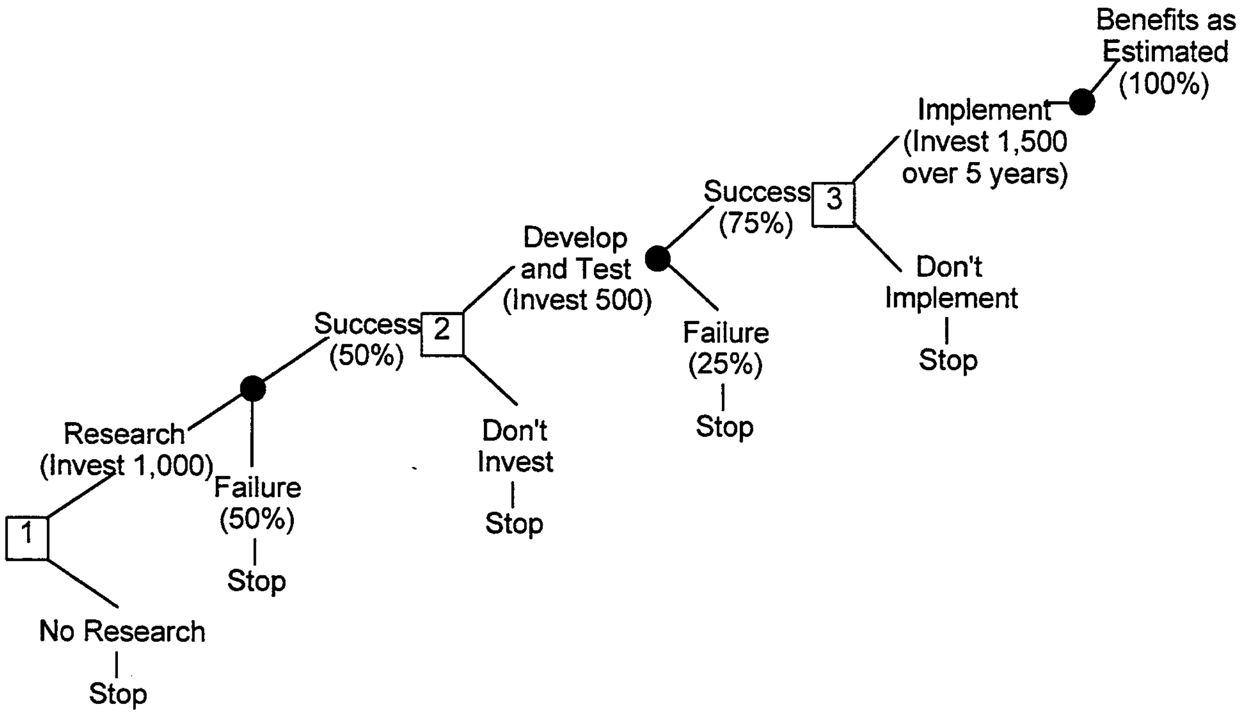
[13] Many of the same concepts are used in option trading in the stock market although the presentations are much more difficult to follow and are not generally relevant to project decision-making.

Figure 6-2
Decision Tree Analysis of Project
($000)



As Figure 6-2 shows, at each decision point, the analyst has allowed for the possibility of stopping the process. That is, the decisionmaker might decide not to do any research in which case the whole program would be canceled; alternatively, the decisionmaker may have the option of canceling the program after the research phase, or after the development and testing phase. As will be shown below, there is sometimes significant value in having these or other types of options.

The main problem confronted by the decisionmaker is whether to go forward with the research program today. To solve the problem, one begins first with what to do if confronted with the implementation decision; that is, one begins at the right side of the decision tree. Table 6-4 illustrates the implementation decision. The only decision that would have to be made in the third year of the project is whether to implement it. Table 6-4 shows that the net present value of implementation is positive, when expressed in Year 3 dollars. That is, standing in Year 3, the analyst would conclude that going forward with the implementation of the ground traffic management project would have a significant positive benefit.

TABLE 6-4

IMPLEMENTATION DECISION ($000)

Year	1	2	3	4	5	6	7
Investment			-1,000	-250	-250	0	
Operating Costs			-400	-500	-600	-600	-600
Benefits			2,042	2,103	2,167	2,232	2,299
NPV (Year 3)			642	$\frac{1,353}{1.07}$	$\frac{1,317}{(1.07)^2}$	$\frac{1,632}{(1.07)^3}$	$\frac{1,699}{(1.07)^4}$
Total NPV (Year 3)			5,685				

The only decision that would have to be made in Year 2 is whether to go forward with the development and testing phase of the program. The analysis of this decision is illustrated in Table 6-5. It uses results from the implementation decision together with other information from the decision tree. We know that the probability of success of development and testing is 75 percent; we also know from Table 6-4 that if development and testing is successful and the decision is made to go forward, then the project will realize a benefit of $5.685 million. If development and testing fails, however, there will be zero benefits because the program will be canceled. In Table 6-5, the expected values for success are calculated as the sum of:

$$[(75\%) \times \$5,685] + [(25\%) \times 0] = \$4,264.$$

That is, the expected value of the benefits from development and testing will be realized in the implementation phase and would have a value in Year 3 of $4.264 million, once the probabilities of success and failure are taken into account. This value is then discounted back into Year 2 dollars and added to the investment costs of development and testing. As shown in Table 6-5, the total net present value of development and testing is also quite positive — $3.485 million. So far, the decision tree analysis suggests that both implementation, and development and testing are likely to have strongly positive net benefits.

TABLE 6-5

DEVELOPMENT and TESTING DECISIONS ($000)

Year	2	3
Investment	-500	
Benefit:		
Success (75%)		5,685
Failure (25%)		0
	-500	4,264
NPV (Year 2)	-500	4,264
		1.07
Total NPV (Year 2)	3,485	

There is now enough information to examine the research decision. Recall from the decision tree that the investment cost of the research program is $1 million and that it has a probability of success of 50 percent and an equal probability of failure. From Table 6-5 we already know that the net present value of the program if the research effort is successful is $3.485 million. If the research program fails, the payoff is zero. Using the same expected value techniques described above, we find, as shown in Table 6-6, that the expected benefits from the program in Year 2 dollars is $1.743 million, which when discounted back to Year 1 and added to the investment costs shows a total net present value for the research program of $629,000. Thus, the ground traffic management technology continues to have an expected positive net present value under assumptions which allow for the chance of failure in the research and development and testing phases.

Once the probabilities are taken into account, the analyst could then repeat the one variable and two variable sensitivity tests described previously.

TABLE 6-6

RESEARCH DECISION ($000)

Year	1	2
Investment	-1,000	
Benefit:		
Success (50%)		3,485
Failure (50%)		0
NPV (Year 1)	-1,000	1,743
		1.07
Total NPV	629	

A. Irreversibility and Abandonment

One of the important issues faced by the FAA is that many of its investment programs are irreversible. That is, once money is spent on a project, it is difficult to recoup any money from it should that program be discontinued because many of the investments made by the FAA tend to be in specialized equipment as opposed to generally available equipment. For example, in industry an airline making an investment in an aircraft does not face an irreversible decision since it is likely that there will be a secondary market in the asset should the airline decide to abandon its use. This may not be the case for all FAA programs if much of the equipment has no other alternative use because it was developed for a specialized purpose like air traffic control.

There is sometimes a significant value in having the option to abandon an investment, and this can be illustrated using the decision tree process described immediately above. Suppose for the moment that part of the research program for the ground traffic management project would involve purchasing general purpose computer equipment which could be sold a year later for $200. That is, part of the $1 million investment in the research program could be reversed if the research program were to fail. Table 6-7 illustrates a method for valuing having this option. The analysis is identical to the one shown in Table 6-6 with the exception that in the event the research program fails the FAA is able to realize $200,000 from the sale of the computer equipment. This raises the expected payoff from the program resulting in a net present value of $722,000.

TABLE 6-7

VALUE of ABANDONMENT OPTION after FAILURE of RESEARCH ($000)

Year	1	2
Investment	-1,000	
Benefit:		
Success (50%)		3,485
Fail and Abandon (50%)		200
NPV (Year 1)	-1,000	1,843
		1.07
Total NPV	722	

Value of Abandonment Option = NPV with abandonment minus NPV without abandonment
= 722 - 629
= 93

The value of being able to abandon the program and reverse some of the investment is merely the difference between the net present value with abandonment and the net present value without it, or $722,000 - $629,000. That is, it is worth $93,000 to the FAA to have the option of selling the computer equipment, or when the FAA is developing a contract that may have an escape clause that allows it to discontinue a program. Having this kind of information may be extremely important to decisionmakers when there are alternative methods for conducting programs with general purpose versus specialized equipment.

B. Valuing Reductions in Uncertainty

Suppose that some of the uncertainty regarding the ground traffic management project could be eliminated if additional research funds were allocated to the project. One can use the decision tree analysis to calculate the value of this uncertainty reduction in order to improve the reliability of the variables included in the analysis.

For example, let us suppose that the 50 percent estimated success rate for the research phase is deemed to be too low. This might happen because the analyst is concerned with the reliability of the 50 percent estimate, or because the net present value estimate for the project is too low. In either case, paying now to reduce uncertainty tomorrow might be beneficial. To determine this, one could posit a circumstance where additional information could improve the chance of success for the development and testing phase of the program. Let us suppose we are interested in knowing how much it is worth to eliminate any uncertainty about the research phase of the program — i.e., that the success rate would increase to 100 percent. How much is that worth? Because the research success rate is now 100 percent, the expected value increases. In order to gain that increase in reliability, suppose that an additional $1 million must be committed in Year 1. The value of the additional research expenditures are computed in Table 6-8.

TABLE 6-8

VALUE of REDUCTION in UNCERTAINTY ($000)

Year	1	2
Investment	-2,000	
Benefit:		
Success (100%)		3,485
Failure (0%)		0
NPV (Year 1)	-2,000	3,485 / 1.07
Total NPV	1,257	

Value of Uncertainty Reduction = 1,257 - 629
= 628

The result is that the net present value of the beefed-up research program with a 100 percent success rate would be $1,257,000 as compared with the estimated $629,000 in Table 6-6. The value of the option of spending additional funds to eliminate research uncertainty is therefore worth $628,000 — a very substantial percentage of the estimated base case. It appears that improving the success rate by spending additional research funds would be of substantial value to the FAA and should be pursued.

This sort of analysis can also be applied to other sorts of options that may be available, e.g., the option to spread out expenditures over a longer period of time, the option to delay the testing and development phase until Year 3, etc.

C. Limitations of Decision Analysis

Decision analysis can be a valuable tool in assessing the risks associated with potential projects that unfold over time because it allows decision-makers to assess projects at certain key points in the process without committing the full measure of financial or other resources. But the requirements needed to conduct a useful analysis can be difficult to meet. The most important practical requirement is that the uncertainty of all relevant variables must be characterized in terms of well-defined alternative discrete events. As described earlier, this may or may not be achievable depending on the sorts of risks being considered. In practice, schedule risks and accident risks may be more amenable to the assigning of probabilities and explicit outcomes to each possible event than other risks associated with, say, technical or compliance risks. Careful judgment is required in assessing whether a decision approach to risk assessment is warranted for any particular application.

CHAPTER 7

INFLATION

I. Introduction

The performance of economic analysis requires that benefits and costs be measured. The yardstick of measurement is the dollar. This yardstick must remain unchanged for all quantities measured if resulting measurements are to be meaningful and comparable with each other. But the value of the dollar is rarely constant from one year to the next. Changes in the prices of goods and services continuously effect the purchasing power of the dollar. This chapter deals with how to manage changes in the value of the dollar over time in order that benefits and costs occurring in different years may be consistently measured.

II. Price Changes

This section is divided into two parts: measuring inflation and measuring price changes for specific commodities. Inflation may be defined as a change in the general price level--this is, a change in the average price of all goods and services produced in the economy or which are regularly purchased by a defined buyer or class of buyers. It is conceptually distinct from the change in the price of any specific commodity, which most likely will be changing at a different rate than the price level or even moving in the opposite direction.

A. Measuring Inflation

Changes in the value of the dollar over time are measured using an index number. For the overall U.S. economy, a broadly based index representing the price of all goods and services such as the Gross Domestic Product (GDP) Implicit Price Deflator is commonly used. When considering the goods and services typically bought by a subset of purchasers, such as households, a more narrowly defined index representing the price of these particular commodities such as the Consumer Price Index is typically employed. Such numbers are a measure of relative value. They indicate the price of the group of goods and services of interest in one year relative to some other year. By convention, index numbers are usually computed as the ratio of the price of the goods and services of interest in one year divided by their price in the base year. The resulting ratio is then multiplied by 100 to produce the index number. Repeating the process for a number of years results in a series of index numbers.

To illustrate the methodology of working with index numbers, consider the two price measures for GDP reported in Table 7-1: The GDP Implicit Price Deflator and the GDP Chain-Type Price Index. Both measures are currently published by the Bureau of Economic Analysis of the Department of Commerce. Because the two series differ only slightly, it is appropriate to use either. The following examples make reference to the deflator series.

Note first that 1992 has a value of 100. Known as the base year, it is an arbitrary selection which is changed from time to time. It indicates that all other values are measured relative to 1992 being equal to 100.

TABLE 7-1

GROSS DOMESTIC PRODUCT IMPLICIT PRICE DEFLATOR on a CHAIN-WEIGHTED BASIS and GROSS DOMESTIC PRODUCT CHAIN-TYPE PRICE INDEX

(1986 - 1996)

YEAR	GDP CHAIN-TYPE PRICE INDEX	GDP IMPLICIT PRICE DEFLATOR
1986	80.6	80.6
1987	83.1	83.1
1988	86.1	86.1
1989	89.7	89.7
1990	93.6	93.6
1991	97.3	97.3
1992	100.0	100.0
1993	102.6	102.6
1994	105.0	104.9
1995	107.6	107.6
1996	109.9	109.7

Source: *Survey of Current Business*, Bureau of Economic Analysis, Department of Commerce, published monthly. In addition, GDP Implicit Price Deflators and Chain-Type Price Indexes are regularly reprinted in the *Economic Report of the President*, published annually and *Economic Indicators*, prepared for the Joint Economic Committee by the Council of Economic Advisers, published monthly.

For example, the 1994 value of the GDP implicit price deflator of 104.9 means that the price level for a given basket of goods and services in 1994 was 4.9 percent higher than it was in 1992, which is readily apparent from inspection. Given the 1992 base, it is not readily apparent, how much greater the price level was in 1993 than in 1987. This can be easily computed as 23.5 percent by dividing the 1993 value by the 1987 value and subtracting 1: (102.6/83.1)-1 = 23.5%. Moreover, the entire index may be restated in terms of any other base year by dividing each value by that of the new base year.[1] Annual changes may be computed by dividing each value by that of the previous year and subtracting 1. For example, the rate of price change between 1995 and 1994 is: (107.6/104.9)-1 = 2.57%.

To make adjustments for general price level changes requires that the concepts of constant dollars and current dollars be recognized. Current dollar estimates are expressed in the price level of the year in which the resource flows they represent occur. They are the actual amount spent or received. Constant dollar estimates represent the same value as current dollar estimates but as measured by the yardstick of the price level of a fixed reference year. Constant dollars can be specified in terms of any reference year that is desired.

To convert a series expressed in current dollars to constant dollars of a particular year requires that all numbers in the series be adjusted for general price level changes. This requires two steps. First, the general price level index must be transformed so that its base year is the one in which the constant dollars are to be stated. As previously noted, this is accomplished by dividing the general price level index through by its value in the desired base year. The second step is to convert the specified price series to constant dollars. This requires that it be divided by the values produced by step 1. The procedure is illustrated in Table 7-2, where the total FAA Operations and Maintenance Budget Appropriation from 1986 through 1996 is converted from current dollars to 1995 constant dollars. To convert constant dollars to current dollars requires that the procedure be reversed. First the deflator series must be divided by its value in the year in which the constant dollars are expressed and multiplied by the constant dollar series.

Another conversion likely to be encountered in practice is the transformation of a series from the constant dollars of one year to those of another. This is accomplished by multiplying the constant dollar series by the ratio of the price index term for the desired year to the price index term for the year in which it is currently expressed, where the base year of the price index is arbitrary. For example, to convert the 1995 constant dollar series in column (4) of Table 7-2 from 1995 constant dollars to 1990 constant dollars

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1 Restating an index in terms of another base year is a simple arithmetic calculation. It is not the same as the complex statistical processes typically involved when the entity which generates an index officially changes its base year. Such a change involves many technical adjustments which may include changes in scope of coverage and weighting schemes.

requires that each number in column (4) be multiplied by 87.0/100 from column (2) or 93.6/107.6 from column (1).

TABLE 7-2

CONVERSION of FAA OPERATIONS and MAINTENANCE APPROPRIATIONS from CURRENT DOLLARS to CONSTANT DOLLARS (Dollars in Millions)

Year	(1) GDP Deflator (1992 =100)	(2) GDP Deflator (1995 = 100)[a]	(3) Total O&M Appropriations in Current Dollars	(4) Total O&M Appropriations in 1995 Constant dollars[b]	(5) Total O&M Appropriations in 1990 Constant dollars[c]
1986	80.6	74.9	2,808	3,749	3,262
1987	83.1	77.2	2,982	3,863	3,361
1988	86.1	80.0	3,184	3,980	3,463
1989	89.7	83.4	3,445	4,131	3,594
1990	93.6	87.0	3,824	4,395	3,824
1991	97.3	90.4	4,037	4,466	3,885
1992	100.0	92.9	4,360	4,693	4,083
1993	102.6	95.4	4,538	4,757	4,139
1994	104.9	97.5	4,580	4,697	4,086
1995	107.6	100	4,583	4,583	3,987
1996	109.7	102.0	4,643	4,552	3,960

Source: *Economic Report of the President*, published annually; "*Federal Aviation Administration Budget in Brief*," Fiscal Year 1998.

a. Divide column (1) by 107.6 and multiply by 100.

b. Column (3) divided by column (2) and multiplied by 100.

c. Column (4) multiplied by 87.0 / 100.

B. Measuring Price Changes of Specific Goods and Services

A related but distinct situation arises when it is necessary to convert the price of a specific item which is known in one time period to what it was in the past or will be in the future. For past prices, this may be accomplished by using an historical price index defined for the particular class of item in question. For example, suppose it is known that a particular generic kind of aircraft was worth $2 million dollars in 1995. A price index defined for this general type of aircraft allows us to determine--using the procedures described above in Section II. A.--that the price of this aircraft has doubled since 1985. We can then estimate the price of this aircraft in 1985 as $1 million. Note that this price adjustment provides no information as to whether this aircraft's price has increased faster than, slower than, or at a rate equal to the overall rate of inflation during this time period.

An estimate of the future price of an item may be made by using a forecast of a price index for the class of item to determine expected change in the price of the item and then adjusting the current price of the item. In the absence of a price index forecast defined for the class of item of interest, it may be necessary to use a broader index for a particular segment of the economy or in some circumstances a general measure of inflation such as the GDP deflator. While data limitations may require use of the broader measure, it must be recognized that in so doing information on changes in the price of the item relative to the general price level may not be totally or even partially captured.

Estimation of prices of items in the future are typically made for two reasons. The first is for budget purposes. It is necessary to know how much will actually be spent in the future so that it may be budgeted for and included in the appropriation process. The second occurs in the conduct of benefit-cost analysis where it is necessary to determine expected benefit or cost value changes relative to changes in the general price level. This can be particularly important when dealing with items which are a large component of the analysis and which have price changes that differ significantly from the overall change in the general price level. Of particular importance in FAA benefit-cost analyses is the decrease in the cost of electronics relative to the general price level. Suggested methods for dealing with this type of problem are presented in Section IV. C. below.

III. Sources of Price Indexes

Numerous different price indexes and forecasts of price indexes are published by governmental and private organizations. They are available for many narrowly defined commodities and services, as well as for broader classifications ranging in scope from selected 4-digit SIC Code[2] industries to the overall economy.

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[2] Industries are classified in the *Standard Industrial Classification Manual 1987*, Office of Management and Budget, 1987. The classification system operates in such a way that the definitions become progressively narrower with successive additions of numerical digits. The broadest classifications contain 2 digits and the narrowest 7 digits.

Available information and the specific situation should govern the selection of an index for any particular price adjustment problem. In general, broadly based measures which reflect the prices of all goods and services typically purchased by a specific buyer or class of buyer should be used to make adjustments for inflation--changes in the general level of prices. Narrowly defined measures are appropriate for estimating past or future prices of specific goods or services. Special care should be taken not to use a narrowly defined index to make adjustments for the general level of inflation. For instance, if the objective is to determine the change in the real price of aircraft over time (as measured relative to other goods and services), it would not be appropriate to deflate an historical time series of aircraft prices by an aircraft price index. The aircraft price index is built from historical aircraft price changes, and its subsequent application to an historical series of aircraft prices would (by definition) give the impression that aircraft prices remained constant. In fact, prices of aircraft may have changed significantly relative to prices of other goods and services in the economy. It would be appropriate to use an index composed of a broad mix of goods and services (such as the implicit GDP deflator), of which aircraft prices are only a small part, to deflate aircraft prices. On the other hand, if the objective is to convert a known aircraft price from an earlier year to a current aircraft price in the study year, the use of an aircraft price index would be appropriate.

The following section identifies several indexes that may be of use to agency analysts. They are organized by categories relevant to potential FAA economic analyses. These indexes are intended only as suggestions.

A. General Price Level

In January 1996 the Bureau of Economic Analysis, compelled by recent dramatic changes in the U.S. economy's structure (particularly the spectacular fall in computer prices), adopted a chain-weighted method of computing real GDP and aggregate growth.[3] Associated with this new approach is the GDP Chain-Type Price Index. Both the new GDP Chain-Type Price Index and the older GDP Implicit Price Deflator represent changes in the prices of all goods and services produced in the United States. Because of their broad coverage, they are widely regarded as the best single measures of changes in the general price level. Either may be used to adjust time series data on current dollar benefits and costs into constant dollars. These measures are compiled by the Bureau of Economic Analysis on a quarterly and annual basis. Data for the most recent three years

[3] For a general discussion of the chain-type method, see Charles Steindel, "Chain-Weighting: The New Approach to Measuring GDP", *Current Issues in Economics and Finance*, Vol. 1, Number 9, Federal Reserve Bank of New York, December 1995, pp. 1-5. A more detailed description is given in Mark Lasky, "Forecasting with the New Data", *DRI/McGraw-Hill U.S. Review*, February 1996, pp. 38-50, and Mark Lasky "A Preview of the New Chain-Weighted GDP Measures", *DRI/McGraw-Hill U.S. Review*, September 1995, pp. 29-37.

are published in the *Survey of Current Business.*[4] Historical data are reprinted in the *Economic Indicators.*[5] Both series is also reprinted annually in the *Economic Report of the President.*[6]

Forecasts for the GDP Implicit Price Deflator and/or GDP Chain-Type Price Index are available from several sources. The Office of Management and Budget provides a projection of the GDP Implicit Price Deflator annually in conjunction with the preparation of the President's Budget. DRI/McGraw-Hill Data Resources provides forecasts of a wide range of deflators and indexes. The WEFA Group, another full-service economic and information consulting firm, also provides a broad range of services including forecasts of deflators and indexes. OMB recommends that the GDP deflator projections prepared in conjunction with the President's Budget be used when it is necessary to forecast the rate of general inflation and that credible private sector forecasts be used to conduct sensitivity analysis.[7]

B. Economic Sector Price Levels

Price levels of sectors of the economy represented by the various components of Gross Domestic Product are measured by either the respective deflator for each component or the respective chain-weighted index. Component deflators or component chain-weighted indexes likely to be of interest to agency analysts are those for total personal consumption expenditures, fixed investment, nonresidential structures, and government purchases of goods and services. They are published in the same sources as the GDP Deflator and Chain-Type Price Index. Historical data on a chain-weighted basis are available back to 1959. Forecasts of these series are available from the same sources as the GDP Deflator and Chain-Type Price Index. (Section III. A., page 10).

C. Construction

Several widely known indexes of construction costs are available in addition to the implicit deflator. The Boeckh Building Cost Index is compiled monthly by E.H. Boeckh Company, the property division of Mitchell International (internet address:

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4 *Survey of Current Business*, Bureau of Economic Analysis, Department of Commerce, Washington, D.C., published monthly.

5 *Economic Indicators*, prepared for the Joint Economic Committee by the Council of Economic Advisers, U.S. Government Printing Office, Washington, 1996, published monthly.

6 *Economic Report of the President*, Council of Economic Advisers, Washington, D.C., published annually in January.

7 OMB Circular A-94 (Revised--October 29, 1992) p. 8.

http://www.mitchell.com/boeckh/bcontact.html). It represents construction costs for three types of buildings: (1) apartments, hotels, and office buildings, (2) commercial and factory buildings, and (3) residential buildings. The *Engineering-News Record* (ENR) publishes monthly its Construction Cost, Common Labor, Skilled Labor, Building Cost and Material Cost (comprised of cement, steel and lumber) Indexes. These indexes are available separately for 20 U.S. cities. In addition, the ENR uses the Department of Commerce fixed-weighted Construction Cost index to deflate the value of New Construction Put-In-Place to constant 1992 dollars. On a quarterly basis, the ENR compiles various construction cost indexes : general-purpose cost, valuation, and special-purpose indexes. Each December the ENR forecasts these indexes for the next 12 months.[8]

The Federal Highway Administration publishes a quarterly index of highway construction costs in "Price Trends for Federal-Aid Highway Construction."[9] It is based on pricing of six components of highway construction: common excavation, to indicate the price trend for all roadway excavation; Portland cement concrete pavement and bituminous concrete pavement, to indicate the price trend for all surfacing types; and reinforcing steel, structural steel, and structural concrete, to indicate the price trend for structures.

D. Energy

As a component of the Producer Price Index (PPI), the Bureau of Labor Statistics compiles monthly indexes for the prices of coal, coke, gas fuels, electric power, crude petroleum, and refined petroleum products--gasoline, kerosene and jet fuels, light fuel oils, residual fuels--as well as a composite of them. These are published in the *PPI Detailed Report*[10] or in *The Monthly Labor Review*.[11] The PPI indexes are also available on the BLS web site at http://stats.bls.gov.

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8 For a detailed description of the index, see "Materials and Labor Cost Trends in the U.S.," *Engineering News-Record*, (March 9, 1981); pp. 132-137. Also see fourth quarterly Cost Report in ENR for December 23, 1996, and Forecast' 97 in ENR for January 27, 1997.

9 "Price Trends for Federal-Aid Highway Construction," Office of Engineering, Federal-Aid and Design Division, Federal Highway Administration, publication number FHWA-PD-95-006.

10. *The PPI Detailed Report*, Bureau of Labor Statistics, Department of Labor, published monthly.

11 *The Monthly Labor Review*, Bureau of Labor Statistics, Department of Labor, published monthly.

In addition, the Energy Information Administration of the U.S. Department of Energy , publishes the *Annual Energy Review* and *Annual Energy Outlook.* For most series, historical energy statistics are given from 1949 through the current year. The *Annual Energy Outlook* contains projections to 2015. Most of the data are also available electronically at http://www.eia.doe.gov.

E. Electronics and Computers

Also contained in the Producer Price Indexes are several components representing electric and electronic devices. The broadest category is for electrical machinery and equipment. It represents such items as wiring devices, instruments, motors, transformers, switching gear, electric lamps, and electronic components and accessories. An index for each of these subcomponents is also available. The electric and electronic devices index is published in the *Monthly Labor Review* and the subcomponent indexes in the monthly *PPI Detailed Report.*[12] In addition, the monthly *PPI Detailed Report* provides indexes for specific SIC electronics industries--electron tubes (SIC 3671), printed circuit boards (SIC 3672), semiconductors (SIC 3674), electronic capacitors (SIC 3675), electronic resistors (SIC 3676), electronic coils and transformers (SIC 3677) and electronic connectors (SIC 3678). Computers are aggregated under a broad category--Office, Computing, and Accounting Machines (SIC 357). At the four-digit level, the computer industry is represented in the PPI by electronic computers (SIC 3571), computer storage devices (SIC 3572), computer terminals (SIC 3575), and computer peripheral equipment, n.e.c. (SIC 3578).

F. Aircraft and Parts

In addition, BLS publishes the PPI indexes for aircraft and parts. These consist of an aggregate index for aircraft and parts (SIC 372) and more detailed indexes: aircraft (SIC 3721), aircraft engine and engine parts (SIC 3724), and aircraft parts and auxiliary equipment, n.e.c. (SIC 3728). DRI provides a forecast of these indexes upon customer request.

IV. Treatment of Inflation in Benefit-Cost Analysis

As a general rule, inflation should not be permitted to affect the outcome of benefit-cost analyses. Such studies are concerned with real quantities--resources consumed and

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[12] *The PPI Detailed Report*, Bureau of Labor Statistics, Department of Labor, published monthly.

benefits provided. The dollar is used only as the yardstick of value measurement. Because changes in the unit of measurement cannot affect the relationship between the real quantities, allowing price changes to affect the analysis will distort the results. This section presents methodology for ensuring that inflation does not impact benefit-cost analyses and produce such distortions.

A. Constant or Nominal Dollars

OMB now permits benefit-cost analyses to be conducted in either nominal or current dollars or in constant dollars of a particular year.[13] Effects of inflation are excluded by choosing *either* nominal dollars *or* constant dollars and avoiding mixing-up both in the same analysis and by using a nominal discount rate if the analysis is conducted in nominal dollars and a real discount rate if the analysis is conducted in constant dollars. (See Chapter 5, II. C.) OMB implies a preference for the use of constant dollars unless most of the underlying values are initially available in nominal dollars. Although some conversion from nominal to constant or vice-versa may be necessary to get all values into one form or the other, the choice of nominal or constant dollars should be made so as to minimize the conversions required.

Another consideration in selecting nominal or constant dollars is whether or not private sector optimizing behavior is endogenous within the analysis to be undertaken. If it is, the analyst must recognize that private sector actions are based on after tax impacts and that taxes are typically a function of nominal values. (For example, an analysis of alternative policies designed to influence aircraft operators to replace older aircraft with newer, quieter ones would need to incorporate tax impacts of replacement.) Where the outcome of an analysis depends significantly on such behavior, the analyst should seriously consider use of nominal values when designing the study.

Current FAA practice is to conduct benefit-cost analyses in constant dollars. Although use of nominal values may be advantageous in certain cases, FAA analyses should continue the use of constant dollars as normal practice unless there is good reason to do otherwise. The following guidance presumes the use of constant dollars.

B. Period Between Analysis Date and Project Start Date

The selection of the yardstick of value measurement is arbitrary. The constant dollars of one year are as good as the constant dollars of any other year as far as the economics of the analysis goes. However, for practical considerations it is recommended that the

[13] "OMB Circular A-94" (Revised--October 29, 1992) p. 8. The previous version of Circular A-94 (March 27, 1972) p. 3, had required that all analyses be conducted in constant dollars.

constant dollars of the year of the analysis be selected as the unit of measurement. This procedure is a natural approach because it permits benefits and costs to be valued at their current prices. Moreover, it avoids the need to transform current prices into past or future year dollars and, with respect to future years, the need to forecast inflation. Note that this recommendation is not a hard and fast rule and should not be followed when other circumstances so indicate.

C. Inflation During Project Life

During the projected life of the proposed investment or regulation, changes in the general level of prices should not be allowed to impact the analysis. Benefits and costs are real quantities; they consist of the goods and services provided by a project and the resources consumed in providing them. Dollars enter the analysis only as the yardstick of value. To allow the unit of measurement to vary would assign different valuation to the same benefits or costs depending on the variation in the unit of measurement over the project's lifetime.[14] With the typical investment or regulation during times of increasing prices, large costs occurring early in the project's life would be assigned less value than benefits stretching out over the years. This could lead to projects being undertaken which are not worthwhile because inflation had been allowed to increase benefit values relative to cost values. To avoid such distortions, all benefits and costs associated with an investment or regulation must be measured in the constant dollars of a particular year--preferably the year of the analysis for reasons noted in Section IV. B. of this chapter.

There is an important qualification (not exception) to the general rule of expressing all quantities in the constant dollars of a particular year. Quantities that increase or decrease in value more or less than the general price level should have their values adjusted by the difference between changes in their value and the general price level. This must be done to reflect that their real values relative to the real values of other goods and services have changed apart from any changes in the general level of prices.

Adjustment for real price changes requires that the difference between forecast general price level changes and prices of the items in question be computed. This may be accomplished by taking the ratio of the specific item price index to the GDP Deflator (or GDP Chain-Type Price Index). The resultant index will show how much the specific item is forecast to increase or decrease in price once the impact of overall price level changes is removed. The resultant index may then be multiplied by the constant dollar estimate of the item in question in each year to adjust it for real changes in value. This procedure is demonstrated by equations (7-1) and (7-2):

[14] This statement assumes use of a real discount rate such as the OMB specified 7 percent rate. It would not hold if a nominal discount rate were used because the inflation premium built into the nominal rate should remove, at least approximately, the impacts of inflation.

$$RI_t = \frac{SPI_t}{GDPI_t} \tag{7-1}$$

$$XA_t = XO_t\ (RI_t) \tag{7-2}$$

where: SPI_t = specific item price index in year t,
$GDPI_t$ = implicit GDP deflator in year t,
RI_t = resultant index in year t,
XO_t = unadjusted real value, and
XA_t = real value adjusted for relative real price changes.

In practice, another procedure is often used. If a particular item is known to be changing in real value at an approximately constant rate, its value may be projected by equation (7-3):

$$XA_t = XO_t\ (1+f)^m \tag{7-3}$$

where: m = the number of years between year t and the year in which the constant dollars of measurement are stated, and
f = the annual rate of real relative price change.

This adjustment can be combined with the discounting procedure developed in Chapter 5 and defined in equation (5-6). Combination is possible because two ratios are being applied similarly to the same benefit or cost figure. This is indicated in equation (7-4):

$$NPV = \sum_{t=o}^{k} \frac{(B-C)'}{(1+r)^t} + \sum_{t=0}^{k} X_t \left[\frac{1+f}{1+r}\right]^t \tag{7-4}$$

where: X_t = the quantity in year t being adjusted expressed in constant dollars of the year of initial project implementation,
$(B\text{-}C)_t'$ = all benefits and costs other than those contained in X_t,
r = the discount rate, and
k = the total number of periods in the evaluation period of the project or regulation.

A typical situation where real cost changes must be considered arises with respect to replacement projects. One advantage of the proposed new system over the old often is that it replaces an old technology with a new one. In cases where the real cost of the old technology is projected to increase with time, the absolute amount of the new system's advantage continually increases. While it is proper to include such an ever increasing advantage in an evaluation, the burden of establishing an appropriate rate of increase rests squarely on the shoulders of the analyst. Conclusions which result solely from assuming large real cost increases in the existing system which are not thoroughly justified are not convincing and are easily contested.

CHAPTER 8

DISTRIBUTIONAL IMPACTS

I. Introduction

Benefit-cost analysis, properly applied, will yield answers to the two economic questions of what to produce and how to product it. By carefully identifying all relevant alternatives for achieving each proposed objective and undertaking only that alternative with the highest positive net present value (or not undertaking any alternative when none have positive net present value) society's welfare as a whole will be improved by as much as possible. This will occur because more total value--benefits net of the costs of the resources consumed to produce them--will be created than for any other alternative that might be undertaken. However, it is very likely that not all members of society will be better off after the alternative is undertaken than before. This is because the recipients of the benefits of governmental investments or regulations are frequently not those who bear the costs of these investments or regulations. Nonetheless, the potential will exist for all individual members of society to be made better off because those who benefit from the governmental actions could fully compensate those who loose and still be better off than before.

II. Requirement

In order to fully inform decisionmakers of the distributional impacts of the benefits and costs of proposed governmental actions, OMB has directed that when benefits and costs of proposed governmental actions have significant distributional effects, an analysis and discussion of these effects should be included in the benefit-cost analysis.[1] In practice, a distributional assessment should be undertaken only when significant distributional effects can be reasonably anticipated to occur. Many FAA investment projects will most likely not require this assessment in that the beneficiaries of these investments are the ones who pay for them through direct user investment, the aviation excise taxes, and/or direct fees. Where cross subsidization between user groups or subsidization by others

[1] "OMB Circular A-94" (Revised--October 29, 1992) pp. 13-14, and "OMB Economic Analysis of Federal Regulation Under Executive Order 12866" (January 11, 1996) pp. 23-24.

including the general taxpayer is anticipated, an assessment should be completed. For many regulations, the same is probably also true in that those groups that receive the benefits also ultimately bear the costs of the regulation. (A noted exception are environmental impacts, where those who are exposed to pollution or noise do not pay the costs of its mitigation and are rarely compensated for their exposure.) Again, where one group or groups is anticipated to gain significantly while others bear the costs, an assessment should be undertaken. Finally, it should be noted that the requirement for an analysis of distributional impacts applies principally to benefit-cost analyses, not to cost-effectiveness analyses. In cost-effectiveness analyses, the benefits provided to the public are generally unchanged; the analysis is focused on identifying the lowest cost method of providing them. Because there are no public gainers or losers, a distributional analysis is unnecessary.

In addition, it may be necessary to develop distributional information to demonstrate U.S. Government compliance with accepted international principles for charging--via direct fees or indirect excise taxes--for air traffic control, certification, and other FAA services. ICAO guidelines specify that costs incurred to provide services to one group of users should not be charged to others. Moreover, the *Chicago Convention* requires that foreign operators be charged the same fees that domestic operators are charged, where both classes of operators are providing the same type--e.g. international scheduled carriage--of service.[2]

III. Distributional Categories

The first step in assessing distributional impacts is to establish categories of individuals or groups that may be differentially impacted. Although this process will depend upon the specific governmental action being analyzed, characteristics of groups for distributional assessment could include one or more of the following characteristics:

- Geographical area (including those living within and outside airport noise footprints)
- Demographic group such as age, race, etc.
- Income class (divided by quintile, for example)
- Traditional aviation user group (including domestic air carriers, international air carriers, general aviation, etc.)

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2 "Statements by the Council to Contracting States on Charges for Airports and Air Navigation Services," Fifth Edition, Document 9082/5, International Civil Aviation Organization; and *Convention on International Civil Aviation,* Sixth Edition, Document 7300/6, International Civil Aviation Organization, Article 15.

- Recipients of FAA services (passengers, air carriers, airports, manufactures, airmen, designated examiners, etc.)
- Industry or occupation group

For any specific analysis, groups should be constructed so as to characterize relevant gainers and losers from pursuing a governmental action. As an example, analysis of a proposed action which would change the amount and distribution of aircraft noise should identify what groups--classified by income level, age, and geographic location--would be exposed to more or less noise. The analysis would also need to identify what groups would gain or loose--passengers, air carriers, airports, etc.--from the proposed actions impact on the number or routing of flights.

As another example, a proposed action such as establishment of a Terminal Control Area that would impose airspace use restrictions based on type of operation and aircraft equipage could be expected to restrict general aviation use of certain airspace or condition its use on acquisition of particular equipment while improving safety and efficiency for the flying public in general. For the analysis of such an action, it would be important to establish groupings that recognize such groups as general aviation, air carriers, and passengers.

In addition, the presence and extent of intergenerational transfers, if any, should be identified. Such transfers occur where particular generations receive the benefits stemming from a governmental action while others bear the costs of this action. An example would be an environmental regulation which permitted the current generation to pollute (thus avoiding the costs of pollution mitigation) at the expense of future generations which would inherit the damage done by the pollution and the costs of dealing with it. Another example would be an investment which must be made today but which would yield benefits primarily to future generations. It should be noted that because most FAA investments or regulations begin to generate benefits within several years of when costs begin to be incurred, it is unlikely that intergenerational transfers will be significant for most FAA actions. Exceptions might include actions concerning airports where decisions made today will have long lasting impacts on land use, potentially generate benefits for many years beyond the current generation, or in the case of landbanking, incur significant current costs yet generate no benefits for many years to come before having the potential to generate very large benefits.

IV. Distributional Assessment

For purposes of a distributional assessment, identified gains and losses should consist of both benefits and cost, as described elsewhere in this guide, as well as transfers of property rights or wealth from one group to another. Benefits and costs are different than transfers in that benefits and costs represent, respectively, value created or resources consumed as a result of a governmental action. Transfers represent merely a redistribution of wealth or rights. Examples of benefits and costs are the improved safety and efficiency of investments in the National Airspace System and the resources consumed to make them. An example of a transfer is the loss of environmental quality in one neighborhood and its gain in another resulting from the rerouting of aircraft so as to shift noise from one area to another.

For each identified group that may potentially gain or loose as a result of a governmental action, the analysis should, if possible, estimate the amount of gain or loss. Where quantitative estimates can not be made, a qualitative assessment should be presented. If gainers provide compensation to losers, who pays and who receives such compensation and its amount should be reported. The present value of the gains or losses experienced by each identified group together with the flows of gains and losses in each time period should be presented. Present values provide a convenient summary. The time distributed flows permit an assessment of the intergenerational impact of the action, if any.

Gains and losses from an action ultimately impact individuals and households even though they may initially affect intermediate groups first. In addition to identifying immediate impacts on intermediate groups, the distributional assessment should also focus on the ultimate economic incidence of the proposed governmental action. For example, an investment which reduced delays at an airport would initially save airline operating costs and passengers time. If the airlines were subject to competition, reduced costs would result in reduced ticket prices and the benefits of reduced operating costs would ultimately flow to the passenger. Passengers would thus be the ultimate recipients of both time saving and reduced airline operating costs. Alternatively, if the airline(s) serving the airport were not subject to competition, reduced costs would result in higher profits which would flow to their owners, not to their passengers.

There are no generally accepted principles for judging the merits of certain groups gaining at the expense of others. Accordingly, the distributional assessment should be confined to describing them in order to provide the decisionmaker with complete information. No judgments should be made in the analysis.

V. An Example--The High Density Rule Study

The High Density Rule (HDR) specifies the number of operations per hour that may be conducted at four airports--Washington National, Chicago O'Hare, New York Kennedy, and New York LaGuardia. The Department of Transportation conducted a study and prepared a report to Congress on the merits of terminating or modifying this rule.[3] This study developed and presented estimates of benefits and costs at each airport for three identified groups--passengers, airlines, and airports--as well as transfers between groups. Selected analytical results for immediately removing the HDR at LaGuardia Airport are presented in Table 8-1.

Removal of the HDR permits more service to be provided which results in lower fares. Consumers gain in two ways. First, current passengers enjoy lower fares. Second, additional consumers fly at the lower fares. More service also results in increased delay to consumers, but overall they enjoy a net gain.

For airlines, the results are somewhat different. The gain to current consumers comes at the expense of the airlines--this is a transfer between groups in that value is neither created nor consumed, merely redistributed. Airlines do benefit from serving new incremental demand. (This benefit is over and above the value provided to consumers by this new service.) Airlines also experience the costs associated with increased delays. In sum, airlines are net losers.

Finally, the airport provides increased services to support the additional demand incident to removal of the HDR. The revenue earned by the airport over and above the costs of providing these increased services accrues to the airport.

Consumers and airports are net gainers from elimination of the HDR. However, these gains are more than offset by transfers from airlines to passengers and increased delay cost incurred by airlines. Even if the increased airline cost were ultimately passed on to consumers, as might be expected where airlines are subject to competition, airlines would still be net losers. This is because the transfer to existing consumers from airlines stemming from fare declines is greater than the gains earned from serving incremental demand increases.

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3 "A Study of the High Density Rule," Report to the Congress, Department of Transportation, May 1995.

TABLE 8-1

SELECTED BENEFIT-COST RESULTS for IMMEDIATE ELIMINATION of HDR at LAGUARDIA AIRPORT

Benefits and Costs by User Group	**1995**	**2000**
Dollar Benefits and Costs ($ Mil. per Year):		
Consumers:		
Fare Reductions	$160	$167
New Service	$78	$101
Increased Delay Cost	($149)	($226)
NET BENEFIT to CONSUMERS	$89	$42
Airlines:		
Loss of Fare Premium	($160)	($167)
Incremental Demand Impact	$104	$111
Increased Airline Delay Costs	($64)	($97)
NET BENEFIT (LOSS) to AIRLINES	($120)	($153)
Net Revenue to Airports:	$14	$24
TOTAL BENEFITS	$193	$236
TOTAL COSTS	($213)	($323)
NET DOLLAR BENEFIT OF ELIMINATING HDR	($17)	($87)

Source: "Report to Congress: A Study of the High Density Rule Study," May 1995, pp. 90-94.

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APPENDIX A

DOCUMENTS REQUIRING ECONOMIC ANALYSIS

The requirement to conduct economic analyses of investment projects and regulatory actions is documented in the following Executive Orders, Office of Management and Budget (OMB) Circulars and guidance, FAA policy documents, and DOT Orders and guidance.

A. INVESTMENT PROJECTS

1. OMB CIRCULAR A-94 (Revised) (October 29, 1992): "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs"--Provides general guidance to be followed by all agencies of the Executive Branch in the conduct of benefit-cost and cost-effectiveness analyses, including measurement of benefits and costs, treatment of uncertainty, and related issues. It also provides specific guidance on the discount rates to be used in evaluating Federal programs whose benefits and costs are distributed over time. The guidance must be followed in all analyses submitted to OMB in support of legislative and budget programs in compliance with OMB Circulars No. A-11, "Preparation and Submission of Annual Budget Estimates," and No. A-19, "Legislative Coordination and Clearance." It is also applicable to economic analyses of regulatory actions required by Executive Order 12866.

   The Circular applies to any analysis used to support Government decisions to initiate, renew, or expand programs or projects which would result in a series of measurable benefits or costs extending for three or more years into the future, specifically:

   - benefit-cost or cost-effectiveness analysis of federal programs or policies,
   - economic analysis of proposed regulatory actions,
   - analysis of decisions of whether to lease or purchase, and
   - asset valuation and sale analysis.

   It does not apply to evaluation of decisions regarding (1) water resource projects, (2) acquisition of commercial-type services by Government or contractor operation (guidance for which is provided in OMB Circular A-76), or (3) Federal energy management programs. Except as noted below under Executive Order 12893 "Principles for Federal Infrastructure Investments" and its implementing guidance, this Circular does not apply to non-Federal recipients of loans, contracts, or grants, although these recipients are encouraged to follow its guidance when preparing analyses in support of Federal activities. This Circular replaces and rescinds OMB Circular No. A-94, "Discount Rates to be Used in Evaluating Time-Distributed Costs and Benefits," dated March 27, 1972. It also replaces Circular No. A-104, "Evaluating Leases of Capital Assets," dated June 1, 1986, which was rescinded previously.

2. OMB CIRCULAR A-109 (April 5, 1976): "Major System Acquisitions"--Establishes policies to be followed by executive agencies in the acquisition of major systems. These include a well defined management process with clear lines of authority, responsibility, and accountability for major system acquisitions. Among other policies set out are those requiring formulation of alternatives to achieve agency objectives, life cycle costing techniques, and assessment of anticipated benefits.

3. "Federal Aviation Administration Acquisition Management System," June 1997:--Presents key elements of the Federal Aviation Administration's acquisition reform undertaken in response to Section 348 of the *1996 DOT Appropriations Act* (Public Law 104-50). This system retains key precepts of OMB Circular A-109 and tailors them to meet FAA acquisition reform principles and goals. An important element of this system is the Investment Analysis which provides information upon which to base a decision to undertake a new program. An investment analysis is similar, but broader in scope, than a benefit-cost analysis. It includes the following activities:

- identification of alternatives--Initial requirements are used to identify all viable material and non-material candidate solutions. The principal objective is to identify commercial items, non-developmental items, or non-material solutions that are cost-effective and operationally suitable to satisfy the need and requirements.

- analysis of alternatives--Candidate solutions are evaluated by compiling and analyzing such economic factors as life cycle cost, benefits and costs, and risk. Additional factors such as technical performance, schedule, human factors, environmental impact, radio frequency spectrum, logistics support, compatibility with NAS Architecture, regulatory and procedural impact, and operational suitability are also evaluated.

- affordability assessment--FAA policy is to authorize a new program only if a commitment can be made to fully fund it. This assessment is intended to determine if that commitment can be made.

B. REGULATORY ACTIONS

1. REGULATORY FLEXIBILITY ACT OF 1980 as amended by the SMALL BUSINESS REGULATORY ENFORCEMENT FAIRNESS ACT OF 1996-- Requires agencies to publish an Initial Regulatory Flexibility Analysis, or summary of it, in the *Federal Register* for any regulatory action requiring a Notice of Proposed Rulemaking at the time the notice is published. The Act further requires that agencies publish a Final Regulatory Flexibility Analysis at the time the final rule is published. This final analysis must contain:

- a succinct statement of the need for and objectives of the rule,

- a summary of the significant issues raised by public comments in response to the initial regulatory flexibility analysis, a summary of the proposed agency's assessment of such issues, and a statement of any changes made in the proposed rule as a result of such comments,

- a description and an estimate of the number of small businesses to which the rule will apply or an explanation of why no estimate is available,

- a description of the projected reporting, record keeping and other compliance requirements of the rule, including an estimate of the classes of small entities that will be subject to the requirement and the types of professional skills necessary for the preparation of the report or record, and

- a description of the steps the agency has taken to minimize the significant economic impacts on small entities consistent with the stated objectives of applicable statutes, including a statement of the factual, policy, and legal reasons for selecting the alternative adopted in the final rule, and the reasons for rejecting each of the other significant alternatives.

Preparation of a Regulatory Flexibility analysis may be avoided in those situations where the head of the agency "certifies that the rule will not, if promulgated, have (1) a significant economic impact on (2) a substantial number of (3) small entities," where small entities are defined as small business, small organizations, and small government jurisdictions.

2. <u>EXECUTIVE ORDER 12866 (September 30, 1993)</u>: "Regulatory Planning and Review"--Identifies regulatory philosophy and principles to be followed by Federal agencies in promulgating regulations and establishes a regulatory planning mechanism coordinated by OMB. This order revokes Executive Order 12291.

The regulatory philosophy provides that:

- Federal agencies should promulgate only such regulations that are required by law, are necessary to interpret law, or are made necessary by compelling public need,

- Federal agencies should assess all costs and benefits of available regulatory alternatives, including the alternative of not regulating, and

- Federal agencies, in choosing among alternative regulatory approaches, should select those approaches that maximize net benefits (including potential economic, environmental, public health and safety, and other advantages; distributive impacts; and equity), unless a statute requires another regulatory approach.

Principles of regulation identified by this Executive Order include requirements to:

- identify the problem and its significance,

- base decisions on the best reasonably obtainable information,

- identify and assess available alternatives to direct regulation, including establishing of economic incentives to achieve desired outcomes, and providing information upon which the public can act,

- identify and assess alternative forms of regulation and to the extent feasible specify performance objectives rather specific behavior or manner of compliance,

- design regulations in the most cost-effective manner,

- tailor regulations so as to impose the least burden on society

- assess both the costs and benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon determination that benefits justify costs.

This Executive Order also provides for centralized review of regulations by OMB. Agencies are required to provide OMB with a list of planned regulatory actions, indicating those which the agency believes to be significant. Significant regulatory action is defined in Section 3 (f) of the Executive Order as "any regulatory action that is likely to result in a rule that may:

> "(1) Have an annual effect on the economy of $100 million or more or adversely affect in a material way the economy, a sector of the economy, productivity, competition, jobs, the environment, public health or safety, or State, local, or tribal governments or communities;
>
> "(2) Create a serious inconsistency or otherwise interfere with an action taken or planned by another agency;
>
> "(3) Materially alter the budgetary impact of entitlements, grants, user fees, or loan programs or the rights and obligation of recipients thereof; or
>
> "(4) Raise novel legal or policy issues arising out of legal mandates, the President's priorities, or the principles set forth in this Executive Order."

This Order provides that OMB review those regulatory actions identified by the agency to OMB as significant, or determined by OMB to be significant. For each significant regulatory action the agency is required to provide OMB:

- the text of the draft regulatory action together with a description of the need for the regulatory action and an explanation as to how the proposal meets this need and

- an assessment of the benefits and costs of the proposal (including an explanation as to how the proposal is consistent with statutory mandates and, to the extent permitted by law, promotes Presidential priorities and avoids undue interference with State, local, and tribal governments).

For those significant regulatory actions that may have an annual effect on the economy of $100 million or more or an adverse material affect on the economy, State, local, or tribal governments or communities, agencies must also provide OMB with the underlying analysis of benefits and costs quantified to the extent possible. Further, agencies must provide an assessment of the benefits and costs of reasonably feasible alternatives to the planned regulation and an explanation as to why the planned action is preferable to the alternatives.

3. "OMB Economic Analysis of Federal Regulation Under Executive Order 12866" (January 11, 1996)--Provides guidance for meeting the economic analysis requirements of Executive Order 12866 as well as those of the Unfunded Mandates Reform Act of 1995 and the Regulatory Flexibility Act. In accordance with the regulatory philosophy and principles of the Executive Order, it indicates that an Economic Analysis of proposed or existing regulations should inform decisionmakers of the consequences of alternative actions. In particular, it should contain information allowing decisionmakers to determine that:

- there is adequate information indicating the need for and consequences of the proposed action,

- potential benefits to society justify the potential costs, recognizing that not all benefits and costs can be described in monetary or even in quantitative terms, unless a statute requires another regulatory approach.

- the proposed action will maximize net benefits to society, unless a statute requires another regulatory approach,

- where a statute requires a specific regulatory approach, the proposed action will be the most cost-effective, including reliance on performance objectives to the extent feasible, and

- agency decisions are based on the best reasonably obtainable scientific, technical, economic and other information.

It requires that "preliminary and final Economic Analyses of economically "significant" rules (as defined in Section 3(f)(1) of the executive Order) should contain three elements:

- a statement of the need for the proposed action,
- an examination of alternative approaches, and
- an analysis of benefits and costs."

The document also identifies and describes best practices for the conduct of economic analyses including rationales for regulation, framing of alternative approaches, and appropriate measurement of benefits and costs including treatment of risk and uncertainty.

4. <u>ORDER DOT 2100.5 (May 22, 1980)</u>: "Policies and Procedures for Simplification, Analysis, and Review of Regulations"--Requires that a regulatory analysis be conducted for essentially all regulations for which an economic analysis (per "OMB Economic Analysis of Federal Regulation under Executive Order 12866") is required and that a regulatory evaluation be conducted for all other regulations. It defines a regulatory analysis as containing "(1) a succinct statement of the problem and issues that make the regulation significant; (2) a description of the major alternative ways of dealing with the problem that were considered by the initiating office; (3) an analysis of the economic and any other relevant consequences of each of these alternatives; and (4) a detailed explanation of the reason for choosing one alternative over the others." A regulatory evaluation "includes an analysis of the economic consequences of the proposed regulation quantifying to the extent practicable, its estimated cost to the private sector, consumers, Federal, state, and local governments, as well as its anticipated benefits and impact."

C. FEDERAL INFRASTRUCTURE PROJECTS INCLUDING DIRECT SPENDING AND GRANTS

1. <u>EXECUTIVE ORDER 12893 (January 31, 1994)</u>: "Principles for Federal Infrastructure Investments"--Instructs Federal agencies to conduct a systematic analysis of benefits and costs of infrastructure investments. It also requires Federal agencies to conduct periodic reviews of management practices, including operations and maintenance activities, contracting practices, and pricing policies; to seek private sector participation in infrastructure investment and management; and to promote efficient use of Federal infrastructure funds by encouraging State and local recipients of Federal grants to implement planning and information

management systems that support the principles of the order. The Order required all Federal agencies to submit initial plans to implement its principles no later than March 15, 1994. It applies to major infrastructure investment and grant programs--defined as those with annual budgetary resources in excess of $50 million--beginning with the fiscal year 1996 OMB budget submissions. The order also applies to authorization and reauthorization requests submitted for OMB approval beginning March 15, 1994.

The Order requires that the analysis of benefits and costs be conducted in accordance with OMB circular A-94 and:

- quantify and monetize benefits and costs to the maximum extent practicable.
- measure and appropriately discount benefits and costs over the full life cycle of each project.
- recognize and address uncertainty through appropriate quantitative and qualitative assessments.
- compare a comprehensive set of options that include, among other things, managing demand, repairing facilities, and expanding facilities, and
- consider not only quantifiable measures of benefits and costs but also qualitative measures reflecting values that are not readily quantified.

2. "Guidance on Executive Order No. 12893, Principles for Federal Infrastructure Investments"--Provides implementation guidance as required by Executive Order 12893. It indicates that the Executive Order covers spending for transportation, water resources, energy, and environmental protection. For FAA, it specifically applies to Facilities and Equipment and Grants-in-Aid for Airports. It reiterates that all analyses provided shall be consistent with OMB Circular A-94 including the use of a base rate discount rate--7 percent when the Executive Order was issued--as specified by A-94.

3. Title 49, *United States Code*:--Codifies certain U.S. Transportation Laws. Section 47115(d) specifies that, in selecting projects for discretionary grants or Letters of Intent (LOI) to preserve and enhance capacity at airports, the Secretary of Transportation must consider the projects benefits and costs. (An LOI is an

announcement by the Secretary of Transportation of the intention to obligate funds for certain airport development projects in advance of an AIP grant, subject to the availability of funds.) It should be noted that FAA does not have statutory authority to require airport authorities receiving AIP formula monies to conduct benefit-cost analyses. However, FAA provides technical assistance to airports seeking to estimate the capacity, delay, environmental, or other impacts of airport investments.

4. "Policy for Letter of Intent Approvals under the Airport Improvement Program," *Federal Register*, Vol. 59, No. 209, October 31, 1994:--clarifies FAA's policies on reviewing and analyzing requests for LOI's under AIP at primary or reliever airports for airside capacity development projects. It indicates that FAA will consider three factors in reviewing requests for LOI's: the project's effects on overall national air transportation capacity; project benefits and costs; and the airport sponsor's financial commitment to the project. The policy further requires that a project must have present value benefits which exceed present value costs to be considered for an LOI.

5. "Policy Regarding Revision of Selection Criteria for Discretionary Airport Improvement Program Grant Awards," *Federal Register*, Vol. 59, No. 209, October 31, 1994:--Requires benefit-cost analysis for any discretionary capacity AIP grant application which is expected to equal or exceed $10 million (subsequently lowered to $5 million--see item 6 below) in AIP grant funds over the life of the project. Although FAA had used a "Priority System" for ranking Airport Improvement Program (AIP) applications for grants for many years, it had not employed benefit-cost analysis. To implement Executive Order 12893 and comply with guidance provided in Congressional hearings regarding the use of economic analysis in evaluating Federal investment in airport infrastructure, FAA adopted the benefit-cost requirement for all new projects to be considered for AIP grant awards in fiscal year 1995 and subsequent years.

6. "Policy and Guidance Regarding Benefit-Cost Analysis for Airport Capacity Projects Requesting Discretionary Airport Improvement Program Grant Awards and Letters of Intent," *Federal Register*, Vol. 62, No. 121, June 24, 1997--Issues interim guidance--published in "FAA Airport Benefit-Cost Analysis Guidance," June 1997--for conducting airport benefit-cost analysis for capacity projects seeking AIP grants or LOI's. This notice provides that a benefit-cost analysis accompany all AIP grant applications for $5 million or more in AIP capacity discretionary funds for grants commencing in FY-1998 and for any request for an LOI to be issued in FY-1997 or thereafter. Although FAA staff had initially conducted many of the benefit-cost analyses completed in support of such projects under the Policy Notices issued in 1994, this notice places responsibility for conducting these analyses upon the airport sponsor. Sponsors are encouraged to

perform the analysis during the development of their airport master plans, in conjunction with environmental studies, or concurrently with other project formulation activities. FAA is responsible for reviewing the analyses as part of the AIP request evaluation process, may request further details, and may undertake an independent benefit-cost analysis.

APPENDIX B

PRESENT VALUE TABLES

TABLE B-1

PRESENT VALUE OF $1 FLOWING AT THE END
OF THE PERIOD

(Discrete Compounding)

	Annual Effective Discount Rate						
Period	2%	4%	5%	7%	10%	15%	20%
1	0.980392	0.961538	0.952381	0.934579	0.909091	0.869565	0.833333
2	0.961169	0.924556	0.907029	0.873439	0.826446	0.756144	0.694444
3	0.942322	0.888996	0.863838	0.816298	0.751315	0.657516	0.578704
4	0.923845	0.854804	0.822702	0.762895	0.683013	0.571753	0.482253
5	0.905731	0.821927	0.783526	0.712986	0.620921	0.497177	0.401878
6	0.887971	0.790315	0.746215	0.666342	0.564474	0.432328	0.334898
7	0.870560	0.759918	0.710681	0.622750	0.513158	0.375937	0.279082
8	0.853490	0.730690	0.676839	0.582009	0.466507	0.326902	0.232568
9	0.836755	0.702587	0.644609	0.543934	0.424098	0.284262	0.193807
10	0.820348	0.675564	0.613913	0.508349	0.385543	0.247185	0.161506
11	0.804263	0.649581	0.584679	0.475093	0.350494	0.214943	0.134588
12	0.788493	0.624597	0.556837	0.444012	0.318631	0.186907	0.112157
13	0.773033	0.600574	0.530321	0.414964	0.289664	0.162528	0.093464
14	0.757875	0.577475	0.505068	0.387817	0.263331	0.141329	0.077887
15	0.743015	0.555265	0.481017	0.362446	0.239392	0.122894	0.064905
16	0.728446	0.533908	0.458112	0.338735	0.217629	0.106865	0.054088
17	0.714163	0.513373	0.436297	0.316574	0.197845	0.092926	0.045073
18	0.700159	0.493628	0.415521	0.295864	0.179859	0.080805	0.037561
19	0.686431	0.474642	0.395734	0.276508	0.163508	0.070265	0.031301
20	0.672971	0.456387	0.376889	0.258419	0.148644	0.061100	0.026084
21	0.659776	0.438834	0.358942	0.241513	0.135131	0.053131	0.021737
22	0.646839	0.421955	0.341850	0.225713	0.122846	0.046201	0.018114
23	0.634156	0.405726	0.325571	0.210947	0.111678	0.040174	0.015095
24	0.621721	0.390121	0.310068	0.197147	0.101526	0.034934	0.012579
25	0.609531	0.375117	0.295303	0.184249	0.092296	0.030378	0.010483
26	0.597579	0.360689	0.281241	0.172195	0.083905	0.026415	0.008735
27	0.585862	0.346817	0.267848	0.160930	0.076278	0.022970	0.007280
28	0.574375	0.333477	0.255094	0.150402	0.069343	0.019974	0.006066
29	0.563112	0.320651	0.242946	0.140563	0.063039	0.017369	0.005055
30	0.552071	0.308319	0.231377	0.131367	0.057309	0.015103	0.004213
31	0.541246	0.296460	0.220359	0.122773	0.052099	0.013133	0.003511
32	0.530633	0.285058	0.209866	0.114741	0.047362	0.011420	0.002926
33	0.520229	0.274094	0.199873	0.107235	0.043057	0.009931	0.002438
34	0.510028	0.263552	0.190355	0.100219	0.039143	0.008635	0.002032
35	0.500028	0.253415	0.181290	0.093663	0.035584	0.007509	0.001693

TABLE B-2

PRESENT VALUE OF $1 FLOWING UNIFORMLY
OVER THE STATED PERIOD

(Continuous Compounding)

	Annual Effective Discount Rate						
Period	2%	4%	5%	7%	10%	15%	20%
1	0.990164	0.980644	0.975997	0.966921	0.953824	0.933264	0.914136
2	0.970749	0.942926	0.929521	0.903664	0.867112	0.811534	0.761780
3	0.951714	0.906660	0.885258	0.844546	0.788284	0.705682	0.634817
4	0.933053	0.871789	0.843103	0.789295	0.716622	0.613636	0.529014
5	0.914758	0.838258	0.802955	0.737659	0.651474	0.533597	0.440845
6	0.896822	0.806017	0.764719	0.689401	0.592249	0.463997	0.367371
7	0.879237	0.775017	0.728304	0.644300	0.538409	0.403476	0.306142
8	0.861997	0.745208	0.693623	0.602150	0.489462	0.350848	0.255119
9	0.845095	0.716547	0.660593	0.562757	0.444966	0.305086	0.212599
10	0.828525	0.688987	0.629136	0.525941	0.404514	0.265292	0.177166
11	0.812279	0.662488	0.599177	0.491534	0.367740	0.230689	0.147638
12	0.796352	0.637007	0.570645	0.459377	0.334309	0.200599	0.123032
13	0.780737	0.612507	0.543472	0.429324	0.303918	0.174434	0.102526
14	0.765429	0.588949	0.517592	0.401238	0.276289	0.151681	0.085439
15	0.750420	0.566297	0.492945	0.374989	0.251172	0.131897	0.071199
16	0.735706	0.544517	0.469471	0.350457	0.228338	0.114693	0.059332
17	0.721281	0.523574	0.447115	0.327530	0.207580	0.099733	0.049444
18	0.707138	0.503436	0.425824	0.306102	0.188709	0.086724	0.041203
19	0.693272	0.484073	0.405547	0.286077	0.171554	0.075413	0.034336
20	0.679679	0.465455	0.386235	0.267362	0.155958	0.065576	0.028613
21	0.666352	0.447553	0.367843	0.249871	0.141780	0.057023	0.023844
22	0.653286	0.430339	0.350327	0.233524	0.128891	0.049585	0.019870
23	0.640477	0.413788	0.333644	0.218247	0.117173	0.043117	0.016559
24	0.627918	0.397873	0.317757	0.203969	0.106521	0.037493	0.013799
25	0.615606	0.382570	0.302625	0.190625	0.096838	0.032603	0.011499
26	0.603535	0.367856	0.288215	0.178154	0.088034	0.028350	0.009583
27	0.591701	0.353708	0.274490	0.166499	0.080031	0.024652	0.007985
28	0.580099	0.340103	0.261419	0.155607	0.072755	0.021437	0.006655
29	0.568725	0.327023	0.248971	0.145427	0.066141	0.018641	0.005545
30	0.557573	0.314445	0.237115	0.135913	0.060128	0.016209	0.004621
31	0.546641	0.302351	0.225824	0.127022	0.054662	0.014095	0.003851
32	0.535922	0.290722	0.215070	0.118712	0.049693	0.012257	0.003209
33	0.525414	0.279540	0.204829	0.110946	0.045175	0.010658	0.002674
34	0.515112	0.268789	0.195075	0.103687	0.041069	0.009268	0.002229
35	0.505011	0.258451	0.185786	0.096904	0.037335	0.008059	0.001857

TABLE B-3

PRESENT VALUE OF A UNIFORM SERIES OF
$1 PAYMENTS FLOWING AT THE END OF EACH PERIOD

(Discrete Compounding)

	Annual Effective Discount Rate						
Period	2%	4%	5%	7%	10%	15%	20%
1	0.980392	0.961538	0.952381	0.934579	0.909091	0.869565	0.833333
2	1.941561	1.886095	1.859410	1.808018	1.735537	1.625709	1.527778
3	2.883883	2.775091	2.723248	2.624316	2.486852	2.283225	2.106481
4	3.807729	3.629895	3.545951	3.387211	3.169865	2.854978	2.588735
5	4.713460	4.451822	4.329477	4.100197	3.790787	3.352155	2.990612
6	5.601431	5.242137	5.075692	4.766540	4.355261	3.784483	3.325510
7	6.471991	6.002055	5.786373	5.389289	4.868419	4.160420	3.604592
8	7.325481	6.732745	6.463213	5.971299	5.334926	4.487322	3.837160
9	8.162237	7.435332	7.107822	6.515232	5.759024	4.771584	4.030967
10	8.982585	8.110896	7.721735	7.023582	6.144567	5.018769	4.192472
11	9.786848	8.760477	8.306414	7.498674	6.495061	5.233712	4.327060
12	10.575341	9.385074	8.863252	7.942686	6.813692	5.420619	4.439217
13	11.348374	9.985648	9.393573	8.357651	7.103356	5.583147	4.532681
14	12.106249	10.563123	9.898641	8.745468	7.366687	5.724476	4.610567
15	12.849264	11.118387	10.379658	9.107914	7.606080	5.847370	4.675473
16	13.577709	11.652296	10.837770	9.446649	7.823709	5.954235	4.729561
17	14.291872	12.165669	11.274066	9.763223	8.021553	6.047161	4.774634
18	14.992031	12.659297	11.689587	10.059087	8.201412	6.127966	4.812195
19	15.678462	13.133939	12.085321	10.335595	8.364920	6.198231	4.843496
20	16.351433	13.590326	12.462210	10.594014	8.513564	6.259331	4.869580
21	17.011209	14.029160	12.821153	10.835527	8.648694	6.312462	4.891316
22	17.658048	14.451115	13.163003	11.061240	8.771540	6.358663	4.909430
23	18.292204	14.856842	13.488574	11.272187	8.883218	6.398837	4.924525
24	18.913926	15.246963	13.798642	11.469334	8.984744	6.433771	4.937104
25	19.523456	15.622080	14.093945	11.653583	9.077040	6.464149	4.947587
26	20.121036	15.982769	14.375185	11.825779	9.160945	6.490564	4.956323
27	20.706898	16.329586	14.643034	11.986709	9.237223	6.513534	4.963602
28	21.281272	16.663063	14.898127	12.137111	9.306567	6.533508	4.969668
29	21.844385	16.983715	15.141074	12.277674	9.369606	6.550877	4.974724
30	22.396456	17.292033	15.372451	12.409041	9.426914	6.565980	4.978936
31	22.937702	17.588494	15.592811	12.531814	9.479013	6.579113	4.982447
32	23.468335	17.873551	15.802677	12.646555	9.526376	6.590533	4.985372
33	23.988564	18.147646	16.002549	12.753790	9.569432	6.600463	4.987810
34	24.498592	18.411198	16.192904	12.854009	9.608575	6.609099	4.989842
35	24.998619	18.664613	16.374194	12.947672	9.644159	6.616607	4.991535

TABLE B-4

PRESENT VALUE OF A UNIFORM SERIES OF $1 PAYMENTS FLOWING UNIFORMLY THROUGHOUT EACH PERIOD

(Continuous Compounding)

	Annual Effective Discount Rate						
Period	2%	4%	5%	7%	10%	15%	20%
1	0.990164	0.980644	0.975997	0.966921	0.953824	0.933264	0.914136
2	1.960912	1.923570	1.905518	1.870585	1.820936	1.744798	1.675916
3	2.912627	2.830230	2.790776	2.715131	2.609220	2.450479	2.310732
4	3.845680	3.702019	3.633878	3.504427	3.325841	3.064116	2.839746
5	4.760439	4.540277	4.436833	4.242086	3.977316	3.597712	3.280591
6	5.657260	5.346294	5.201553	4.931487	4.569565	4.061709	3.647962
7	6.536497	6.121311	5.929856	5.575788	5.107974	4.465185	3.954104
8	7.398494	6.866520	6.623479	6.177937	5.597436	4.816034	4.209222
9	8.243590	7.583066	7.284072	6.740694	6.042402	5.121119	4.421821
10	9.072114	8.272053	7.913209	7.266635	6.446916	5.386411	4.598987
11	9.884394	8.934541	8.512386	7.758169	6.814656	5.617100	4.746625
12	10.680746	9.571548	9.083031	8.217546	7.148965	5.817699	4.869656
13	11.461483	10.184055	9.626503	8.646870	7.452883	5.992132	4.972183
14	12.226912	10.773004	10.144095	9.048108	7.729172	6.143814	5.057622
15	12.977332	11.339302	10.637039	9.423097	7.980343	6.275711	5.128820
16	13.713038	11.883818	11.106511	9.773553	8.208681	6.390404	5.188153
17	14.434319	12.407392	11.553626	10.101083	8.416261	6.490137	5.237597
18	15.141457	12.910828	11.979450	10.407185	8.604970	6.576861	5.278800
19	15.834729	13.394901	12.384997	10.693262	8.776523	6.652274	5.313136
20	16.514408	13.860356	12.771232	10.960624	8.932481	6.717850	5.341749
21	17.180760	14.307909	13.139075	11.210495	9.074261	6.774872	5.365593
22	17.834046	14.738248	13.489402	11.444019	9.203152	6.824457	5.385463
23	18.474522	15.152036	13.823046	11.662265	9.320325	6.867575	5.402022
24	19.102441	15.549909	14.140803	11.866234	9.426846	6.905068	5.415821
25	19.718047	15.932479	14.443428	12.056860	9.523684	6.937671	5.427320
26	20.321582	16.300335	14.731643	12.235014	9.611718	6.966021	5.436902
27	20.913283	16.654043	15.006133	12.401513	9.691749	6.990674	5.444888
28	21.493383	16.994146	15.267552	12.557120	9.764504	7.012111	5.451542
29	22.062108	17.321169	15.516522	12.702547	9.830646	7.030752	5.457088
30	22.619681	17.635613	15.753637	12.838460	9.890774	7.046961	5.461709
31	23.166321	17.937964	15.979461	12.965482	9.945436	7.061056	5.465560
32	23.702244	18.228686	16.194531	13.084194	9.995129	7.073313	5.468769
33	24.227657	18.508226	16.399360	13.195139	10.040305	7.083971	5.471443
34	24.742769	18.777015	16.594435	13.298827	10.081373	7.093238	5.473672
35	25.247780	19.035465	16.780221	13.395731	10.118708	7.101297	5.475529