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# A STUDY OF CHARACTERISTICS OF INTERCITY TRANSPORTATION SYSTEMS

# PHASE I: DEFINITION OF TRANSPORTATION COMPARISON METHODOLOGY

by


J. Morley English
Jeffrey L. Smith
Melvin W. Lifson


prepared for

NASA-Ames Research Center
and
U. S. Department of Transportation


NASA Contract No. NAS2-9814

Econergy Report No. 12-801



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# 1. INTRODUCTION

## 1.1 Need For a New Approach

Societal pressures and national policies emphasize "the protection and enhancement of the natural and human environment, the need for coordinating transportation improvement projects with related social, economic and environmental programs, and the desirability of fostering an open, informed and participatory decision-making process. These national policies have been articulated in such Federal legislation as the Department of Transportation Act of 1966 which requires:

> '...the development of national transportation policies and programs conducive to the provision of fast, safe, efficient, and convenient transportation at the lowest cost consistent therewith and with other national objectives, including the efficient utilization and conservation of the Nation's resources,'

the Federal-Aid Highway Act of 1970, which requires:

> '...that possible adverse economic, social, and environmental effects relating to any proposed project on any Federal-aid system have been fully considered in developing such projects and that the final decisions on the project are made in the best overall public interest, taking into consideration the need for fast, safe, and efficient transportation, public services, and the costs of eliminating or minimizing such adverse effects,'

and the National Environmental Policy Act of 1969, which requires:

> '...a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision-making which may have an impact on man's environment.'" (U.S. Department of Transportation, 1975.)

Furthermore, attention is becoming increasingly focused on the initial activities of the system acquisition process, on demonstrating that a choice of transportation concept or technology will achieve stated objectives, and on generally satisfying the information requirements of major decision milestones in the planning and development of major systems (OMB Circular No. A-109, 1976).

A new and innovative methodology is needed if transportation analysis and evaluation are to be responsive to these pressures and policies. The need arises as a consequence of the nature of an intercity transportation system, of the requirements for transportation decision-making, and of the state-of-the-art in transportation planning.

Intercity transportation systems are inherently large-scale, complex systems requiring long lead-time programs for their planning and acquisition. Furthermore, they have major social and economic consequences for the nation, as well as for the region they serve directly. Assessing alternative transportation concepts during the initial phases of the system life cycle, when supportive research and technology development activities are defined, requires estimates of transportation, environmental, and socio-economic impacts throughout the system life cycle -- a period of some forty or fifty years.

Decisions concerning intercity transportation concepts and technology necessarily involve the evaluation of projected time flows of consequences extending forty or fifty years into the future. Conventional discounting practices are inadequate for evaluating these long term estimates of life cycle costs and benefits. Of particular concern is the fact that benefits of an investment in transportation technology are not realized until the last twenty or thirty years of the system life cycle, and current discounting practices tend to degrade such long range values to relative insignificance. This consequence of using standard discounting methods can be incompatible with societal goals and government policies.

The increasing emphasis on satisfying the needs of defined decision situations demands an evaluation methodology that focuses on the decision, on the decision-makers, and on pertinent policies and objectives. Since objectives include environmental and socio-economic considerations, evaluating transportation decisions requires estimates of environmental and socio-economic impacts of those decisions. "Transportation alternatives should evolve from a set of explicit public and private sector goals and objectives relating to both the transportation system and to the broader community context into which the transportation system is to be integrated. A major flaw in early transportation planning processes was the extent to which transportation considerations were isolated from social, economic and environmental planning" (U.S. Department of Transportation, 1975). Decision-making at the national level must be responsive to complex value systems representing transportation, environmental, societal, and economic policies and objectives.

Unfortunately, current planning technology has neither the analysis models nor the data base for adequately dealing with:

- the complexity of intercity transportation systems
- the complexity of the interactions between a transportation system and the environments in which it is embedded
- definition and application of the complex value systems that underlie transportation decision-making
- a long term planning period

Present forecasting methods are based on extrapolation of historical trends and are rarely considered valid for more than a few years (e.g., Martino, 1972). More sophisticated prediction techniques (e.g., Saaty, 1977) are becoming available. Deficient data bases, however, prevent adequate validation of the models designed to deal with the complexities of a transportation system and its impacts.

As a result of pressures on the transportation analyst to use "hard" data and validated or, at least, reasonably well known models, there is a tendency to limit transportation studies to traffic and cost analyses and to avoid the problems of long range predictions, discounting, and degree of achievement of agency policies and objectives. Study outputs are frequently, therefore, not compatible with the information needs of transportation decision-making.

What is needed is a methodological approach that focuses on the decision to be made and its information requirements. The decision situation, including the policies and objectives of the decision-makers and their organization, can provide explicit guidance for planning the transportation study and its information outputs. The advantages of a decision-oriented methodology include:

- identification of the information elements needed by the decision-makers
- selection of the best available data and models for estimating needed information elements
- identification of gaps and deficiencies in data bases and modeling capabilities so that transportation planning tools and techniques can be improved within an organizing framework

A decision-oriented methodology for the analysis and evaluation of intercity modal concepts is presented and illustrated in this report.

## 1.2 Objectives

The objectives of the ECONERGY study are:

- to develop a unified methodological framework for the comparison of intercity passenger and freight transportation systems
- to review the attributes of existing and future transportation systems for the purpose of establishing measures of comparison

These objectives have been achieved and, in addition, were made more specific to include:

- development of a methodology for comparing long term transportation trends arising from implementation of various R&D programs
- definition of value functions and attribute weightings needed for comparing alternative policy actions for furthering transportation goals

It was not an objective of the Phase I study to implement the methodology beyond an illustrative example. While as much realism as possible and actual data, where readily available, were utilized, the conclusions concerning transporation alternatives are, nevertheless, only illustrative.

## 1.3 Scope

During the present study, the decision-oriented methodology was adapted to needs of:

- decision-makers in an agency of the Executive Branch of the U.S. Government
- decisions concerning intercity transportation technologies and modal concepts during the initial concept phase of the system life cycle

This Phase I effort focused on the evaluation framework of the comparison methodology. An evaluation model was developed and its application in guiding the planning of transportation analysis activities, as well as in the evaluation of intercity transportation alternatives, was illustrated. The analysis and evaluation of intercity transportation alternatives for an actual decision situation will be a follow-on Phase II effort.

## 1.4 Organization of Report

The reader may be guided in his reading of this report by knowing, in advance, some of the things to look for. In Chapter 2, the theoretical principles which underly the ECONERGY methodology are established. The basic structure of the decision problem is exemplified by Figures 2.1 and 2.2. The basic building blocks are synthesis of alternative transportation systems, analysis of these systems, and finally evaluation. Chapters 3, 4, 5 and 6 specifically address these separate aspects of the methodology.

The theoretical development in each chapter is treated first but, in order to relate this development with its practice, a hypothetical example case is used for illustration. The case chosen was that of the Los Angeles-San Francisco corridor. The formulation of the case was predicated on a long-term projection of the U.S. GNP, the proportionate share of economic activity attributable to the counties of the California corridor, physical constraints on expansion of various modes, and other attributes of the regional system. Because of the largely hypothetical nature of the illustration, detailed discussion of how the various parameters and variables were obtained was not considered relevent. However, the data on which the case was structured were reasonably accurate although incomplete. Some assumed values were merely based on reasonable judgments.

As the development of the methodology proceeds through Chapters 3, 4, 5 and 6, more and more emphasis is placed on the example case until in Chapter 7 where the major discussion is related to the example. Appendices A, B and C provide back up material and amplifications of the case.

In order to develop a sound background, a number of other transportation related questions had to be examined. Some very important theoretical issues had to be studied in depth. However, it was deemed advisable to follow the logic of the methodology without interspersing other concepts. Therefore, these basic background questions were addressed in Appendix D. Two very important issues raised in Appendix D should be considered in depth because of their importance to the methodology. These are:

- The need for a long-term perspective and the formulation of transportation aspirations.
- The question of the underlying concept of discounting as an important factor in relative-worth evaluation of all performance criteria.

## 2. TECHNICAL APPROACH

### 2.1 Decision Orientation

The primary purpose underlying comparison of intercity transportation systems is to provide information for *decision-making* in transportation planning, design, and management. The comparison methodology is focused, therefore, on the decision to be made and on the implied information requirements.

The development of a methodological framework for the evaluation of alternative intercity transportation concepts has been guided by the following decision-making requirements as listed on page 6 of the ECONERGY proposal for this contract:

- it is desirable to be able to review, discuss and communicate the bases for major decisions concerning the selection of intercity transportation modal concepts
- evaluation of alternatives should be consistent from alternative to alternative
- evaluation of alternatives should be compatible with stated policies and objectives of the responsible agency

The comparison methodology developed by ECONERGY is adaptable to changing technologies and changing priorities. In particular, the methodology permits current attitudes towards federal intercity transportation decision-making to be reflected. These attitudes were abstracted from the following federal documents:

(1) The comparison methodology is designed to assure compliance with policy statements of OMB Circular No. A-109 (1976) that federal agencies, when acquiring major systems:

- will express needs and program objectives in mission terms and not in equipment terms
- will place emphasis on the initial activities of the system acquisition process to allow competitive exploration of alternative system design concepts in response to mission needs

- should ensure appropriate trade-offs among investment costs, ownership costs, schedules and performance characteristics

(2) The comparison criteria are derived from DOT policy and RD&D management objectives (DOT, 1972; OSTIS, June 1977) to assure compatibility with DOT policies, goals and objectives.

(3) The evaluation framework represents explicit implementation of Step 2 of Task A of the Transportation Planning Process defined in DOT (1975, pp. 19-27).

In addition, display techniques incorporated in the ECONERGY methodology demonstrate a capability to highlight:

- strengths and weaknesses of each candidate alternative with respect to the defined comparison criteria
- an aggregated relative score for each alternative that is compatible with selected weighting functions which represent explicit trade-off relationships
- sensitivity of aggregated relative scores to changes in transportation system descriptors, relative worth functions and weighting functions

## 2.2 Methodological Framework

Every decision involves, either explicitly or implicitly, the activities indicated in Figure 2.1 (Lifson, 1972).

*Synthesis of Alternatives*

A decision implies a set of alternatives from which the decision-maker chooses an alternative to be implemented. (Decision-maker, as used here, means a person or set of people.) There must, therefore, be some activity that synthesizes and describes this set of alternatives.

An alternative transportation system is defined as a set or portfolio of intermodal systems (i.e., highway, fixed guideway, air, etc.,) that are combined to satisfy specified transportation goals and objectives.

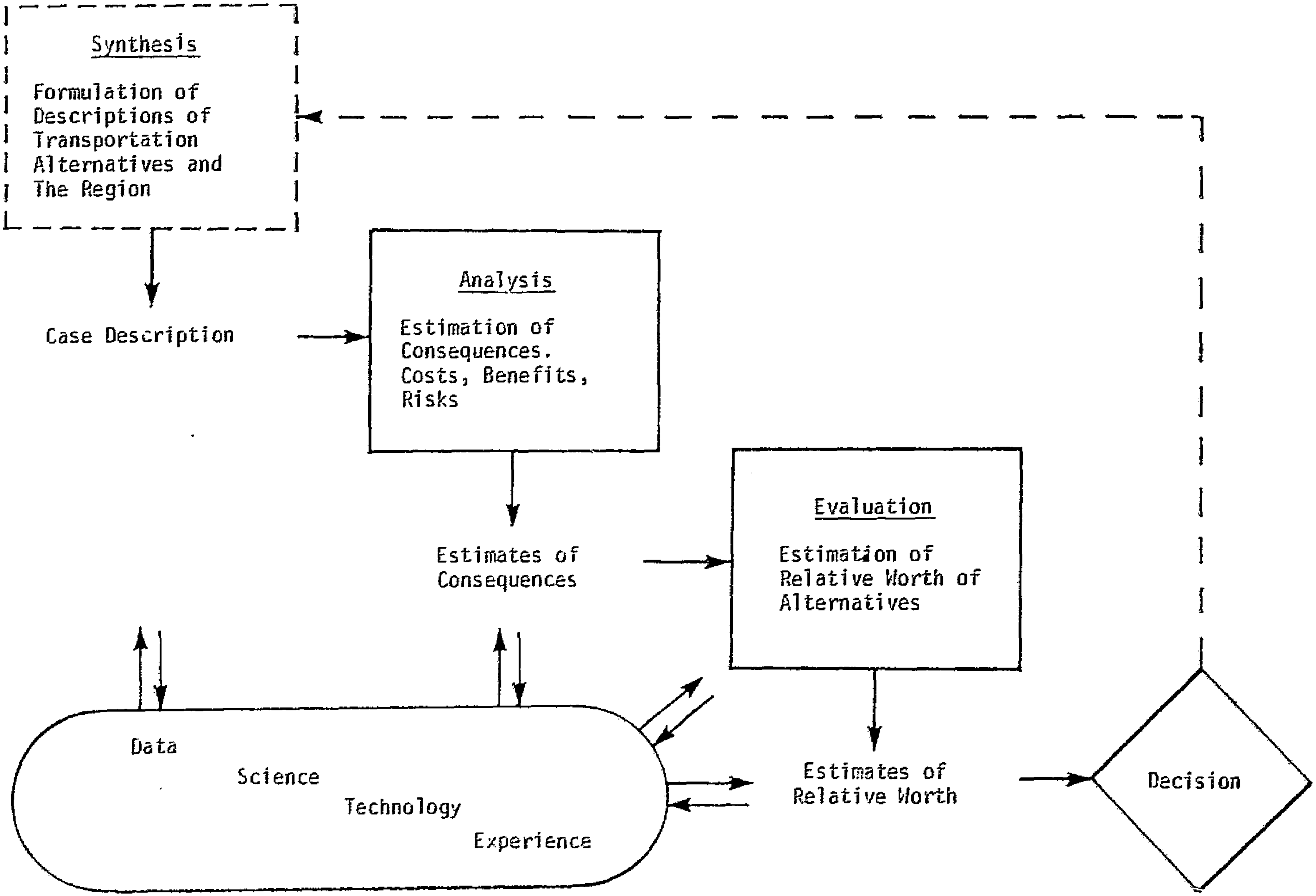



Figure 2.1 - Information Processing for Decision-Making

The question is not whether one mode alone is better than another but rather which combination of modes best satisfies a societal aspiration for future transportation, with today's system as the given initial configuration from which all projected alternatives must flow.

*Analysis*

A decision-maker has some beliefs concerning the consequences associated with each alternative. The process by which estimates of such consequences are made is here defined as *analysis*.

Consequences of a decision are, in general, multidimensional. A decision concerning transportation systems, for example, can affect travel times, costs, land values, demography of the area, the physical environment, health, etc. The set of these consequences are defined as the *comparison criteria*. Dimensions of the comparison criteria are measured in physical or economic units such as kilometers (miles) per hour, number of passengers, dollars, etc.

Analysis, therefore, requires knowledge of the physical, economic, social, and political relationships associated with transportation systems and the environments in which they are embedded. The consequences to be estimated are inherently in the future (where future is relative to the time of the decision) and are therefore uncertain.

*Evaluation*

The identification of the best alternative depends not only on estimated consequences but also on what the decision-maker considers important and desirable. When a choice is made, the decision-maker has rated the alternatives by applying a value system (or set of value systems) to the estimates of consequences. The selected alternative measures highest on some scale of relative worth that represents this value system. *Evaluation is here defined as the transformation of the multidimensional uncertain estimates of consequences to a measure* *of relative worth.* Evaluation requires knowledge of the value system(s) to be used in making the specified decision; quantification of the evaluation activity requires a quantitative model of the appropriate value system(s) - an *evaluation model.*

Figure 2.1 illustrates how synthesis, analysis, evaluation and the decision are influenced by the available data base, science and technology, and by the background and experience of the people involved. In addition, the process represented has iterations and feedback loops, only one of which is shown, i.e., the use of the information obtained from synthesis, analysis, and evaluation to formulate additional (better) alternatives.

Each of the decision-making requirements on the decision process of Figure 2.1 implies not only that the physical, economic and social systems should be quantitatively modeled for *analysis,* but also that it is important for the appropriate value system itself to be modeled so as to meet the objectives of communication, consistency and compatability.

Furthermore, the evaluation relationships and their required input data (estimates of the comparison criteria) define the outputs needed from analysis and how such outputs are to be processed. An explicit quantitative representation of the evaluation activity (the evaluation model), therefore, provides unambiguous guidelines for planning and managing the analysis activity. The evaluation model is, therefore, a critical element in the comparison methodology.

Estimation of the significant effects of a candidate transportation system requires analysis not only of the system itself but also of its interrelated effects on other socio-economic and environmental systems. Mutually interactive effects of transportation with the physical environment (through, for example, noise and air pollution) and with the socio-economic environment (through, for example, land use, demography and urban development) must be dealt with explicitly and quantitatively.

The synthesis and analysis, as well as the evaluation of transportation modal systems, involve many variables besides the comparison criteria. Environmental, demographic, and demand factors are specified in a scenario defining the conditions in which the alternative transportation modes would be embedded. System descriptors are the result of the synthesis activity and are needed to identify a transportation modal system in sufficient detail to permit meaningful analysis. Analysis introduces intermediate computational variables for computing the output variables of the analysis framework, i.e., the comparison criteria. Evaluation identifies elements of value systems other than the comparison criteria. Not only are these elements identified and defined, but they are also classified according to their roles in the decision process.

Management has no choice as to whether the activities identified in Figure 2.1 will be performed in a given decision situation. One way or another, synthesis, analysis and evaluation will be performed, in that sequence, in order to generate the information on which the decision is based.

Management does, however, have options concerning:

(1) the type of information to be explicitly generated
(2) the models to be used for analysis and evaluation
(3) the sources of needed data
(4) the physical, financial and personnel resources to be assigned to synthesis, analysis and evaluation
(5) the timing of the development of the synthesis, analysis and evaluation capabilities

The decision-oriented problem-solving methodology of Figure 2.2 presents a sequence of activities designed to provide maximum guidance for determining the five options above.

In general, management recognizes that, in order to achieve its goals and objectives, decisions must be made and resources must be allocated

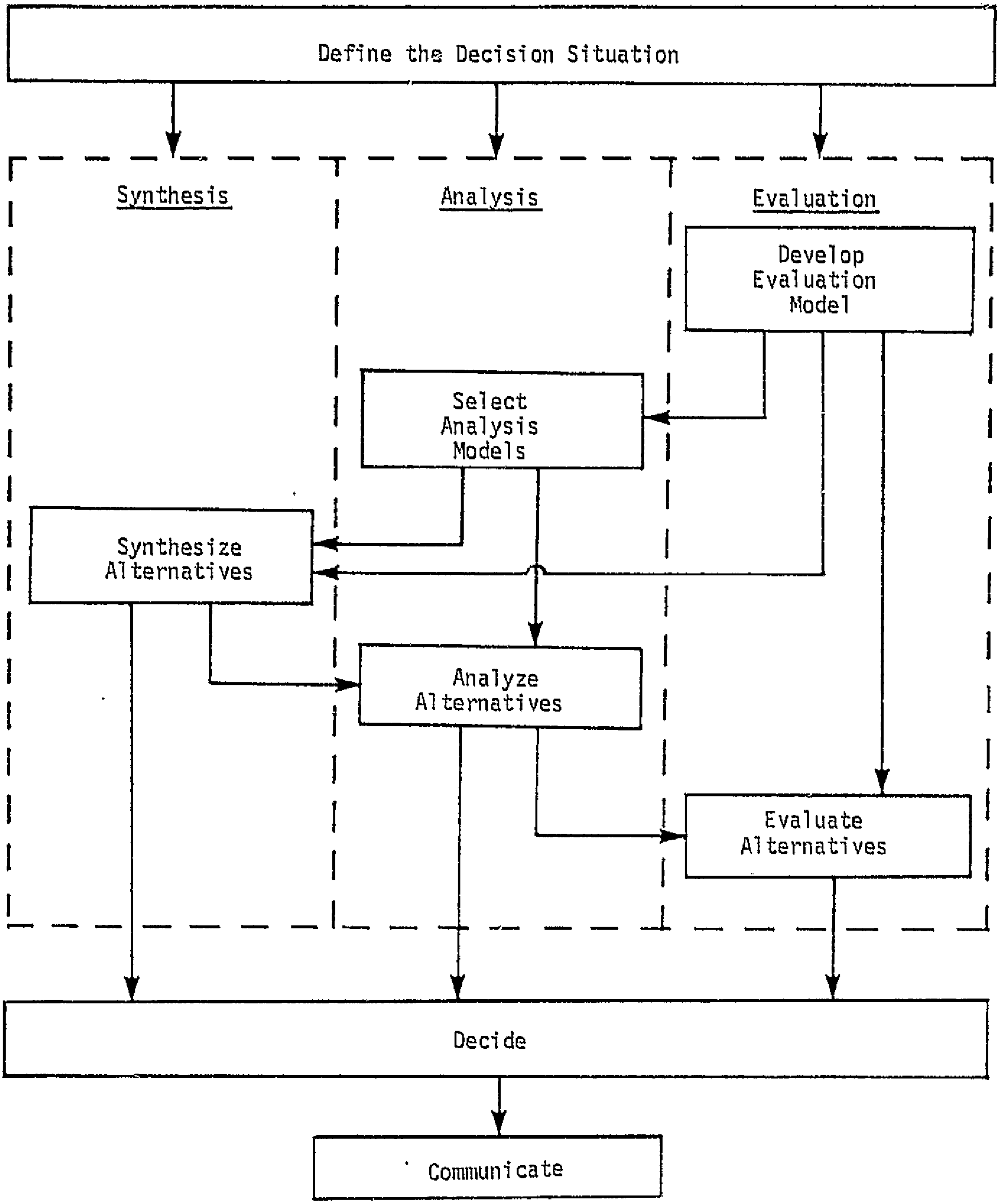



Figure 2.2 - The Decision-Oriented Problem Solving Process
(The Decision Process)

to activities that provide information to support these decisions. It is assumed that an understanding of the goals and objectives motivating these decisions is important not only for effective management of decision-related activities but also for effective performance of component technical tasks. Definition of the decision situation and development of the evaluation model that identifies and interprets these goals and objectives are, therefore, initial activities of the decision process.

Since the inputs to evaluation are the outputs from analysis (Figures 2.1 and 2.2), development of the evaluation model defines the output expected of the analysis activity. Data items needed by evaluation and not supplied are deficiencies of synthesis and analysis; information items supplied and not needed for evaluation are superfluous. Both deficiencies and excesses of information are costly. To assure compatability of analysis outputs with evaluation data requirements, the evaluation model should be developed prior to planning the analysis activity as indicated in Figure 2.2

The models selected for analysis define, in turn, the analytical data requirements. Sources of such data include organization records, libraries, government agencies, surveys and tests, technical societies, journals and the synthesis activity. The output of synthesis is defined, at least in part, by analysis; alternatives should be described in a manner that permits efficient analysis. The selection of analysis models should, therefore, precede synthesis. When a cost analysis is to be performed, for example, the drawings and descriptions of alternatives should include information needed not only to produce each alternative but also to estimate its cost.

The foregoing considerations dictate that the sequence in which models are developed is the reverse of the order in which they are applied. This principle is incorporated in the decision-oriented approach to problem-solving of Figure 2.2. Its application is discussed and illustrated in Chapters 3, 4, and 5.

Analysis and evaluation for decision-making do not fit the mold of a scientific research task. Uncertainties concerning priorities abound; useful data are limited; identification of key issues is frequently difficult; and topics important for the decision to be made cannot be ignored simply because they cannot be treated in a manner consistent with good research requirements or because pertinent hard, objective data are unavailable. It must be emphasized that judgment and uncertainty cannot be èliminated from synthesis, analysis or evaluation of alternative intercity modal concepts nor from the decision concerning the modes to be supported through Federal funding.

The methodological framework recognizes the foregoing decision-making facts of life; it incorporates provisions for focusing judgment on key decision elements, for displaying judgmental elements to permit review and discussion, and for assuring consistent application of judgmental elements in the evaluation of transportation alternatives.

## 2.3 Long Range Planning Requirements

The alternatives to be evaluated and compared are necessarily long term when advanced or new technologies are included and when long lead times are needed to develop them into viable components of the total transportation system. However, since it is impossible to predict what will occur over a very long term future, such as 50 years, it is useful to describe an *aspiration* for a future economy which will, in turn, provide a basis for establishing a corresponding *aspiration* for future transportation needs. The physical realizability of achieving an aspiration level for passenger and freight traffic can be tested by examination of technical, economic and social constraints. With an aspiration defined, the kinds of developments which must take place to achieve the aspiration will determine the growth path of the system from the present to the hypothesized future.

The concept of a *planning horizon* serves to illustrate the nature of the long term future associated with transportation system development. The concept has been drawn from an analogy of the physical horizon pertaining to the curvature of the earth, where the horizon represents the limit of visibility. As used in practice, the planning horizon often connotes the limit of futurity beyond which no values are considered. However, as in the case of terrestrial navigation, planning for future decisions must extend beyond the horizon. The horizon then, in the planning sense, should be the limit of visibility for decisions needed to implement new transportation trends. Because the long term future associated with transportation systems extends well beyond the planning horizon, it is recognized that current decisions must anticipate the kinds of decisions which will be needed beyond the horizon.

The value system described in Section 2.2 applies to current time. In order for the methodology to relate future values to the present perception of these values, the concept of discounting is used. This discounting procedure is applicable in principle to all measures of worth--social, environmental, etc., as well as economic--over the entire planning period.

# 3. THE DECISION SITUATION

## 3.1 Decision and Decision-Makers

The primary objective of the Phase I Study was "to develop a unified framework for the comparison of intercity passenger and freight transportation systems." The Study was "to establish a consistent, uniform framework whereby any set of modal transportation systems may be evaluated in the context of a defined decision situation" (ECONERGY proposal, 1977).

The methodological framework discussed in Chapter 2 is generally applicable for providing information in support of a large class of decisions, i.e., major decision milestones in a program or project. The general methodology has been adapted to the needs of a particular decision milestone (choice of alternative system concept) concerning a particular type of system (intercity transportation). The decision for which the methodology has been particularized involves:

1. A long-range planning period - 50 years is considered appropriate to include planning, design and development, construction and operation of an intercity transportation system.
2. A broad geographic region - a region comprised of an intercity corridor, urban centers, and a non-urban, non-corridor area.
3. Consideration of significant social and economic (including demographic and environmental) effects.
4. Identification of future needs, expressed not only in terms of travel demands but also in terms of housing, recreation, and other community quality objectives. A key element of the methodology is the specifying of aspiration levels for transportation, for societal and for economic factors and using these aspirations as explicit guidelines for the transportation planning and design activities.
5. Evaluation of a multi-mode transportation system as opposed to single-mode evaluation. The alternatives include most or all modes but with varied modal splits.

6. Identification of long-term transportation investment and improvement priorities and implementation schedules that reflect those priorities.

The decision that the comparions methodology is designed to support is:

The selection of the "best" intercity modal transportation concept for support by the Federal government, where support may be either through direct financial aid ~~or through R&D funding of promising technologies~~. [The use of the comparison methodology for evaluating R&D allocations was neither required by the RFP nor specified in the Proposal; the evaluation of R&D for intercity transportation is, however, naturally accommodated within the methodological framework (see Chapter 7 ).]

To illustrate the application of the methodology, a particular intercity region (Los Angeles-San Francisco) is selected. A case description for this region is discussed in Chapter 6. For purposes of this illustrative example, it is assumed that NASA and DOT policy is to improve intercity transportation in the United States. In support of this policy, NASA and DOT wish to identify the most promising modal concepts to be supported by R&D funding and to motivate appropriate decision-making at the state and local levels. [An actual assessment of intercity transportation for the nation (Phase II of the Study) would involve the selection of various representative intercity regions and analyzing and evaluating alternatives in each region.]

## 3.2 Evaluation Framework

The evaluation framework is designed for decision-makers in agencies of the Executive Branch of the Federal government. Policies and objectives specified by OMB (1976) and DOT (OSTIS, 1977) are the primary guidelines used to identify the comparison criteria appropriate for the evaluation of alternative intercity modal concepts.

In compliance with the purposes and constraints of the Phase I Study, the evaluation framework and its use are illustrated by a numerical example (Chapter 4).

### 3.3 The Analysis Framework

The time and budget of the Phase I Study precluded utilizing available mathematical models or structured judmental techniques for estimating outcomes associated with alternative intercity transportation systems. The analysis framework is described, however, and illustrative outputs are presented for the selected numerical example (Chapter 5).

## 4. THE EVALUATION FRAMEWORK

Management requirements for decision-oriented evaluation (Section 2.1) imply not only that physical and socio-economic systems be modeled for *analysis* (the estimation of outcomes) but also that the appropriate *value system* be modeled for purposes of communication, consistency, and compatibility. Furthermore, having a model of the value system to be used in evaluating alternatives explicitly defines the outputs required of analysis and, hence, guides the identification of models to provide such outputs. As a consequence, the ECONERGY Phase I effort was focused on modeling the appropriate value system for the evaluation of alternative intercity transportation modal concepts.

The evaluation model should:

- Identify and define the *decision criteria*, the "specific, quantifiable variables...suitable for comparison of alternative intercity passenger-freight transportation systems." (NASA-Ames RFP, June, 1977).
- Display how the decision criteria are derived from and relate to "those general and conceptual measures of transportation and service which will appropriately portray the overall economic and technical characteristics of any transportation system." (NASA-Ames RFP, June, 1977).
- Present quantitative weighting relationships to be used in transforming estimates of consequences, measured in physical or economic units, into relative worth.
- Combine weighting relationships of the individual criteria into an objective function for computing the relative worth of each transportation alternative. The objective function will provide the "uniform means of...comparing the attributes of the different modal systems." (NASA-Ames RFP, June, 1977).

### 4.1 The Hierarchy of Values

Available theory does not provide explicit guidance for selection of an appropriate set of decision criteria. There is no generally accepted, objective, automatically applicable procedure for identifying a set of criteria which contain all significant criteria that are relevant to the decision to be made. The formulation of the set of criteria is primarily judgmental. (In terms of the ECONERGY comparison methodology, the term "comparison criteria" is used in place of the term "decision criteria".)

The technique that has become established as the most useful approach to guiding judment in identification of a set of criteria is the *hierarchy of values* or relevance tree (Fischer, 1970; Keeney and Raiffa, 1976; Lifson, 1972). The usefulness of this technique derives from the observation that goals and objectives can be analyzed to define general factors influencing their achievement. These factors can be similarly analyzed to yield subfactors. The process is continued until an appropriate set of comparison criteria is identified. The hierarchy developed for the evaluation of alternative intercity modal transportation systems is presented in Figure 4.1. Its development is discussed below.

ECONERGY has assumed that the evaluation of intercity transportation modal systems for decision-makers in the Federal government should be responsive to and compatible with policies and objectives of the U.S. Department of Transportation. The starting point for the hierarchy of values is, therefore, Department of Transportation policy and RD&D management objectives (Office of the Secretary of Transportation Systems, 1977, Section V). Three major classes of effects are identified:

- Transportation
- Economic
- Societal

In addition, DOT policy and RD&D management objectives are specified (Figure 4.2). These were reviewed to identify the objectives that would be appropriate for evaluating intercity transportation alternatives.

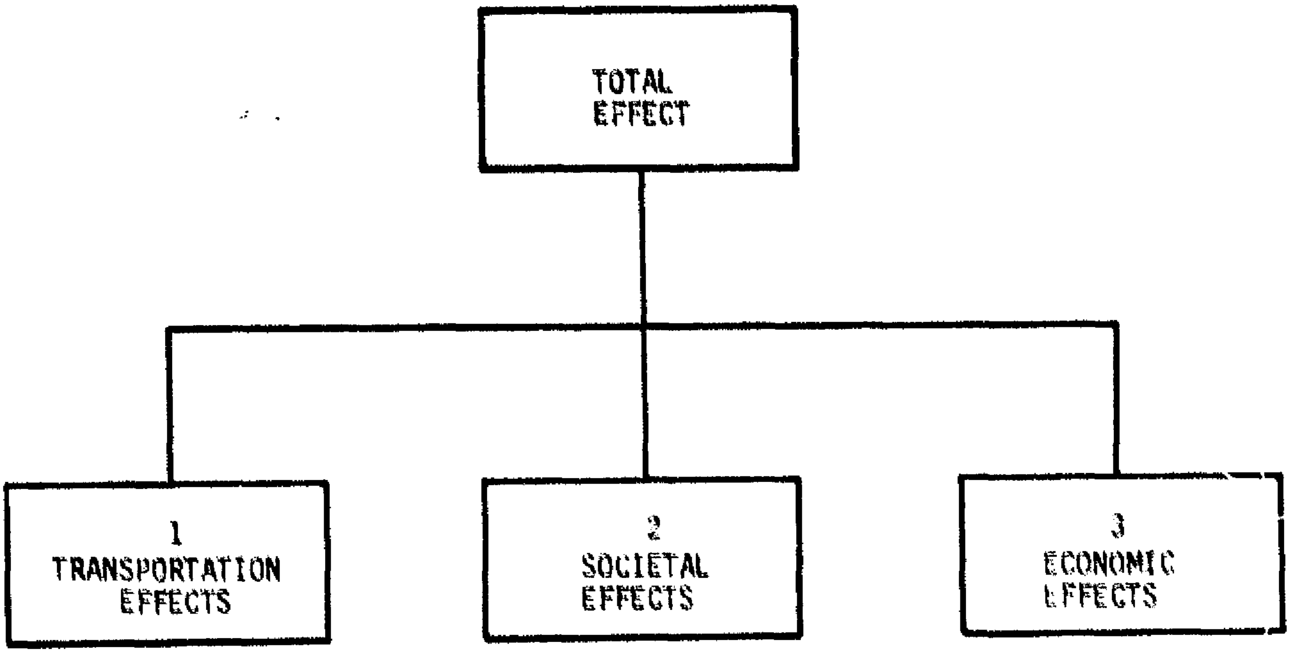



Figure 4.1a - Hierarchy of Values (Top Level)

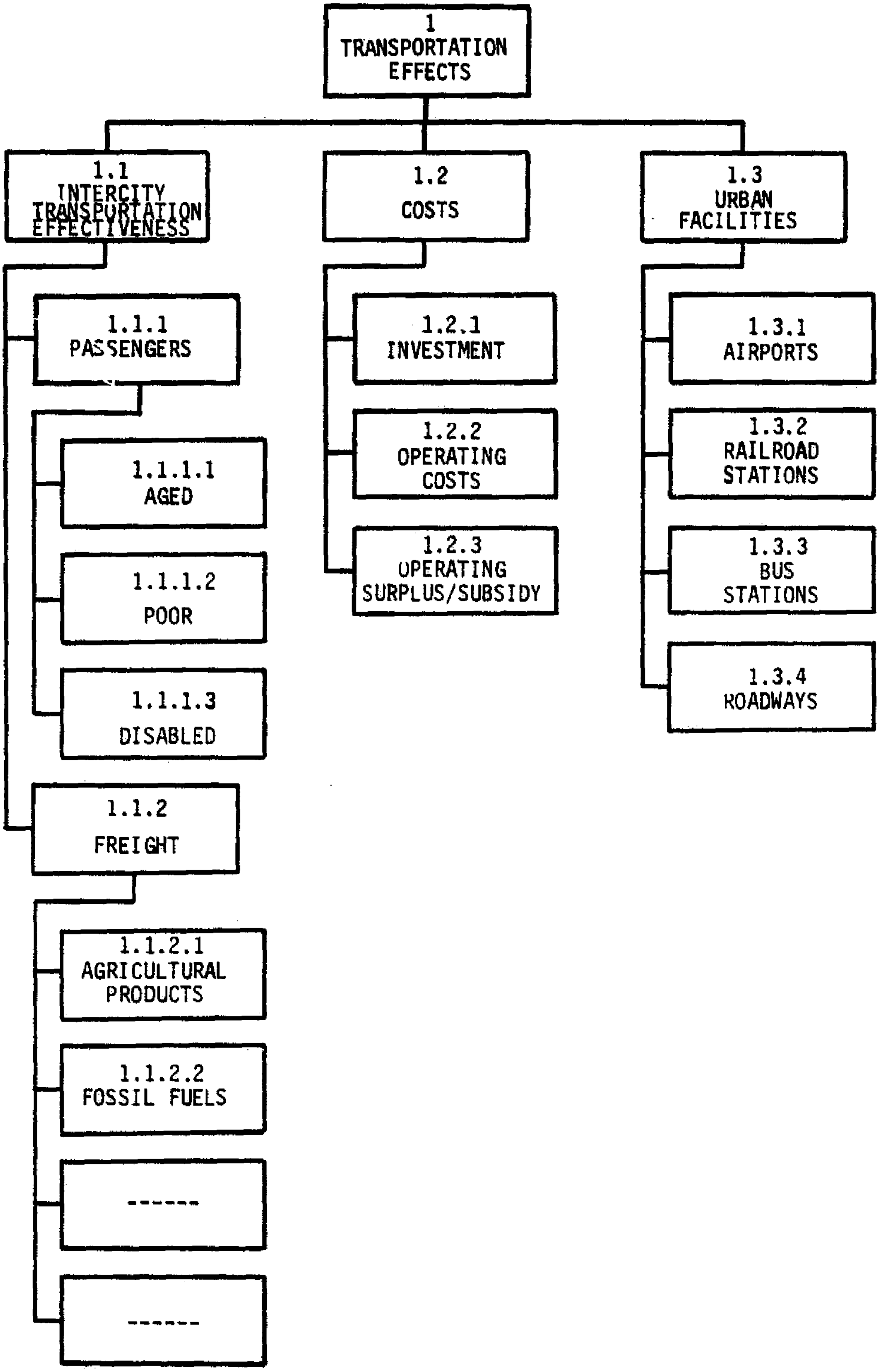



Figure 4.1b - Hierarchy of Values (Transportation Effects)

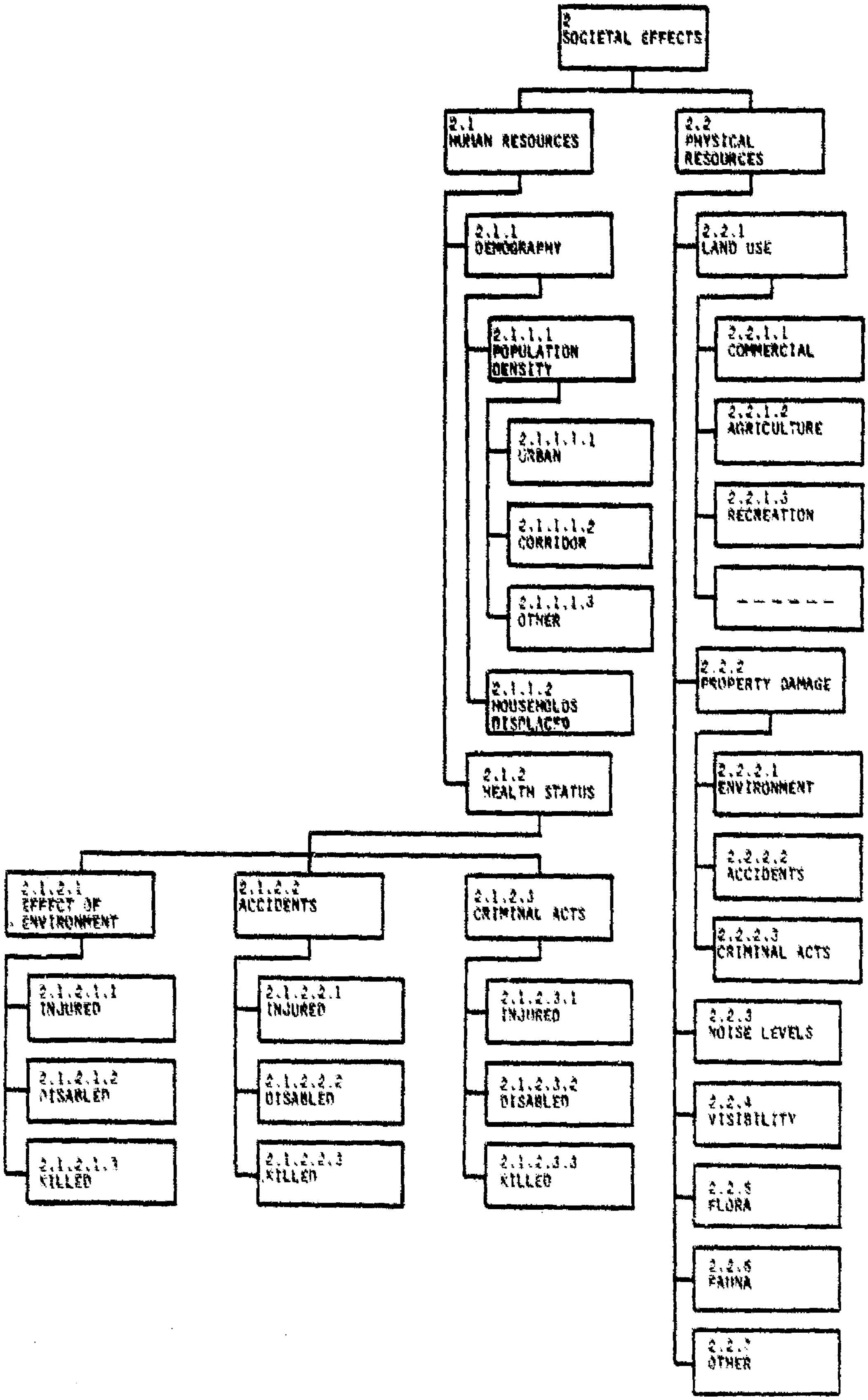



Figure 4.1c - Hierarchy of Values (Societal Effects)

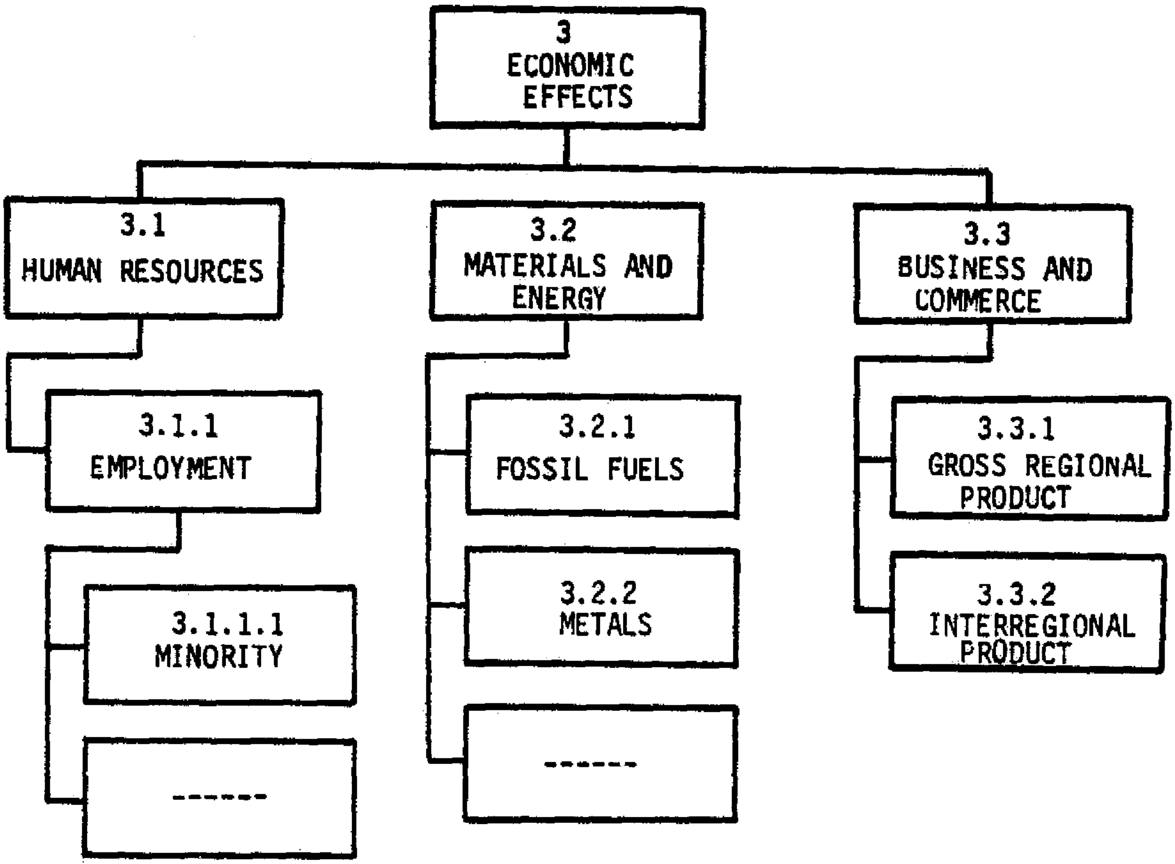



Figure 4.1d - Hierarchy of Values (Economic Effects)

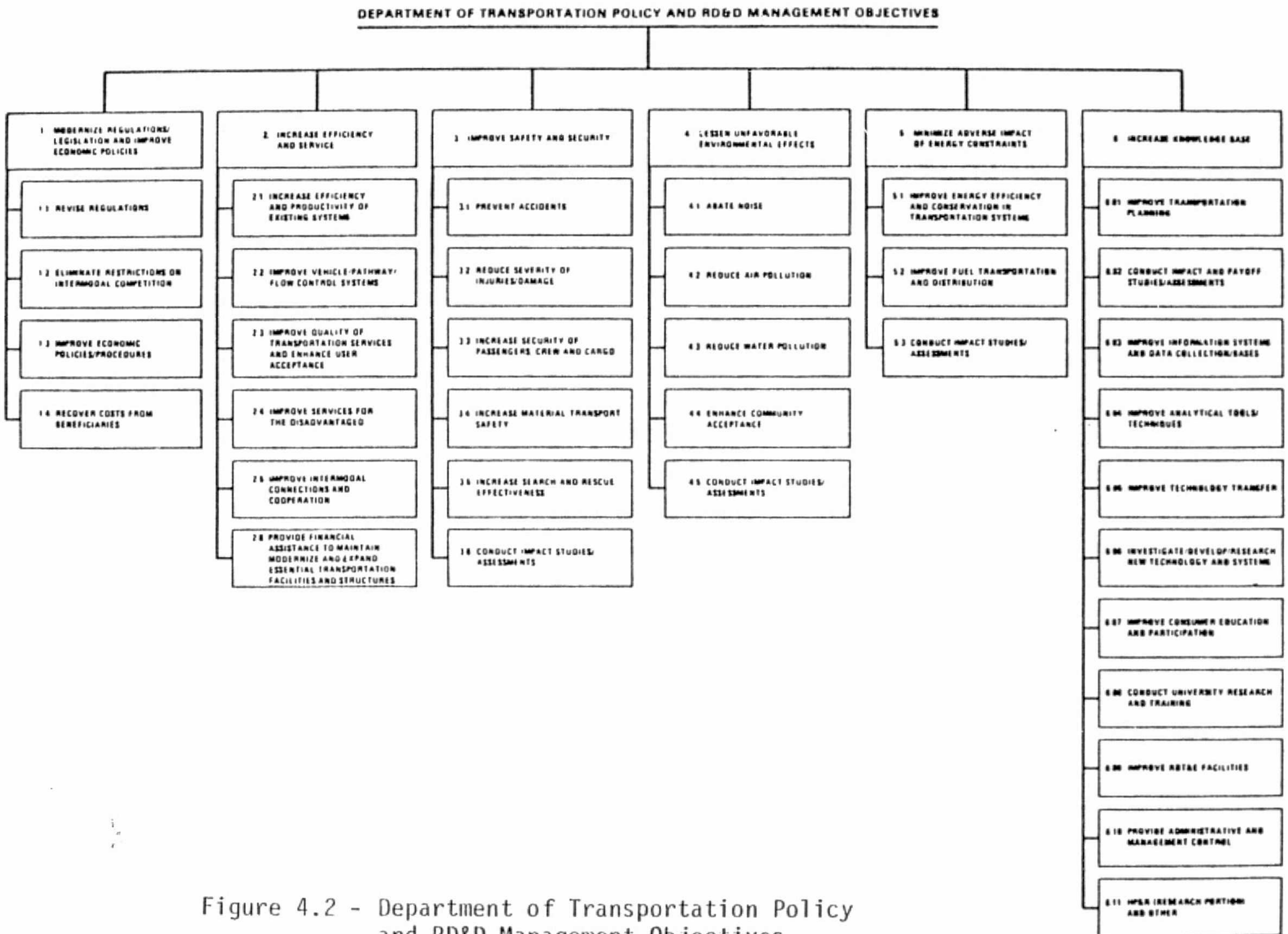



Figure 4.2 - Department of Transportation Policy and RD&D Management Objectives



(Reference: Office of Secretary of Transportation Information Systems, 1977)

1. *Modernize regulations/legislation and improve economic policies.* The only member of this set of objectives that is pertinent to the evaluation of intercity transportation modes is Item 1.4, Recover Costs from Beneficiaries. The implication is that the amount of subsidy for each alternative should be a comparison criterion.

2. *Increase efficiency and service.* Most members of this set of objectives deal with either the management of operating systems, financial assistance to transportation, or intermodal cooperation and, hence, are not elements of a hierarchy developed for the evaluation of intercity modal alternatives. This set does, however, specify that:
   - Operating and acquisition costs should be minimized
   - Transportation service should be improved for the disadvantaged

   These factors are incorporated into the ECONERGY hierarchy of values.

3. *Improve safety and security.* The intent of this set of objectives is incorporated into the Hierarchy by including the effects of accidents and criminal actions on people (measured by health status) and on property (measured by property damage in dollars).

4. *Lessen unfavorable environmental effects.* The intent of this set of objectives is incorporated into the hierarchy through elements measuring the effects of atmospheric, water and ground pollution through measures of:
   - Noise level
   - Visibility
   - Health status
   - Impact on flora and fauna.

   In addition, this set specifies that dislocation of homes and business, population shifts and land use are significant consequences of transportation alternatives. These, as well as provisions for other elements appropriate for consideration in the Environmental Impact Statement of a particular decision situation, are included in the hierarchy.

5. *Minimize adverse impact of energy constraints.* The hierarchy provides for a set of comparison criteria that would permit the evaluation of intercity transportation alternatives with respect to the consumption of scarce resources (materials and energy). As conditions change and priorities shift, the hierarchy can be adapted to the needs of each decision situation.

6. *Increase knowledge base.* This set of objectives does not provide criteria for the evaluation of transportation alternatives. The methodological framework presented in this report does, however, contribute significantly to the achievement of these objectives by:
   - Providing a management decision-oriented problem-solving framework adapted to major decisions concerned with transportation system alternatives
   - Developing an explicit, quantitative evaluation model based on agency policies and objectives
   - Identifying the strengths and weaknesses in available data bases and analysis modeling capabilities

The guidance provided by DOT policy and RD&D management objectives was augmented by review of available transportation studies which are included in the References.

Figure 4.1 represents a hierarchy adaptable to the class of decisions defined in Chapter 3. For a particular decision situation, some branches may require additional partitioning and some may need to be pruned. For example, under Intercity Transportation Effectiveness (1.1), various categories of passengers are shown in order to reflect DOT interest in transportation "for the poor, handicapped and elderly" (OSTIS, 1977, p. V-7). Some or all of these categories may not be pertinent to the evaluation of some intercity transportation links.

Similarly, categories of freight appropriate for some situations may be different from those depicted; or overall quantity of freight carried, rather than the quantitites of specified categories, may be the criterion. On the other hand, because of the profusion of potential environmental criteria, only the general classes, Flora 2.2.5, Fauna 2.2.6, and Other 2.2.7 are shown in Figure 9.1. These general classes would be partitioned to identify environmental criteria pertinent to specific decision situations.

The adaptation of Figure 4.1 to the illustrative numerical example (Figure 4.3) is sufficiently detailed to exercise all major segments of the more general hierarchy of Figure 4.1. Elements of the hierarchy are discussed below.

The transportation impacts of an example alternative case are measured under *Transportation Effects (1)* by three categories of criteria: *Intercity Transportation Effectiveness (1.1)*, *Costs (1.2)*, and *Urban Facilities (1.3)*. Effectiveness in achieving the primary mission of a transportation system -- transportation of people and goods -- is measured by two comparison criteria: *Passengers (1.1.1)* and *Freight (1.1.2)*. Both Passengers and Freight, in this illustrative example, are defined to include people and goods, respectively, carried by the intercity system. In those decision situations where it is deemed appropriate to evaluate alternatives with respect to ridership of "the poor, handicapped and elderly" or with respect to various classes of freight to be carried, Passengers or Freight may be partitioned as indicated in Figure 4.1.

The flow of funds into or out of the intercity transportation system is measured under *Costs (1.2)* by three criteria: *Investment (1.2.1)*, *Oper-*

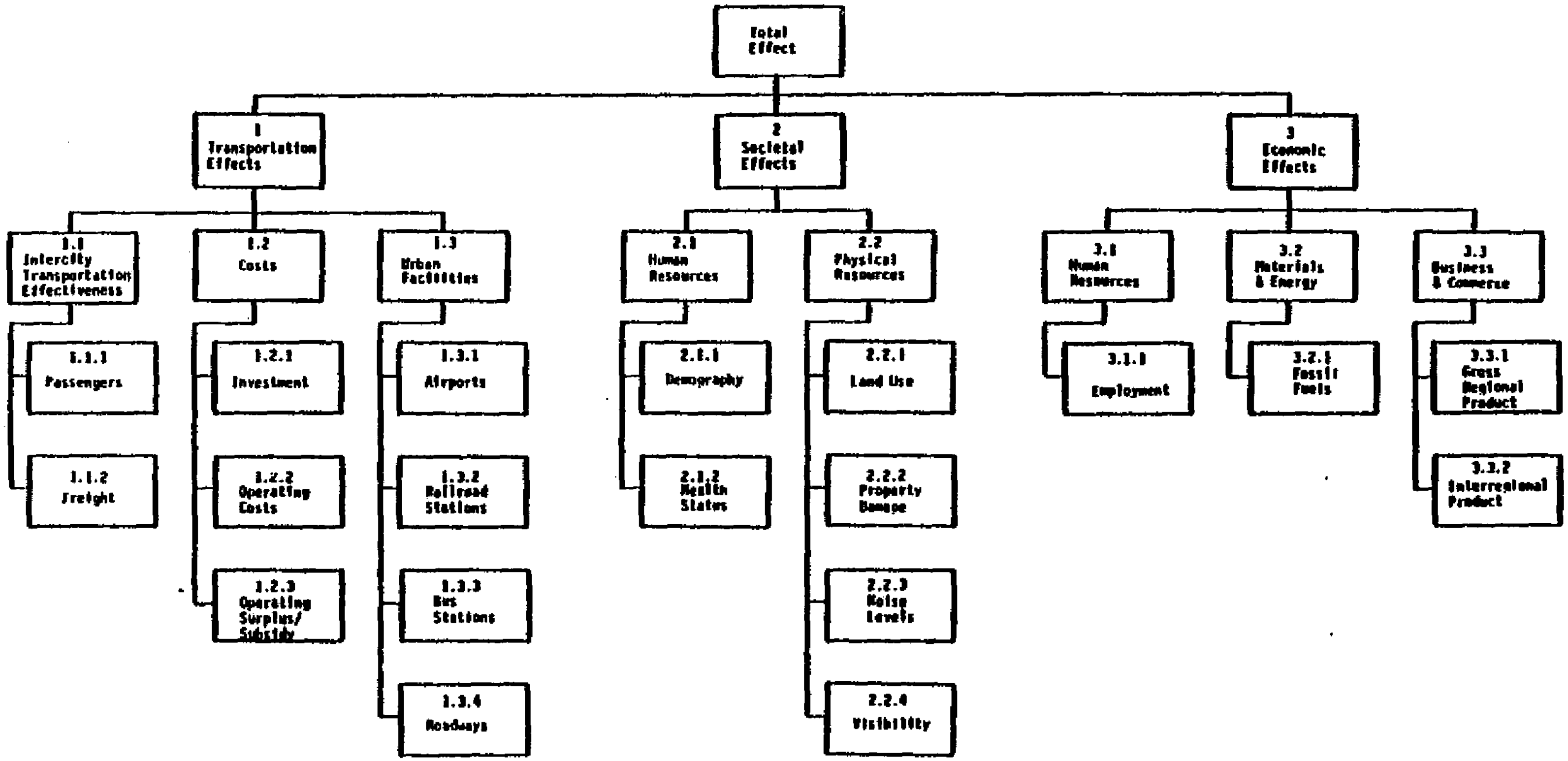



Figure 4.3 - Hierarchy of Values (Illustrative Example)

*ating Costs (1.2.2)*, and *Operating Surplus/Subsidy (1.2.3)*. Investment and Operating Costs are the estimated necessary flows of dollars into the transportation system. Operating Surplus depends on fare structure and ridership and may be either an additional dollar flow into the transportation system, Subsidy, or a return from the system, through Operating Surplus, of some or all of the Investment and Operating Costs.

The urban interface between the intercity transportation system and other transportation systems is represented by *Urban Facilities (1.3)*. Both under-utilization of and excessive demands on urban facilities are represented by *Airports (1.3.1)*, *Railroad Stations (1.3.2)*, *Bus Stations (1.3.3)* and *Roadways (13.4)*.

*Societal Effects (2)* are measured by effects on *Human Resources (2.1)* and on *Physical Resources (2.2)*. *Human Resources (2.1)* is measured by the distribution of people, *Demography (2.1.1)*, and by their *Health Status (2.1.2)*. Demography could be partitioned into population densities of various geographical areas within the defined region and households displaced (Figure 4.1). For purposes of the illustrative example, however, Demography is represented by a population density criterion that measures population shifts into or out of the urban centers. The health impacts of environmental pollution, accidents, and criminal acts could be evaluated separately as indicated on Figure 4.1. Also, various health indices are available for measuring health status (e.g., Berg, 1973; Fanshel and Bush, 1970). For the illustrative example, however, the health effects of environmental pollution, accidents, and criminal acts are all included under Health Status (2.1.2), and impact on health status *per se* is measured by "injuries", which includes all degradation of health, including death.

Impacts on *Physical Resources* (2.2) could be measured by a larger number of criteria, depending on the location of the intercity system and the concerns of the decision-makers. The entire gamut of factors to be considered in Environmental Impact Statements is properly included in this segment of the hierarchy. For purposes of the illustrative example, the effects on Physical Resources are represented by *Land Use (2.2.1)*, *Property Damage (2.2.2)*. *Noise Levels (2.2.3)*, and *Visibility (2.2.4)*. It is to be emphasized that environmental impact is measured through mission *effectiveness* criteria (Section 2.1 ) such as perceived noise level and visibility rather than performance criteria such as operating noise levels and emission levels. These effectiveness criteria are environmental attributes and include contributions from non-transportation sources of, for instance, noise and pollution. The *performance* criteria with respect to noise and air pollution emissions would be the characteristics for use as design requirements during engineering development of the transportation hardware.

Impacts on the regional econony are included under *Economic Effects (3)*. In this category, effects on people, on physical resources, and on the economic system are represented by *Human Resources (3.1)*, *Materials and Energy (3.2)*, and *Business and Commerce (3.3)*, respectively. The effect on Human Resources is measured by *Employment (3.1.1)*. Physical Resources is represented by *Fossil Fuels (3.2.1)* to reflect current priorities. Business and Commerce is measured by two comparison criteria: *Gross Regional Product (3.3.1)* and *Interregional Product (3.3.2)*.

A decision to support a particular intercity modal concept could have profound effects on various socio-economic institutions (such as the petroleum industry, the automobile industry, the health care system, etc.). Incorporation of such effects in either the Phase I or the Phase II effort is beyond the scope of the present project. The category, Socio-Economic Institutions (2.3), does not, therefore, appear in either Figure 4.1 or Figure 4.3.

## 4.2 The Comparison Criteria

The comparison criteria identified by means of the hierarchy of Figure 4.3 for the illustrative example are listed in Table 4.1. For each of these criteria, a normalized percentage measure is defined:

| 1. Transportation Effects | 2. Societal Effects | 3. Economic Effects |
|---|---|---|
| 1.1.1 Passengers | 2.1.1 Demography | 3.1.1 Employment |
| 1.1.2 Freight | 2.1.2 Health Status | 3.2.1 Fossil Fuels |
| 1.2.1 Investment | 2.2.1 Land Use | 3.3.1 Gross Regional Product |
| 1.2.2 Operating Costs | 2.2.2 Property Damage | 3.3.2 Interregional Product |
| 1.2.3 Operating Surplus/ Subsidy | 2.2.3 Noise Levels | |
| 1.3.1 Airports | 2.2.4 Visibility | |
| 1.3.2 Railroad Stations | | |
| 1.3.3 Bus Stations | | |
| 1.3.4 Roadways | | |

Table 4.1 - Comparison Criteria (Illustrative Example)

$$Y = 100 \frac{Y_N}{Y_D} \quad (4\text{-}1)$$

where $Y_N$ = the quantity (amount, level) of the criterion (measured in usual physical or economic units) estimated for a given alternative

$Y_D$ = a selected quantity (amount, level) of the criterion, measured in the same units as $Y_N$

$Y$ = comparison criterion, %

For all nineteen criteria, the normalizing relationship and its numerator and denominator are defined in Appendix A.

The set of criteria defined for the evaluation of intercity transportation modal concepts is mission oriented; achieving desired levels of the criteria *is* the mission of the intercity transportation system. The best intercity transportation alternative for the specified decision situation is the alternative with the best combination of consequences as measured by tradeoffs among these nineteen criteria--where "best" is defined by the objective function.

The criteria are measured in the environments in which the intercity transportation system is embedded and, hence, are applicable to any modal concept. Furthermore, the set of criteria:

- Provides, together with the case description, an unambiguous description of the mission of the intercity transportation system
- Identifies the attributes by which advantages and deficiencies of various alternative concepts are measured and made visible

Since these functions should be compatible with the value system(s) to be used in decision making, concurrence of agency management in the set of criteria is a key event in the application of the methodology.

The denominators used in the comparison criteria (Equation 4-1) are related to long-term aspiration levels. The aspiration levels provide a mechanism for comparing intercity transportation systems not only with each other, but also with reasonable long-term societal goals.

For the illustrative example, denominators were estimated for each of the nineteen criteria over the 50-year planning period (Table 4.2). To illustrate the use of aspirational levels, the rationale for determining the denominators of Passengers ($Y_{1.1.1}$) and Freight ($Y_{1.1.2}$) is presented. These denominators represent the societal aspirations for these variables; if this level is achieved, the relative worth associated with the value is neutral (zero).

The aspirations for Passengers and Freight are estimated from two national macroeconomic variables that can be reliably forecast for long time periods: Gross National Product (GNP) and population. The reason for this reliability is the tremendous long-term inertia which is reflected in relatively constant growth rates. It is possible to utilize this characteristic of the national economy and population to make reliable predictions of national transportation variables.

Historically, for example, the ratio of national intercity passenger-kilometers to GNP has held remarkably constant (see Table D.2.1). This fact can be used to relate the Gross Regional Product (GRP) to regional intercity passenger demand based on the assumption that a region's socio-economic profile is a representative sample of the nation as a whole. To the extent that it is recognized that a particular region is not representative, regional intercity passenger demand can be adjusted.

For the Los Angeles-San Francisco link, the following equation was used to calculate intercity passenger demand based on the above considerations.

$$Y_{D\ 1.1.1} = (\$\ GRP) \times 1.707 \times 0.0521$$

| YD | | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|---|
| 1.1.1 | PASSENGERS | 12.80 | 17.90 | 25.10 | 35.00 | 49.00 | 68.30 |
| 1.1.2 | FREIGHT | 33.40 | 44.30 | 56.70 | 77.80 | 108.00 | 136.70 |
| 1.2.1 | INVESTMENT | 4.80 | 6.80 | 9.50 | 13.20 | 18.50 | 25.80 |
| 1.2.2 | OPERATING COSTS | .80 | 1.10 | 1.50 | 2.10 | 2.90 | 4.10 |
| 1.2.3 | SURPLUS/SUBIDY | .60 | .80 | 1.10 | 1.60 | 1.60 | 2.20 |
| 1.3.1 | URBAN FACILITY-AIR | 51.00 | 59.00 | 69.00 | 80.00 | 93.00 | 108.00 |
| 1.3.2 | URBAN FACILITY-RR | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1.3.3 | URBAN FACILITY-BUS | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1.3.4 | URBAN FAC.-ROAD | 2290.00 | 3206.00 | 4494.00 | 6269.00 | 8759.00 | 12223.00 |
| 2.1.1 | CORRIDOR DEMOG | 160.00 | 160.00 | 156.00 | 153.00 | 150.00 | 145.00 |
| 2.1.2 | HEALTH STATUS | 454.00 | 432.00 | 410.00 | 390.00 | 371.00 | 357.00 |
| 2.2.1 | CORRID LAND USE | 1.50 | 2.00 | 3.00 | 3.50 | 4.00 | 4.50 |
| 2.2.2 | PROPERTY DAMAGE | 227.00 | 216.00 | 205.00 | 195.00 | 186.00 | 177.00 |
| 2.2.3 | NOISE LEVELS | 88.80 | 101.60 | 112.60 | 123.70 | 136.00 | 146.20 |
| 2.2.4 | VISIBILITY | 16.00 | 14.60 | 13.30 | 12.10 | 11.00 | 10.00 |
| 3.1.1 | EMPLOYMENT | 12.20 | 13.90 | 15.40 | 16.90 | 18.60 | 20.00 |
| 3.2.1 | FOSSIL FUELS | 38.50 | 51.40 | 68.40 | 90.70 | 31.60 | 11.00 |
| 3.3.1 | GROSS REG PROD | 145.00 | 203.00 | 284.00 | 396.00 | 553.00 | 773.00 |
| 3.3.2 | INTERREG PROD | 93.00 | 130.00 | 179.00 | 246.00 | 338.00 | 467.00 |

Table 4.2 - CASE RESULTS: DENOMINATOR

In the above equation, \$GRP is the projected Gross Regional Product in constant 1972 dollars. Values for this variable are obtained by scaling GNP by the ratio of regional to national population (10%). The value 1.707 is the historic ratio of national intercity passenger-kilometers per dollar of GNP. Since scaling national data by regional population results in total regional intercity passenger-kilometers, both interregional and intraregional passenger-kilometers are included. The value 0.0521 results from the Star Study (Chesler and Goeller, 1973) and represents the proportion of the total passenger-kilometers which remain in the region, i.e., the intraregional passenger-kilometers.

Similiar arguments apply for the calculation of intraregional freight demand. For the Los Angeles-San Francisco link, the following equation was used to calculate freight demand projections:

$$Y_{D\ 1.1.2} = (\$GRP) \times TK/GNP \times 0.075$$

TK/GNP is tonne-kilometers per dollar of GNP. This variable reflects an assumed decline from 24% to 18% of agriculture and manufacturing as a percentage of GNP. The values for TK/GNP are shown below.

| 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|
| 2.537 | 2.409 | 2.286 | 2.170 | 1.060 | 1.955 |

The estimated value of 0.075 represents the proportion of freight that not only originates in the region but also stays within the region.

## 4.3 Relative Worth Functions

The analysis activity provides estimates of the criteria in physical or economic units such as passengers, tons, dollars, hectares, etc. It is necessary to transform these estimates into a common measure of relative worth for two basic reasons:

- For each alternative transportation modal concept, the effects of various criteria must be combined to obtain an overall measure of relative degree of achievement of goals and objectives.

- Degree of achievement of a particular objective is, in general, not linearly related to various amounts of a particular criterion; the nonlinearities result from factors underlying current priorities and attitudes towards risk.

For each criterion, therefore, a quantitative relationship is defined to represent the relative contribution of various amounts of the criterion to achievement of intercity transportation goals and objectives. The development of these relative worth functions follows the approach presented in Lifson (1972). This approach:

1. Assures that the relative worth measures of all the criteria are the same units (i.e., the ordinates of all relative worth functions are scaled the same).
2. Provides a scaling such that a positive relative worth indicates a satisfactory alternative and a negative relative worth indicates an unsatisfactory alternative.
3. Provides relative worth functions such that positive worth is bounded by a maximum permissible score on each criterion, and extremely undesirable results with respect to one criterion can assure a large negative total relative worth. (This provision effectively screens out those modal concepts that should be deleted from consideration because they result in unacceptable consequences with respect to one or two key criteria.)

The following procedure is followed in developing each relative worth function:

Step 1. Specify Range of Interest. For each criterion, lower and upper limits of the range of interest are specified (points $Y_L$ and $Y_U$, respectively, of Figure 4.4). These limits are based on an understanding of the particular case description under consideration. The range of interest is broad enough to include all anticipated consequences for any of the modal alternatives. To permit evaluation of achievement

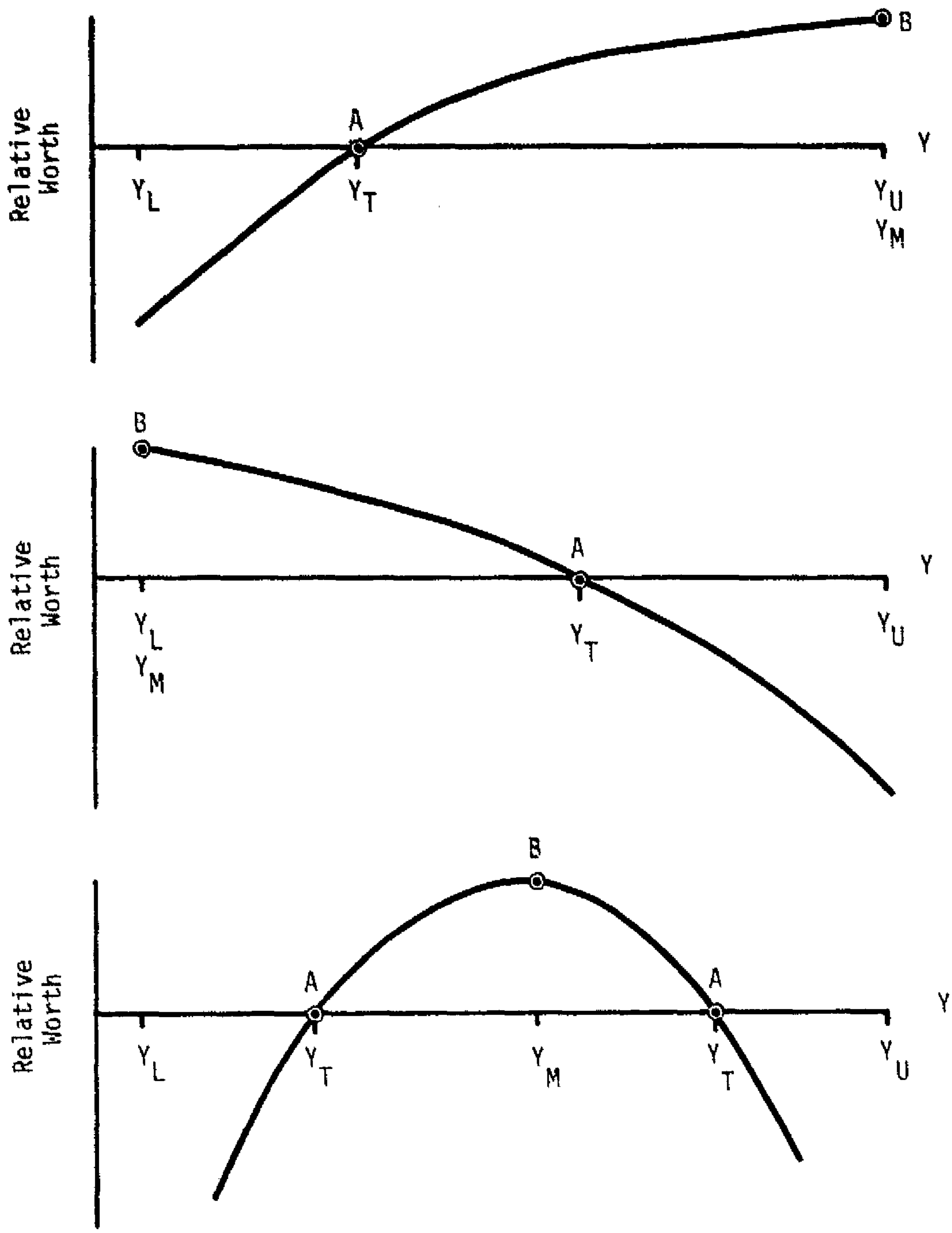



Figure 4.4 - Illustrative Relative Worth Functions

and nonachievement of transportation objectives, the range of interest is broad enough to include all anticipated consequences for any of the modal alternatives. To permit evaluation of achievement and nonachievement of transportation objectives, the range of interest includes both desirable and undesirable magnitudes of each criterion.

If, for example, a preference function for 1.1.1, *Passengers* (Figure 4.3), is to be developed, and lower and upper limits of, say, 20,000,000 passenger-kilometers and 100,000,000 passenger-kilometers are specified for $Y_L$ and $Y_U$, respectively, then it may be inferred that 20,000,000 passenger-kilometers is poor ridership, that 100,000,000 passenger-kilometers is excellent ridership and that the ridership objective for the system lies between $Y_L$ and $Y_U$.

Step 2. Identify Threshold. Since the range of interest specified in Step 1 includes both desirable and undesirable quantities of a criterion, it must also include a neutral contribution to success or failure. This neutral point, or *threshold*, is indicated by $Y_T$ on Figure 4.4.

The importance of specifying the threshold of each criterion lies in the fact that *all thresholds, regardless of criterion, represent the same relative worth -- neutral desirability or neutral contribution to success or failure* -- and may, therefore, be assigned the same relative worth number. A relative worth of zero is assigned to each $Y_T$ (point A on Figure 4.4) so that positive relative worth represents a desirable outcome, i.e., an outcome contributing to achievement of objectives. Negative relative worth represents an undesirable outcome, i.e., an outcome contributing to non-achievement of objectives.

Step 3. Define Relative Worth Functions. The evaluation methodology utilizes a cardinal scale (Stevens, 1959; Torgerson, 1958) for measuring relative worth (see, for example, Fishburn, 1964). Defining a cardinal scale of measurement requires arbitrarily anchoring *two and only two* points on the scale to designated phenomena or quantities. In temperature measurement, for example, the cardinal fahrenheit and celsius scales are arbitrarily anchored to the freezing and boiling points of water.

For each criterion, therefore, two relative worth points are arbitrarily designated. One of these points is defined in Step 2. The relative worth of the threshold $Y_T$ is set equal to zero:

$$u(Y_T) = 0 \tag{4-2}$$

where $u(Y_T)$ = relative worth of $Y_T$

The second point is defined by setting the mpost preferred magnitude of each criterion equal to 1: (Point B on Figure 4.4):

$$u(Y_M) = 1 \tag{4-3}$$

where $Y_M$ most preferred magnitude of the criterion Y

$u(Y_M)$ = relative worth of $Y_M$

$Y_M$ may occur anywhere within the range of interest, that is,

$$Y_L \leq Y_M \leq Y_U \tag{4-4}$$

For those criteria where more is better (e.g., passengers, freight, employment),

$$Y_M = Y_U \tag{4-5}$$

For those criteria where less is better (e.g., costs, people injured, noise levels),

$$Y_M = Y_L \tag{4-6}$$

For those criteria where too much or too little of the criteria is possible (e.g., use of urban facilities, population density),

$$Y_L < Y_M < Y_U \quad (4\text{-}7)$$

In this latter case, two thresholds must be identified: one $Y_T < Y_M$ and one $Y_T > Y_M$ .

With the relative worth scale defined by equations (4-2) and (4-3), the relationship between relative worth and various amounts of the criterion, i.e., the *relative worth function*, is structured. Any of a number of techniques may be used to elicit the judgmental data needed to identify the relative worth function:

- Certainty equivalent method (e.g., Fishburn, 1964; Raiffa, 1968; Lifson, 1972)
- Magnitude estimation (e.g., Stevens, 1959)
- Graphic methods

Whatever the technique, knowledgeable personnel who are willing to respond to questions concerning tradeoffs of various amounts of a criterion are key to defining a relative worth function. Knowledge and understanding of intercity transportation policies and objectives are necessary to assure that the relative worth functions comprise an appropriate model of the value system to be used in a particular decision situation.

The output of the foregoing three steps is a set of relative worth functions with a common definition for the relative worth = 0. Each function is presumed to be internally consistent, that is, the relative worth of various amounts of a given criterion is reasonably represented by the relative worth function.

For each of the nineteen criteria (Table 4.1 and Appendix A):

- the upper and lower limits of the range of interest, $Y_L$ and $Y_U$, were specified
- the threshold, $Y_T$, was identified
- relative worth functions were defined with $U(Y_T) = 0$ and $U(Y_M) = 1$

The resulting relative worth functions are presented in Appendix B. For each criterion, the nonlinearity of the relationship between the quantity of the criterion and the relative worth was recognized and this nonlinearity was modeled by the exponential relative worth relationship (e.g., Raiffa, 1968):

$$u(Y) = Ae^{BY} + C \qquad (4\text{-}8)$$

where $Y$ = measure of comparison criterion

$e$ = base of the natural logarithms

$u(Y)$ = relative worth of $Y$

$A,B,C$ = parameters of the relative worth function

When the relative worth relationship of criteria could not be modeled by a single exponential relationship, two sets of parameters were defined for equation (4-8), with each set applicable over an appropriate range of the variable Y. Sensitivity analysis of particular relative worth functions is demonstrated in Chapter 9.

## 4.4 Relative Weights

The relative worth functions are scaled so that, for all criteria, a relative worth of zero means neutral contribution to achievement of objectives. One point in common, however, is not sufficient to assure a common scaling for all relative worths. A second point in common, a second relationship between criteria, is needed.

The second relationship is obtained by considering $Y_M$, the most preferred magnitude of a criterion Y. In Step 3 of Section 4.3, a relative worth = 1 is assigned without regard for the relative worth of

$Y_M$ in relation to other criteria. The relative worth = 1 may, therefore, mean different contributions to success for the various criteria. The judgment of knowledgeable personnel is again needed to assign numbers to the set of $Y_M$ such that the number assigned to each $Y_M$ represents its relative contribution to achievement of intercity transportation objectives. The numbers so assigned are *relative weights*.

The purpose of the relative weights is to provide the second relationship needed to assure a common scaling for relative worths of all criteria. Transforming relative worths obtained from the relative worth functions to a common scale of relative worth is accomplished by multiplying by the appropriate relative weight (Lifson, 1972).

$$U(Y_j) = W_j\, u(Y_j)$$

where
- $Y_j$ = a criterion.
- $u(Y_j)$ = relative worth of $Y_j$ obtained from the relative worth function.
- $W_j$ = relative weight assigned to $(Y_M)_j$.
- $(Y_M)_j$ = most desired magnitude of $Y_j$.
- $U(Y_j)$ = relative worth $Y_j$ measured on the common relative worth scale.

The relative weights assigned to the criteria, as well as to other elements of the hierarchy, are shown in Figure 4.5 for the illustrative example. With these weights, a perfect intercity transportation system -- one that results in $Y_M$ for all criteria over the entire 50-year planning period -- would receive a relative worth score of 100.

Obviously, no actual system is perfect; tradeoffs among the criteria and imperfections in real systems result in scores less than 100. The relative worths obtained for a given alternative are placed in perspective, however, by considering that 100 is a maximum, the score for perfection, and zero is the score for neutral achievement of policies and objectives. Of course, it is possible for some candidate alternatives to result in a negative score which implies that, considering all trade-

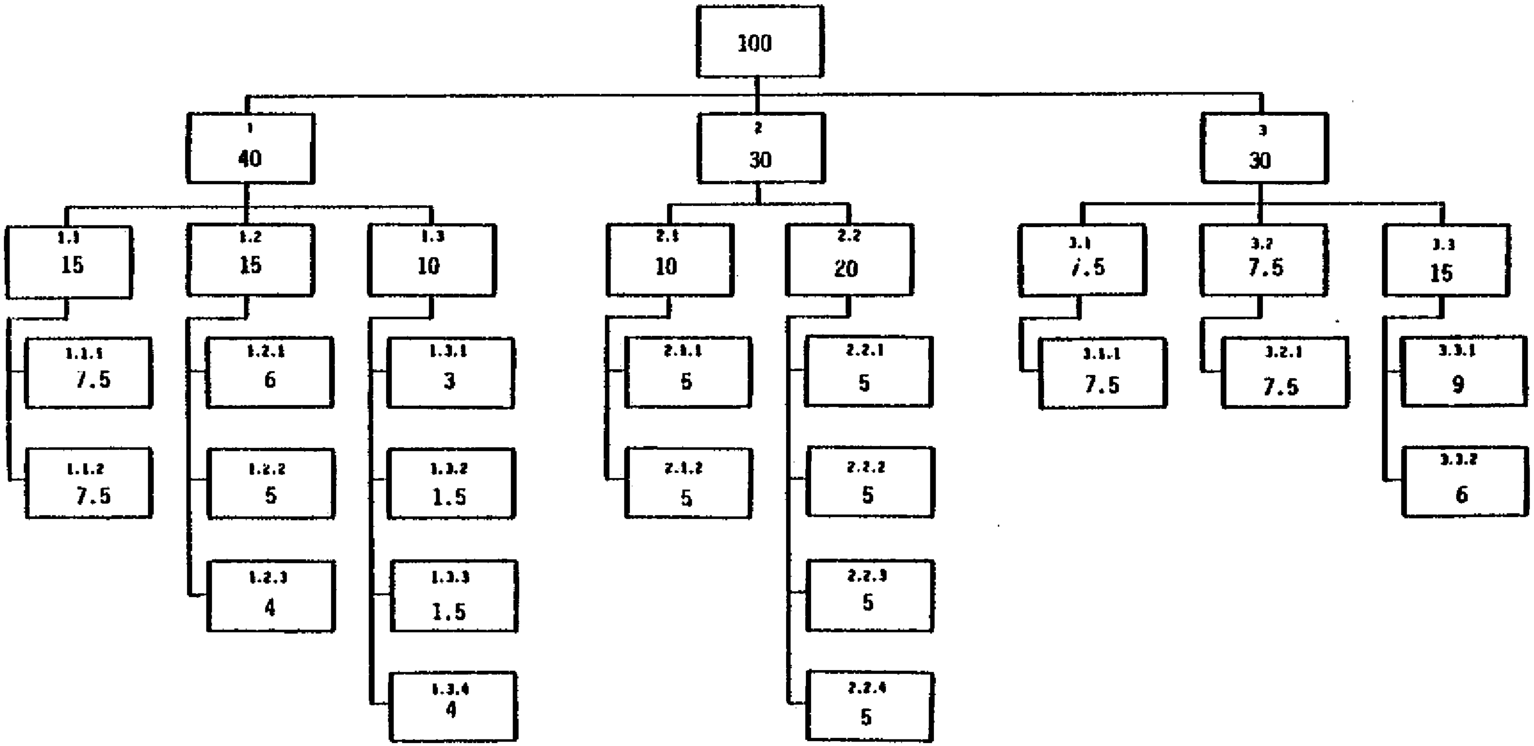



Figure 4.5 - Relative Weights (Reference: Figure 4.3)

offs, policies and objectives have not been met.

The assignment of the relative weights is judgmental. Knowledgeable personnel, preferably including the decision-makers, are asked to allocate the 100 points at each level of the hierarchy. The allocated weights are reviewed and various combinations are compared to assure that they "make sense". Differences of opinion can be dealt with either by combining into averages or by investigating the sensitivity of the results to the differences (see, for example, Section 9.2).

## 4.5 Discount Functions

To obtain a relative worth for each intercity transportation alternative, a 50-year projection must be transformed into an *equivalent relative worth representing the entire 50-year stream.* The transformation should be such that the number that represents each 50-year stream also represents relative contribution to achievement of transportation objectives.

A standard approach for assessing alternative future flows is to convert each flow into an equivalent *present worth*, where *equivalent means equally desired* (see, for example, Fabrycky and Thuesen, 1974; Weston and Brigham, 1975). The *discount function* universally used for this purpose is the relationship used in financial contracting to define the payments owed a lender by a borrower:

$$P = \sum_{t=0}^{N} X_t (1+r)^{-t} \qquad (4\text{-}10)$$

Where $P$ = present worth, a quantity of money at time $t = 0$

$X_t$ = quantity of money at time $t$

$N$ = number of years in the planning period

$r$ = annual discount rate

Although other forms of discount functions need to be researched as improved models for decision-making (English, 1976, 1978; Lifson, 1976), (See Appendix D), equation (4-10) is suitable for initial applications of the evaluation methodology. For computational convenience, the continuous compounding form of equation (4-10) is used to convert the stream of relative worths to an equivalent present worth:

$$P_j = \int_0^N U_j(t) \cdot e^{-rt} \, dt \qquad (4\text{-}11)$$

Where e = base of the natural logarithms

$e^{-rt}$ = discount function

$U_j(t)$ = relative worth of the jth element of the hierarchy at time t

$P_j$ = equivalent present relative worth of the time flow of $U_j(t)$

In response to the needs of the decision situation, the methodology, through equation (4-11), incorporates the following three improvements over standard discounting practice:

1. A non-standard discount function may be used. Discounting transforms prospective relative worths for the various criteria, as values over time, to equivalent relative worths in the present; it accounts for relative worth of the time dimension.

2. Provision is made to discount different value elements differently. Agency transportation policies and objectives may require, for example, that lives saved or numbers of people employed in the year 2000 be discounted to the present differently from the way in which investment or operating costs are discounted.

3. The discount function is applied to the time flow of *relative worth rather than to the time flow of dollars, or passengers, or freight, etc.* In conventional economic evaluation of investment alternatives, projected alternative time flows of dollars (criterion variable) are converted to equivalent present worth of that present value. The problem with this

conventional approach is that cash flows representing financial disaster in some future year may be masked by the present worth conversion. If the time flow of dollars is converted to relative worth representing the impact of the flow of dollars in each year, then the present worth computation can more accurately measure relative contribution of flow over time to achievement of objectives.

The foregoing use of the discount function is consistent with the concept of the discount function as a tool for adjusting the relative worth of consequences separated in time, for evaluating the effects of the timing of alternative consequences on achievement of objectives.

Elements of the hierarchy were selected to illustrate the use of discount functions in the methodology. These elements were chosen in order to permit different discounting of future transportation effectiveness, dollar flows, societal effects, and economic effects. The conventional discount function, $e^{-rt}$, was used. Each hierarchical element was assigned a discount rate r:

| Element of the Hierarchy | | Discount Rate |
|---|---|---|
| 1.1 | Intercity Transportation | 3% |
| 1.2 | Costs | 10% |
| 1.3 | Urban Facilities | 10% |
| 2 | Societal Effects | 0% |
| 3 | Economic Effects | 10% |

Dollar costs and economic effects are assumed discounted at an annual rate of 10%. Future transportation effectiveness and societal qualities are assumed to degrade less rapidly with time than with future dollars; their discount rates are, therefore, significantly less than 10%. Sensitivity of relative worth to discount rates is illustrated in Section 9.3.

## 4.6 Total Effect: The Objective Function

A mathematical expression, or set of expressions, *an objective function*, is needed in order to assure a consistent aggregation of relative worths into an overall relative score for each alternative intercity transportation concept.

The hierarchy of values (Figure 4.1) is the overall guide for aggregating relative worths. For each set of related comparison criteria, the time flows of relative worths are summed to obtain a time flow of the relative worth score for their higher level value factor. These are summed, in turn, until time flows of relative worth are obtained for those elements of the hierarchy that are to be converted into equivalent present worths through application of the appropriate discount functions. The present worths are then summed "up the hierarchy" to obtain a relative score for the total effect of each alternative. The advantage of this approach is that alternatives may be compared at any level of the hierarchy; strengths and weaknesses of the alternatives may be made visible at the level of the comparison criteria or at any level of aggregation.

The simple summation of relative worths assumes *valuewise independence* of the comparison criteria, i.e., the relative worth function of a comparison criterion does not depend on the levels or quantities of the other criteria. In fact, conventional economic evaluation of alternative investments -- whether present worth, equivalent annual worth, or rate of return technique is used -- assumes valuewise independence with respect to time. This assumption is necessary for the evaluation methodology to be manageable (see, for example, Fishburn, 1964). Valuewise independence is also a good assumption, capturing most of the total effect even in situations where high valuewise dependency is intuitively present or deliberately structured. Care must be exercised, however, to assure that flagrant violations of valuewise independence do not occur in structuring the hierarchy. (It is to be emphasized that no assumption is made concerning independence in the physical or socio-economic world.

Changing an attribute of a transportation system can effect changes in any or all of the comparison criteria. The criteria may be highly interrelated in transportation, societal and economic systems. It is only in the value world, in relative contribution to achievement of success, that independence is assumed.)

The details of aggregating the relative worths of the comparison criteria into a measure of the total relative effect of an intercity transportation alternative depend on the needs of a particular decision situation:

- The way the hierarchy of values is partitioned to identify comparison criteria should be responsive to current transportation policies and objectives.
- The choice of hierarchy elements to be discounted should be dictated by the needs of the particular decision situation. For the illustrative example, there are nineteen 50-year time flows to be evaluated. These time flows are converted to relative worth flows by means of the relative worth functions of Appendix B and the relative weights of Figure 4.5:

$$U(Y_j)_t = W_j \, u(Y_j)_t \tag{4-12}$$

where $U(Y_j)_t$ = weighted relative worth of $Y_j$ at time t

$W_j$ = relative weight assigned $Y_j$

$Y_j$ = a comparison criterion

$j$ = element of hierarchy of Figure 4.3

A time flow of relative worth is computed for each element to be discounted:

$$(U_{1.1})_t = U(Y_{1.1.1})_t + U(Y_{1.1.2})_t \tag{4-13}$$

$$(U_{1.2})_t = \sum_{i=1}^{3} U(Y_{1.1.i})_t \tag{4-14}$$

$$(U_{1.3})_t = \sum_{i=1}^{4} U(Y_{1.3.i})_t \tag{4-15}$$

$$(U_2)_t = \sum_{i=1}^{2} U(Y_{2.1.i})_t + \sum_{i=1}^{4} U(Y_{2.2.i})_t \tag{4-16}$$

$$(U_3)_t = U(Y_{3.1.1})_t + U(Y_{3.2.1})_t + \sum_{i=1}^{2} U(Y_{3.3.i})_t \tag{4-17}$$

The time flows represented by equations 4-13 through 4-17 are discounted to obtain an equivalent set of present relative worths:

$$P_{1.1} = \frac{1}{50} \int_{1980}^{2030} (U_{1.1})_t e^{-.03t} dt \tag{4-18}$$

$$P_{1.2} = \frac{1}{50} \int_{1980}^{2030} (U_{1.2})_t e^{-.10t} dt \tag{4-19}$$

$$P_{1.3} = \frac{1}{50} \int_{1980}^{2030} (U_{1.3})_t e^{-.10t} dt \tag{4-20}$$

$$P_2 = \frac{1}{50} \int_{1980}^{2030} (U_2)_t dt \tag{4-21}$$

$$P_3 = \frac{1}{50} \int_{1980}^{2030} (U_3)_t e^{-.10t} dt \tag{4-22}$$

To complete the computation of total relative worth of an intercity transportation alternative, the relative present worths are aggregated:

$$P_1 = \sum_{i=1}^{3} P_{1.i} \tag{4-23}$$

$$P = \sum_{i=1}^{3} P_i \tag{4-24}$$

The objective function, the set of equations for computing a relative score for each intercity transportation alternative, is comprised of equations (4-12) through (4-24), together with the conversion relationships of equation (4-1) and Appendix A. The computations using the objective function are structured to permit comparison of alternatives with respect to any element of the hierarchy. Strengths and weaknesses of each alternative may, therefore, be displayed.

## 5. ANALYSIS FRAMEWORK

### 5.1 Overview

The analysis framework is the link between a specific transportation case description and the comparison criteria ($\bar{Y}$ variables), Figure 5.1. The purpose of analysis is to compute values for the $\bar{Y}$ variables. In the comparison methodology, computation runs from left to right in the figure, i.e., from system synthesis to analysis to evaluation. However, development of the computational models, as pointed out in Chapter 2, is from right to left. The evaluation activity determines the comparison criteria or $\bar{Y}$ variables from knowledge of the decision situation and the decision-makers' policies and objectives. The $\bar{Y}$ variables themselves then suggest the type of analysis that would be required in order to calculate values for each of them.

Proceeding to the left through the analysis framework, the type of input variables required by analysis can be defined. In general, there are two types, which we have called *regional descriptors* and *system descriptors*, that comprise a case description.

The *regional descriptors* ($\bar{Z}$ variables) define the intercity region in which the transportation system is imbedded. The intercity region geographically includes urban areas that define the ends of the intercity link, as well as the corridor region in between the cities and non-corridor areas that may be affected by the intercity transportation system. The $\bar{Z}$ variables include descriptors of the historic, current, and projected status of the region's economic, demographic and societal characteristics.

*System descriptors* refer to variables that describe a transportation alternative. In contrast with regional descriptors, which are transportation independent, system descriptors ($\bar{X}$ variables) are concerned only with the transportation system. Intercity transportation alternatives differ only in their $\bar{X}$ descriptors; initial regional $\bar{Z}$ variables are unchanged from alternative to alternative.

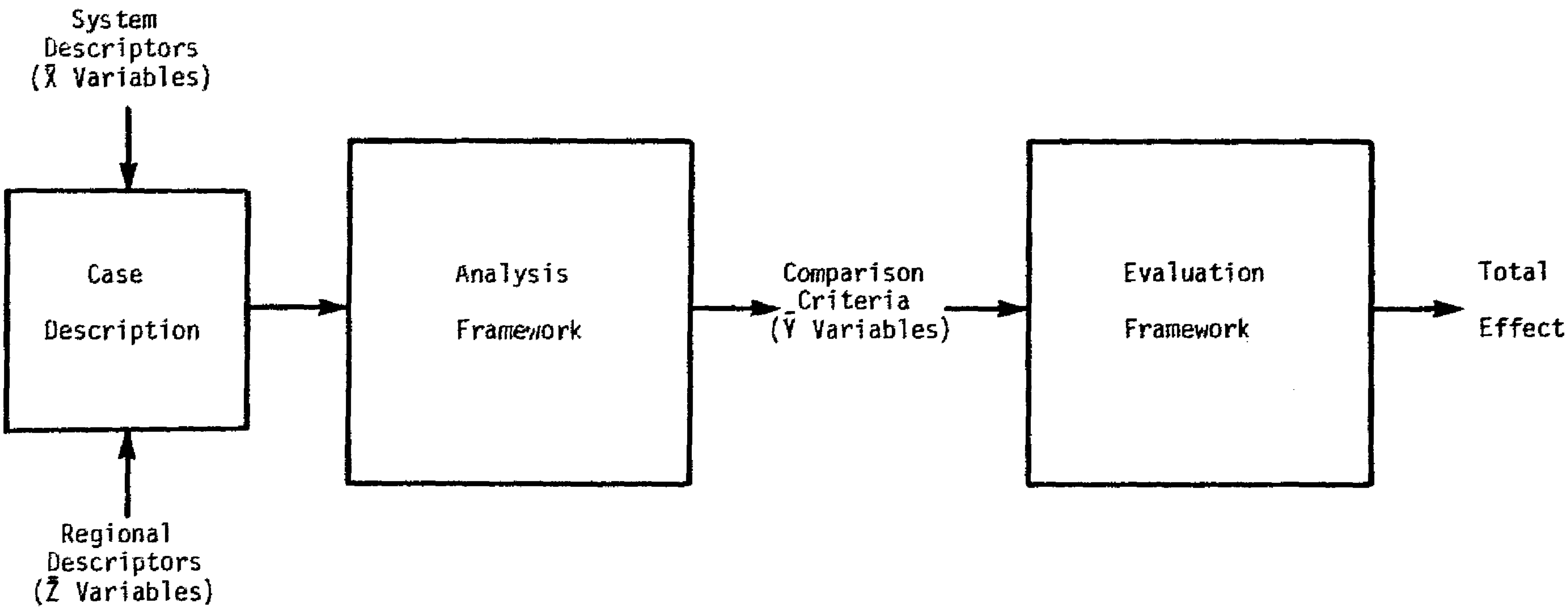



Figure 5.1 - Role of Analysis in Comparison Methodology

The $\bar{X}$ variables are used to describe alternatives in sufficient detail to permit calculation of the specified $\bar{Y}$ variables. For example, since fossil fuel consumption is a $\bar{Y}$ variable, there would need to be $\bar{X}$ variables describing propulsion technology and its energy requirements on a unit basis such as BTU/track-mile. On the other hand, a potential $\bar{Y}$ variable, passenger comfort, was not chosen because the decision situation deals with the early concept phase of the program life cycle rather than with the design or operating phases. No $\bar{X}$ variable related to passenger comfort, e.g., passenger seating configurations, seating density, etc., is, therefore, required.

## 5.2 Analysis Models

For each $\bar{Y}$ variable, some sort of computation model is required. The inputs to the computation are $\bar{X}$ and $\bar{Z}$ variables and, some cases, intermediate variables resulting from a prior model in the analysis framework. Estimates of the $\bar{Y}$ variables themselves are the output from the analysis framework. As noted in Section 4.1, three classes of $\bar{Y}$ variables are specified:

- intercity transportation system
- societal effects
- economic effects

Models in the analysis framework are conveniently classified according to the $\bar{Y}$ variables to be estimated: those models used to estimate transportation effects, societal effects, and economic effects, respectively. Figure 5.2 depicts the analysis framework partitioned into these three categories. Based on a reasonable review of analytic models that are currently available, the following conclusions were reached.

- A preponderance of existing models relate to a description of the transportation system and its attributes.
- Most of these models are inappropriate because either they have been developed for detailed design or they do not provide estimates of required variables.
- Relatively few models have been developed to describe the soci-

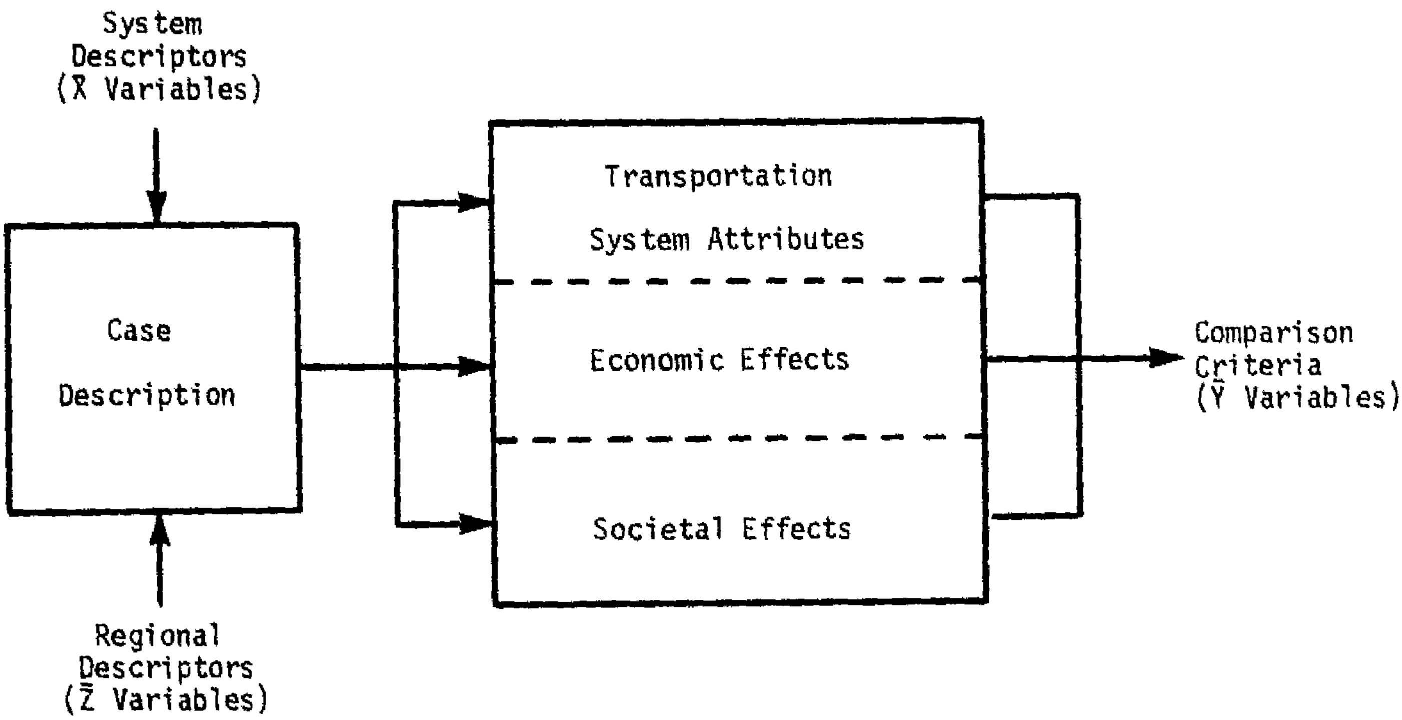



Figure 5.2 - Conceptual Partitioning
of Analysis Framework

etal and economic effects of an intercity transportation system.

- Models that compute appropriate variables frequently require relatively high levels of effort to use.

A fundamental flexibility of the comparison methodology is that the procedures used to estimate $\bar{Y}$ variables are independent of the methodology itself. Implementation of the analysis framework might range from judgmental estimates of $\bar{Y}$ variables to an integration of sophisticated computer models requiring several man-years to exercise.

The analysis capabilities required to estimate the comparison criteria (the $\bar{Y}$ variables) of the illustrative example may be represented by Figure 5.3. If fully implemented by means of state-of-the-art mathematical models, man-years of model validation, data collection, and computations would be required. On the other hand, Figure 5.3 can be viewed as defining judgments that could be made by knowledgeable personnel aided by available data and minicomputers. The appropriate level of effort for each activity within the analysis framework depends on the decision situation and resources available for a particular study.

Implementation of the analysis framework is a Phase II activity. Analysis models and techniques compatible with the Phase II level of effort will be defined early in the Phase II study.

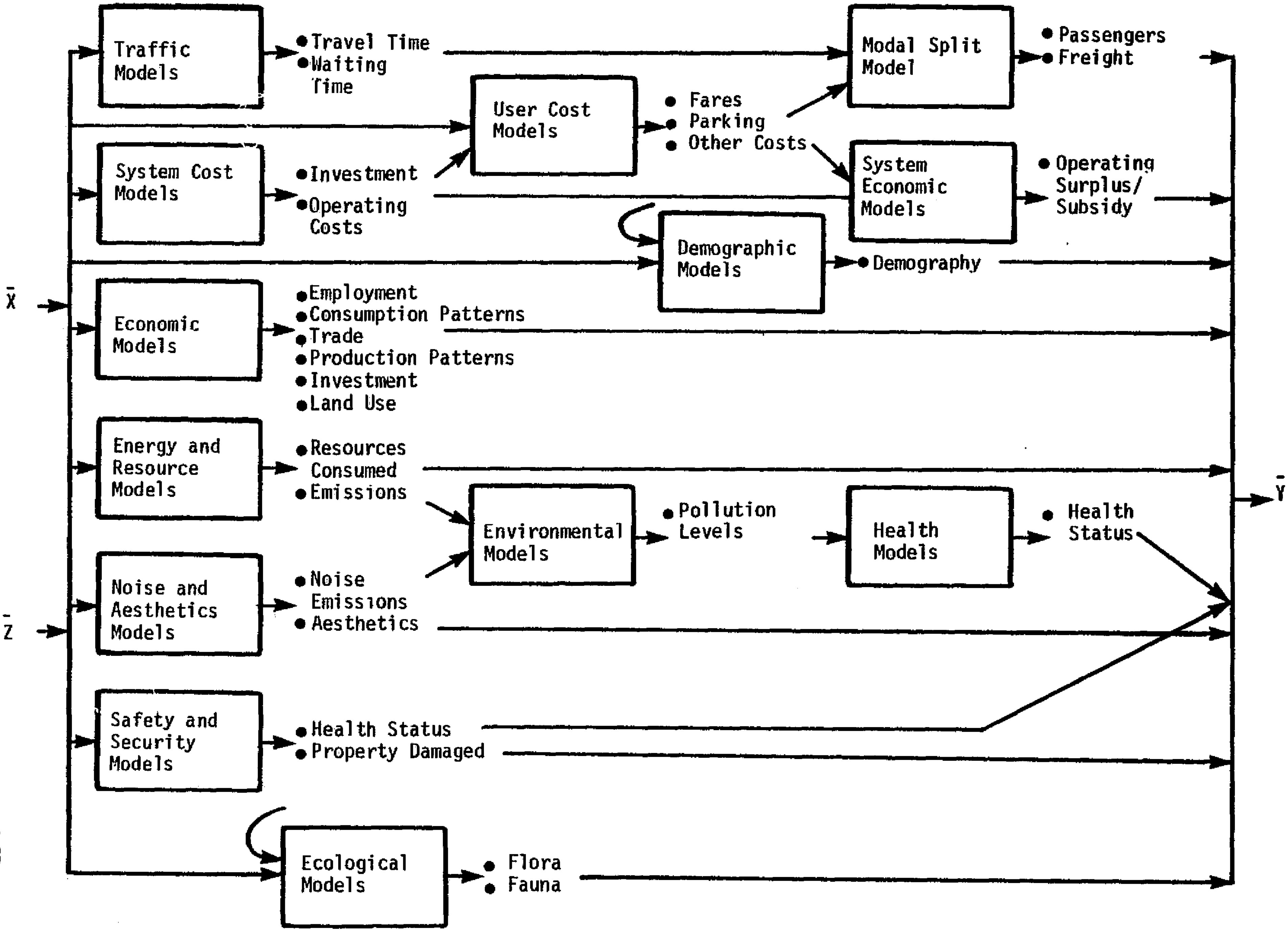



Figure 5.3 - Potential Models for Analysis Framework

## 6. SYNTHESIS: CASE DESCRIPTIONS

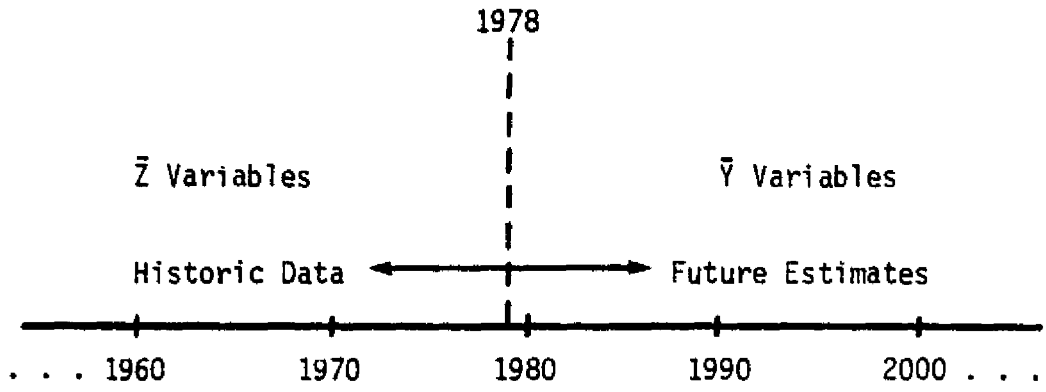
### 6.1 Regional Descriptors

Regional descriptors ($\bar{Z}$ variables) are used to measure historic values for characteristics of the intercity region that may affect or be affected by a new intercity transportation system. $\bar{Y}$ variables are, by definition, all those regional characteristics which will be affected by a new transportation system. The corresponding $\bar{Z}$ variables are required in order to describe the past and current values of those affected characteristics.

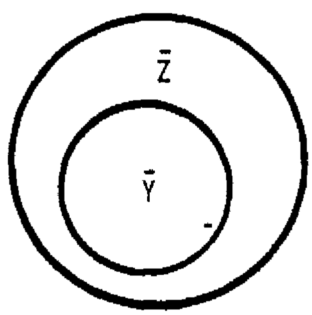
The relationship between regional descriptors and comparison criteria is illustrated in Figure 6.1a $\bar{Y}$ variables are future estimates while the corresponding $\bar{Z}$ variables are historic data. There are some $\bar{Z}$ variables, however, which, although they affect the transportation system decision, are not themselves affected by the choice of alternative. This situation is illustrated in Figure 6.1b. Examples of this kind of $\bar{Z}$ variables are topography, which may affect ground system construction costs, and institutional factors, which may affect fare structure and hence ridership.

The $\bar{Z}$ variables include the $\bar{Y}$ variables listed in Table 4.1 and regional characteristics that affect but are unaffected by the transportation modal decision. The list of $\bar{Z}$ variables is given in Table 6.1. These $\bar{Z}$ variables should be regarded as tentative because the list can only be finalized with definition of the analysis framework during Phase II.

The intercity region used for the illustrative example is the Los Angeles-San Francisco transportation corridor. This region is defined by the California counties that are affected by an intercity transportation system within the Los Angeles-San Francisco corridor. These counties include not only those from which potential demand arises but also those which may be affected socio-economically even though they do not contribute significantly to passenger demand or freight demand. These counties




(a) Historic-Future Relationship




All $\bar{Y}$ variables are $\bar{Z}$ variables, but not all $\bar{Z}$ variables are $\bar{Y}$ variables.

(b) Venn Diagram Relationship

Figure 6.1 - Relationship Between $\bar{Z}$ Variables and $\bar{Y}$ Variables

| | |
|---|---|
| Population (Regional) | Operating Costs |
| Population (National) | Operating Surplus/Subsidy |
| Topography | Airports - Service Level |
| Weather Conditions | Railroad Stations - Service Level |
| Weight Limits | Bus Stations - Service Level |
| Time Restrictions | Roadways - Service Level |
| Tax Policy | Demography |
| Subsidy Levels | Health Status |
| Peak Demand | Land Use |
| Off-Peak Demand | Property Damage |
| Gross National Product | Noise Levels |
| Potentional For Vandalism | Visibility |
| Passengers | Employment |
| Freight | Fossil Fuel |
| Investment | Gross Regional Product |
| | Interregional Product |

Table 6.1 Regional Descriptors (Phase I $\bar{Z}$ Variables)

are designated in Table 6.2 as Urban or Corridor corresponding to two urban ends and the corridor of the transportation link.

## 6.2 System Descriptors

System descriptors ($\bar{X}$ variables) are the transportation alternative variables used to supply modal input information to the analysis framework. The $\bar{X}$ variables are similar to the $\bar{Z}$ variables in that they are selected because they affect at least one $\bar{Y}$ variable. $\bar{X}$ and $\bar{Z}$ variables are also similar because both types are used to describe the region in a broad sense. The primary distinction is that $\bar{X}$ variables are used to describe technological characterisitics of the region's current and potential intercity transportation alternatives while $\bar{Z}$ variables describe the regional environment in which each transportation alternative is embedded.

Because $\bar{X}$ variable values are dependent on a specific proposed transportation alternative, there will be as many sets of $\bar{X}$ variables as there are proposed alternatives for evaluation. Conversely, for an intercity region, there is only one set of the (system independent) $\bar{Z}$ variables. The $\bar{X}$ variable values for one transportation alternative, together with the $\bar{Z}$ variables, form a case description. This case description is the complete set of input data required by the analysis framework in order to produce the set of $\bar{Y}$ variables.

The $\bar{X}$ variables for the illustrative example are presented in Table 6.3. This list, like the $\bar{Z}$ variables, should be regarded as interim until the analysis framework is finalized in Phase II.

The illustrative example considers four transportation alternatives. The first is defined as the Base Case - the present transportation system projected to the year 2030. It is assumed that no new system is introduced and that the same transportation modes remain, i.e., air, auto, train and bus. The other three alternatives are similar to the base case, but each includes the mode to be evaluated as part of the

Urban Counties - San Francisco Area:

| | |
|---|---|
| Alameda | San Joaquin |
| Contra Costa | San Mateo |
| Marin | Santa Clara |
| Monterey | Santa Cruz |
| Napa | Solano |
| Placer | Sonoma |
| Sacramento | Yolo |
| San Francisco | |

Corridor Counties:

| | |
|---|---|
| Fresno | Merced |
| Kern | Stanislaus |
| Kings | Tulare |
| Madera | |

Urban Counties - Los Angeles Area:

| | |
|---|---|
| Los Angeles - Long Beach | San Diego |
| Riverside | Santa Barbara |
| San Bernardino | Ventura |

Table 6.2 - Region Counties

| | |
|---|---|
| Speed | Vehicle Construction Costs |
| | R&D Appropriations |
| Capacity | Guideway Acquisition and Construction Costs |
| Frequency | Operating Costs |
| Terminal Accessibility | Accident-Rates |
| Energy Requirements | Persons Killed - Rates |
| Emissions | Access/Egress Times |
| Route Land Requirements | Access/Egress Costs |
| Route Air Requirements | Headway Requirements |
| Noise Levels | Terminal Requirements |

Table 6.3 System Descriptors (Phase I $\bar{X}$ Variables)

transportation system. The three new technologies to be considered are:

- tracked air cushion vehicle (TACV) - a high speed fixed guideway system
- improved passenger train (IPT) - an advanced railroad train capable of 240 km/hr (150 mi/hr)
- improved conventional takeoff or landing aircraft (CTOL) - the next generation of commercial aircraft

In the Phase II application of the comparison methodology, the general description above would be replaced by quantitative regional and system descriptors ($\bar{Z}$, $\bar{X}$ variables) for each of the transportation alternatives.

# 7. ANALYSIS

Each comparison criterion in the illustrative example (Table 4.1 and Appendix A) is a ratio. The denominators are discussed in Section 4.2 and are listed in Table 4.2. The numerators depend on the particular transportation alternative being considered. For example, ($Y_{N\ 1.1.1}$) would be found, for a particular alternative, by calculating individual modal ridership with a modal split model and then summing ridership across all modes. Such computations will be made in Phase II, but were beyond the scope of the Phase I Study.

For the illustrative example of Phase I, educated judgment was used to estimate the numerators of the comparison criteria. The rationale for the analysis of each of the four alternatives is summerized in Tables 7.1 through 7.4. The numerical results are presented in Appendix C. (Appendix C includes results for a fifth alternative, a tracked air cushion vehicle operational in the year 2000, the Early TACV.)

Table 7.1 - Base Case - Numerator

For the base case, there are no new systems introduced. There are some evolutionary changes but no revolutionary alterations in transportation systems. The rationale for the comparison criteria of the base case is a simple extrapolation of past transportation trends with analysis of possible growth restraints.

| Hierarchical Number | Comparison Criterion | Rationale |
|---|---|---|
| 1.1.1 | Passengers | Lower than aspirations since no revolutionary change; primary mover is the auto. |
| 1.1.2 | Freight | Only slightly lower than aspirations. |
| 1.2.1 | Investment | Lower than aspirations since no revolutionary change need be supported. |
| 1.2.2 | Operating Costs | Lower than aspirations since no new system is being considered. |
| 1.2.1 | Operating Surplus/ Subsidy | Since no new system is being operated, primary carrier of passengers is still the auto. Thus, the heavy operating subsidy on the auto continues and grows. |
| 1.3.1 | Airports | All these facilities are under capacity and can be expanded although congestion and pollution from auto use reduces passenger travel demand. |
| 1.3.2 | Railroad Stations | |
| 1.3.3 | Bus Stations | |
| 1.3.4 | Roadways | Increased auto use means this facility exceeds aspirations. |
| 2.1.1 | Demography | There is no new system to draw people to corridor. Therefore, urban population density continues to rise relative to the population density of the region as a whole. Thus, corridor demography exceeds aspirations by growing amounts. Aspirations reflect desire for lower urban population density and for people to move into corridor area. |

(Table 7.1 continued)

| Hierarchical Number | Comparison Criterion | Rationale |
|---|---|---|
| 2.1.2 | Health Status | With more auto use there are more accidents, hence, more injuries. Thus, in general, this variable exceeds aspirations but because of lower travel demand, initially this variable is closer to aspirations. The aspiration is a steady 1% decline in injuries from present 465,200/yr. The aspirations also reflect technological advancement with a dramatic decrease in injuries by the year 2010. |
| 2.2.1 | Land Use | Urban land continues to grow relative to urban plus farm land in the corridor but no new system implies no new population influx into the corridor. Hence, this variable is lower than aspiration. The aspirations reflect a desire to induce people to move into the corridor. |
| 2.2.2 | Property Damage | Aspiration is for steady 1% decline from present \$239 x $10^6$/yr. (i.e., 10% of Economic Loss due to auto accidents). Increased auto use implies this variable exceeds aspiration levels by growing amounts. |
| 2.2.3 | Noise Levels | More autos, congestion, population density growth implies large increase over aspiration levels. |
| 2.2.4 | Visibility | As in 2.2.3, the base case shows a large increase over aspiration levels. The aspiration is for a steady decline as air quality improves. |
| 3.1.1 | Employment | Slightly lower than aspiration (94% of labor force) due to low investment and slower growth in corridor. |
| 3.2.1 | Fossil Fuels | Increased auto use implies this variable exceeds aspirations by growing amounts. The aspiration reflects the assumption that fusion power is commercially available in 2010 and that autos start using fusion-produced hydrogen as fuel. |

(Table 7.1 continued)

| Hierarchical Number | Comparison Criterion | Rationale |
|---|---|---|
| 3.3.1 | Gross Regional Product | As in 3.1.1, this variable is slightly lower than aspiration level. |
| 3.3.2 | Interregional Product | No new system implies interregional product lower than aspiration levels. |

Table 7.2 - Tracked Air Cushion Vehicle - Numerator

The TACV is a revolutionary change which is capital intensive due to the tracked guideway. Proposed system stops at 3 stations in the corridor. The TACV is very fast with a minimum travel time of only 84 minutes between San Jose and Los Angeles. Thus, TACV competes with air transportation. The TACV becomes available in 2010.

| Hierarchical Number | Variable | Rationale for Change from Base Case |
|---|---|---|
| 1.1.1 | Passengers | After TACV introduction, large increase in passenger-km base case and less auto traffic. As in base case before introduction of TACV. |
| 1.1.2 | Freight | TACV is passenger oriented - no interference with railroad freight due to new track guideway. Freight aspiration is met or slightly exceeded. Large TACV investment leads to more freight. |
| 1.2.1 | Investment | There are large investments in TACV with long lead times for R&D and construction beginning in 1990; investment aspiration is exceeded. |
| 1.2.2 | Operating Costs | As in base case before introduction of TACV: then rise to aspiration then slightly exceed aspiration. |
| 1.2.3 | Operating Surplus/ Subsidy | As in base case before TACV introduction. Auto operating subsidy drops after introduction but additional subsidy needed for lower-income groups to use TACV. Thus, only slight increase (or equal) over aspiration. |
| 1.3.1 | Airports | After TACV introduction, there is a significant drain-off of air flights per day from aspirations. |
| 1.3.2 | Railroad Station | More of the unused railroad station capacity is utilized. |
| 1.3.3 | Bus Station | As in base case. |

(Table 7.2 continued)

| Hierarchical Number | Variable | Rationale for Change from Base Case |
|---|---|---|
| 1.3.4 | Roadways | As in base case before TACV introduction, then large decline in auts/day. |
| 2.1.1 | Demography | As in base case until TACV introduction than dramatic decreases from base case as relatively greater population growth occurs in the corridor along the guideway path. |
| 2.1.2 | Health Status | As in base case until TACV introduction then dramatic decrease from base case as auto use declines. |
| 2.2.1 | Land Use | As in base case until TACV introduction then dramatic increases over base case to meet aspiration. |
| 2.2.2 | Property Damage | As in base case until TACV introduction then dramatic decrease from base case as auto use drops. This variable then meets aspirations and finally exceeds them. |
| 2.2.3 | Noise Levels | As in base case until TACV introduction then moderate to dramatic decrease from base case as auto use, and hence, congestion declines and urban density drops due to population growth in corridor; these decreases accelerate with time. |
| 2.2.4 | Visibility | As 2.2.3 above. |
| 3.1.1. | Employment | Increased investment leadds to increased employment as the investment is made. Further, corridor growth also stimulates employment and together these influences result in higher employment. After introduction of TACV aspirations are slightly exceeded. |
| 3.2.1 | Fossil Fuel | As in base case until TAC introduction then dramatic decrease as auto use drops, then reaches but probably does not exceed aspirations. |
| 3.3.1 | GRP | As in 3.1.1 but the effects of investment and growth are more strongly felt. |

(Table 7.2 continued)

| Hierarchical Number | Variable | Rationale for Change from Base Case |
|---|---|---|
| 3.3.2 | Interre- gional Product | As in base case until TACV introduction then steady improvement with corridor growth (3.5%). |

Table 7.3 - Improved Passenger Train - Numerator

The IPT is a major, though evolutionary, change. With the advanced IPT, the travel time from Los Agneles to San Francisco is 3 hours including three stops (Fresno, Bakersfield, Stockton). The IPT uses existing rail tracks so requires less investment than the TACV. The IPT becomes available in 1990. Main effects are felt in the corridor.

| Hierarchial Number | Variable | Rationale for Change From Base Case |
|---|---|---|
| 1.1.1 | Passengers | After introduction of IPT, there is only a small increase in passenger-km over the base case beginning in 1990. The IPT then draws some passengers away from autos and buses but total passenger-km go up slightly. |
| 1.1.2 | Freight | The speed of IPT precludes mixing IPT and freight trains on the same tracks at the same time. However, in some cases, there are alternative tracks available. Hence, the impact of the IPT on freight is small though negative over the base case at first then zero as freight movements adapt. |
| 1.2.1 | Investment | The proposed IPT costs less than 500 million (Chesler and Goeller, 1973). Hence, all investment is embedded in the base case investment (i.e., evolutionary). |
| 1.2.2 | Operating Costs | Very slight increase over base case due to the fact that even though the IPT draws passengers from the auto and bus modes the cost of operating the highway system remains the same. |
| 1.2.3 | Operating Surplus/ Subsidy | Slight increase in subsidy because small additional IPT subsidy is added to base case. |
| 1.3.1 | Airports | IPT has no effect on air transportation system. |
| 1.3.2 | Railroad Station | A greater percentage of unused capacity is utilized by the IPT. |

(Table 7.3 continued)

| Hierarchial Number | Variable | Rationale For Change From Base Case |
|---|---|---|
| 1.3.3 | Bus Station | Expandable to meet all demand in this case. |
| 1.3.4 | Roadways | After introduction vehciles/day drop slightly below neutral level. |
| 2.1.1 | Corridor Demography | After introduction there is a slight decrease from the base case followed by moderate steady decline as greater relative growth of population occurs in the corridor. |
| 2.1.2 | Health Status | After introduction, there is a slight decrease that remains relatively constant as a result of reduced auto passenger-km. |
| 2.2.1 | Land Use | As in 2.1.1, with same growth. |
| 2.2.2 | Property Damage | As in 2.1.2, with same relative decrease. |
| 2.2.3 | Noise Levels | Slight decrease over base case because even though the IPT itself is loud, the effects of the IPT actually reduces noise levels. That is, there is less congestion on highway, lower urban density, etc. |
| 2.2.4 | Visibility | Slight decrease from base case due to reduced auto use. |
| 3.1.1 | Employment | Same as base case until corridor population growth can produce slight increase. That is a delayed but slightly positive effect. |
| 3.2.1 | Fossil Fuels | Slight reduction over base case due to reduced auto use. |
| 3.3.1 | GRP | Same as base case followed by same relative increase as in 3.1.1. |
| 3.3.2 | Interregional Product | After introduction, there is a slight decrease comparable to freight decrease and then a return to the base case. |

Table 7.4 - Improved Conventional Take-Off Or Landing Aircraft - Numerator

The improved CTOL is essentially a more efficient form of the aircraft flying now and has larger capacity. As such, its introduction into the aircraft fleet will be evolutionary as ageing aircraft are replaced with the CTOL. Since air transportation accounts for only a small though growing share of total intercity passenger kilometers, the effects of the improved CTOL will be a small and growing desirable change over the base case. The improved CTOL is introduced in 1990.

All comparison criteria not listed are the same as in the base case.

| Hierarchical Number | Comparison Criterion | Rationale For Change From Base Case |
|---|---|---|
| 1.1.1 | Passengers | Small increase over base case. |
| 1.3.1 | Airports | Since larger aircraft can carry more passengers per plane, slight decrease from base case. |
| 2.2.2 | Property Damage | Better aircraft induce more people to fly, and hence, lower auto use and auto accidents resulting in a slight decrease from base case. |
| 2.2.3 | Noise Levels | As in 2.2.2, there is a slight decrease from base case. |
| 2.2.4 | Visibility | The slight decrease in auto use leads to a slight decrease from the base case beginning in 2020. |
| 3.2.1 | Fossil Fuels | Exactly as in the base case except for the year 2010 when there is a slight decrease. The evolutionary introduction of the improved CTOL does not make any impact until 2010, and fusion produced hydrogen fuel dominates after 2010. |
| 3.3.1 | GRP | A slight increase over the base case as the aircraft manufacturing industry is within the region. |

## 8. EVALUATION

The data presented in Appendix C were used as input data to the evaluation model comprised of:

- the relative worth curves (Appendix B)
- relative weights (Equation (4-12) and Figure 4.5)
- objective function (Equations (4-13) through 4-24) and the discount rates on pages 50 and 51).

The results are presented in Table 8.1. For the data of the illustrative example, the Early TACV is the clearly preferred alternative; moveover, it is the only alternative that yields a positive total effect, i.e., that represents overall achievement of objectives.

To illustrate the computation of total effect, P, for a given alternative, consider the cirterion Passengers ($Y_{1.1.1}$) and the Early TACV. The results of analysis from Appendix C are:

| Year | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|
| $Y_{N\ 1.1.1}$ | 10.90 | 15.20 | 30.00 | 45.00 | 59.00 | 78.00 |
| $Y_{D\ 1.1.1}$ | 12.80 | 17.90 | 25.10 | 35.00 | 49.00 | 68.30 |
| $Y_{1.1.1}$ | 85.00 | 85.00 | 120.00 | 129.00 | 120.00 | 114.00 |

The relative worth of $Y_{1.1.1}$, $U_{1.1.1}$, for each year is obtained from the relative worth relationship (Appendix B):

| | | | | | | |
|---|---|---|---|---|---|---|
| $(U_{1.1.1})_t$ | -0.406 | -0.406 | +0.382 | +0.510 | +0.382 | +0.283 |

The time flow of $U_{1.1.1}$ is multiplied by its relative weight 7.5 (from Table 4.5) according to equation (4-12):

| | | | | | | |
|---|---|---|---|---|---|---|
| $(U_{1.1.1})_t$ | -3.05 | -3.05 | +2.87 | +3.83 | +2.87 | +2.14 |

These data, together with the time flows for the Base Case and the TACV, are shown in Figure 8.1. It is time flows such as these that are aggregated and then evaluated by means of the discount functions.

| Present Relative Worths<br>Ref: Equations (4-21) through (4-24) | | ALTERNATIVES | | | | |
|---|---|---|---|---|---|---|
| | | 1<br>Base Case | 2<br>TACV | 3<br>IPT | 4<br>Early TACV | 5<br>Improved CTOL |
| | $P_1$, Transportation Effects | - 4.15 | -2.33 | -3.56 | 0.36 | - 3.91 |
| | $P_2$, Societal Effects | -16.51 | -2.25 | -1.83 | 6.04 | -15.41 |
| | $P_3$, Economic Effects | - 3.83 | -0.63 | -3.17 | 1.57 | - 3.74 |
| | $P_4$, Total Effects | -24.48 | -5.22 | -8.57 | 7.93 | -23.06 |
| | RANK | 5 | 2 | 3 | 1 | 4 |

Table 8.1 - Results for Illustrative Example

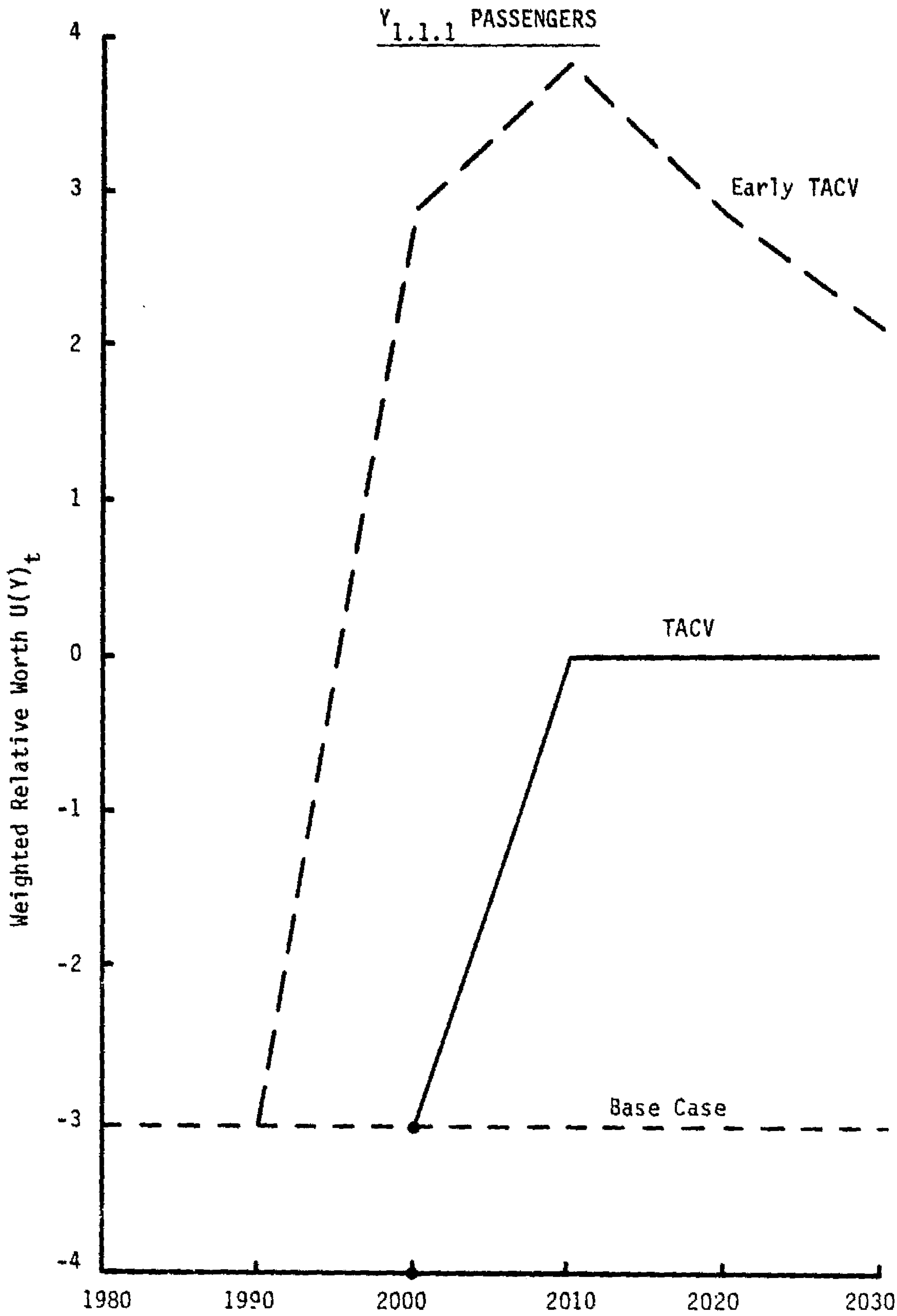



Figure 8.1 - Time Flow of Weighted Relative Worth

The time flows of weighted relative worths of the other criteria are similarly computed, e.g.,

| | | | | | | |
|---|---|---|---|---|---|---|
| $(Y_{1.1.2})_t$ | 100 | 100 | 104 | 102 | 102 | 102 |
| $(U_{1.1.2})_t$ | 0 | 0 | 0.323 | 0.173 | 0.173 | 0.173 |
| $(U_{1.1.2})_t$ | 0 | 0 | 2.42 | 1.30 | 1.30 | 1.30 |

The time flows of weighted relative worth are aggregated using equations (4-13) through (4-17), e.g.,

$$(U_{1.1})_t = (U_{1.1.1})_t + (U_{1.1.2})_t$$

$$(U_{1.1})_{1980} = -3.05 + 0 = -3.05$$

The resulting time flow in relative worth is:

| | | | | | | |
|---|---|---|---|---|---|---|
| $(U_{1.1})_t$ | -3.05 | -3.05 | +5.29 | 5.13 | 4.17 | 3.44 |

With linear interpolation to obtain data for intermediate years, the present relative worth of this time flow is, from equation (4-18):

$$P_{1.1} = +0.68$$

Similarly, the time flows of relative worths -- $(U_{1.2})_t$, $(U_{1.3})_t$, $(U_3)_t$ -- are converted to present worths through equations (4-19), (4-20), (4-21), (4-22), respectively. The aggregation of present worths is represented by Figure 8.2 and is accomplished with equations (4-23) and (4-24). The results are summaraized in Table 8.1.

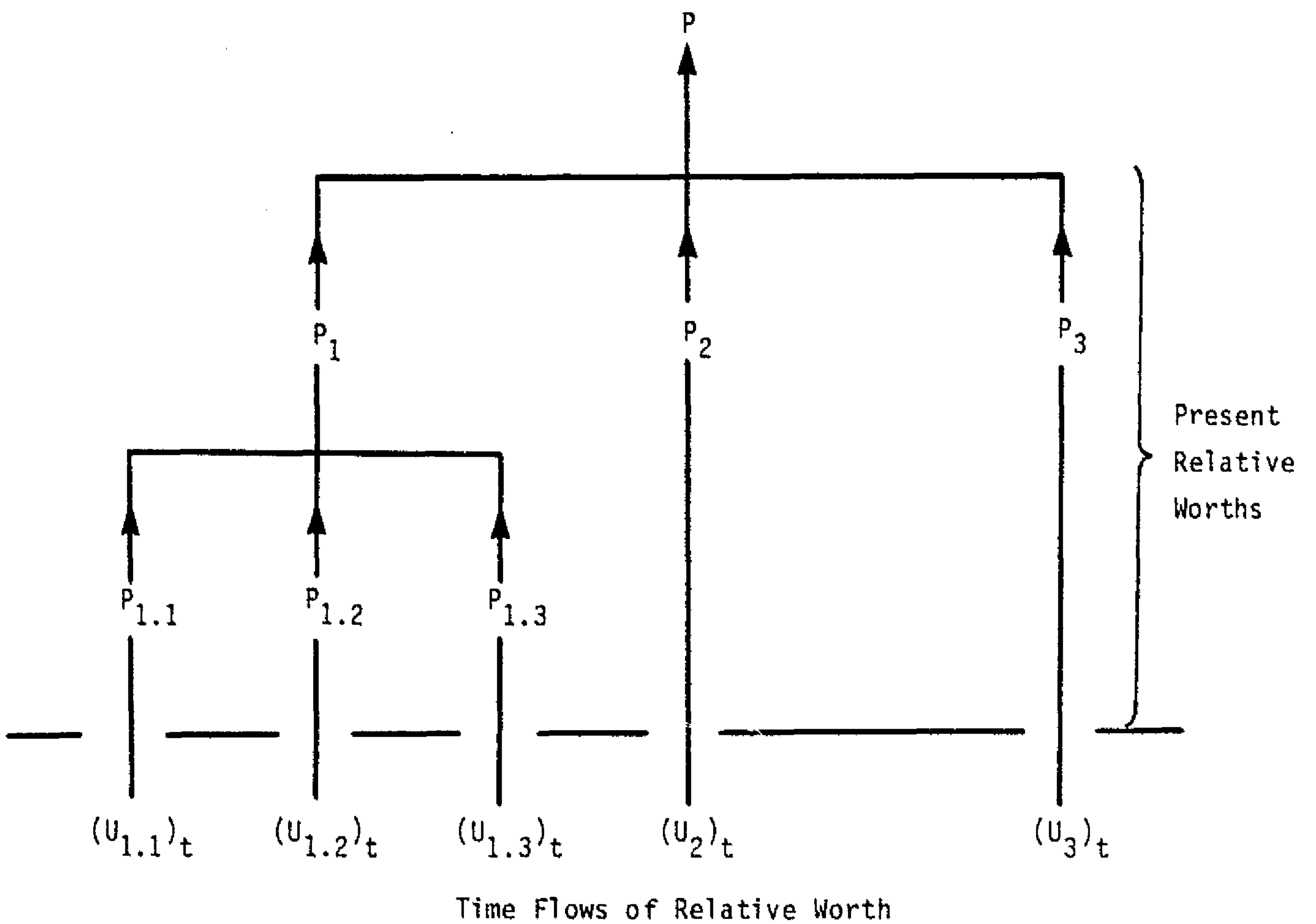



Figure 8.2 - Aggregation to Total Effect

## 9. SENSITIVITY ANALYSES

Ability to investigate sensitivity of the results of the evaluation model is illustrated for (1) changes in relative worth functions, (2) changes in relative weights, and (3) changes in discount rate.

### 9.1 Relative Worth Functions

Sensitivity to the shape of the relative worth functions is illustrated by assuming a straight line through $U(Y_T) = 0$ and $U(Y_M) = 1$ (Figure 9.1). The results are tabulated in Table 9.1.

Linearizing the relative worth functions resulted in a significant increase in all the present relative worths. The increase in relative scores was expected because all alternatives were unacceptable, with negative relative worths, and linear functions do not penalize unsatisfactory consequences as severely as nonlinear relationships.

For example, let us consider the criterion *Investment* ($Y_{1.2.1}$). The nonlinear and linear relative worth functions are shown in Figure 9.2. For the TACV in the year 2000, $Y_{1.2.1}$ is estimated to be 132 (Equation (4-1) and Appendix C). From Figure 9.2:

$$U(Y_{1.2.1})_N = -0.567 \text{ (nonlinear relative worth function)}$$

$$U(Y_{1.2.1})_L = -0.320 \text{ (linear relative worth function)}$$

Applying the relative weight $W_{1.2.1} = 6$ (Figure 4.5):

$$U(Y_{1.2.1})_N = -3.40$$

$$U(Y_{1.2.1})_L = -1.92$$

For this one criterion, therefore, the use of the linearized function to approximate relative worth results in an increase of 1.48 in relative worth.

An advantage of the nonlinear functions is demonstrated by the effect on TACV, where the relative score changed from negative to positive.

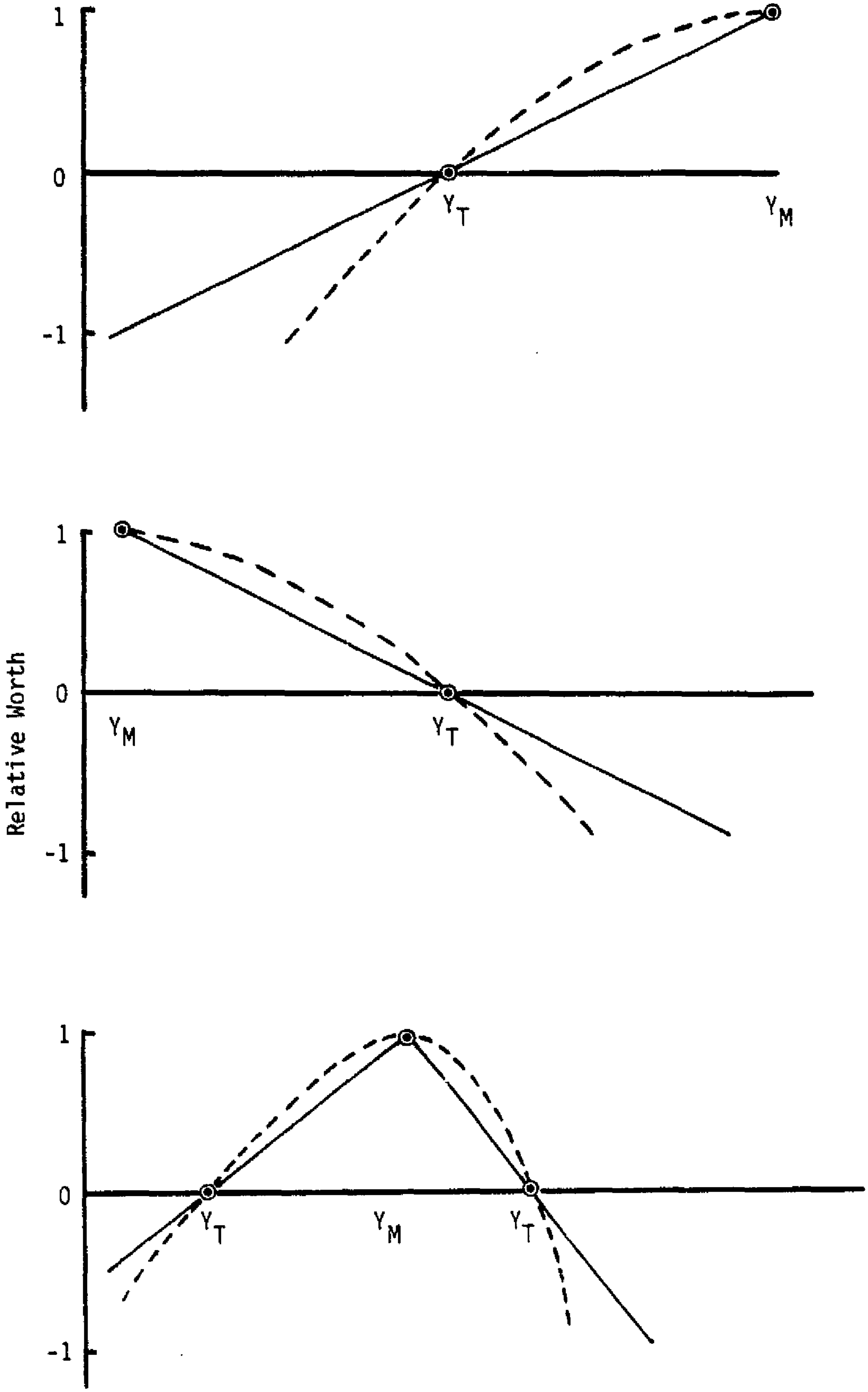



Figure 9.1 - General Form of Linearized Relative Worth Functions

| | Baseline Data U | Baseline Data Rank | Linear Relative Worth U | Linear Relative Worth Rank |
|---|---|---|---|---|
| <u>BASECASE</u> | | | | |
| $P_1$ | - 4.15 | 4 | - .33 | 4 |
| $P_2$ | -16.51 | 4 | -5.16 | 4 |
| $P_3$ | - 3.83 | 4 | - .79 | 4 |
| P | -24.48 | 4 | -6.28 | 4 |
| <u>TACV</u> | | | | |
| $P_1$ | - 2.33 | 1 | .36 | 2 |
| $P_2$ | - 2.25 | 2 | 1.05 | 1 |
| $P_3$ | - .63 | 1 | .30 | 1 |
| P | - 5.22 | 1 | 1.72 | 1 |
| <u>IPT</u> | | | | |
| $P_1$ | - 3.56 | 2 | .13 | 1 |
| $P_2$ | - 1.83 | 1 | .18 | 2 |
| $P_3$ | - 3.17 | 2 | - .64 | 2 |
| P | - 8.57 | 2 | - .34 | 2 |
| <u>CTOL</u> | | | | |
| $P_1$ | - 3.91 | 3 | - .29 | 3 |
| $P_2$ | -15.41 | 3 | -4.92 | 3 |
| $P_3$ | - 3.74 | 3 | - .78 | 3 |
| P | -23.06 | 3 | -5.99 | 3 |

Table 9.1 - Effect of Linearized Relative Worth

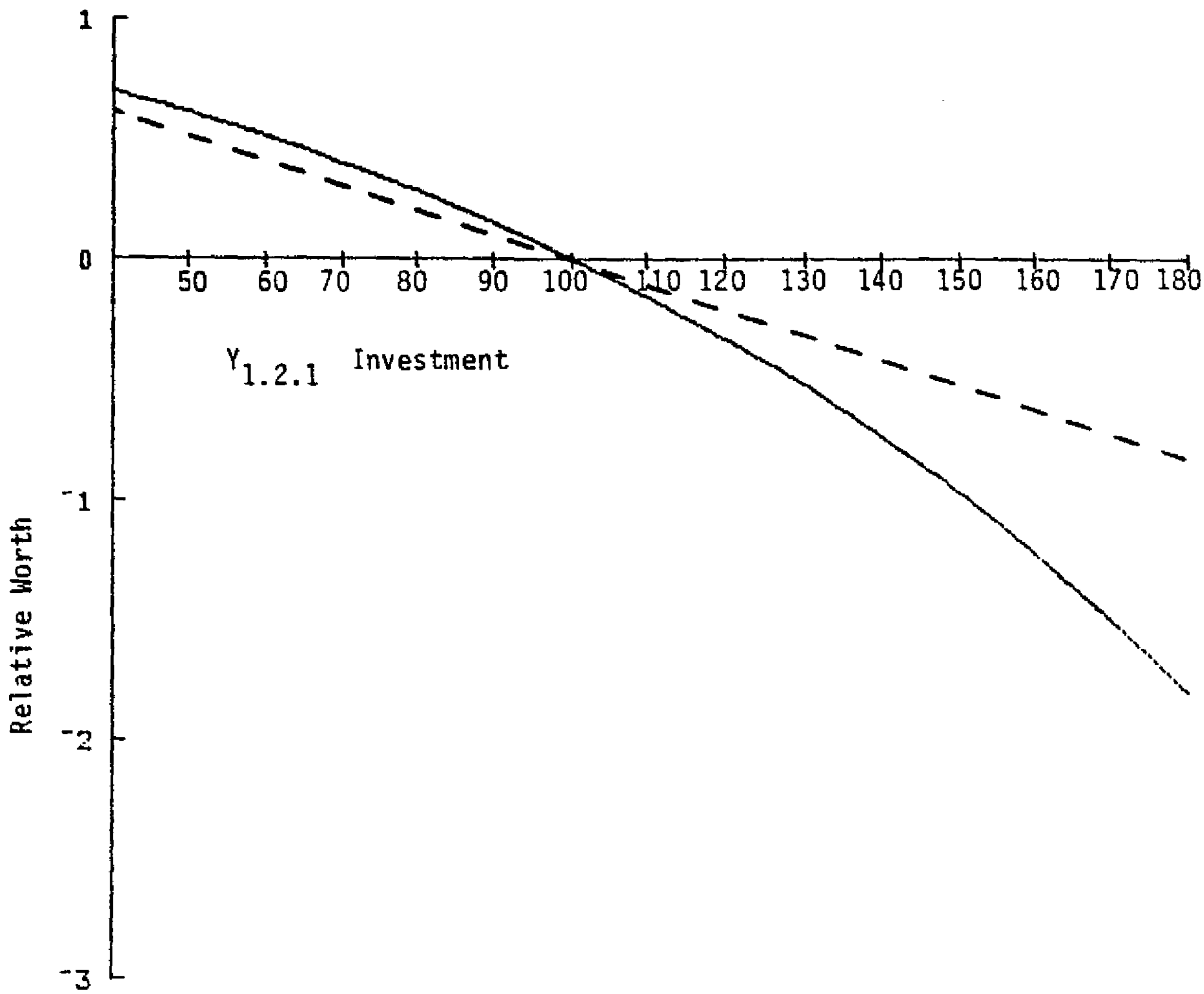



Figure 9.2 - Linear and Nonlinear Relative Worth Function

With zero relative worth defined to mean neutral contribution to success, the negative score indicates an unsatisfactory alternative and the positive score indicates an acceptable alternative. The linearized functions may not permit penalizing a truly unacceptable result on one criterion sufficiently to cause rejection of an alternative, while maintaining a consistent scoring for neutral and desirable results.

## 9.2 Relative Weights

Sensitivity to the choice of relative weights is illustrated by assuming an "environmentalist", who weights societal effects most heavily, an "economist", who weights economic effects most heavily (Table 9.2). The results are presented in Table 9.3 and Figures 9.3a,b, and c.

It is interesting that the four alternatives were ranked the same by three quite different sets of relative weights. The implication of this insensitivity is that there is little need to be concerned with establishing weights with great precision. Different interests and different priorities may be caused by disagreements concerning either the relative worth functions or estimates of the outcomes. In rating alternatives, both desirability of various amounts of a criterion and beliefs in what will occur can be more influential than is the relative importance of the criteria with respect to each other.

An advantage of the methodology is its ability to disaggregate a decision problem into its elements and to provide visibility for those elements where disagreements exist. Furthermore, signficance of the disagreements can be investigated.

## 9.3 Discount Rate r

Sensitivity to the choice of discount rate is illustrated by assuming that r (Section 4.5) is a constant over all criteria. The alternatives are evaluated for $r = 0$, 0.10, and 0.20. Results are presented in Table 9.4.

Although the change in discount rate did not alter the ranking of

| | Baseline Data | Environmentalist | Economist |
|---|---|---|---|
| 1.1.1 Passengers | 7.50 | 3.75 | 7.50 |
| 1.1.2 Freight | 7.50 | 3.75 | 7.50 |
| 1.2.1 Investment | 6.00 | 3.00 | 6.00 |
| 1.2.2 Operating Costs | 5.00 | 2.50 | 5.00 |
| 1.2.3 Surplus/Subsidy | 4.00 | 2.00 | 4.00 |
| 1.3.1 Urban Facility-Air | 3.00 | 1.50 | 3.00 |
| 1.3.2 Urban Facility-RR | 1.50 | .75 | 1.50 |
| 1.3.3 Urban Facility-Bus | 1.50 | .75 | 1.50 |
| 1.3.4 Urban Fac.-Road | 4.00 | 2.00 | 4.00 |
| 2.1.1 Corridor Demog. | 5.00 | 10.00 | 2.50 |
| 2.1.2 Health Status | 5.00 | 10.00 | 2.50 |
| 2.2.1 Corrid. Land Use | 5.00 | 10.00 | 2.50 |
| 2.2.2 Property Damage | 5.00 | 10.00 | 2.50 |
| 2.2.3 Noise Levels | 5.00 | 10.00 | 2.50 |
| 2.2.4 Visibility | 5.00 | 10.00 | 2.50 |
| 3.1.1 Employment | 7.50 | 5.00 | 11.25 |
| 3.2.1 Fossil Fuels | 7.50 | 5.00 | 11.25 |
| 3.3.1 Gross Reg. Prod. | 9.00 | 6.00 | 13.50 |
| 3.3.2 Interreg. Prod. | 6.00 | 4.00 | 9.00 |

Table 9.2 - Sensitivity to Relative Weights

| | Weights From Figure 11.2 U | RANK | Environmentalist U | RANK | Economist U | RANK |
|---|---|---|---|---|---|---|
| 1. Base Case | | | | | | |
| $P_1$ | - 4.15 | 5 | - 2.07 | 5 | - 4.15 | 5 |
| $P_2$ | -16.51 | 5 | -33.01 | 5 | - 8.25 | 5 |
| $P_3$ | - 3.83 | 5 | - 2.55 | 5 | - 5.74 | 5 |
| P (Total Effect) | -24.48 | 5 | -37.64 | 5 | -18.14 | 5 |
| 2. TACV | | | | | | |
| $P_1$ | - 2.33 | 2 | - 1.17 | 2 | - 2.33 | 3 |
| $P_2$ | - 2.25 | 3 | - 4.51 | 3 | - 1.13 | 3 |
| $P_3$ | - .63 | 2 | - .42 | 2 | - .34 | 2 |
| P | - 5.22 | 2 | - 6.09 | 2 | - 4.40 | 2 |
| 3. IPT | | | | | | |
| $P_1$ | - 3.56 | 3 | - 1.78 | 3 | - 3.56 | 2 |
| $P_2$ | - 1.83 | 2 | - 3.67 | 2 | - .92 | 2 |
| $P_3$ | - 3.17 | 3 | - 2.11 | 3 | - 4.76 | 3 |
| P | - 8.57 | 3 | - 7.56 | 3 | - 9.24 | 3 |
| 4. Early TACV | | | | | | |
| $P_1$ | .36 | 1 | .2[illegible] | 1 | .53 | 1 |
| $P_2$ | 6.04 | 1 | 12.07 | 1 | 3.03 | 1 |
| $P_3$ | 1.54 | 1 | 1.02 | 1 | 2.30 | 1 |
| P | 7.93 | 1 | 13.36 | 1 | 5.85 | 1 |
| 5. CTOL | | | | | | |
| $P_1$ | - 3.91 | 4 | - 1.95 | 4 | - 3.91 | 4 |
| $P_2$ | -15.41 | 4 | -30.82 | 4 | - 7.70 | 4 |
| $P_3$ | - 3.74 | 4 | - 2.49 | 4 | - 5.61 | 4 |
| P | -23.06 | 4 | -35.26 | 4 | -17.22 | 4 |

Table 9.3 - Sensitivity to Relative Weights - Results

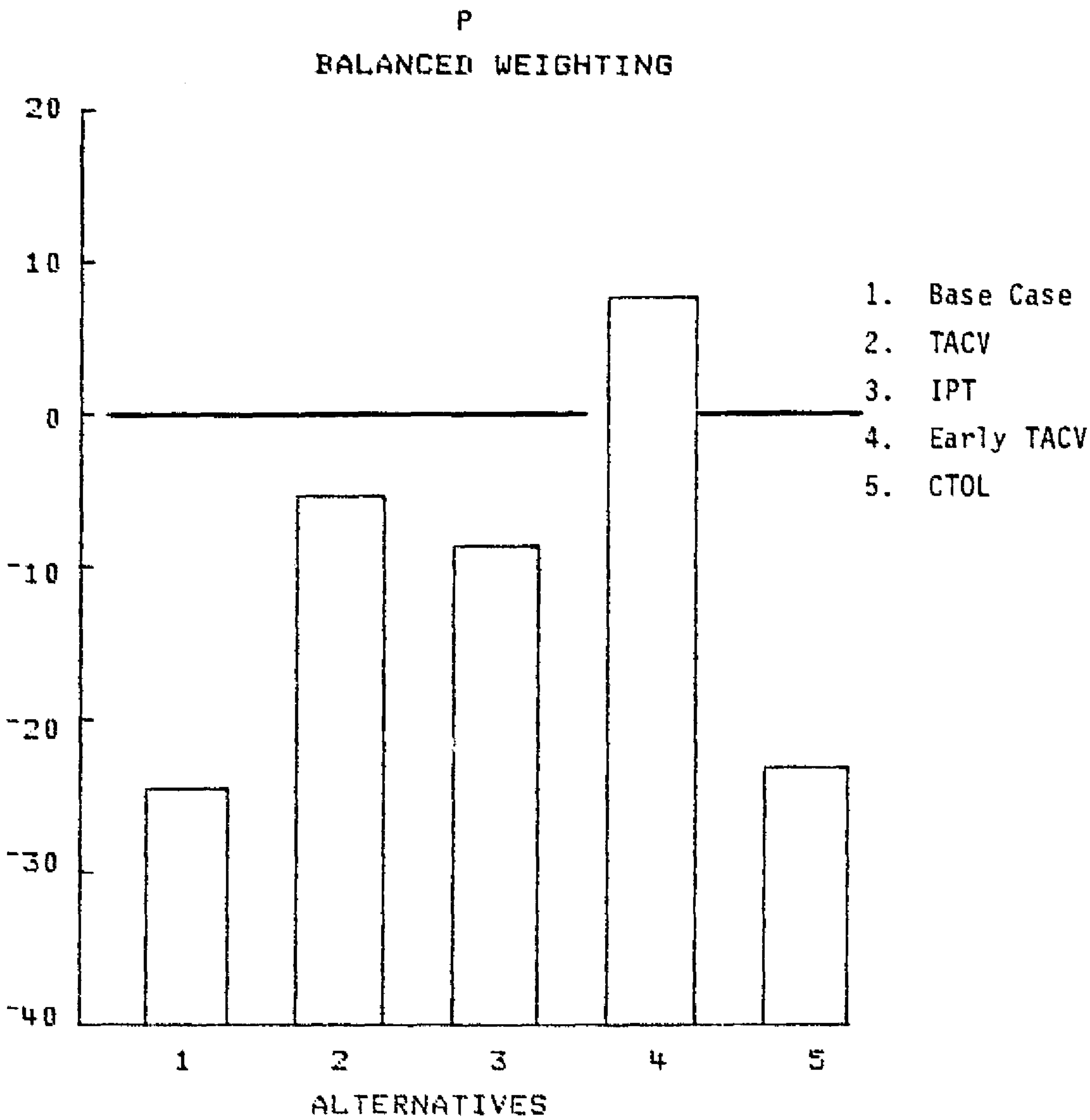



Figure 9.3a - Total Relative Worth: Baseline Data

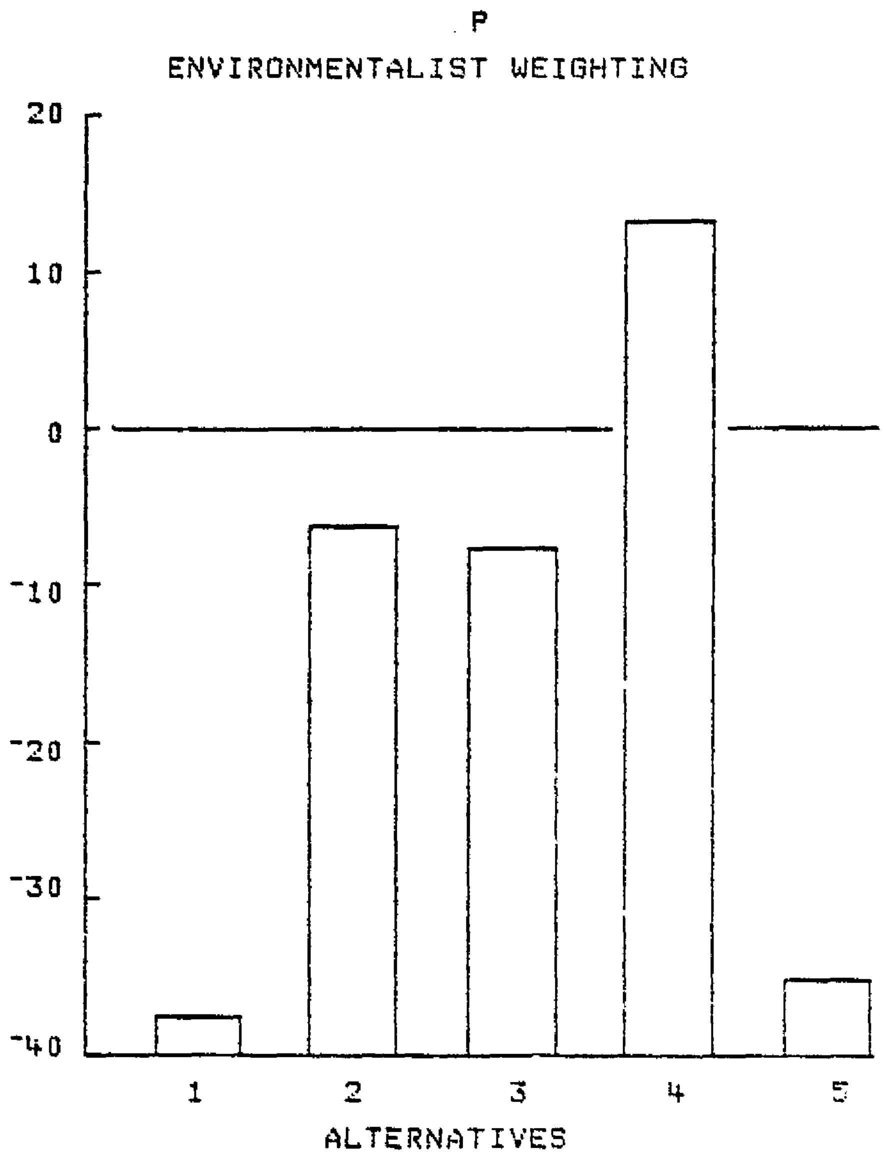



Figure 9.3b - Total Relative Worths:
"Environmentalist's" Relative Weights

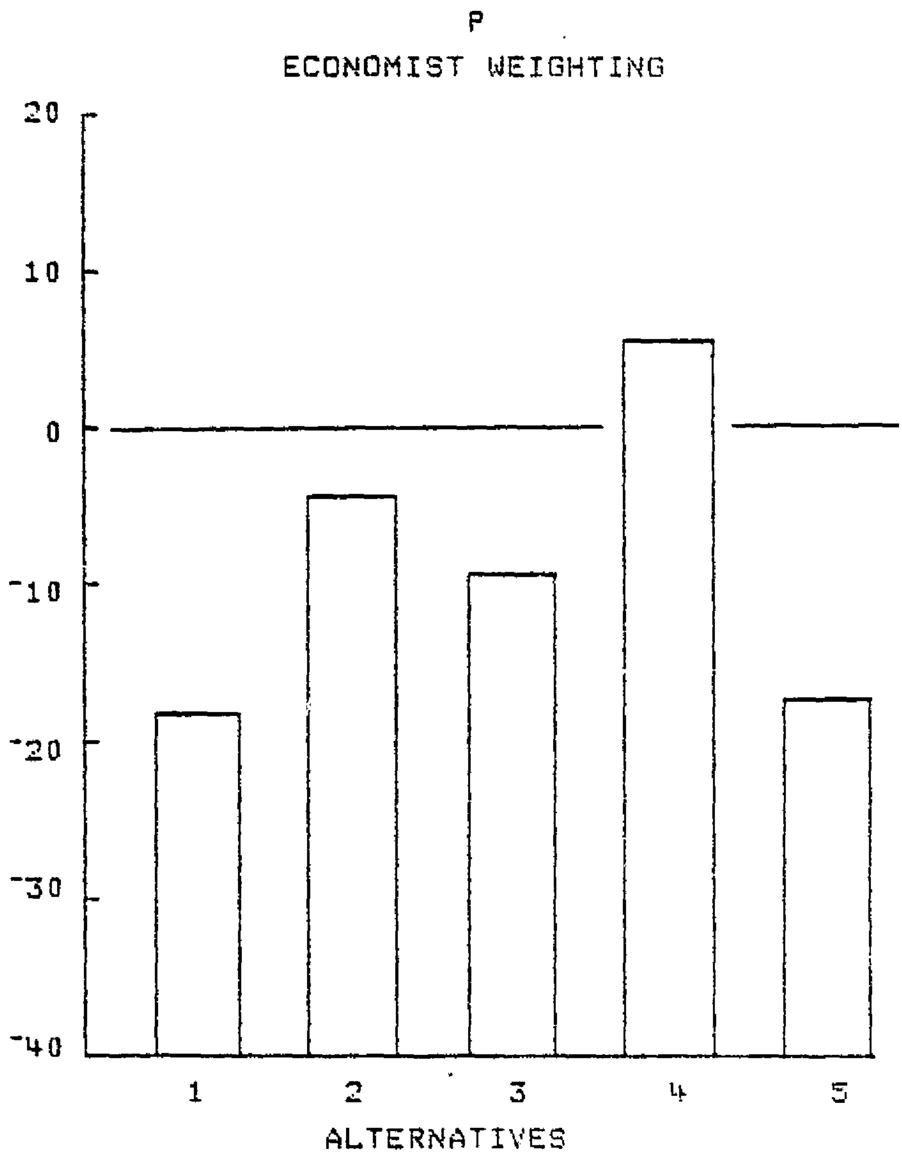



Figure 9.3c - Total Relative Worth:
"Economist's" Weights

| | BASELINE DATA | | R = 0 | | R = .10 | | R = .20 | |
|---|---|---|---|---|---|---|---|---|
| | U | RANK | U | RANK | U | RANK | U | RANK |
| 1. Base Case | | | | | | | | |
| $P_1$ | - 4.15 | 5 | - 6.80 | 5 | - 1.18 | 5 | - .58 | 4 |
| $P_2$ | -16.51 | 5 | -16.51 | 5 | - 1.54 | 5 | - .35 | 5 |
| $P_3$ | - 3.83 | 5 | -22.44 | 5 | - 3.83 | 5 | - 1.88 | 5 |
| P(Total Effect) | -24.48 | 5 | -45.74 | 5 | - 6.55 | 5 | - 2.81 | 5 |
| 2. TACV | | | | | | | | |
| $P_1$ | - 2.33 | 2 | + 1.23 | 2 | - 1.08 | 3 | - .64 | 5 |
| $P_2$ | - 2.25 | 3 | - 2.25 | 3 | - 1.10 | 3 | - .32 | 3½ |
| $P_3$ | - .63 | 2 | + .28 | 2 | - .63 | 2 | - .41 | 2 |
| P | - 5.22 | 2 | - .75 | 2 | - 2.81 | 2 | - 1.37 | 2 |
| 3. IPT | | | | | | | | |
| $P_1$ | - 3.56 | 3 | - 3.66 | 3 | - .80 | 2 | - .40 | 2 |
| $P_2$ | - 1.83 | 2 | - 1.83 | 2 | + .07 | 1 | + .13 | 1 |
| $P_3$ | - 3.17 | 3 | -10.74 | 3 | - 3.17 | 3 | - 1.78 | 3 |
| P | - 8.57 | 3 | -16.23 | 3 | - 3.91 | 3 | - 2.06 | 3 |
| 4. Early TACV (2000) | | | | | | | | |
| $P_1$ | + .36 | 1 | + 3.23 | 1 | - .52 | 1 | - .38 | 1 |
| $P_2$ | + 6.04 | 1 | + 6.04 | 1 | - .19 | 2 | - .15 | 2 |
| $P_3$ | + 1.54 | 1 | +11.54 | 1 | + 1.54 | 1 | + .60 | 1 |
| P | + 7.93 | 1 | +20.80 | 1 | + .82 | 1 | + .06 | 1 |
| 5. CTOL | | | | | | | | |
| $P_1$ | - 3.19 | 4 | - 6.38 | 4 | - 1.12 | 4 | - .56 | 3 |
| $P_2$ | -15.41 | 4 | -15.41 | 4 | - 1.45 | 4 | - .32 | 3½ |
| $P_3$ | - 3.74 | 4 | -21.78 | 4 | - 3.74 | 4 | - 1.85 | 4 |
| P | -23.06 | 4 | -43.57 | 4 | - 6.30 | 4 | - 2.73 | 4 |

Table 9.4 - Sensitivity to Discount Rate, R

alternatives, the effect of high interest rates applied to all criteria was to reduce the differences between alternatives, while r = 0 magnified such differences:

| r | Range of P<br>Early TACV - Base Case |
|---|---|
| Baseline data | 7.93-(-24.48) = 32.41 |
| 0 | 20.80-(-45.74) = 66.54 |
| 0.20 | 0.06-(- 2.81) = 2.87 |

The reason for this effect is that major differences between systems do not occur until they start to operate in the relatively distant future. High discount rates reduce to insignificance both costs and benefits taking place in 30 to 50 years. At r = 0.20, for example, a relative worth = 10 thirty years from now has a present worth = .024; a relative worth = 10 fifty years from today has a present worth = .000. Hence, if the benefits of new technologies are to significantly influence transportation decision-making, either discounting must be ignored (equivalent to setting r = 0) or the discount rates applied to transportation and societal benefits must be different from (lower than) the rate applied to dollar flows.

A further consequence of this phenomenon is illustrated in the data for the Early TACV. For the baseline data and for r = 0, the relative worth indicates this alternative to be definitely desirable, a transportation system representing signficant achievement of the specified policies and goals. At r = 0.20 on the other hand, the relative worth indicates marginal acceptability, with mildly undesirable transportation and societal effects. With a slightly higher r or small changes in the estimates of a few criteria, a negative relative worth could result. This is a special case of the general principle: at high discount rates, it is most difficult to justify investment in social systems requiring lengthy acquisition periods before benefits are realized through use of the system.

## 10. EVALUATION OF R&D

One way the Federal government can support a given intercity transportation mode or technology is through the funding of related R&D. To provide a timely impact on intercity transportation, decisions concerning the R&D activities to be funded should be made prior to or during the competitive exploration of alternative transportation system modal concepts. The purpose of this chapter is to illustrate how the comparison methodology evaluates both the mode technology and magnitude of such R&D.

The Tracked Air Cushion Vehicle (TACV) was chosen as the transportation mode to illustrate the evaluation of R&D funding. The TACV was selected because it is a high-technology, capital intensive candidate for Federal support.

Four levels of investment over a period of years were explored. The first level represents the evolutionary development of TACV, i.e., no new investment over the base case and an operational TACV in the year 2020. The second level of investment represents moderate Federal R&D funding that brings the TACV on line ten years earlier, in the year 2010. The third level of investment reflects heavy Federal support in all phases of research, development and demonstration, leading to the introduction of the TACV in the year 2000. The fourth level represents excessive funding, since it is believed that little advance in operational date can be achieved regardless of any practical R&D investments. The assumed relationship between funding level and operational date is shown in Figure 10.1.

Figure 10.1 also shows the effects of both the additional R&D investment and the early introduction of TACV benefits on total relative worth. The results incorporate the tradeoffs between the undesirable higher investment and timing of desirable benefits of the TACV transportation mode as measured by the relative worth functions, relative weights, and objective function of Chapter 4. From these assumed data, it would be concluded that the optimal investment in TACV, as measured by the total

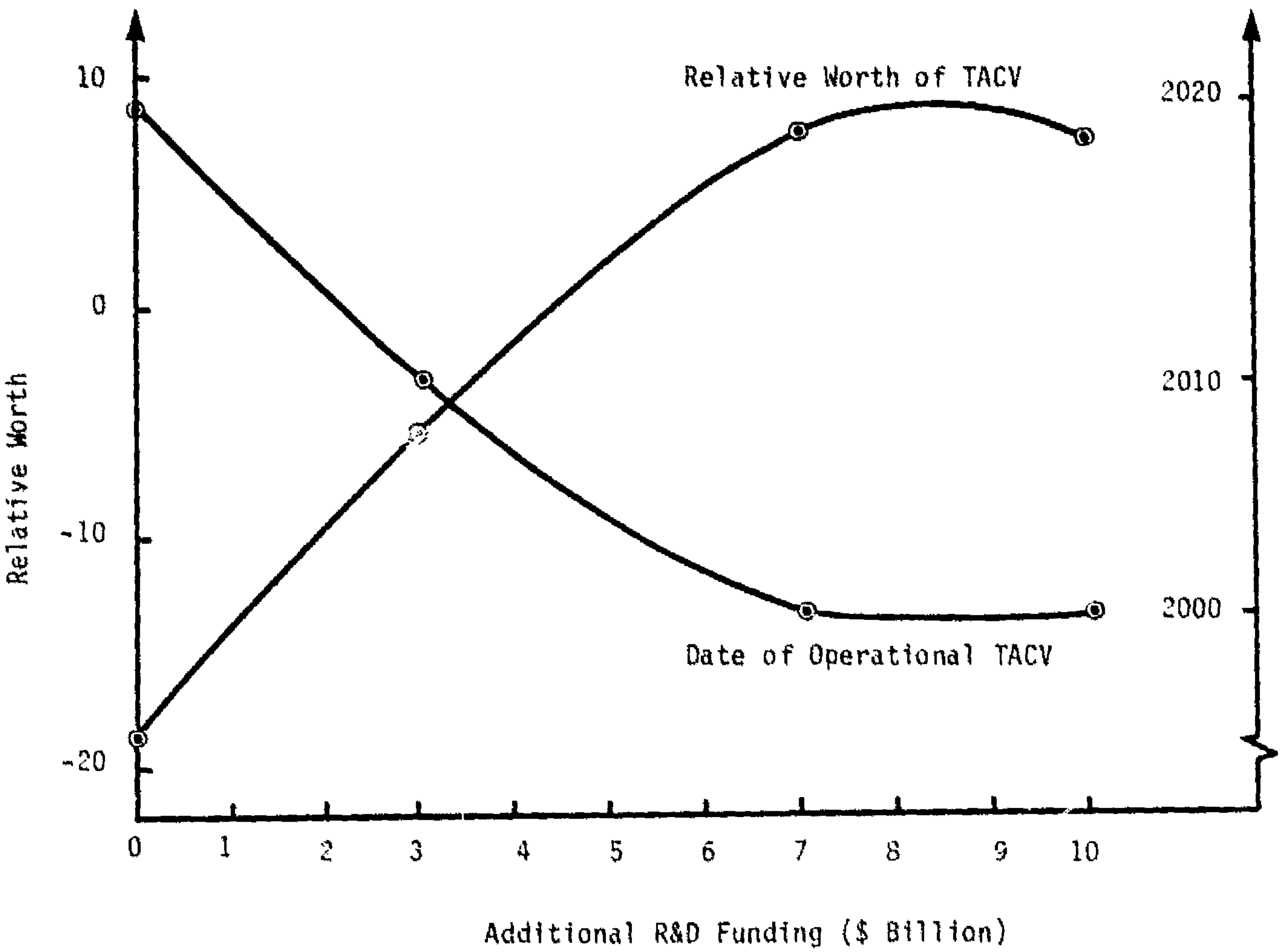



Figure 10.1 - Effects of Additional R&D Funding

effect on the selected intercity transportation system, would be between $7 billion and $8 billion.

Similar analyses and evaluations could be performed for other R&D candidates and for other intercity systems, as required. Quantitative results, directly and demonstrably related to achievement of DOT policies and objectives, would be available for selection and justification of R&D programs.

# 11. EVALUATION OF RISK

Risk associated with a transportation alternative arises from the uncertainty in the estimates of the comparison criteria. The standard technique for quantifying risk so that it can be reviewed, discussed and evaluated is to define a probability function over the range of uncertainty of the esimate.

The methodological framework defined and illustrated in the preceding chapters provides the tools and techniques for evaluating risk with the following two modifications:

(1) The analysis framework estimates a probability function rather than a best estimate for each comparison criterion.

(2) An expected relative worth is computed rather than the relative worth of the best estimate of a criterion:

$$E(u) = \int_{Y_L}^{Y_U} u(Y)\, F(Y)\, dY$$

where $Y$ = a comparison criterion

$u(Y)$ = relative worth of $Y$

$F(Y)$ = ordinate of probability function

$E(u)$ = expected relative worth

When risk is quantified, the expected relative worth rather than the relative worth of the best estimate is used for the balance of the evaluation computation. The only change in the evaluation model of Chapter 4 is the to use $E(u)$ for $u(Y)$ in equation (4-9).

To illustrate the application of this risk evaluation technique, (which is theoretically sound, e.g., Fishburn, 1974; Lifson, 1972), uncertainty in the criterion *Passengers* was assumed. Uncertainties were assumed to be relatively small (i.e., the variance of the distribution is small) in the near future and to increase with futurity. The probability distributions for the years, 1980, 2000, and 2030 are shown in Figure 11.1. The best estimate and the range of uncertainty over the planning

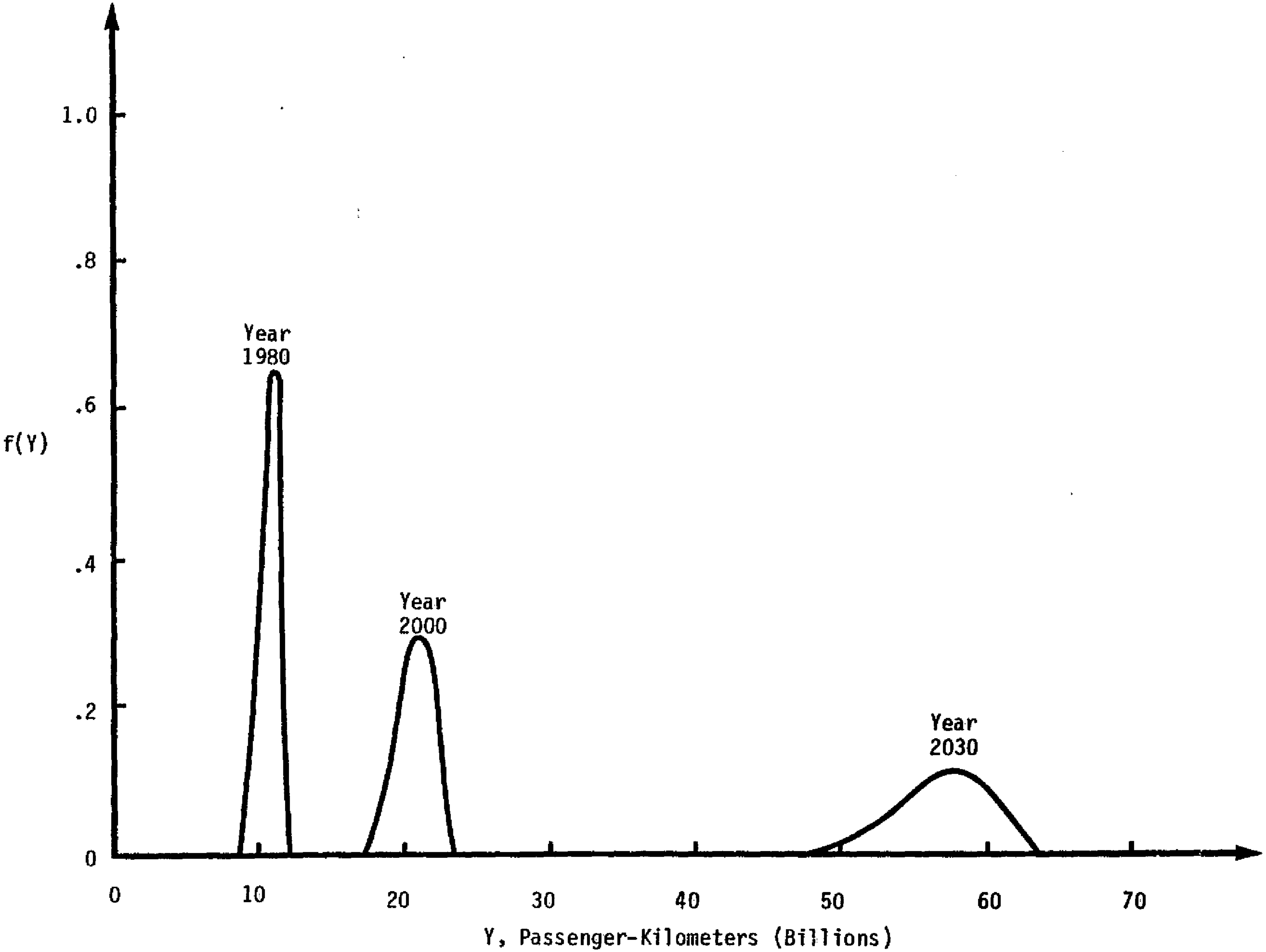



Figure 11.1 - Qualifications of Risk: Passengers

period is shown in Figure 11.2.

For the data of Figure 11.1 and the relative worth function (Appendix B) and weight (Figure 4.5) for the criterion *Passengers*, the results of computing E(u) rather than the relative worth of the best estimate are as follows:

| Year | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|
| E(u) | -3.24 | -3.31 | -3.47 | -3.43 | -3.42 | -3.47 |
| Best Estimate | -3.01 | -3.07 | -3.08 | -3.01 | -3.07 | -3.03 |

As desired, the relative worth with risk is lower (more negative) than for the best estimate with no uncertainty. This result is a consequence of the nonlinearity and shape of the relative worth function. If the nonlinearity were increased, the effects of risk on expected relative worth would be more negative, indicating greater aversion to risk.

The computations required for the evaluation of risk are rational and feasible. The limiting constraints on the application of the methodology lie in the willingness and ability to estimate probabilities as part of the analysis activity.

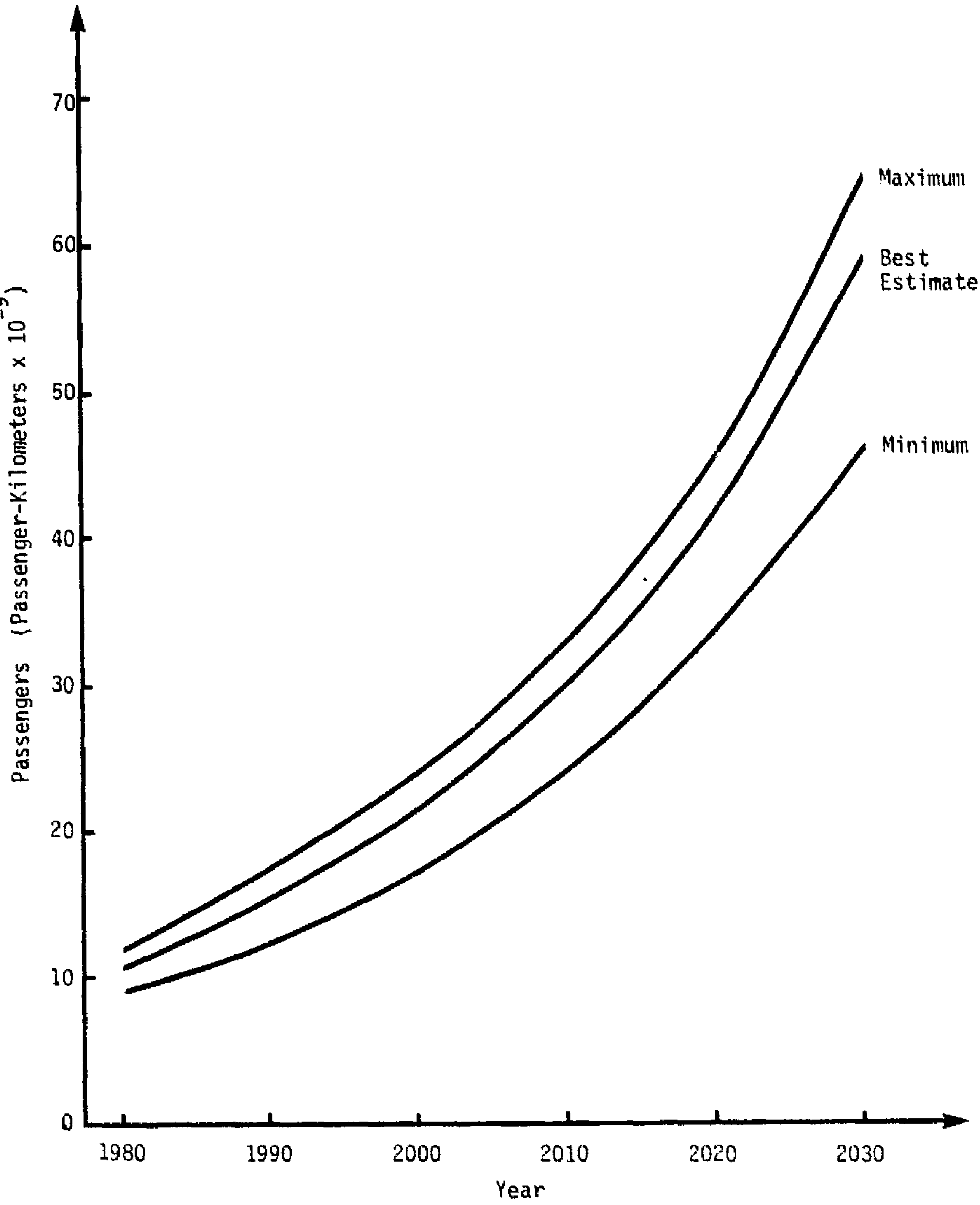



Figure 11.2 - Assumed Range of Uncertainty in Estimates of Criterion: Passengers

## 12. CONCLUSIONS AND RECOMMENDATIONS

Based on the development of the ECONERGY comparison methodology for intercity transportation systems as described in this report, the following conclusions are reached.

- A new method for dealing satisfactorily with long-term development of new technology for transportation systmes has been introduced. This new method is based on establishing an aspiration for desirable transportation features in a long-run future, compatible with long-term socio-economic projections.

- Risk is innate in new technology. However, the risk in any proposed technology should be assessed in the overall context of system risk. The ECONERGY method, by considering alternatives as portfolios of technologies, meets this essential.

- Traditional methodologies for comparing transportation systems have been used for specific technologies and for specific regional systems. Comparisons are made in terms of performance measures usually limited in number and with short-term horizons. The ECONERGY methodology provides a means for considering any number of variables, but what is more significant, shifts the focus from performance to worth of performance. By systematic emphasis on concern for those values on which judgmental decisions can best be made and providing an integrating mechanism, a manageable and readily applied technique is provided.

- In one way or another, a decision is reached by applying some value system -- always judgmental. The ECONERGY methodology calls for breaking down the problem into bite-sized elements -- the performance variables -- and applying judgments to obtain relative worths. The degree to which this subdivision is carried out may improve the results, but this is up to the analyst. The level of effort to accomplish the evaluation can range from modest to extensive, depending on the degree of involvement of expert opinion. The comparison methodology has a great degree of flexibility in the level of effort needed for its successful application. For the illustrative example included in this report, the level of effort was measured in man-weeks. Calculations for this report were performed on a small desk-top computer and hand-held calculators. However, if a number of sophisticated analytic models were desired for the analysis framework, man-years and large-scale computers might be required. The necessary level of effort for effective use of the methodology is appropriately defined during Phase II.

- The definition of alternative transportation systems includes the kinds of R&D needed, its funding level and schedule. Thus, the conclusion of the comparison exercise reveals the required amounts of R&D as well as the potential loss for not launching timely R&D programs.

- The Executive Office has specified policies governing new systems aquisition and DOT has established long-term National transportation objectives. The ECONERGY Methodology is designed to best meet both requirements.

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# APPENDIX A

# COMPARISON CRITERIA DEFINITIONS

# FOR

# ILLUSTRATIVE EXAMPLE

| CRITERION NAME | UNIT OF MEASUREMENT FOR NUMERATOR AND DENOMINATOR | DEFINITIONS |
|---|---|---|
| $Y_{1.1.1}$ Passengers (%) | $\frac{\text{Passenger-Kilometers}}{\text{Year}}$ | $Y_{1.1.1} = 100 \frac{Y_{N\ 1.1.1}}{Y_{D\ 1.1.1}}$<br>$Y_{N\ 1.1.1}$ = Ridership on intercity system<br>$Y_{D}\ 1.1.1$ = Ridership that represents neutral achievement of ridership goals |
| $Y_{1.1.2}$ Freight (%) | $\frac{\text{Tonne-Kilometers}}{\text{Year}}$ | $Y_{1.1.2} = 100 \frac{Y_{N\ 1.1.2}}{Y_{D\ 1.1.2}}$<br>$Y_{N\ 1.1.2}$ = Number of tonne-kilometers of freight expected to be carried on intercity system<br>$Y_{D\ 1.1.2}$ = Number of tonne-kilometers of freight that represents neutral achievement of goals |

| CRITERION NAME | UNIT OF MEASUREMENT FOR NUMERATOR AND DENOMINATOR | DEFINITIONS |
|---|---|---|
| 1.2.1 Investment (%) | Dollars/Year | $Y_{1.2.1} = 100 \frac{Y_{N\ 1.2.1}}{Y_{D\ 1.2.1}}$<br><br>$Y_{N\ 1.2.1}$ = Funds expended in specified time period (one year) for non-recurring costs of acquiring and bringing to operational status the land, structures, equipments, software, and organizational elements of the intercity transportation system, including *R&D*, training and logistic support elements<br><br>$Y_{D\ 1.2.1}$ = Funds expended (as defined above) that represent neutral acheivement of investment budgetary objectives |

| CRITERION NAME | UNIT OF MEASUREMENT FOR NUMERATOR AND DENOMINATOR | DEFINITIONS |
|---|---|---|
| 1.2.3 Operating Surplus/ Subsidy (%) | Dollars/Year | $Y_{1.2.3} = 100 \dfrac{\text{Usercharges} - Y_{N\,1.2.2}}{Y_{N\,1.2.2}}$<br>$Y_{D\,1.2.3} = Y_{N\,1.2.2}$<br>When $Y_{1.2.3} > 0$, $Y_{1.2.3} \triangleq$ Operating Surplus<br>When $Y_{1.2.3} < 0$, $Y_{1.2.3} \triangleq$ Operating Subsidy |
| 1.3.1 Airports (%) | Flights/Day | $Y_{1.3.1} = 100 \dfrac{Y_{N\,1.3.1}}{Y_{D\,1.3.1}}$<br>$= 100 \dfrac{\text{Number of flights/day}}{\text{Airport design capacity}}$ |
| 1.3.2 Railroad Stations (%) | Trains/Day | $Y_{1.3.2} = 100 \dfrac{Y_{N\,1.3.2}}{Y_{D\,1.3.2}}$<br>$= 100 \dfrac{\text{Number of trains/day}}{\text{Station design capacity}}$ |

| CRITERION NAME | UNIT OF MEASUREMENT FOR NUMERATOR AND DENOMINATOR | DEFINITIONS |
|---|---|---|
| 1.2.2 Operating Costs | Dollars/Year | $Y_{1.2.2} = 100 \frac{Y_{N\ 1.2.2}}{Y_{D\ 1.2.2}}$<br>$Y_{N\ 1.2.2}$ = Funds expended in specified time period (one year) for operation of the intercity transportation system, including maintenance, repair, other logistic support elements and taxes<br>$Y_{D\ 1.2.2}$ = Fund expended (as defined above) that represent neutral achievement of operating budget goals |

| CRITERION NAME | UNIT OF MEASUREMENT FOR NUMERATOR AND DENOMINATOR | DEFINITIONS |
|---|---|---|
| 1.3.3 Bus Stations (%) | Buses/Day | $Y_{1.3.3} = 100 \frac{Y_{N\ 1.3.3}}{Y_{D\ 1.3.3}}$<br>$= 100 \frac{\text{Number of buses/day}}{\text{Station design capacity}}$ |
| 1.3.4 Roads (%) | Vehicles/Day | $Y_{1.3.4} = 100 \frac{Y_{N\ 1.3.4}}{Y_{D\ 1.3.4}}$<br>$= 100 \frac{\text{Number of vehicles/day}}{\text{Roadway design capacity}}$ |
| 2.1.1 Demography (%) | $\frac{\text{People/Hectare}}{\text{People/Hectare}}$ | $Y_{2.1.1} = 100 \frac{Y_{N\ 2.1.1}}{Y_{D\ 2.1.1}}$<br>$Y_{N\ 2.1.1} = \frac{\text{Urban population/urban area}}{\text{Population in Region/Region area}}$<br>$Y_{D\ 2.1.1}$ = Level of $Y_{N\ 2.1.1}$ that represents neutral achievement of demographic objective |

| CRITERION NAME | UNIT OF MEASUREMENT FOR NUMERATOR AND DENOMINATOR | DEFINITIONS |
| --- | --- | --- |
| 2.1.2 Health Status (%) | Number of people Injured/year | $Y_{2.1.2} = 100 \frac{Y_{N\ 2.1.2}}{Y_{D\ 2.1.2}}$<br><br>$Y_{N\ 2.1.2}$ = Number of people injured per year as a result of:<br>• pollution<br>• accidents<br>• criminal acts<br><br>$Y_{D\ 2.1.2}$ = Number of people injured that represents neutral achievement of intercity transportation goals |

| CRITERION NAME | UNIT OF MEASUREMENT FOR NUMERATOR AND DENOMINATOR | DEFINITIONS |
|---|---|---|
| 2.2.1 Land Use (%) | Hectares | $Y_{2.2.1} = 100 \frac{Y_{N\ 2.2.1}}{Y_{D\ 2.2.1}}$<br>$Y_{N\ 2.2.1} = \frac{\text{Urban area, hectares}}{\text{Urban + farm area, hectares}}$<br>$Y_{D\ 2.2.1} = \frac{\text{Magnitude of ratio, urban area}}{\text{Urban area + farm area}}$, that represents neutral achievement of land use goals |
| 2.2.2 Property Damage (%) | Dollars/Year | $Y_{2.2.2} = 100 \frac{Y_{N\ 2.2.2}}{Y_{D\ 2.2.2}}$<br>$Y_{N\ 2.2.2}$ = Property damage due to environmental pollution, accidents and criminal acts, dollars<br>$Y_{D\ 2.2.2}$ = Property damage that represents neutral achievement of inter-city transportation system objectives, dollars |

| CRITERION NAME | UNIT OF MEASUREMENT FOR NUMERATOR AND DENOMINATOR | DEFINITIONS |
|---|---|---|
| 2.2.3 Noise Levels | People/Year | $Y_{2.2.3} = 100 \frac{Y_{N\ 2.2.3}}{Y_{D\ 2.2.3}}$<br>$Y_{N\ 2.2.3}$ = Number of people per year exposed to objectionable noise levels on a regular basis<br>$Y_{D\ 2.2.3}$ = Number of people per year that represents neutral achievement of noise abatement goals |
| 2.2.4 Visibility (%) | People | $Y_{2.2.4} = 100 \frac{Y_{N\ 2.2.4}}{Y_{D\ 2.2.4}}$<br>$Y_{N\ 2.2.4}$ = The number of people exposed to undesirable levels of visibility on a regular basis<br>$Y_{D\ 2.2.4}$ = Number of people exposed to undesirable levels of visibility on a regular basis that represents |

| CRITERION NAME | UNIT OF MEASUREMENT FOR NUMERATOR AND DENOMINATOR | DEFINITIONS |
| --- | --- | --- |
| 2.2.4 (Continued) | | neutral achievement of visibility goals |
| 3.1.1 Employment (%) | Number of People | $Y_{3.1.1} = 100 \frac{Y_{N\ 3.1.1}}{Y_{D\ 3.1.1}}$<br>$Y_{N\ 3.1.1}$ = Number of people employed<br>$Y_{D\ 3.1.1}$ = Number of people in the labor pool |
| 3.2.1 Fossil Fuels (%) | Liters/Year | $Y_{3.2.1} = 100 \frac{Y_{N\ 3.2.1}}{Y_{D\ 3.2.1}}$<br>$Y_{N\ 3.2.1}$ = Number of liters/year of fossil fuels consumed by the intercity transportation system<br>$Y_{D\ 3.2.1}$ = Number of liters/year of fossil fuels consumed by the intercity |

| CRITERION NAME | UNIT OF MEASUREMENT FOR NUMERATOR AND DENOMINATOR | DEFINITIONS |
|---|---|---|
| 3.2.1 (Continued) | | transportation system that represents neutral achievement of intercity transportation goals |
| 3.3.1 Gross Regional Product (%) | Dollars/Year | $Y_{3.3.1} = 100 \frac{Y_{N\ 3.3.1}}{Y_{D\ 3.3.1}}$<br>$Y_{N\ 3.3.1}$ = Gross regional product, dollars/year<br>$Y_{D\ 3.3.1}$ = Gross regional product that represents neutral achievement of intercity transportation goals, dollars/year |

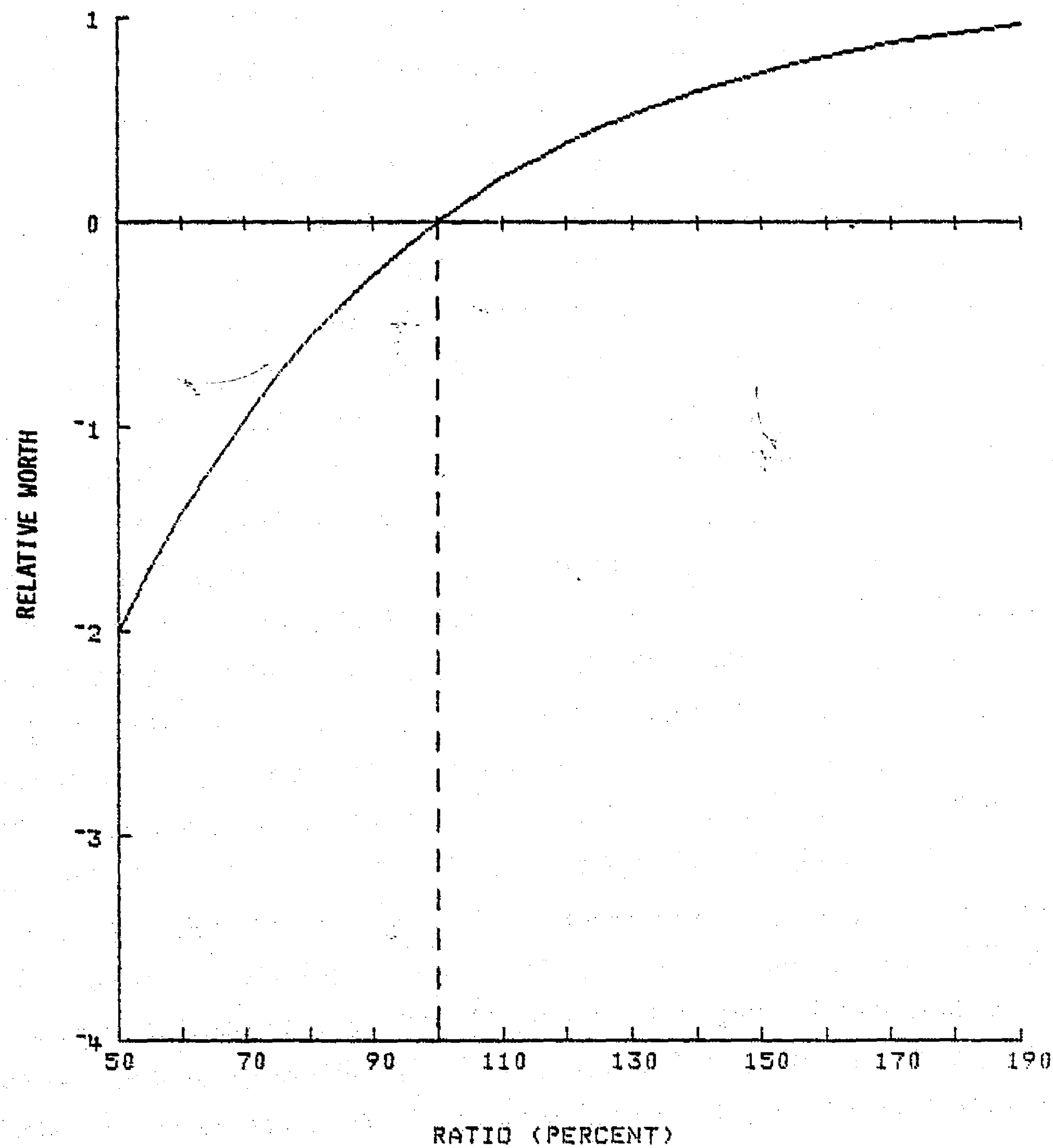
| CRITERION NAME | UNIT OF MEASUREMENT FOR NUMERATOR AND DENOMINATOR | DEFINITIONS |
|---|---|---|
| 3.3.2 Interregional Product | Dollars/Year | $Y_{3.3.2} = 100 \frac{Y_{N\ 3.3.2}}{Y_{D\ 3.3.2}}$<br><br>$Y_{N\ 3.3.2}$ = Value of goods and services that cross regional boundaries, dollars/year<br><br>$Y_{D\ 3.3.2}$ = Value of goods and services that cross regional boundaries that represent neutral achievement of intercity transportation system goals, dollars/year |

# APPENDIX B

# RELATIVE WORTH FUNCTIONS

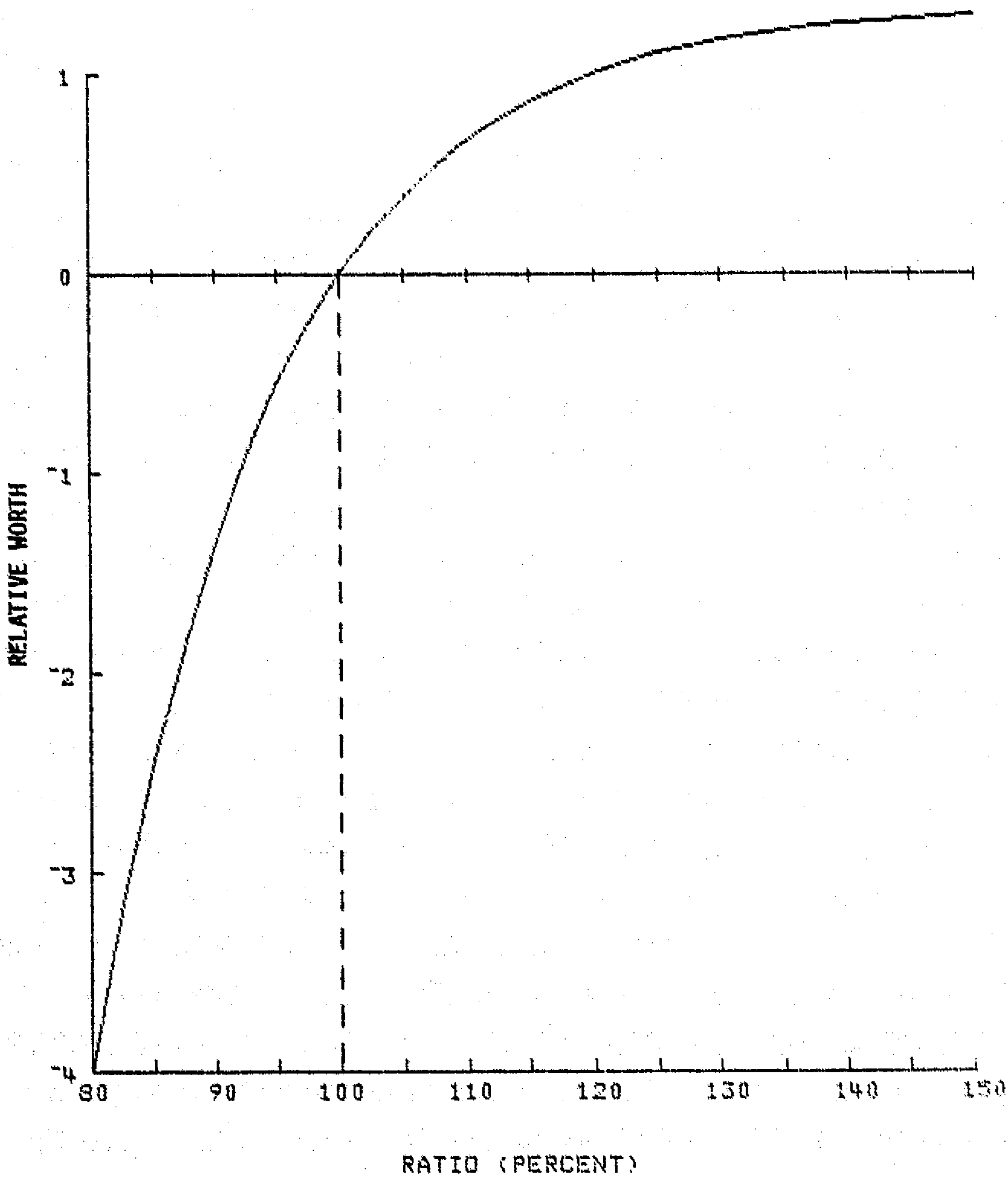
RELATIVE WORTH

1.1.1 Passengers



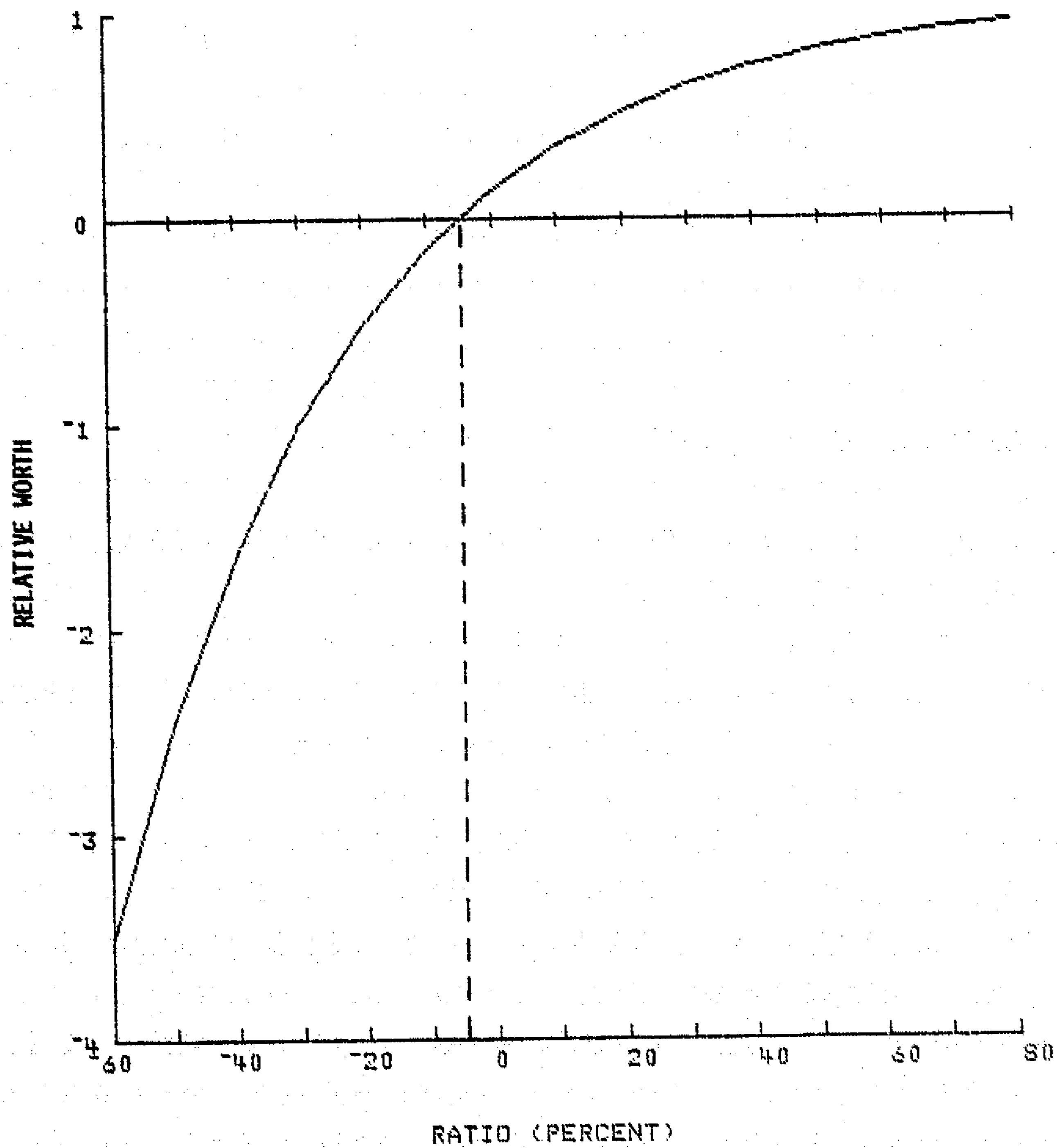
RELATIVE WORTH

1.1.2 Freight

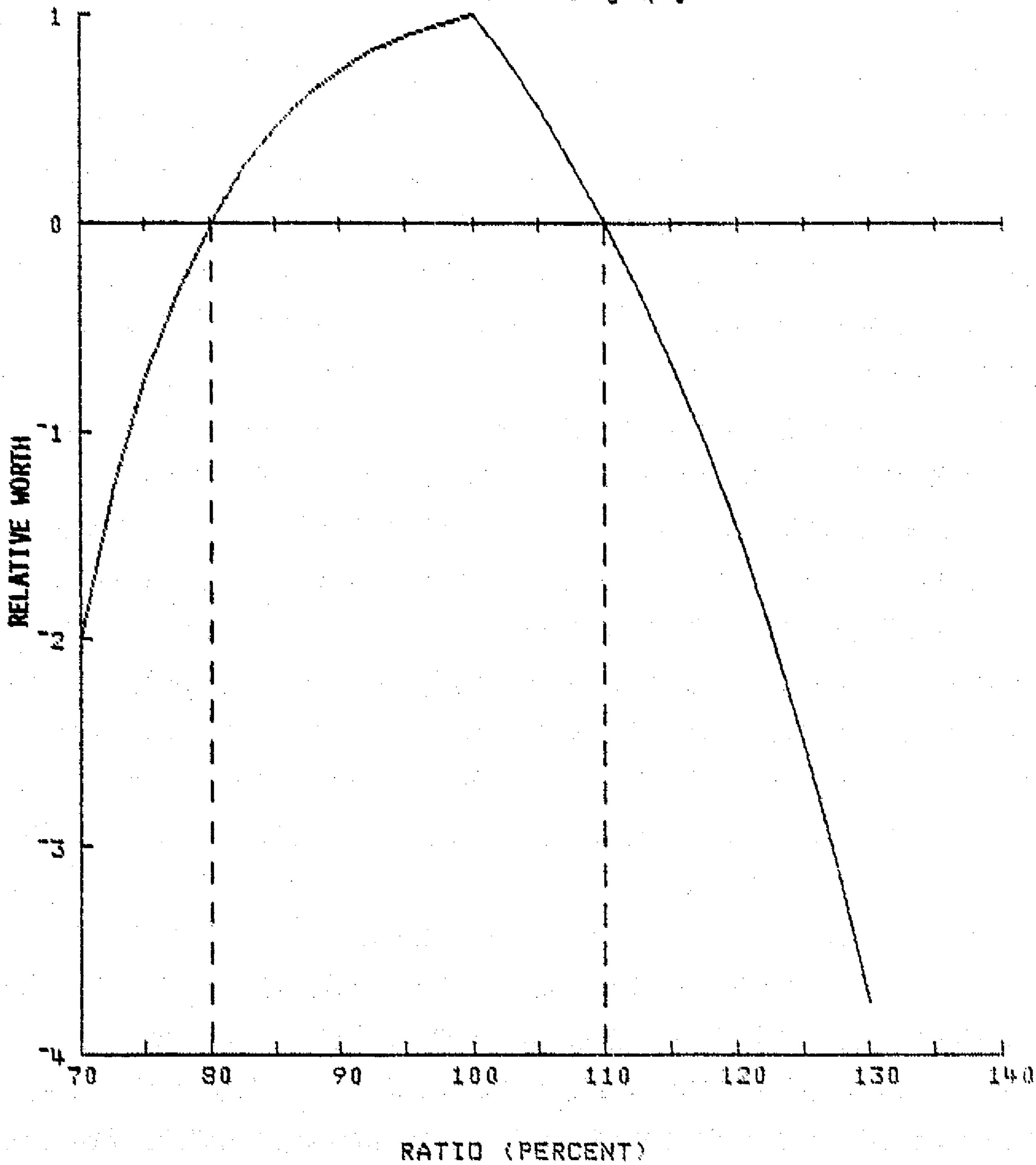


RELATIVE WORTH

1.2.3 Operating Surplus/Subsidy

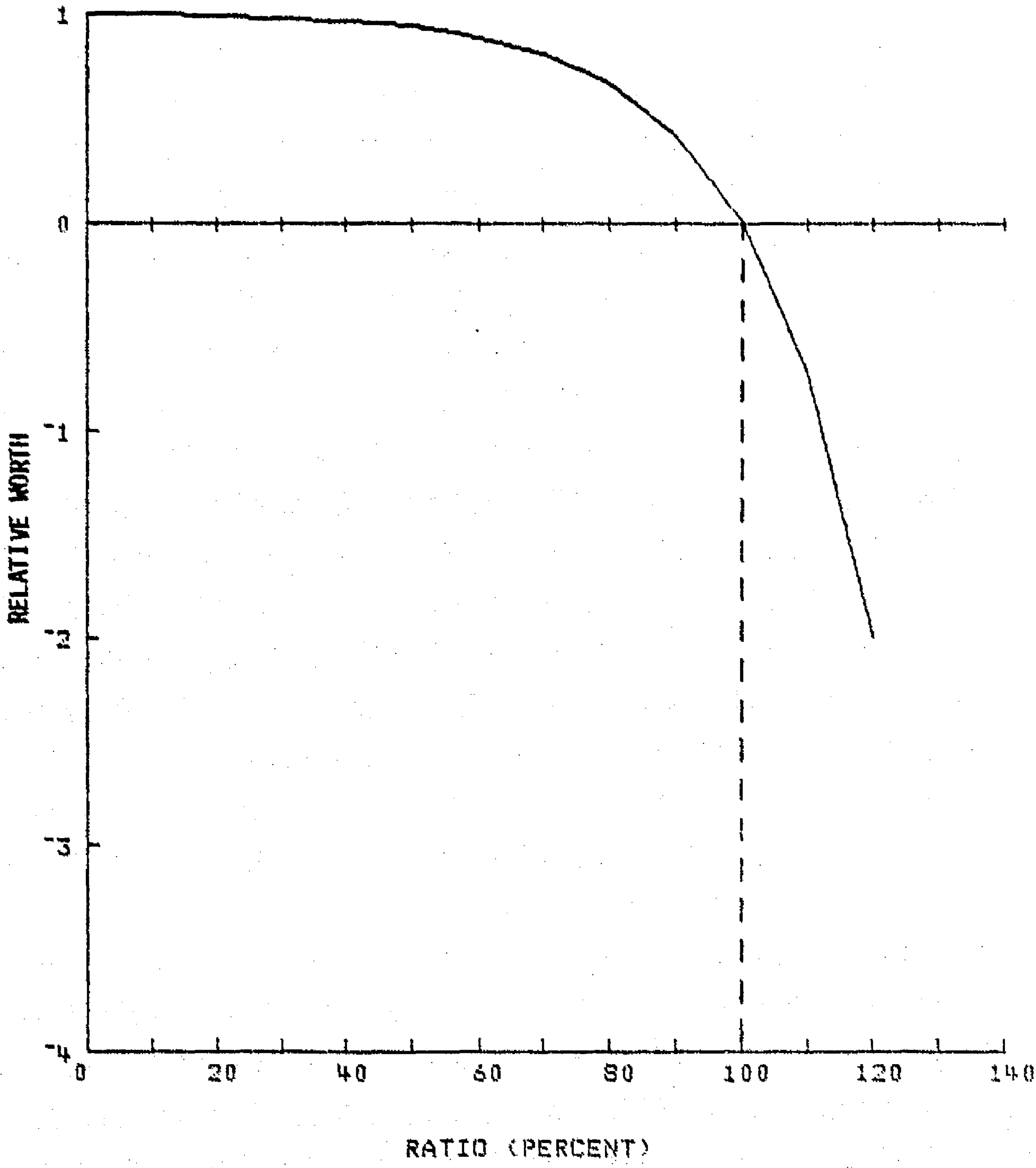


1.3.1 Airports
1.3.2 Railroad Stations
1.3.3 Bus Stations
1.3.4 Roadways
2.1.1 Demography



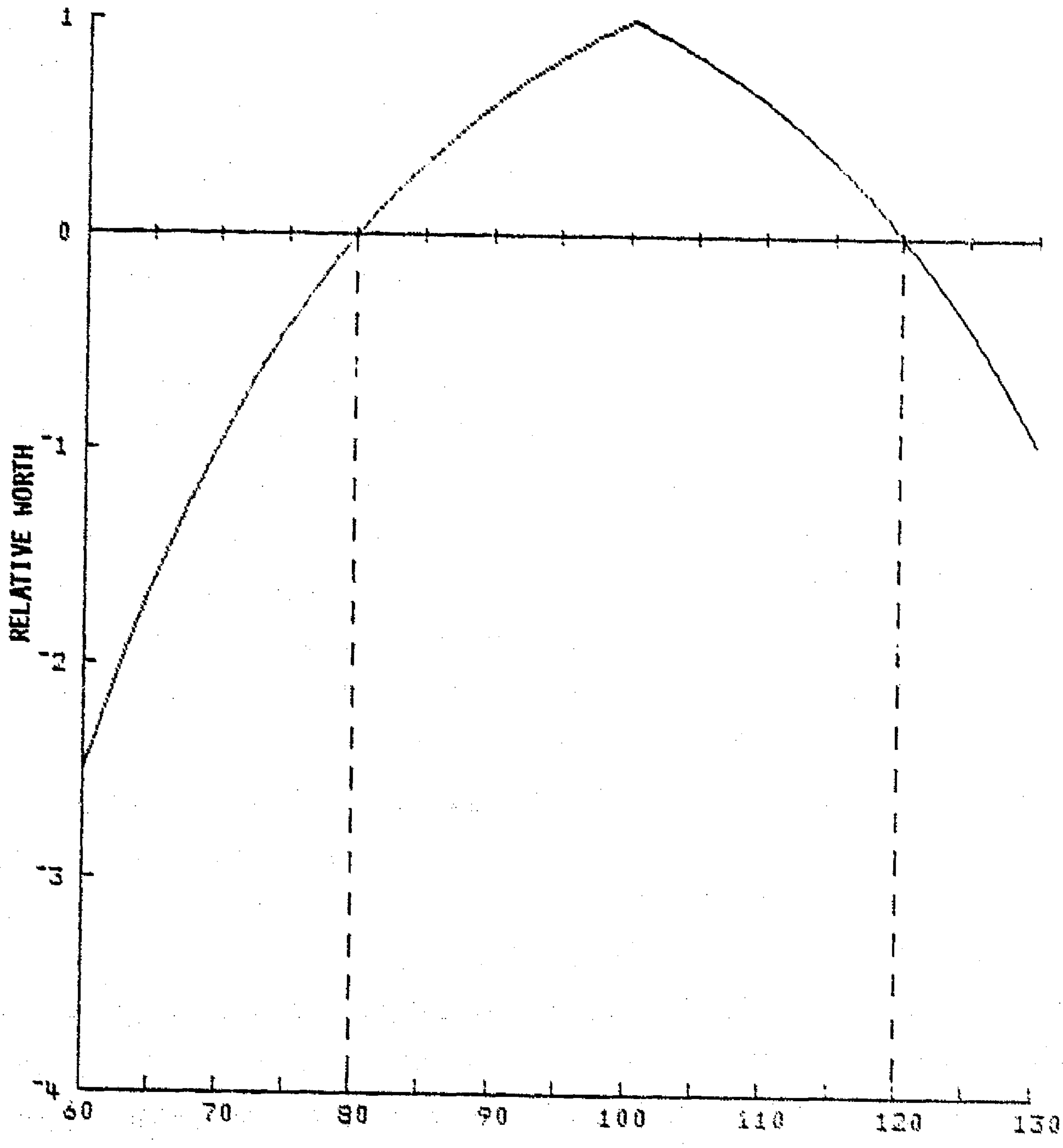
RELATIVE WORTH

2.1.2 Health Status



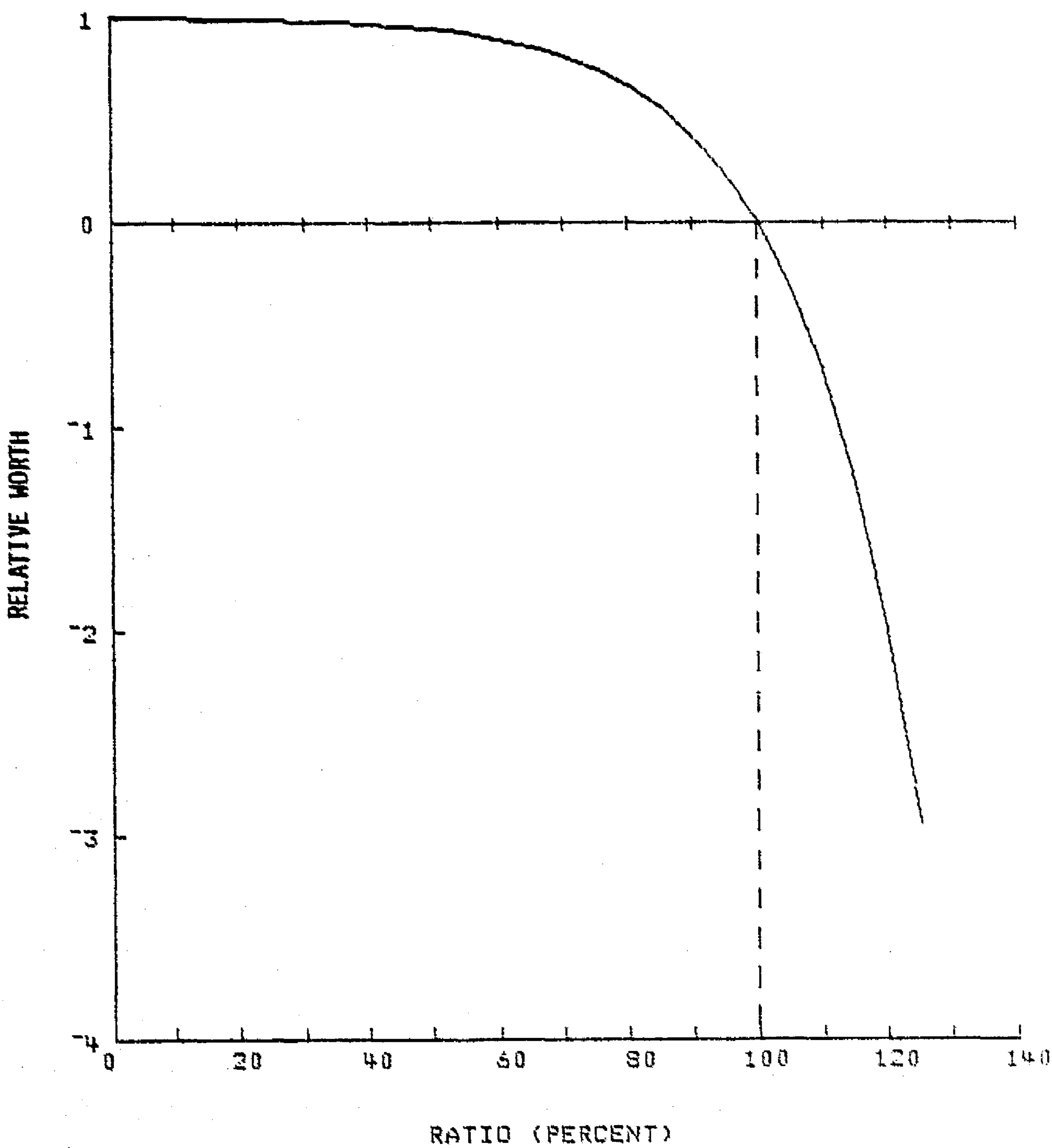
RELATIVE WORTH

2.2.1 Land Use



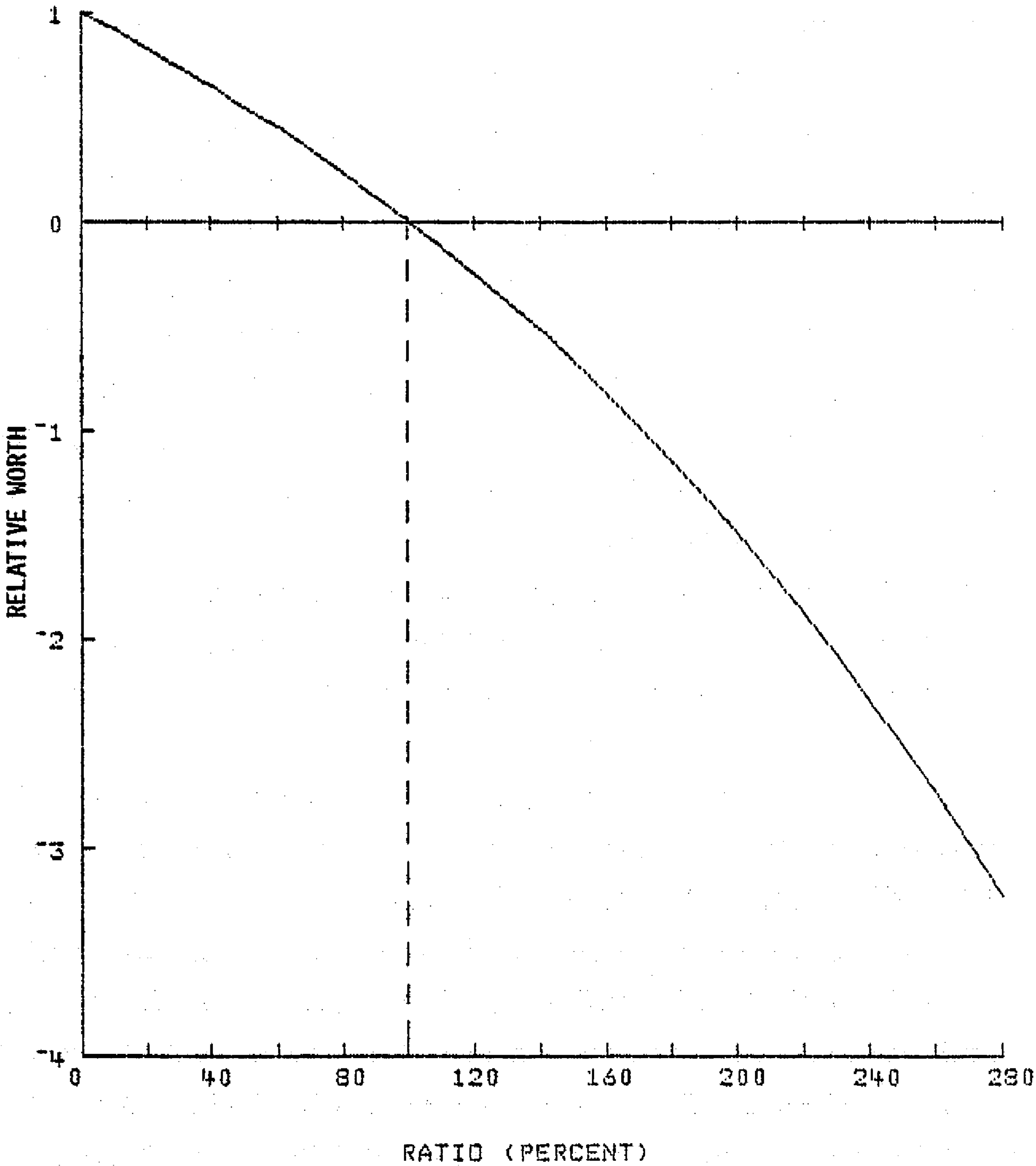
RELATIVE WORTH

2.2.2 Property Damage



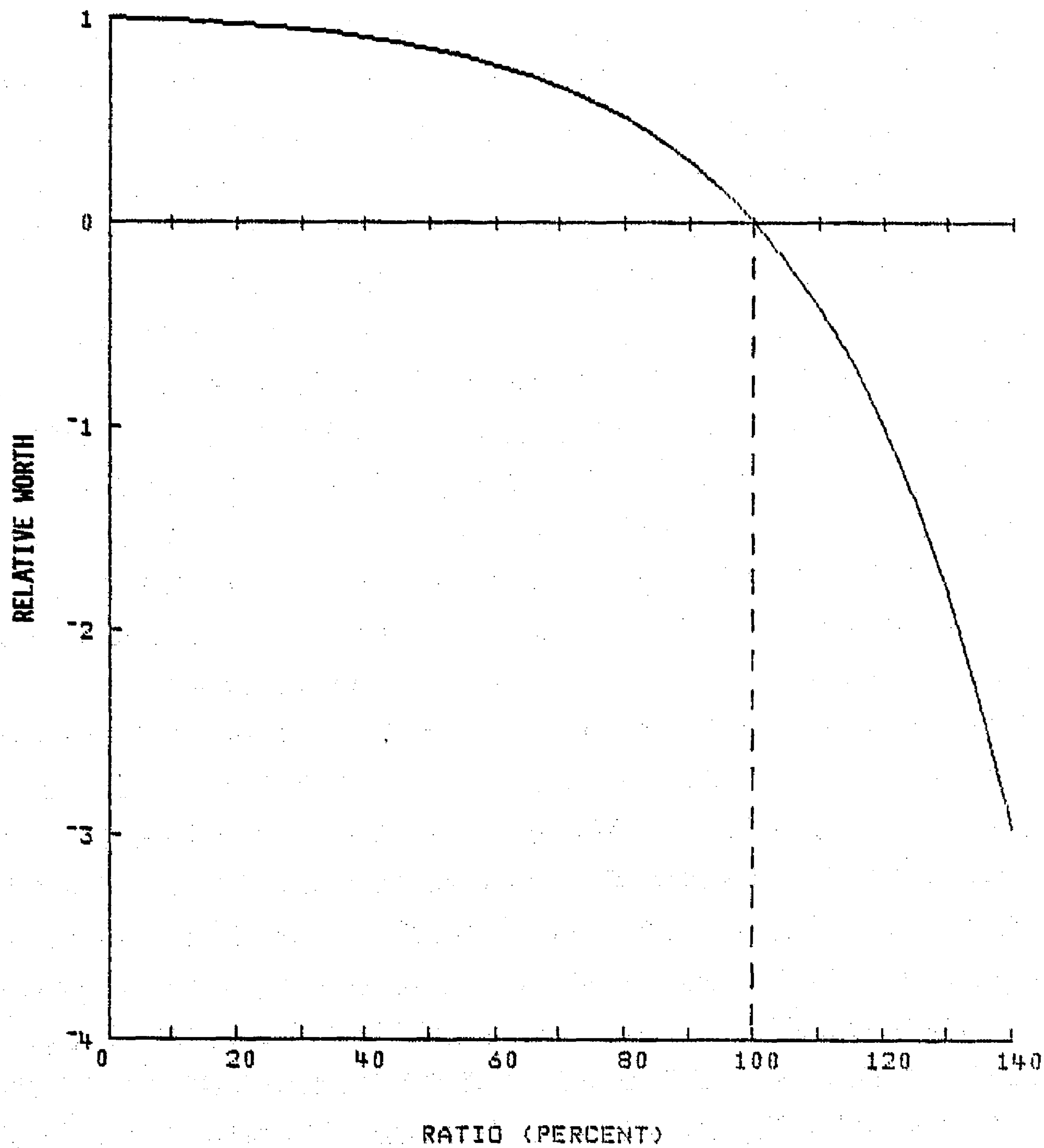
RELATIVE WORTH

2.2.3 Noise Levels



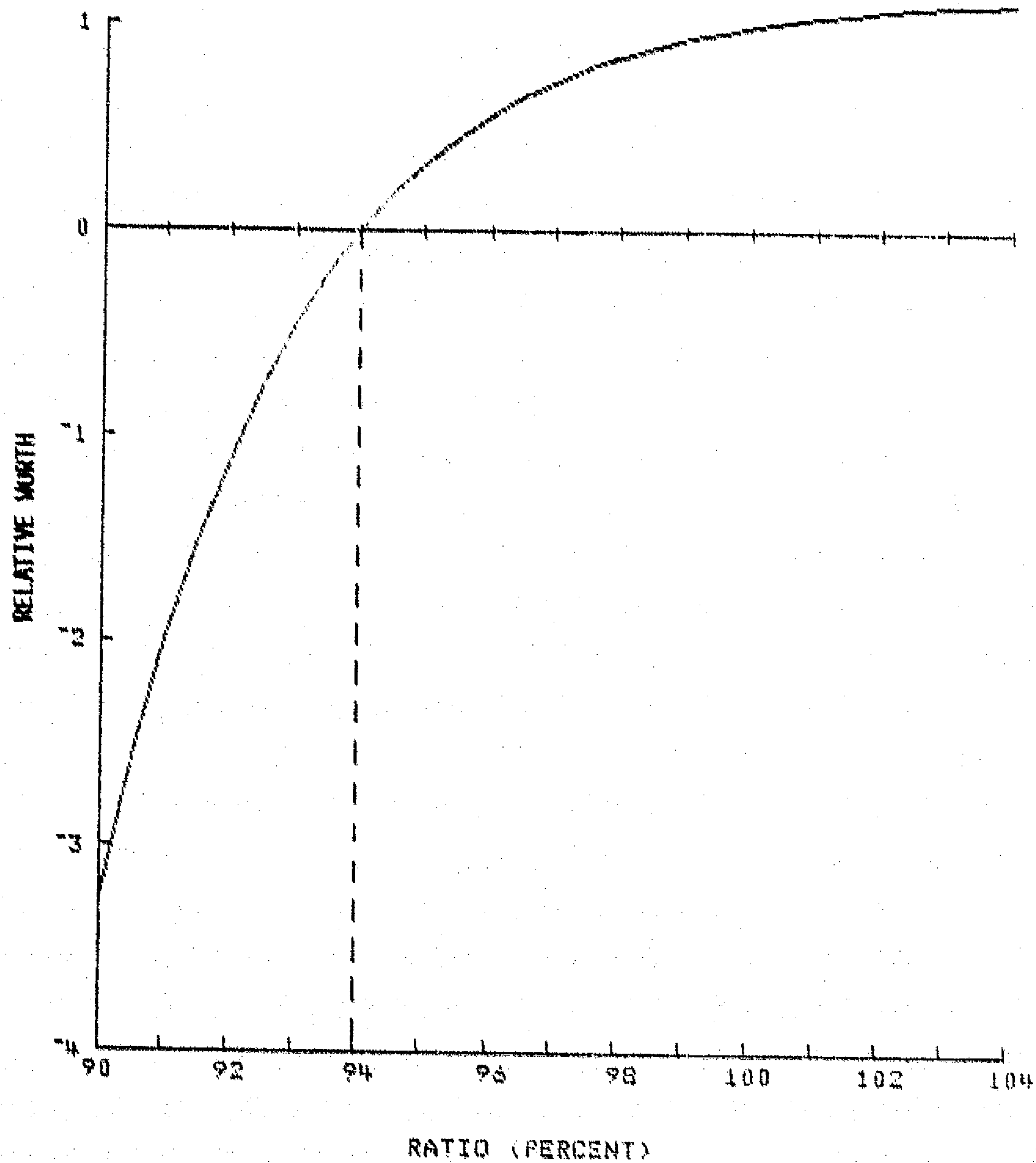
RELATIVE WORTH

2.2.4 Visibility



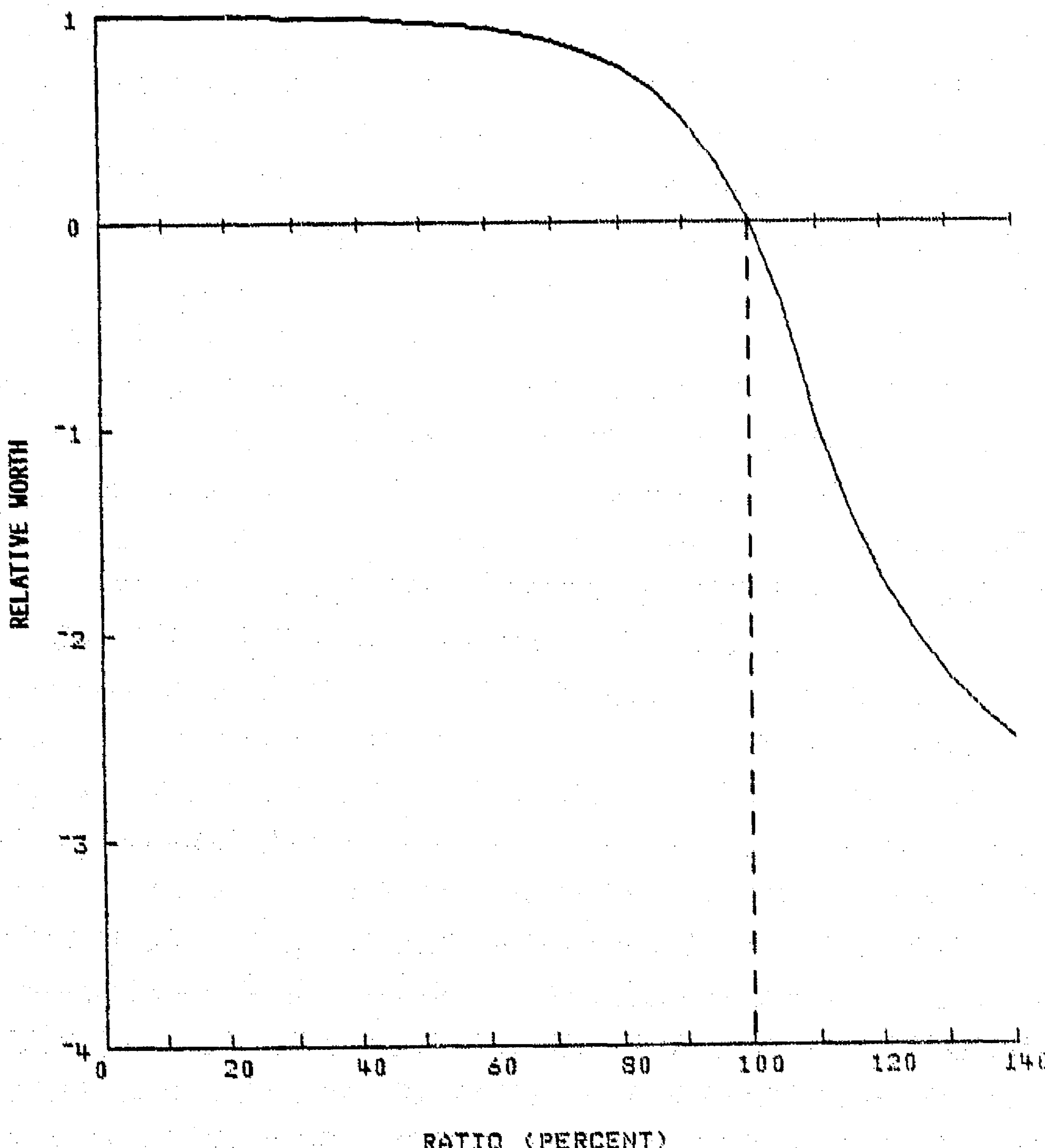
RELATIVE WORTH

3.1.1. Employment



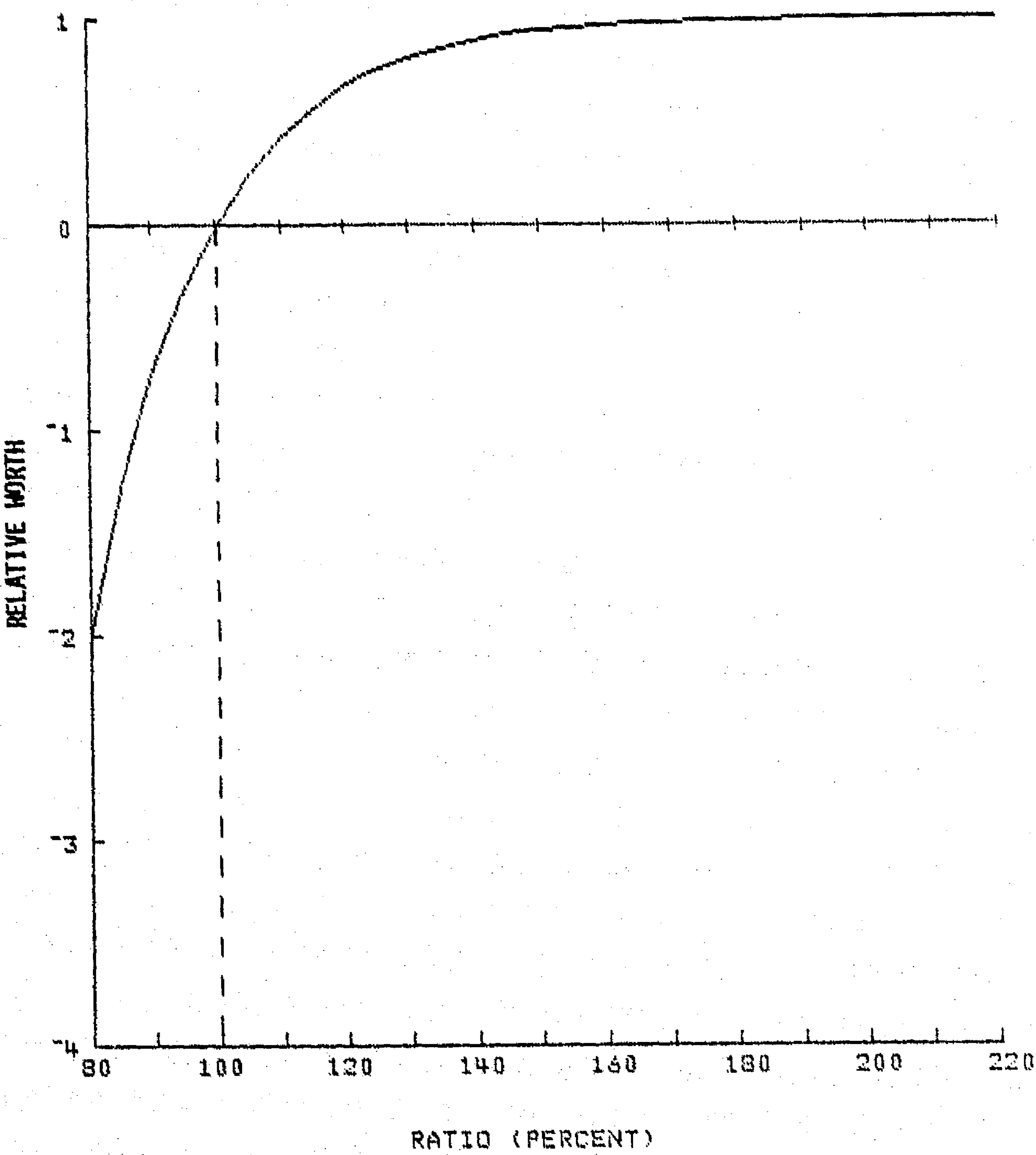
RELATIVE WORTH

3.2.1 Fossil Fuels



RELATIVE WORTH

3.3.1 Gross Regional Product
3.3.2 Interregional Product



# APPENDIX C

## ILLUSTRATIVE EXAMPLE

## ANALYSIS FRAMEWORK RESULTS

| YD 1 | | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|---|
| 1.1.1 | PASSENGERS | 12.80 | 17.90 | 25.10 | 35.00 | 49.00 | 68.30 |
| 1.1.2 | FREIGHT | 33.40 | 44.30 | 56.70 | 77.80 | 108.00 | 136.70 |
| 1.2.1 | INVESTMENT | 4.80 | 6.80 | 9.50 | 13.20 | 18.50 | 25.80 |
| 1.2.2 | OPERATING COSTS | .80 | 1.10 | 1.50 | 2.10 | 2.90 | 4.10 |
| 1.2.3 | SURPLUS/SUBIDY | .60 | .80 | 1.10 | 1.60 | 1.60 | 2.20 |
| 1.3.1 | URBAN FACILITY-AIR | 51.00 | 59.00 | 69.00 | 80.00 | 93.00 | 108.00 |
| 1.3.2 | URBAN FACILITY-RR | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1.3.3 | URBAN FACILITY-BUS | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1.3.4 | URBAN FAC.-ROAD | 2290.00 | 3206.00 | 4494.00 | 6269.00 | 8759.00 | 12223.00 |
| 2.1.1 | CORRIDOR DEMOG | 160.00 | 160.00 | 156.00 | 153.00 | 150.00 | 145.00 |
| 2.1.2 | HEALTH STATUS | 454.00 | 432.00 | 410.00 | 390.00 | 371.00 | 357.00 |
| 2.2.1 | CORRID LAND USE | 1.50 | 2.00 | 3.00 | 3.50 | 4.00 | 4.50 |
| 2.2.2 | PROPERTY DAMAGE | 227.00 | 216.00 | 205.00 | 195.00 | 186.00 | 177.00 |
| 2.2.3 | NOISE LEVELS | 88.80 | 101.60 | 112.60 | 123.70 | 136.00 | 146.20 |
| 2.2.4 | VISIBILITY | 16.00 | 14.60 | 13.30 | 12.10 | 11.00 | 10.00 |
| 3.1.1 | EMPLOYMENT | 12.20 | 13.90 | 15.40 | 16.90 | 18.60 | 20.00 |
| 3.2.1 | FOSSIL FUELS | 38.50 | 51.40 | 68.40 | 90.70 | 31.60 | 11.00 |
| 3.3.1 | GROSS REG PROD | 145.00 | 203.00 | 284.00 | 396.00 | 553.00 | 773.00 |
| 3.3.2 | INTERREG PROD | 93.00 | 130.00 | 179.00 | 246.00 | 338.00 | 467.00 |

CASE RESULTS: DENOMINATOR ASPIRATION LEVELS

| YN1 | | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|---|
| 1.1.1 | PASSENGERS | 10.90 | 15.20 | 21.30 | 29.80 | 41.60 | 58.10 |
| 1.1.2 | FREIGHT | 31.06 | 41.20 | 52.73 | 72.35 | 100.44 | 127.13 |
| 1.2.1 | INVESTMENT | 3.80 | 5.40 | 7.60 | 10.60 | 14.80 | 20.60 |
| 1.2.2 | OPERATING COSTS | .60 | .80 | 1.10 | 1.60 | 1.60 | 2.20 |
| 1.2.3 | SURPLUS/SUBIDY | ¯.20 | ¯.30 | ¯.40 | ¯.50 | ¯.80 | ¯1.10 |
| 1.3.1 | URBAN FACILITY-AIR | 51.00 | 59.00 | 69.00 | 80.00 | 93.00 | 108.00 |
| 1.3.2 | URBAN FACILITY-RR | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.3 | URBAN FACILITY-BUS | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.4 | URBAN FAC.-ROAD | 2404.50 | 3366.30 | 4718.70 | 6582.40 | 9196.90 | 12834.10 |
| 2.1.1 | CORRIDOR DEMOG | 160.00 | 165.00 | 168.00 | 168.00 | 170.00 | 175.00 |
| 2.1.2 | HEALTH STATUS | 444.00 | 457.00 | 472.00 | 486.00 | 330.00 | 285.00 |
| 2.2.1 | CORRID LAND USE | 1.50 | 1.60 | 2.00 | 2.40 | 2.70 | 3.00 |
| 2.2.2 | PROPERTY DAMAGE | 254.24 | 241.92 | 229.60 | 218.40 | 208.32 | 198.24 |
| 2.2.3 | NOISE LEVELS | 133.20 | 152.40 | 168.90 | 185.50 | 204.00 | 219.30 |
| 2.2.4 | VISIBILITY | 17.44 | 15.91 | 14.50 | 13.19 | 11.99 | 10.90 |
| 3.1.1 | EMPLOYMENT | 11.22 | 12.79 | 14.17 | 15.55 | 17.11 | 18.40 |
| 3.2.1 | FOSSIL FUELS | 40.43 | 53.97 | 71.82 | 104.30 | 36.34 | 12.65 |
| 3.3.1 | GROSS REG PROD | 137.70 | 192.80 | 269.80 | 376.20 | 525.30 | 734.30 |
| 3.3.2 | INTERREG PROD | 83.70 | 117.00 | 161.10 | 221.40 | 304.20 | 420.30 |

CASE RESULTS: NUMERATOR FOR BASE CASE

| Y J | | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|---|
| 1.1.1 | PASSENGERS | .85 | .85 | .85 | .85 | .85 | .85 |
| 1.1.2 | FREIGHT | .93 | .93 | .93 | .93 | .93 | .93 |
| 1.2.1 | INVESTMENT | .79 | .79 | .80 | .80 | .80 | .80 |
| 1.2.2 | OPERATING COSTS | .75 | .73 | .73 | .76 | .55 | .54 |
| 1.2.3 | SURPLUS/SUBIDY | -.33 | -.38 | -.36 | -.31 | -.50 | -.50 |
| 1.3.1 | URBAN FACILITY-AIR | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1.3.2 | URBAN FACILITY-RR | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.3 | URBAN FACILITY-BUS | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.4 | URBAN FAC.-ROAD | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| 2.1.1 | CORRIDOR DEMOG | 1.00 | 1.03 | 1.08 | 1.10 | 1.13 | 1.21 |
| 2.1.2 | HEALTH STATUS | .98 | 1.06 | 1.15 | 1.25 | .89 | .80 |
| 2.2.1 | CORRID LAND USE | 1.00 | .80 | .67 | .69 | .67 | .67 |
| 2.2.2 | PROPERTY DAMAGE | 1.12 | 1.12 | 1.12 | 1.12 | 1.12 | 1.12 |
| 2.2.3 | NOISE LEVELS | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 |
| 2.2.4 | VISIBILITY | 1.09 | 1.09 | 1.09 | 1.09 | 1.09 | 1.09 |
| 3.1.1 | EMPLOYMENT | .92 | .92 | .92 | .92 | .92 | .92 |
| 3.2.1 | FOSSIL FUELS | 1.05 | 1.05 | 1.05 | 1.15 | 1.15 | 1.15 |
| 3.3.1 | GROSS REG PROD | .95 | .95 | .95 | .95 | .95 | .95 |
| 3.3.2 | INTERREG PROD | .90 | .90 | .90 | .90 | .90 | .90 |

YN/YD RATIO FOR BASE CASE

| | | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|---|
| YN2 | | | | | | | |
| 1.1.1 | PASSENGERS | 10.90 | 15.20 | 21.30 | 35.00 | 49.00 | 70.00 |
| 1.1.2 | FREIGHT | 31.00 | 41.00 | 55.00 | 77.80 | 108.00 | 136.70 |
| 1.2.1 | INVESTMENT | 5.00 | 7.80 | 12.50 | 14.20 | 18.50 | 25.80 |
| 1.2.2 | OPERATING COSTS | .60 | .80 | 1.10 | 2.08 | 3.05 | 4.26 |
| 1.2.3 | /SUBIDY | ¯.20 | ¯.30 | ¯.40 | ¯.30 | ¯.30 | ¯.30 |
| 1.3.1 | URBAN FACILITY-AIR | 51.00 | 59.00 | 69.00 | 72.00 | 84.00 | 98.00 |
| 1.3.2 | URBAN FACILITY-RR | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.3 | URBAN FACILITY-BUS | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.4 | URBAN FAC.-ROAD | 2404.50 | 3366.30 | 4718.70 | 5015.00 | 7007.00 | 9778.00 |
| 2.1.1 | CORRIDOR DEMOG | 160.00 | 165.00 | 168.00 | 165.00 | 155.00 | 145.00 |
| 2.1.2 | HEALTH STATUS | 444.00 | 457.00 | 472.00 | 390.00 | 330.00 | 300.00 |
| 2.2.1 | CORRID LAND USE | 1.50 | 1.60 | 2.09 | 2.60 | 3.30 | 4.00 |
| 2.2.2 | PROPERTY DAMAGE | 254.00 | 242.00 | 230.00 | 190.00 | 160.00 | 150.00 |
| 2.2.3 | NOISE LEVELS | 133.20 | 152.40 | 168.90 | 150.00 | 140.00 | 130.00 |
| 2.2.4 | VISIBILITY | 17.44 | 15.91 | 14.50 | 11.61 | 10.55 | 9.59 |
| 3.1.1 | EMPLOYMENT | 11.71 | 13.34 | 14.78 | 16.22 | 17.86 | 19.20 |
| 3.2.1 | FOSSIL FUELS | 40.43 | 53.97 | 71.82 | 90.70 | 31.60 | 11.00 |
| 3.3.1 | GROSS REG PROD | 140.00 | 205.00 | 286.00 | 410.00 | 567.00 | 783.00 |
| 3.3.2 | INTERREG PROD | 83.70 | 117.00 | 161.10 | 229.00 | 326.00 | 465.00 |

CASE RESULTS: NUMERATOR FOR TACV

| Y 2 | | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|---|
| 1.1.1 | PASSENGERS | .85 | .85 | .85 | 1.00 | 1.00 | 1.02 |
| 1.1.2 | FREIGHT | .93 | .93 | .97 | 1.00 | 1.00 | 1.00 |
| 1.2.1 | INVESTMENT | 1.04 | 1.15 | 1.32 | 1.08 | 1.00 | 1.00 |
| 1.2.2 | OPERATING COSTS | .75 | .73 | .73 | .99 | 1.05 | 1.04 |
| 1.2.3 | /SUBIDY | -.33 | -.38 | -.36 | -.14 | -.10 | -.07 |
| 1.3.1 | URBAN FACILITY-AIR | 1.00 | 1.00 | 1.00 | .90 | .90 | .91 |
| 1.3.2 | URBAN FACILITY-RR | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.3 | URBAN FACILITY-BUS | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.4 | URBAN FAC.-ROAD | 1.05 | 1.05 | 1.05 | .80 | .80 | .80 |
| 2.1.1 | CORRIDOR DEMOG | 1.00 | 1.03 | 1.08 | 1.08 | 1.03 | 1.00 |
| 2.1.2 | HEALTH STATUS | .98 | 1.06 | 1.15 | 1.00 | .89 | .84 |
| 2.2.1 | CORRID LAND USE | 1.00 | .80 | .67 | .74 | .83 | .89 |
| 2.2.2 | PROPERTY DAMAGE | 1.12 | 1.12 | 1.12 | .97 | .86 | .85 |
| 2.2.3 | NOISE LEVELS | 1.50 | 1.50 | 1.50 | 1.21 | 1.03 | .89 |
| 2.2.4 | VISIBILITY | 1.09 | 1.09 | 1.09 | .96 | .96 | .96 |
| 3.1.1 | EMPLOYMENT | .96 | .96 | .96 | .96 | .96 | .96 |
| 3.2.1 | FOSSIL FUELS | 1.05 | 1.05 | 1.05 | 1.00 | 1.00 | 1.00 |
| 3.3.1 | GROSS REG PROD | .97 | 1.01 | 1.01 | 1.04 | 1.03 | 1.01 |
| 3.3.2 | INTERREG PROD | .90 | .90 | .90 | .93 | .96 | 1.00 |

YN/YD RATIO FOR TACV

| | | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|---|
| YN3 | | | | | | | |
| 1.1.1 | PASSENGERS | 10.90 | 16.72 | 23.43 | 32.78 | 45.76 | 63.91 |
| 1.1.2 | FREIGHT | 31.06 | 40.00 | 52.00 | 72.35 | 100.44 | 127.13 |
| 1.2.1 | INVESTMENT | 3.80 | 5.40 | 7.60 | 10.60 | 14.80 | 20.60 |
| 1.2.2 | OPERATING COSTS | .60 | .84 | 1.16 | 1.68 | 1.68 | 2.31 |
| 1.2.3 | /SUBIDY | ¯.20 | ¯.32 | ¯.42 | ¯.53 | ¯.84 | ¯1.16 |
| 1.3.1 | URBAN FACILITY-AIR | 51.00 | 59.00 | 69.00 | 80.00 | 93.00 | 108.00 |
| 1.3.2 | URBAN FACILITY-RR | .80 | .90 | .90 | .90 | .90 | .90 |
| 1.3.3 | URBAN FACILITY-BUS | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.4 | URBAN FAC.-ROAD | 2404.50 | 3029.67 | 4246.83 | 5924.16 | 8277.21 | 11550.69 |
| 2.1.1 | CORRIDOR DEMOG | 160.00 | 165.00 | 163.00 | 162.00 | 160.00 | 159.00 |
| 2.1.2 | HEALTH STATUS | 444.00 | 411.30 | 424.80 | 437.40 | 297.00 | 256.50 |
| 2.2.1 | CORRID LAND USE | 1.50 | 1.60 | 2.20 | 2.64 | 2.97 | 3.30 |
| 2.2.2 | PROPERTY DAMAGE | 254.24 | 217.73 | 206.64 | 196.56 | 187.49 | 178.42 |
| 2.2.3 | NOISE LEVELS | 133.20 | 137.16 | 152.01 | 166.95 | 183.60 | 197.37 |
| 2.2.4 | VISIBILITY | 17.44 | 15.12 | 13.77 | 12.53 | 11.39 | 10.36 |
| 3.1.1 | EMPLOYMENT | 11.22 | 12.79 | 14.37 | 15.85 | 17.51 | 18.95 |
| 3.2.1 | FOSSIL FUELS | 40.43 | 48.57 | 64.64 | 93.87 | 32.71 | 11.38 |
| 3.3.1 | GROSS REG PROD | 137.70 | 192.80 | 273.61 | 383.46 | 537.58 | 756.25 |
| 3.3.2 | INTERREG PROD | 83.70 | 105.64 | 158.87 | 221.40 | 304.20 | 420.30 |

CASE RESULTS: NUMERATOR FOR IPT

| Y 3 | | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|---|
| 1.1.1 | PASSENGERS | .85 | .93 | .93 | .94 | .93 | .94 |
| 1.1.2 | FREIGHT | .93 | .90 | .92 | .93 | .93 | .93 |
| 1.2.1 | INVESTMENT | .79 | .79 | .80 | .80 | .80 | .80 |
| 1.2.2 | OPERATING COSTS | .75 | .76 | .77 | .80 | .58 | .56 |
| 1.2.3 | /SUBIDY | -.33 | -.38 | -.36 | -.31 | -.50 | -.50 |
| 1.3.1 | URBAN FACILITY-AIR | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1.3.2 | URBAN FACILITY-RR | .80 | .90 | .90 | .90 | .90 | .90 |
| 1.3.3 | URBAN FACILITY-BUS | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.4 | URBAN FAC.-ROAD | 1.05 | .94 | .94 | .94 | .94 | .94 |
| 2.1.1 | CORRIDOR DEMOG | 1.00 | 1.03 | 1.04 | 1.06 | 1.07 | 1.10 |
| 2.1.2 | HEALTH STATUS | .98 | .95 | 1.04 | 1.12 | .80 | .72 |
| 2.2.1 | CORRID LAND USE | 1.00 | .80 | .73 | .75 | .74 | .73 |
| 2.2.2 | PROPERTY DAMAGE | 1.12 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 |
| 2.2.3 | NOISE LEVELS | 1.50 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 |
| 2.2.4 | VISIBILITY | 1.09 | 1.04 | 1.04 | 1.04 | 1.04 | 1.04 |
| 3.1.1 | EMPLOYMENT | .92 | .92 | .93 | .94 | .94 | .95 |
| 3.2.1 | FOSSIL FUELS | 1.05 | .94 | .94 | 1.03 | 1.03 | 1.03 |
| 3.3.1 | GROSS REG PROD | .95 | .95 | .96 | .97 | .97 | .98 |
| 3.3.2 | INTERREG PROD | .90 | .91 | .89 | .90 | .90 | .90 |

YN/YD RATIO FOR IPT

| | | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|---|
| YN4 | | | | | | | |
| 1.1.1 | PASSENGERS | 10.90 | 15.20 | 30.00 | 45.00 | 59.00 | 78.00 |
| 1.1.2 | FREIGHT | 33.50 | 44.40 | 59.00 | 79.00 | 110.00 | 140.00 |
| 1.2.1 | INVESTMENT | 7.04 | 9.80 | 14.50 | 15.20 | 18.50 | 25.80 |
| 1.2.2 | OPERATING COSTS | .60 | .80 | 1.49 | 2.18 | 3.06 | 4.26 |
| 1.2.3 | SURPLUS/SUBIDY | ¯.20 | ¯.30 | ¯.20 | ¯.20 | ¯.30 | ¯.30 |
| 1.3.1 | URBAN FACILITY-AIR | 51.00 | 59.00 | 61.00 | 72.00 | 84.00 | 98.00 |
| 1.3.2 | URBAN FACILITY-RR | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.3 | URBAN FACILITY-BUS | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.4 | URBAN FAC.-ROAD | 2404.50 | 3366.30 | 3418.00 | 5015.00 | 7007.00 | 9778.00 |
| 2.1.1 | CORRIDOR DEMOG | 160.00 | 165.00 | 165.00 | 155.00 | 150.00 | 145.00 |
| 2.1.2 | HEALTH STATUS | 444.00 | 457.00 | 400.00 | 330.00 | 300.00 | 300.00 |
| 2.2.1 | CORRID LAND USE | 1.50 | 1.60 | 2.20 | 2.93 | 3.60 | 4.50 |
| 2.2.2 | PROPERTY DAMAGE | 254.00 | 242.00 | 200.00 | 168.00 | 158.00 | 155.00 |
| 2.2.3 | NOISE LEVELS | 133.20 | 152.40 | 140.00 | 135.00 | 130.00 | 125.00 |
| 2.2.4 | VISIBILITY | 17.44 | 15.91 | 12.30 | 11.60 | 10.55 | 9.59 |
| 3.1.1 | EMPLOYMENT | 12.00 | 14.00 | 15.00 | 17.00 | 18.70 | 21.00 |
| 3.2.1 | FOSSIL FUELS | 40.43 | 53.97 | 62.46 | 90.70 | 31.60 | 11.00 |
| 3.3.1 | GROSS REG PROD | 146.00 | 210.00 | 300.00 | 435.00 | 597.00 | 834.00 |
| 3.3.2 | INTERREG PROD | 93.64 | 134.48 | 189.10 | 270.23 | 364.90 | 503.90 |

CASE RESULTS: NUMERATOR FOR EARLY TACV

| Y 4 | | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|---|
| 1.1.1 | PASSENGERS | .85 | .85 | 1.20 | 1.29 | 1.20 | 1.14 |
| 1.1.2 | FREIGHT | 1.00 | 1.00 | 1.04 | 1.02 | 1.02 | 1.02 |
| 1.2.1 | INVESTMENT | 1.47 | .44 | 1.53 | 1.15 | 1.00 | 1.00 |
| 1.2.2 | OPERATING COSTS | .75 | .73 | .99 | 1.04 | 1.06 | 1.04 |
| 1.2.3 | SURPLUS/SUBIDY | -.33 | -.38 | -.13 | -.09 | -.10 | -.07 |
| 1.3.1 | URBAN FACILITY-AIR | 1.00 | 1.00 | .88 | .90 | .90 | .91 |
| 1.3.2 | URBAN FACILITY-RR | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.3 | URBAN FACILITY-BUS | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.4 | URBAN FAC.-ROAD | 1.05 | 1.05 | .76 | .80 | .80 | .80 |
| 2.1.1 | CORRIDOR DEMOG | 1.00 | 1.03 | 1.06 | 1.01 | 1.00 | 1.00 |
| 2.1.2 | HEALTH STATUS | .98 | 1.06 | .98 | .85 | .81 | .84 |
| 2.2.1 | CORRID LAND USE | 1.00 | .80 | .73 | .84 | .90 | 1.00 |
| 2.2.2 | PROPERTY DAMAGE | 1.12 | 1.12 | [illegible] | .86 | .85 | .88 |
| 2.2.3 | NOISE LEVELS | 1.50 | 1.50 | 1.24 | 1.09 | .96 | .85 |
| 2.2.4 | VISIBILITY | 1.09 | 1.09 | .92 | .96 | .96 | .96 |
| 3.1.1 | EMPLOYMENT | .98 | 1.01 | .97 | 1.01 | 1.01 | 1.05 |
| 3.2.1 | FOSSIL FUELS | 1.05 | 1.05 | .91 | 1.00 | 1.00 | 1.00 |
| 3.3.1 | GROSS REG PROD | 1.01 | 1.03 | 1.06 | 1.10 | 1.08 | 1.08 |
| 3.3.2 | INTERREG PROD | 1.01 | 1.03 | 1.06 | 1.10 | 1.08 | 1.08 |

YN/YD RATIO FOR EARLY TACV

| YN5 | | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|---|
| 1.1.1 | PASSENGERS | 10.90 | 15.66 | 21.94 | 30.69 | 42.85 | 59.84 |
| 1.1.2 | FREIGHT | 31.06 | 41.20 | 52.73 | 72.35 | 100.44 | 127.13 |
| 1.2.1 | INVESTMENT | 3.80 | 5.40 | 7.60 | 10.60 | 14.80 | 20.60 |
| 1.2.2 | OPERATING COSTS | .60 | .80 | 1.10 | 1.60 | 1.60 | 2.20 |
| 1.2.3 | SURPLUS/SUBIDY | ¯.20 | ¯.30 | ¯.40 | ¯.50 | ¯.80 | ¯1.10 |
| 1.3.1 | URBAN FACILITY-AIR | 51.00 | 57.82 | 67.62 | 78.40 | 90.21 | 104.76 |
| 1.3.2 | URBAN FACILITY-RR | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.3 | URBAN FACILITY-BUS | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.4 | URBAN FAC.-ROAD | 2404.50 | 3366.30 | 4718.70 | 6582.40 | 9196.90 | 12834.10 |
| 2.1.1 | CORRIDOR DEMOG | 160.00 | 165.00 | 168.00 | 168.00 | 170.00 | 175.00 |
| 2.1.2 | HEALTH STATUS | 444.00 | 457.00 | 472.00 | 486.00 | 330.00 | 285.00 |
| 2.2.1 | CORRID LAND USE | 1.50 | 1.60 | 2.00 | 2.40 | 2.70 | 3.00 |
| 2.2.2 | PROPERTY DAMAGE | 254.24 | 239.50 | 227.30 | 214.03 | 204.15 | 194.28 |
| 2.2.3 | NOISE LEVELS | 133.20 | 150.88 | 167.21 | 181.79 | 199.92 | 214.91 |
| 2.2.4 | VISIBILITY | 17.44 | 15.91 | 14.50 | 13.19 | 11.75 | 10.68 |
| 3.1.1 | EMPLOYMENT | 11.22 | 12.79 | 14.17 | 15.55 | 17.11 | 18.40 |
| 3.2.1 | FOSSIL FUELS | 40.43 | 53.97 | 71.82 | 102.22 | 36.34 | 12.65 |
| 3.3.1 | GROSS REG PROD | 137.70 | 194.73 | 272.50 | 379.96 | 525.30 | 734.30 |
| 3.3.2 | INTERREG PROD | 83.70 | 117.00 | 161.10 | 221.40 | 304.20 | 420.30 |

CASE RESULTS: NUMERATOR FOR IMPROVED CTOL

| Y | 5 | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|---|
| 1.1.1 | PASSENGERS | .85 | .87 | .87 | .88 | .87 | .88 |
| 1.1.2 | FREIGHT | .93 | .93 | .93 | .93 | .93 | .93 |
| 1.2.1 | INVESTMENT | .79 | .79 | .80 | .80 | .80 | .80 |
| 1.2.2 | OPERATING COSTS | .75 | .73 | .73 | .76 | .55 | .54 |
| 1.2.3 | SURPLUS/SUBIDY | -.33 | -.38 | -.36 | -.31 | -.50 | -.50 |
| 1.3.1 | URBAN FACILITY-AIR | 1.00 | .98 | .98 | .98 | .97 | .97 |
| 1.3.2 | URBAN FACILITY-RR | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.3 | URBAN FACILITY-BUS | .80 | .80 | .80 | .80 | .80 | .80 |
| 1.3.4 | URBAN FAC.-ROAD | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| 2.1.1 | CORRIDOR DEMOG | 1.00 | 1.03 | 1.08 | 1.10 | 1.13 | 1.21 |
| 2.1.2 | HEALTH STATUS | .98 | 1.06 | 1.15 | 1.25 | .89 | .80 |
| 2.2.1 | CORRID LAND USE | 1.00 | .80 | .67 | .69 | .67 | .67 |
| 2.2.2 | PROPERTY DAMAGE | 1.12 | 1.11 | 1.11 | 1.10 | 1.10 | 1.10 |
| 2.2.3 | NOISE LEVELS | 1.50 | 1.48 | 1.48 | 1.47 | 1.47 | 1.47 |
| 2.2.4 | VISIBILITY | 1.09 | 1.09 | 1.09 | 1.09 | 1.07 | 1.07 |
| 3.1.1 | EMPLOYMENT | .92 | .92 | .92 | .92 | .92 | .92 |
| 3.2.1 | FOSSIL FUELS | 1.05 | 1.05 | 1.05 | 1.13 | 1.15 | 1.15 |
| 3.3.1 | GROSS REG PROD | .95 | .96 | .96 | .96 | .95 | .95 |
| 3.3.2 | INTERREG PROD | .90 | .90 | .90 | .90 | .90 | .90 |

YN/YD RATIO FOR IMPROVED CTOL

# APPENDIX D

# BACKGROUND CONCEPTS UNDERLYING THE ECONERGY METHODOLOGY

# APPENDIX D

## BACKGROUND CONCEPTS UNDERLYING THE ECONERGY METHODOLOGY

This appendix contains five sections, orginally envisioned to follow Chapter 2 of the report. However, the material, while providing important background, does not relate directly to the logical development and presentation of the ECONERGY methodology.

Section D.1, *Historical Perspective,* provides an overall perspective of U.S. transportation - its evolution and its present status. Section D.2. *National Transportation Goals,* represents the frame of reference from which intercity transportation systems need be studied. It provides a philosophical basis for projecting a long-term socio-economic environment into which all future transportation systems must be embedded. In particular, two futures, both based on eventual successful futures are discussed. These are the steady but modest economic growth case and an energy constrained case. The latter might well be a plausible future if liquid fuels for transportation were to become critical.

Section D.3, *Economic Considerations*, introduces very important economic concepts. In particular, a new approach to discounting is suggested. However, this new approach was not utilized in the example case used for demonstrating the methodology. Its use should be considered in the Phase II because it reveals time-effect sensitivities that conventional approaches fail to show.

Section D.4, *Societal Considerations,* is an attempt to place social issues into context with economic issues. Section D.5, *Technological Potentials for the Year 2030,* represents a brief overview of the technological potentials which will be influencing possible future transportation developments.

### D.1 Histcrical Perspective

While transportation will develop in response to social and economic needs, it also shapes the character of a society and underpins its economic development. Massive U.S. development in the nineteenth century was made possible by exploiting natural waterways, building a huge system of canals and expanding railroads into the West. Selection of transport modes and choice of routes determined which regions would be favored and which economic activities would prosper.

The automobile, in the early twentieth century, increased mobility of people but did little to alter patterns of freight movement until a sufficiently large highway network, demanded by motorists, made trucking economical. Truck transportation received a major boost with the introduction of the interstate highway network financed through the Highway Trust Fund initiated in 1956. A great deal of this truck freighting occurred at the expense of the railroad.

The railroad, which by 1920 accounted for nearly 98% of intercity travel, lost all but a 15% share of the intercity passenger travel market to the highway in the brief period of 20 years before World War II. Air transport,which was barely started as a viable system before World War II, emerged in the last 30 years as a significant component of the passenger transportation system, accounting for more than 10% of all intercity passenger-kilometers.

In retrospect, phenomenal changes in transportation since World War I came about with the transition of the U.S. from an agrarian to an industrial economy. With agriculture now employing scarcely 4% of the labor force, and still maintaining the U.S. as the world's greatest agricultural producer,agriculture-related transport must stablize to match the general economic growth. Industrial activity also has reached its peak, relative to the general level of economic activity, and has actually begun to decline as a percentage of GNP. The growing sector now consists of services, based to a great extent in the information sciences. It would be difficult, therefore, to envision another major economic change comparable to those of the first half of the century which would create the need for still another revolution in transportation within the next 50 years.

There may be one force for change which, while not altering the basic character of transportation, will affect transportation technology and its relative economics. Transportation has developed on an energy base of liquid fuels. While liquids may continue to fuel transportation, their source must change dramatically and the relative structure of prices can be expected to alter. Thus, the relative cost of energy for transportation will also change. During the long period when (real) petroleum prices were declining, the energy intensity of transportation within each mode was also declining. As a result, the relative energy cost had been in a long-term downward trend. With a four-fold increase in petroleum prices in 1974, the relative cost of energy in transportation reverted to what it had been twenty or thirty years earlier.

At present, transportation, including both direct and indirect expenditures, accounts for 20% of the GNP divided about equally between freight and passengers. Transportation currently accounts for 26% of total U.S. energy consumption and 55% of petroleum consumption. The breakdown of Transportation components is illustrated in Tables D.1 and D.1.2.

## D.2 National Transportation Goals

The framework for comparing proposed new intercity transportation systems must necessarily be structured in such a way that specific decisions conform with regional and local goals, consider regional and local economic and social impacts, and satisfy needs for forecasted traffic demands on particular route segments. On the other hand, all transportation linkages ultimately become components of an overall national transportation system which will evolve in a manner compatible with the general socio-economic environment. How the national transportation system grows, adapts and changes over time will be influenced by many things, not the least of which could be national aspirations for conveniences in transportation, compatible with some perceived level of affluence and related life style.

| Year | Total Traffic Volume | (1) Railroads | | Motor Vehicles | | (2) Inland Waterways | | Oil Pipelines | | (3) Airways | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Volume | % of Tot | Volume | % of Tot | Volume | % of Tot | Volume | % of Tot | Volume | % of Tot |
| 1975 | 2,080 | 757 | 36.4 | 488 | 23.5 | 343 | 16.5 | 488 | 23.5 | 3.7 | 0.2 |
| 1970 | 1,936 | 771 | 39.8 | 412 | 21.3 | 319 | 16.5 | 431 | 22.3 | 3.3 | 0.2 |
| 1965 | 1,651 | 721 | 43.7 | 359 | 21.8 | 262 | 15.9 | 306 | 18.6 | 1.9 | 0.1 |
| 1960 | 1,330 | 595 | 44.7 | 285 | 21.5 | 220 | 16.6 | 229 | 17.2 | 0.8 | 0.1 |
| 1955 | 1,298 | 655 | 50.4 | 223 | 17.2 | 217 | 16.7 | 203 | 15.7 | 0.6 | * |
| 1950 | 1,094 | 628 | 57.4 | 173 | 15.8 | 163 | 14.9 | 129 | 11.8 | 0.3 | * |

(1) Includes electric railways, express and mail.
(2) Includes Great Lakes, Alaska for all years and Hawaii since 1960.
(3) Domestic revenue service only, includes express, mail and excess baggage.
* Less than 50 million ton-miles, or less than 0.05%.

Table D.1.1 - Volume of Domestic Intercity Freight Traffic By Type of Transport: 1950-1975 ( in Billions of Ton-Miles Except %)

| Year | Total Traffic Volume | Private Automobile | | (1) Airways | | (2) Buses | | (3) Railroads | | (4) Inland Waterways | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Volume | % of Tot | Volume | % of Tot | Volume | % of Tot | Volume | % of Tot | Volume | % of Tot |
| 1974 | 1,331 | 1,143 | 85.9 | 146 | 11.0 | 28 | 2.1 | 10 | 0.75 | 4.1 | 0.3 |
| 1970 | 1,185 | 1,026 | 86.6 | 119 | 10.0 | 25 | 2.1 | 11 | 0.9 | 4.0 | 0.3 |
| 1965 | 920 | 818 | 88.7 | 58 | 6.3 | 24 | 2.6 | 18 | 1.9 | 3.1 | 0.3 |
| 1960 | 784 | 706 | 90.1 | 34 | 4.3 | 19 | 2.5 | 22 | 2.8 | 2.7 | 0.3 |
| 1955 | 716 | 637 | 89.0 | 23 | 3.2 | 25 | 3.6 | 29 | 4.0 | 1.7 | 0.2 |
| 1950 | 508 | 438 | 86.2 | 10 | 2.0 | 26 | 5.2 | 32 | 6.4 | 1.2 | 0.2 |

(1) Includes domestic commercial revenue service and private pleasure and business flying.
(2) Excludes school buses.
(3) Includes electric railways.
(4) Includes Great Lakes.

Table D.1.2 - Volume of Domestic Intercity Passenger Traffic By Type of Transport: 1950-1974 (in Billions of Passenger-Miles except %)

While decisions to invest in individual components of specific transportation modes may be made from the localized perspective of relatively short-term profitability criteria, the future system must be viewed as a long-term development. Thus, societal transportation alternatives must be evaluated within a framework of long-term socio-economic predictions even where specific decisions are short-term. At the same time, it must be recognized that transportation policy will, in turn, shape the future character of the economy. Thus, prediction of an economic future will not be independent of the type of transportation we, as a nation, decide to develop. On the other hand, the effects of such feedback are so complex that, at least initially, it may be necessary to assume independence of feedback effects and therefore to assume that the transportation policies, whatever they turn out to be, are compatible with the projected economic growth of the nation.

While it is evident that such evolution will take place as a result of a very large number of individual decisions, these decisions will be influenced by other policy decisions made at the societal or governmental level. For example, the decision for the people of California to fund a new, high speed rail system will be conditioned by the kinds of federally funded R&D programs which will make such a system possible.

### D.2.1 The Long Term Socio-Economic Environment

By its very nature, prediction of future events is a risky exercise. Nevertheless, all investment decisions to undertake a new transportation system must be predicated on some idea of how the future will unfold. This, in turn, must be coupled with an expression of confidence that the proposed system will prove to be economically and socially viable. Furthermore, a go-ahead decision on a new system takes on the characterisitics of a self-fulfilling prediction in that there is an implied commitment to make the program successful in spite of unforeseen or unforeseeable obstacles which must be overcome. Traditionally, investments in the individual components of a system are based on relatively short-term forecasts of specific benefits and costs which usually assume, either explicitly or implicitly, a constant economic environment over that time period. Thus, an individual may invest in an automobile by planning ahead for only three or four years; an airline will buy a new model airplane with perhaps a 10-year or 12-year perspective and have confidence that the new model will continue to be competitive for perhaps twice that time. In neither case is there a need to consider what future or follow-on investments will be required. The airline will ad to its fleet only as demand grows. On the other hand, the decision to develop a new technology for, say, a high-speed rail system requires a decision to invest in a whole new infrastructure to anticipate how the system may operate in the very long-term. However, the expansion of rolling stock for the railway will be incremental, made only as the demand grows. These questions indicate a need to examine in depth the long-term prediction problem.

### D.2.1.1 The Prediction Problem

Conventional methods for evaluating proposed transportation systems have started with traffic demand *forecasts*. A *forecast* represents an extrapolation from past data into the future (Brown, 1962). The more precisely and completely the future system is described, the wider will be its ultimate divergence from the forecast state as the futurity of the forecast is extended. This divergence expands exponentially with time, Figure D.2.1. Furthermore, if one expects to reach some level of system performance, this level will presumably be reached, but the variance for the point in time at which the target performance is reached may be many times greater than the variance of the estimate itself. This spread in estimates with futurity means that for each forecast there will be some time beyond which the variance becomes too excessive for expected outcomes to be meaningful in decision-making. Thus, one can only broadly specify the system performance being forecast if a long-term forecast is desired. Otherwise, specific estimates must be limited to a short-term planning horizon over which the variance in forecasts is reasonably small.

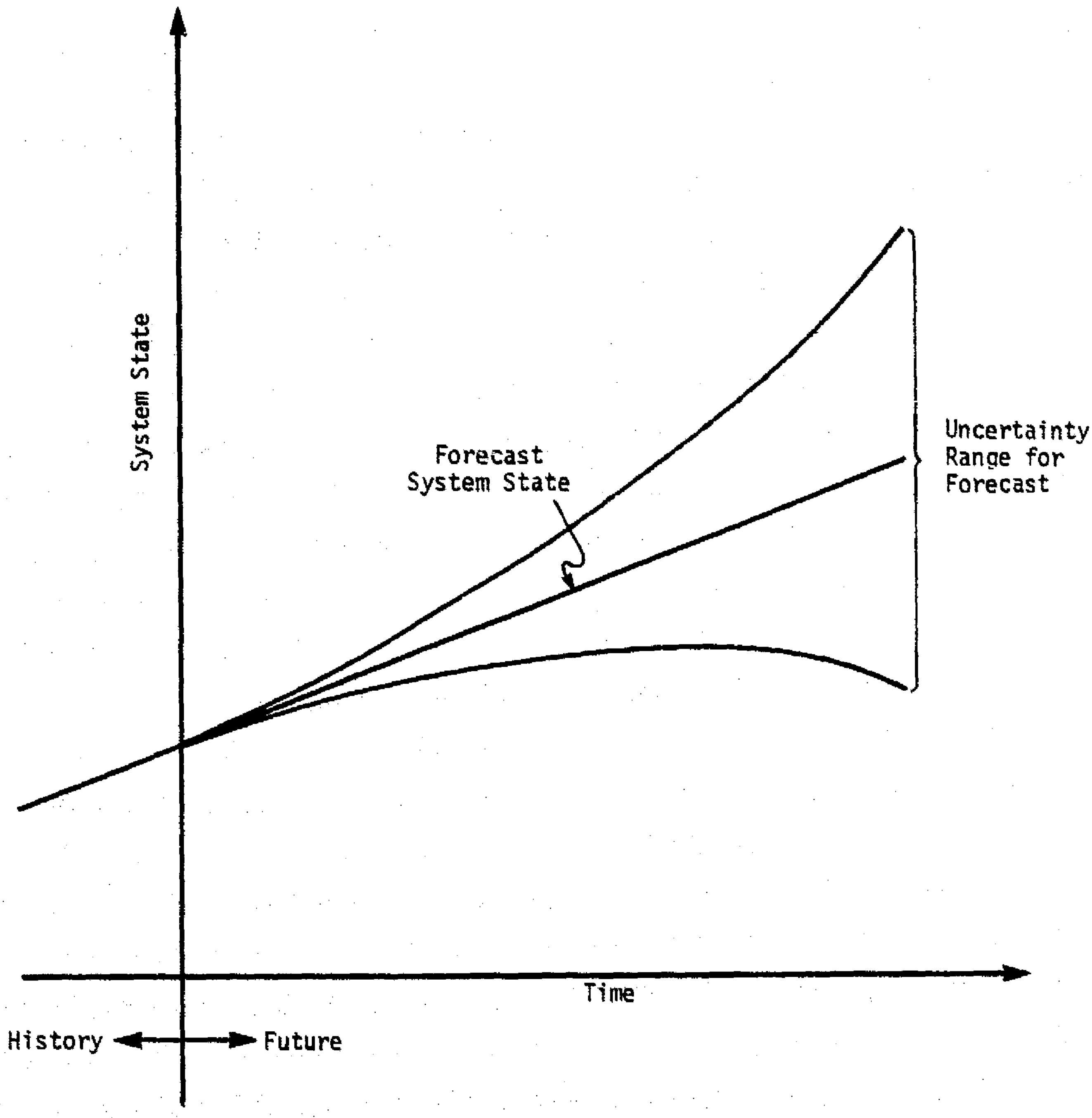



Figure D.2.1 - Forecast Divergence

A prediction as differentiated from a forecast, which is an extrapolation, is a *pre-statement* of the future. A prediction includes the forecast, with the addition of conditional judgments of influencing factors which serve to restrict the variance of future outcomes to fall within some reasonable range, thereby providing some insights into the future course of events.

A fifty year span may be a relatively short time to plan for new transportation systems which will require many years to develop and grow to a scale that is viable in competition with existing systems. This is far too long a time for forecasting any transportation system growth. Therefore, a prediction methodology rather than a more limited forecasting technique becomes an essential part of establishing a methodological framework.

Fifty years may be the limit of our forecasting ability to establish a meaningful range of economic conditions and even this forecast is only feasible provided these economic conditions are described quite broadly. In other words, we might be comfortable in extrapolating real GNP to the year 2030, for instance, by simply assuming that the historic growth rate of the past century, amounting to 3.4% per year, will continue indefinitely. However, we are on shakey ground if we extrapolate the composition of GNP by sector or geographical distribution. We can, however, predict what the distribution might be by introducting a number of conditional assumptions which each reader could, himself, assess for reasonableness. With such an approach, some idea may then be obtained for predicting the future transportation system. This predicted system may then be taken as the national aspiration for the long-term transportation system.

Caution must be exercised even here to keep the description of the transportation aspiration sufficiently broad that, within the variance of encompassing forecasts, they provide a meaningful frame of reference. At the same time, the description must be sufficiently detailed to provide a focus for planning intermediate stages of transportation development along with needed R&D policies for achieving the goal.

*In effect, the methodology calls for designing a way to proceed from the system as it exists at the present to a fairly broadly described new transportation system over a long-run future.*

D.2.1.2 Planning for Success

The predicted socio-economic future should be based on realistic assumptions which, on the whole, are optimistic. It is always possible to develop a set of plausible scenarios resulting in pessimistic outcomes at one extrme and overly optimistic outcomes at the other. However, we are attempting to establish a goal or aspiration which people in general would agree is desirable. *These are always* in the nature of *self-fulfilling predictions which lead to decisions for success*. While failure and digressions from the plan can and do occur, it is the *achievable* objective which should form the basis for planning. This is not to imply that contingency planning is unnecessary but rather to point out that extremely pessimistic long-term scenarios do not furnish a useful basis for describing the aspiration transportation system.

A range of futures may nevertheless be desirable. However, it is not the purpose of Phase I to do more than illustrate the technique. Therefore, in addition to the 3.4% steady growth case, only one other case will be reviewed. This second case calls for a prolonged interruption of economic growth.

It is felt there is the real possiblity of a major shortfall of energy for a period of some years during the 1980s and possibly extending into the 1990s. Under such circumstances, a prolonged interruption of economic growth might very well occur. While the optimistic outcome calls for a resumption in economic growth, such an interruption would probably impact social attitudes in such a way as to alter perceived transportation values seriously. Furthermore, the nation, in coming out of such a depression, would be doing so with a significantly altered institutionalism and a significantly changed relative price set.

### D.2.1.3 Depicting the World of 2030

While the aspiration approach has been suggested above, it should be emphasized that ECONERGY does not purport to make depictions of desirable futures except as "for instances." Actual implementation of the methodlogy could utilize the opinions of experts. Furthermore, a consumer survey is not a practical mechanism for accomplishing this task because people tend to judge their own future values in relation to their own current circumstances. While they might extrapolate, they don't, in general, have the ability to predict how they might feel about various values if their own circumstances should turn out to be materially different from those with which they are familiar. Furthermore, individual values are influenced to a great extent by the common views of others. A herd instinct will tend to take hold; there will be a "keeping up with the Joneses" syndrome. Therefore, there might be some assessment by sociologists of what kinds of future values people may come to hold.

### D.2.2 The Base Case - Steady Economic Growth

Given that the average national economic growth of 3.4%, characteristic of this century, continues into the foreseeable future, then the forecast of total economic activity, as measured by GNP, will climb to about $7.5 trillion (1972 dollars) by 2030. There may be some question about population growth over this interval. Clearly, there has been a dramatic slowing of the birth rate in recent years. However, birth rates do fluctuate, partly reflecting changing social attitudes. The U.S. Bureau of the Census projects that if fertility rates approach replacement levels of 2100 births per 1,000 women and if there is a slight drop in the mortality rate and annual net immigration continues at 400,000, then U.S. population will reach 300 million in 2030. Thus, population level is considered by the Census Bureau to be the middle projection bracketed by higher and lower projections. A population of 300 million by 2030 implies an average annual growth rate of 0.6%. This would mean a per capita GNP of $25,000 (in 1972 dollars) or about five times the present value. The question now is how much of this increased affluence is likely to be allocated to transportation and, in particular, to intercity transportation. If past trends of urban growth continue; if the ratios of business versus pleasure travel were to remain the same; if the same logistic system for distribution of goods holds true; then it would be a simple matter to predict that transportation expenditures will grow in phase with GNP. This may be a reasonable first approximation. Figure D.2.2 shows how proportionate spending for transportation grew from the time the automobile was introduced in 1909 until World War II. Since then, it has remained essentially constant at about 13 percent. On the other hand, the composition of transportation has changed. The ratio of intercity to urban transport has altered significantly. The ratio of freight to passenger expenditures had remained essentially constant at approximately one to one with the total cost of transportation representing almost a constant 20% of GNP (Transportation Association of America, 1977).

While these ratios have been constant over the post WWII time period, this was not always so. Increasing proportions of spending on transportation came about as we transitioned from an agrarian to an industrial based economy. Thus, these constant ratios may be representative of a *mature* industrial society. If the next transition in the economy is from an industrial to a service economy, the percent of GNP for transportation might well decline for freight and increase for passengers (i.e., tourism).

The surge in an increased spending ratio for intercity transportation after World War II may have occurred because of the increased convenience and speed of air travel. People might well have been willing to spend a larger portion of their incomes for travel before that time if transportation service had provided a higher utility for them. Thus, in formulating a plausible transportation aspiration for 2030, some

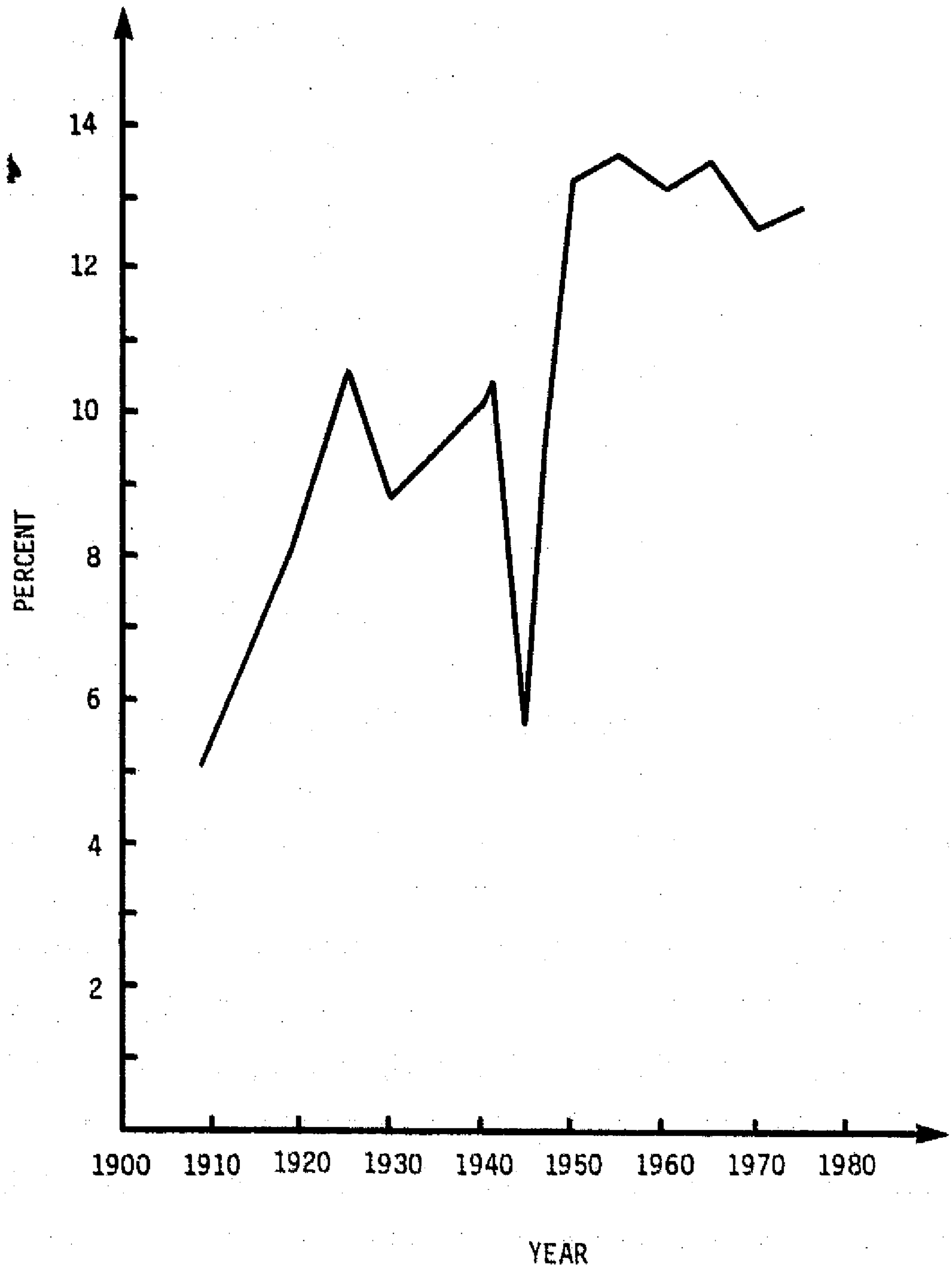



Figure D.2.2 - Percent Personal Consumption Spent for Transportation judgment must be made as to how the extra transportation spending will be allocated to more passenger miles versus more comfort, convenience, speed, etc.

Because we are describing an aspiration for a 50-year future, it will not pay to become too precise in describing what the transportation situation will be nor what the trade-offs between speed and other values will be. It may be sufficient to hypothesize such conditions as:

1. Passenger-kilometers per dollar of GNP will remain constant, as it has in the recent past (1960-1975), after introduction of jet travel. The urban/non-urban split will remain the same.

2. Agriculture (now 4% of GNP) and manufacturing (now about 20% of GNP) which together dominate demand for freight, will together decline to 18% of GNP. If freight costs maintain the same proportion to other costs, this will mean 7.5% of GNP will be spent for freight transport.

3. Capital costs for transportation will rise from 15% of total capital cost to 18% of total capital cost, or say 3.3% of GNP.

4. Comfort, speed and safety will improve by some unspecified amount as dictated by physical constraints rather than by cost.

With these assumptions, the amount of travel and freight which must be accomodated 50 years hence is shown in table D.2.1.

With the national transportation aspiration described in terms of magnitudes of travel and freight to be accomodated, it then becomes necessary to allocate this transportation load to regions. Changing population patterns, income levels, characteristics of commerce, etc., of each region with its network linkages provides a means for deter-

| Transportation Attribute | 1950 | 1955 | 1960 | 1965 | 1970 | 1975 |
|---|---|---|---|---|---|---|
| U.S. Passenger-Kilometers (Billions) | 813 | 1,146 | 1,254 | 1,472 | 1,896 | 2,096 |
| U.S. Tonne-Kilometers (Billions) | 1,925 | 2,284 | 2,341 | 2,906 | 3,407 | 3,661 |
| GNP (1972 Dollars-Billions) | 534 | 655 | 737 | 926 | 1,075 | 1,192 |
| U.S. Passenger-Kilometers/ $GNP | 1.52 | 1.75 | 1.70 | 1.59 | 1.76 | 1.76 |
| U.S. Tonne-Kilometers/ $GNP | 3.60 | 3.49 | 3.18 | 3.14 | 3.17 | 3.07 |

(a) Historic

| Transportation Attribute | 1980 | 1990 | 2000 | 2010 | 2020 | 2030 |
|---|---|---|---|---|---|---|
| U.S. Passenger-Kilometers (Billions) | 2,480 | 3,464 | 4,840 | 6,763 | 9,447 | 13,196 |
| U.S. Tonne-Kilometers (Billions) | 4,310 | 5,720 | 7,560 | 10,100 | 13,300 | 17,700 |
| GNP (1972 Dollars-Billions) | 1,409 | 1,968 | 2,750 | 3,842 | 5,367 | 7,497 |

(b) Projections

Table D.2.1 -Transportation Levels of Service mining actual transportation demands for 2030 by specific corridors. This is illustrated in the example case for the Los Angeles/San Francisco corridor.

The next question to examine is the kind of technologies that could be developed to meet a long-run level of demand. In some cases, such an exercise might reveal that the implied volume of traffic is simply not physically realizable. In other cases, it will show the scale of revision for the transportation system which must be made. It will also demonstrate when R&D programs must be initiated. This question is addressed in Chapter 10.

### D.2.3 The Resource-Constrained Case

Various studies such as the WAES study of MIT have indicated a major energy shortfall developing on a world-wide scale sometime during the mid 1980s. This will be largely due to a petroleum shortage and, as such, is likely to impact transportation more severly than other components of the economy. A UCLA study (English and Liu, 1977) develops a plausible scenario based on this shortfall occurring but it also includes the assumption that we will adapt successfully and devise suitable alternatives. These alternatives will include development of synthetic hydrocarbon fuels. Nevertheless, the higher relative fuel cost will probably bring about a major change in the values which we place on transportation. The technical options chosen will tend to favor less energy-intensive modes rather than more energy-intensive modes. The changing relative cost of freight transportation will influence trends in location of production facilities in order to reduce overall transport. The effect may be to induce a move towards some decentralization of industry.

The probability of such a resource-constrained future could be quite high. The work required to develop a plausible transportation aspiration compatible with it, however, is beyond the scope of the present study. Nevertheless, it is important for an intercity transportation evaluation methodology to be able to reflect different anticipations of long-range futures. It should also be recognized that transportation systems themselves help condition the future. For example, urban decentralization tends to result after the introduction of a major transportation system in a sparsely populated area. The ECONERGY comparison methodology does provide a mechanism for evaluating the effects of different long-range futures on transportation planning.

## D.3 Economic Considerations

A number of important economic questions will be discussed in this section. While not an exhaustive set of questions, they raise the most important issues which bear on application of the comparison methodology.

### D.3.1 Long-Term Investments in Transportation Systems

Incremental investment decisions necessarily are short-term. They all have the same characteristic pattern of an initial net expenditure stream (investment phase) followed by a larger net benefit stream (return) as shown in Figure D.3.1.

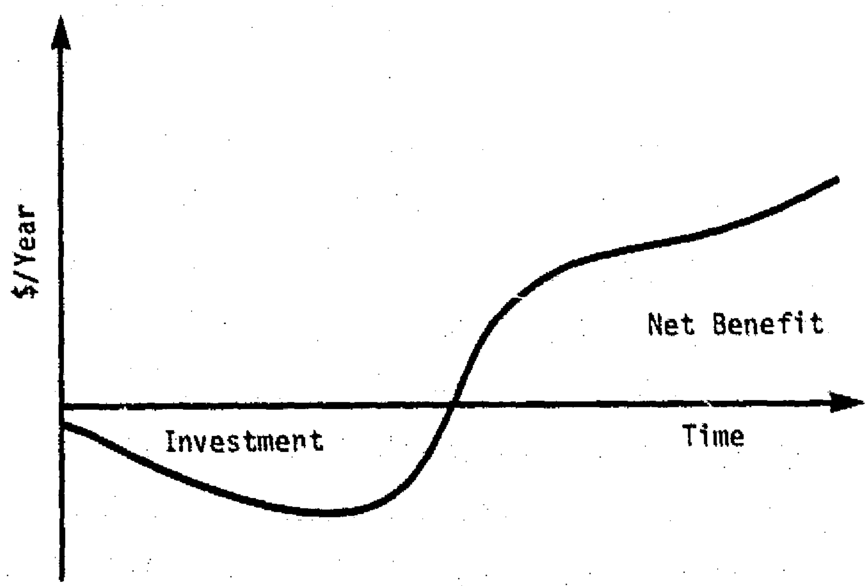



Figure D.3.1 - Typical Project Cash Flow

The justification for each investment, whether that of a personal automobile with its short investment/payback cycle, or a new fixed guideway public system with its relatively long investment/payback cycle, is that expected return flow exceeds investment flow. When the national transportation system is financing its own growth by reinvesting the entire return flows in expansion of new transportation, then the total cost of transportation will grow exponentially, Curve A of Figure D.3.2. If a change in the pattern of the cycle were to occur, as would be the case in shifting the emphasis in transportation from the short-run cycle of automobile systems to fixed guideway systems, a shift from Curve A of Figure D.3.2 to Curve B of Figure D.3.2 would produce a bulge in the cost of transportation. The extra investment represented by the shaded area between Curves A & B and as shown by English and Smith, 1977, is the societal investment needed to change curves from the evolutionary growth patter of A to the new path B. The economic justification of such a shift in emphasis is that the discounted value of the differences over a more-or-less indefinite future is positive. Even if the crossover point does not occur until sometime in the next century, the discounted value of the net benefit/cost flows can be positive, simply because of a favorable difference between the relative growth rates and the discount rates.

### D.3.2 Energy Limitation as a Driving Force for Change

The transportation sector has been fueled by petroleum which currently accounts for about one third of the direct operating cost (DOC) of transportation. This breaks down into about 30% for automobiles, 40% for airplanes, 12% for trains and 33% for trucks. The fourfold increase in world oil prices in 1974 changed the pricing structure of transportation dramatically but the U.S. transportation sector has been sheltered from much of the effect as result of indirect subsidies. For example, U.S. airlines show 38% of DOC for fuel as contrasted with international lines which have fuel costs of 50% of DOC. The relative price of liquid fuels must rise within the next twenty years with the result that fuel costs will continue to represent a rising share of transportation costs.

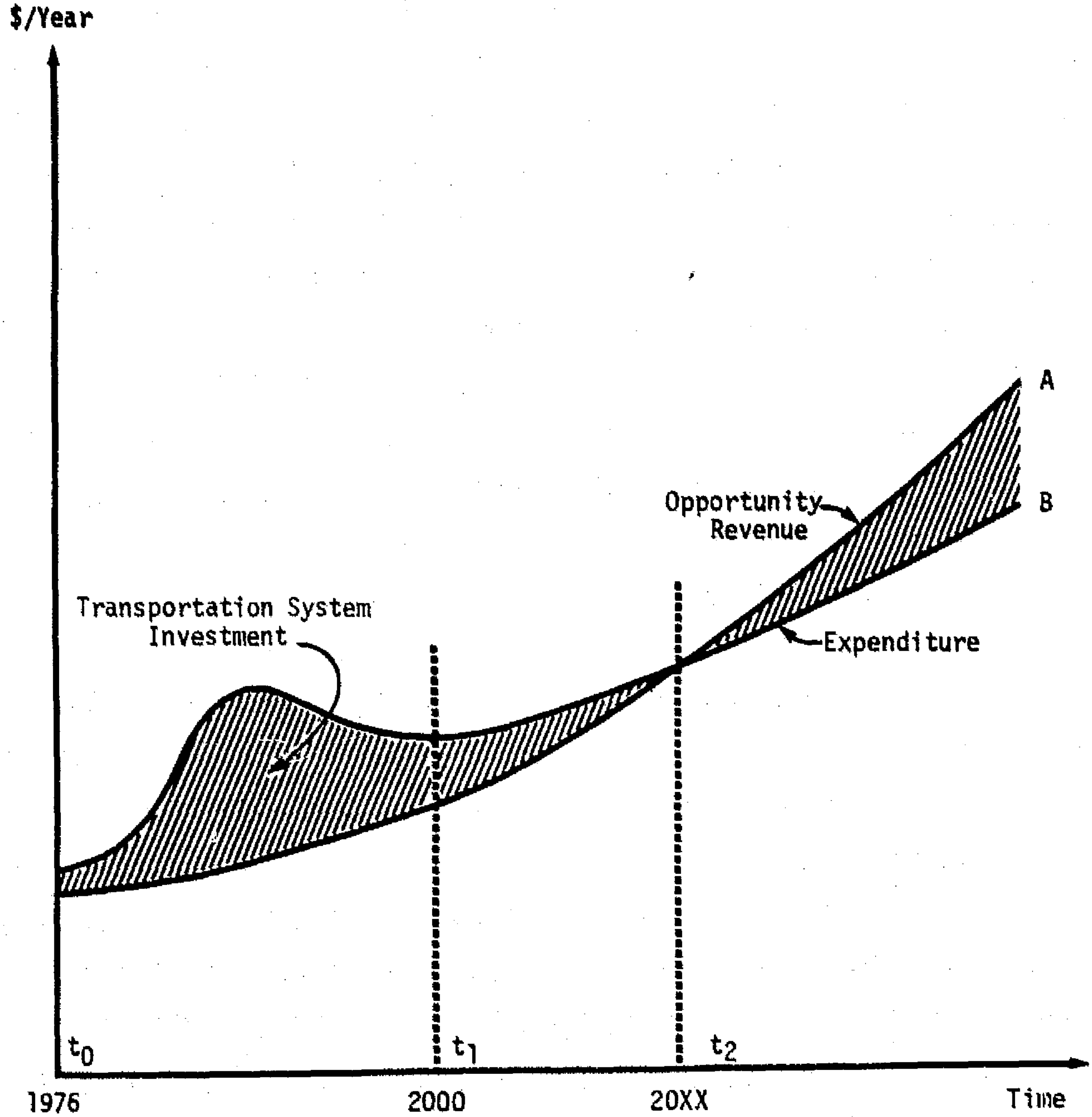



Figure D.3.2 - Long Term Cash Flow for Transportation Investment Alternatives

The effect of rising energy prices will have other impacts on transportation. Transportation now accounts for slightly more than 25% of total U.S. energy consumption for propulsion alone. However, about 20% of total energy use in transportation is consumed in industrial processes required for building transportation equipment. The altered relative price of energy as well as the need for alternative sources of supply will force changes in the characteristics of transportation. These changes will take time, but they are inevitable. They will be reflected in design of lighter vehicles, reduced performance, and longer-lived equipment. However, as people adjust their life-styles to reflect their own value adjustments, the modal splits will also alter. Aside from these altered patterns of transportation, the major impact might well be reduction in the proportion of GNP spent on transportation. In this case, freight transportation might be altered to accomodate the changed economics of plant locations required to balance material sources and market outlets. These are all long-term effects which must be taken into account in developing a plausible aspiration for long-term future transportation systems.

### D.3.3 Finance and Subsidy

As will be emphasized in Section D.3.4.1, *finance* relates to the question of the *how* of the payment for goods and services. It is usually considered in the context of capital expenditures which separate, in time, payment for providing the cability to furnish the service and the realization of the actual benefits from the service. Capital which is financed by debt is usually required to be paid back over some fixed time period at a specified interest rate. Prorating such expense over a given time span establishes a scale of fares or freight rates required to cover "debt service". However, such rates are predicated on allocating all of the costs of each component system to users in proportion to their use of the system. Rates or fares computed in this manner may tend to be overstated to the extent that some part of the investment contributes to the later success of follow-on investments. In other words, fares are based more on allocation of financing than on true economic cost.

Subsidies for capital expenditure, on the other hand, may have the opposite effect of causing an understating of true economic costs. In turn, depending on how subsidies are established, whether to cover capital costs or operating costs, they will be reflected in an adjusted fare structure.

It is true that certain aspects of transportation may properly be regarded as public goods. As such, incremental use of the public component is a *free* good (i.e., zero shadow price) as long as the system operates below capacity. Nevertheless, while the public must pay collectively for use of the system, the individual's decision to utilize the service is strongly influenced by his personal payment for it. Thus, subsidies on the one hand and taxes on the other have a great influence on demand for the service and are instruments for effecting policies for encouraging one mode at the expense of another.

### D.3.4 The Discounting Principle

An important characteristic of the ECONERGY methodology which distinguishes it from all previously developed approaches for transportation planning, is the emphasis on the very long-term. This requires special understanding of the fundamental concepts underlying discounting procedures. Such procedures, now commonly called *discounted cash flow* (DCF) when applied to the private sector, or *benefit/cost* analysis when used in the public domain, are very often used incorrectly and are viewed, almost universally, in an over-simplistic way. The kinds of errors made and the reasons they turn up in investment decision-making need to be reviewed in order to establish a fresh viewpoint for the discounting technique proposed by ECONERGY.

#### D.3.4.1 Economic Justification Versus Financial Feasibility

There is an important distinction between economic justification and financial feasibility. Failure to recognize this difference often results in erroneous analysis. This error is prevalent in transporation studies. That it occurs is evident from a misdirected emphasis on bond issues that appears in most transportation studies. In the minds of many, these two types of analyses are the same thing. But in point of fact, they address completely different problems. An economic analysis is made for the purpose of answering the question: *What* transportation system is the most economical alternative by comparision with all others? On the other hand, a financial analysis is made for the purpose of answering the question: Given the best choice of transportation system, *how* is the cash flow to be managed for implementing that particular system? The distinction is between *what* in terms of economics and *how* in terms of financing. This confusion is evident even in the naming of the two methods for project evaluation: the so-called *utility financing* and the *equity financing* method. As evidenced by their names, these methods, although presented as a means for economic evaluation, are essentially *finance*-oriented. In effect, there is an implicit assumption that any project is good but the real question is which is the easiest one to finance.

#### D.3.4.2 Life Cycle Cost

It is appealing to evaluate a proposed new transportation system over a time-period which may be defined as its *life cycle*. This life cycle is conceptualized as being the physical life of the hardware components of which the system is comprised. However, what is usually done in practice is to define a planning period corresponding with the conventional financing cycle of the equipment to be purchased. This leads to a cut-off time beyond which no further costs or benefits are considered. Such a cut-off is then held to be justifiable because the discounted values beyond the cut-off time tend to be insignificantly small.

Actually, there can be no unique life cycle for a proposed new transportation system. If the decision to proceed with the new system proves to be unsound, it may be abandoned long before the end of any physical life. If, on the other hand, it is viable, the system will grow and expand for an indefinite time. However, its components wear out, break down or become obsolete over a spectrum of physical or economic life cycles. Consider an airline, for example. The procurement of a new airplane model may be predicated on a physical life of, for instance, eighteen years. However, a number of things may dictate that the model type could be serviceable for many fewer or many more years than eighteen. If within eighteen years, the new model proves to be an economical component of the airline network, over those years many more airplanes of the same model will have been purchased. Therefore, the fleet will be comprised of aircraft with a mix of ages. If the model should then become obsolete by a technological advance in, perhaps 22 years, the entire fleet must be replaced when some airplanes in the fleet will be almost new. The present Boeing 707 is representative of such a case, while the Douglas DC 7 was obsoleted less than 10 years after it was introduced into service.

Physical wear and tear and technical obsolenscence are only two considerations in the determination of a life cycle. Capacity limits may be another. When growth in demand reaches the capacity limits of equipment, new identical units may be added but alternatively it may then pay to replace existing equipment with new larger equipment. For example, individiual airplane types may reach load capacity limits, but, while added flights using identical equipment might take care of the problem for a time, larger units to replace the existing equipment might prove more economical. Furthermore, replacement of the smaller equipment by larger units could be dictated by capacity limits of air terminals in terms of flights/day. This tendency for growth to overtake capacity produces accelerations of component life cycles. Thus, if there is a useful concept of a discernible life cycle, it clearly is growth-rate dependent. The concern for identifying the life cycle may be counter-productive in one other way. It leads to a view of independence of the system when in fact each new project is an interactive component of a growing time-interdependent system.

D.3.4.3 Interdependencies

Conventional economic evaluation techniques are largely based on implicit assumptions of independence. The origion of this tendency may lie in the focusing of financial feasibility rather than on economic evaluation. Each proposed system clearly has a fixed capacity limit which, when reached, constrains the outputs to a constant output for the life of that system. However, if an initiating project proves successful, other expanded and improved systems will be required as time unfolds. The complete system includes not only the complementary components to make it immediately serviceable, but also succeeding replications and expansions into a very long-run future. Thus, from the systems viewpoint, the net cash flow (i.e., benefit flow), including allowance for capital spending, will *always* be exponential beyond some planning horizon (Section D.2). See Figure D.3.3.

Clearly, the exponential growth must level off at such time as the system saturates. However, this will generally be a very long time in the future.

Even with the use of conventional discounting and relatively high discount rates, the net present value for a time scale of as much as 50 or 100 years can be significantly large. Therefore, contrary to accepted practice, discounted values beyond 20 years *are not* insignificant but can, in fact, be far more significant than the discounted values of the first 20 years. This is so because the conventional discount function in continuous form is an exponential, $e^{-rt}$ where r is the discount rate. If the benefit flow stream is growing at an exponential rate g, then the sensitive parameter is g-r. If this parameter is positive, the system's present value can approach an arbitrarily large number.

D.3.4.4 Economic Measures

Economic measures are stated in terms of monetary values — dollars.

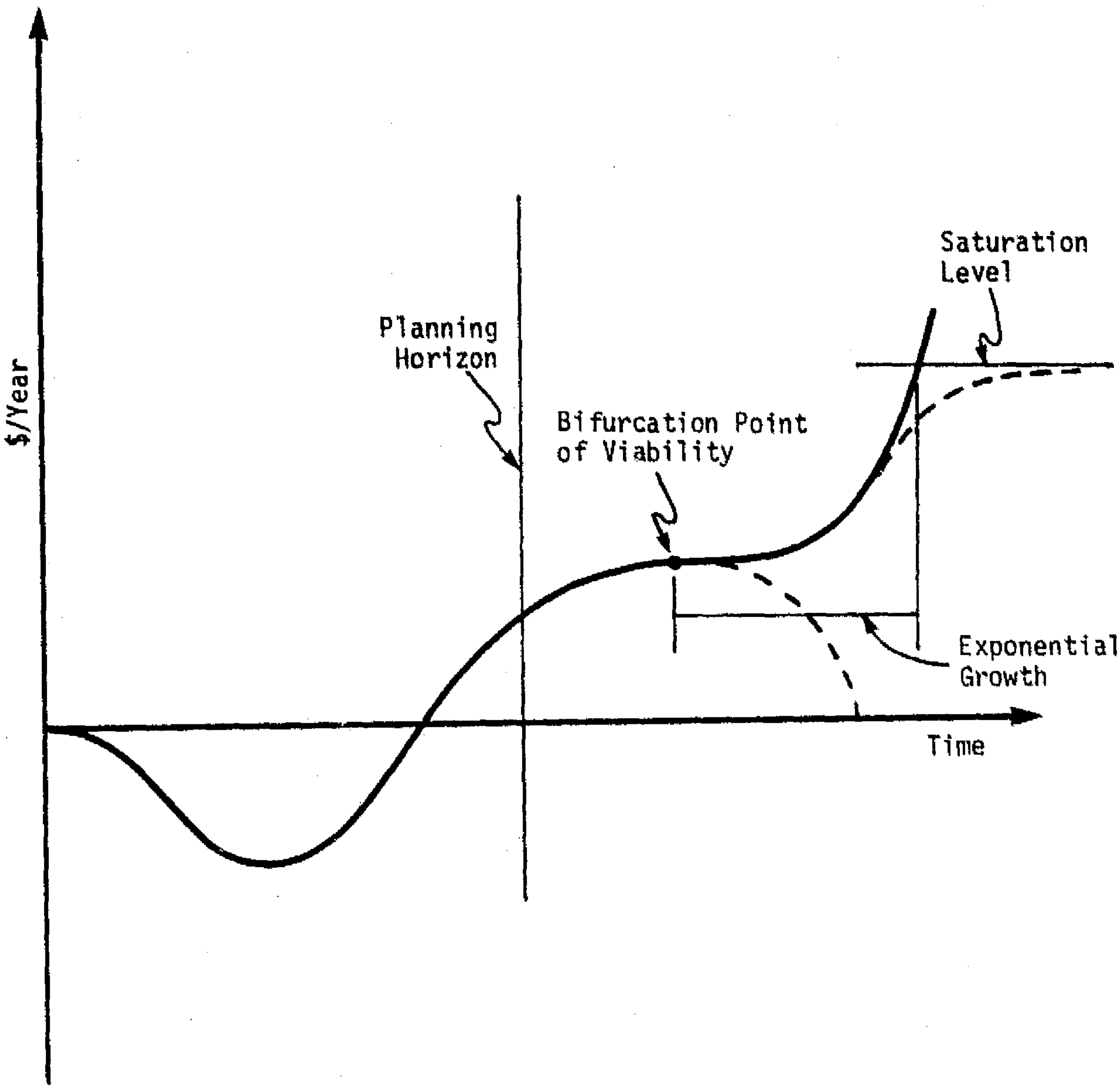



Figure D.3.3 -Typical Cash Flow Stream for a
New Transportation System

That dollar measures do not capture all values of concern is obvious and is the reason why it is necessary to structure the evaluation framework in terms of variables other than economic measures. It is worth considering why one set of variables can be readily aggregated into dollar values while others, such as noise, safety, aesthetics cannot.

Fundamentally, money is a reference value measure where large numbers of trades are being made, so that a statistical average of all trades for a given good establishes its average value in a market. Thus, relative prices of all goods being traded are statisitcal measures of relative value in *current time*. If no market exists, as is the case for most externalities, then the only way to establish a value in monetary terms is either to impute it, or to develop a proxy for an exchange value based on estimates of willingness to pay if a market does, indeed, exist. In many cases, such as for the comparison variables, it is a more feasible approach to proceed directly with the value analysis as discussed in Chapter 4. The point of this discussion is to emphasize that economic value expressed in dollars is only a way of aggregating a large number of physical variables for which prices are determined through the voting mechanism of the market.

It should also be clear from this that the values of only those goods flowing through the market in current time can be so aggregated. Except for a very limited futures market, which is essential short-term, the prospective future flows of goods and services *cannot* be priced by the market. The best that can be done is to estimate what relative values will be in the future, when they actually are priced by the market. Thus all long-term relative values suffer in the same way, in that there can be no market pricing system and thus values must be imputed whether for tangibles such as pounds of aluminum, gallons of gasoline and the like or for intangibles such as noise. In general, the kinds of goods which are priced in the market currently will be those for which future imputed prices are more readily estimated, and which are therefore usually treated as if they were market-determined and so are aggregated accordingly. However, as shown, the values of such imputed dollar amounts are not the same as present prices.

Imputed future prices are on the same monetary scale as at present but do not incoroporate any measure associated with the utility of time.

D.3.4.5 Opportunity Cost Versus Time Preference

Investments in new transportation systems, as for any investment, require foregoing use of certain present resources for the prospect of recovering them - or their equivalent - plus a premium over some future time frame. Two considerations come into play in making the decision. First, the opportunity, which is exogenous to the decision-maker, is determined by physical and technical variables in such a way that the resources invested, such as labor, materials, energy and other less tangible imputs are returned as a later flow of some other mix of service, transformed materials, energy and other less tangible inputs. Not only are the amounts of such resources prescribed by the characteristics of the opportunity but so also is the shape of their flows as shown in Figure D.3.1

The second characteristic for the decision-maker to consider is the measure of worth or utility of the alternative opportunities to be compared. This may be illustrated by Figure D.3.4.

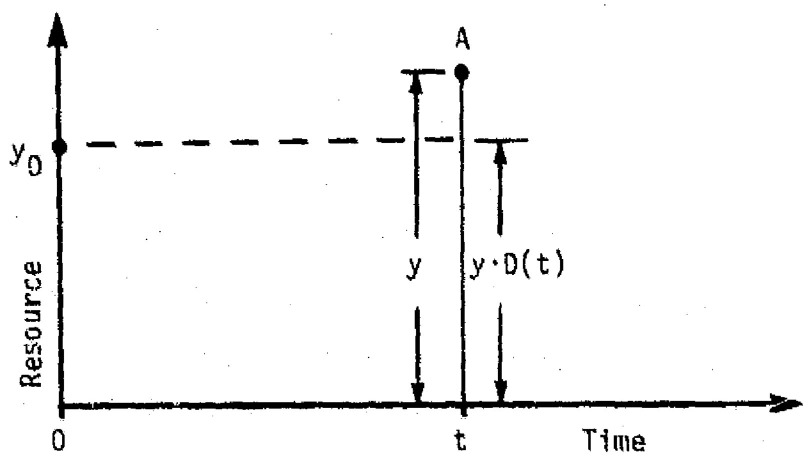



Figure D.3.4 - The Discounting Principle

The opportunity may be exemplified by a point return of resource $y$ at $t$ (point A above) for an investment of $y_0$ at $t=0$. The investor will be satisfied if, when he factors $y$ by a *discounted factor* $D(t)$,

$$y \cdot D(t) > y_0.$$

He will be indifferent at a point where

$$y \cdot D(t) = y_0.$$

The factor $D(t)$ completely captures the measure of this utility for the *prospect* of $y(t)$. This depends on time as well as on how strongly he feels about the prospective gain. Conventionally, as developed by Fisher (1930), the discount function has been taken to be

$$D(t) = \frac{1}{(1+r)^t} \quad .$$

Fisher based his argument for using the above equation as the discount function on the equating of the time-reference for consumption with the opportunity for a return. This principle cannot be disputed, but the way in which time-preference changes with time may well be according to some other relation than a constant rate, r. Two separate but related arguments have been suggested for a more appropriate discount function (Lifson, 1976 and English, 1976, 1978). A further extention by English, "A Question on the Validity of the Discount Function", is currently in preparation for publication.

The essence of English's argument is that while the market may establish the ratio of a future to a present value for the next time-increment at (1+r), this may be more or less constant with time as perceived, but time is not perceived with respect to the present on a linear scale. It may be logarithmic as for all other human sense perceptions. On the basis of a perceptual scale for time as the log of time, the conventional discount function transforms into one which discounts longer term values less severely and therefore provides a significant present worth for cash flows which will be generated in the very long run. Such a discount function might be called a discount function based in *perceptual time*.

It may be shown for perceptual time of $\tau = \frac{1}{b}\ln(1+bt)$ where $\tau$ is perceptual time, t is real time, and b a scaling parameter, that

$$D(t) = (1+bt)^{-r/b} \quad .$$

A discount function incorporating this concept and utilizing a 10% value for r and a 0.2 value for b is shown in Figure D.3.5. Conventional discount functions of 10% and 4% are shown for comparison.

The discount function developed above applies to economic measures in a way which satisfies Fisher's criterion of equating opportunity with time-preference. However, to extend the concept of discounting to other than economic measures such as health status or environmental quality requires further review.

D.3.4.6 Discounting of Other Than Economic Values

The discount factor applied to future measures of worth (utility) converts the utility to the present utility of that prospect. The basic notion is a time-preference idea and is no different in principle from other utilities (developed in Chapter 6). A comparison can be made of alternative transportation systems by comparing the utilities of all of the available opportunities (i.e., alternative systems). The approach to discounting used by Lifson (1976) is based precisely on this concept of comparing utilities.

Any discount function based on equating opportunity with time preference has in effect incorporated a reference or base-line opportunity into the comparison. In conventional discounting, the discount rate is identified as being the *opportunity-cost of capital*. This means that there is an assumed reference opportunity with which capital investments may always be compared implicitly.

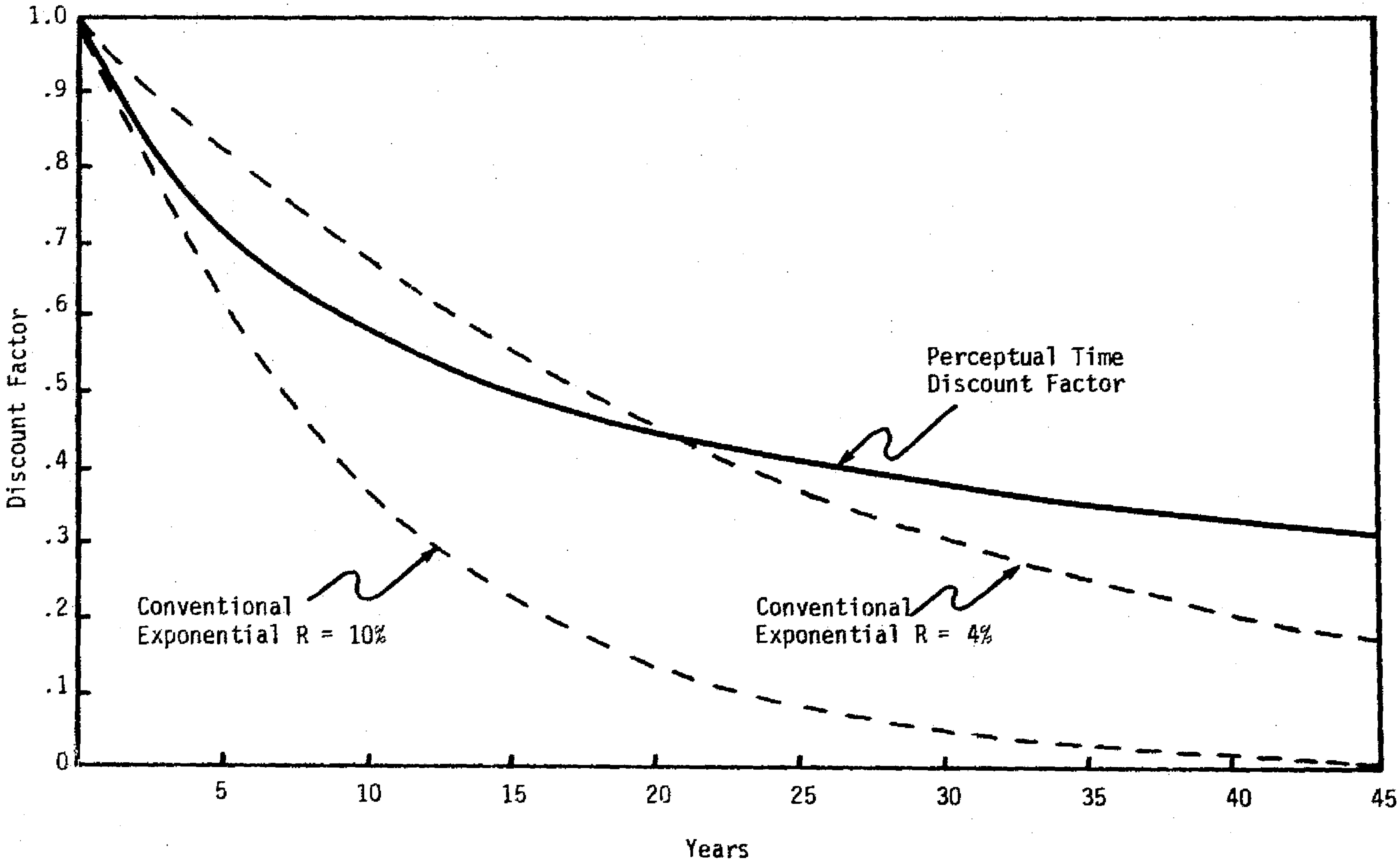



Figure D.3.5 - Discount Factor for Perceptual Time

## D.4 Societal Considerations

Transportation interacts both directly and subtly with all the elements affecting our quality of life. Where we live, where we work, our health, the way we use our land, the noise levels to which we are subjected, our ability to see the world around us, the flora, the fauna -- all these and all the other concerns dealt with in environmental impact statements are influenced by our transportation systems.

In spite of the profound, pervasive consequences of transportation decisions, little is known of the way such consequences are propagated through our physical and social environments. The relationship between air pollution and people's health status, for example, is not understood. Validated analytic models for estimating the effects of emissions of a candidate transportation mode on health are non-existent. As a consequence, emission standards are defined and vehicle emissions are used as criteria in evaluating alternative transportation modal concepts. Vehicle emissions are, however, a *performance* characteristic of a particular system design, not a measure of mission *effectiveness*. For the selection of a modal concept, effectiveness criteria that measure impact by the transportation system on some valued facet of the environment are more appropriate. People's health status, visibility of the areas in which we live, and effects on flora and fauna would define some of the factors that make emissions important to us and would be, therefore, proper transportation system effectiveness criteria. In general, the poor state-of-the-art in modeling the mutual interactions and continuous feedback between transportation and its total environment necessitates the use of makeshift approaches to the analysis and evaluation of alternative transportation modal concepts:

(1) the use of *performance* criteria where *effectiveness* criteria would be more appropriate

(2) the use of effectiveness criteria, with analysis accomplished by eliciting judgmental estimates from knowledgeable personnel

(3) avoiding the problem by omitting troublesome criteria from explicit analysis and evaluation; the impacts omitted from

analysis and evaluation may, of course, be factored into the decision by the decision-maker in some intuitive and, hence, unknown manner.

Approach (3) has been standard practice in transportation planning until the recent pressures for explicit reporting of the bases for decision-making. Approach (1) is used where "hard" data and known models are available; estimation of the relationships between performance criteria and effectiveness criteria is, of course, accomplished by judgment and intuition and is, therefore, not easily reviewed, discussed, or communicated. The ECONERGY methodology is based on approach (2) in order to assure that the information generated by the analysis activity, using the best available techniques and data, is the information responsive to the needs of the decision-maker's value system, and that the output of analysis is explicitly evaluated through application of an agreed-on evaluation model.

## D.5 Technological Potentials for the Year 2030

A number of different technologies and aggregations of these technologies bear directly on transportation systems. For purposes of discussion, these technologies can be grouped in various ways such as by categories of vehicle type, subcomponent technology, scientific discipline, etc. In the following discussion, the areas of technology will be grouped insofar as possible, primarily by subcomponent technologies together with examples discussed in the context of transportation vehicle systems.

All transportation systems require at least one step of energy conversion where the final form of energy is that of the mechanical energy propelling the payload being transported. In this sense, the automobile, for example, can be considered an overall energy conversion device that converts the chemical energy of the fuel into the mechanical energy necessary to transport passengers. Technological efforts are directed toward decreasing costs and energy consumption and improving performance while simultaneously satisfying requirements set by certain social and environmental considerations.

Directions of technological endeavor, primarily at the vehicle level, include the following:

1. Decreasing the energy loss associated with vehicle motion.
   Examples:
   - Decreasing the rolling friction of trains by the method of magnetic levitation.
   - Decreasing aerodynamic drag of a transport aircraft.
2. Storage and regeneration of braking energy.
   Examples:
   - Use of on-board flywheels to store and reuse energy required in braking (called "regeneration").
   - Use of electrical regeneration systems that feed the braking energy back into the feeder system of an electric railroad.
3. Increasing the efficiency of chemical fuels and their energy conversion devices.
   Example:
   - Decreasing the specific fuel consumption of an aircraft turbojet engine by increasing turbine inlet temperature.
4. Decreasing the mass of the vehicle relative to payload.
   Example:
   - Decreasing the mass of a railroad car by means of all-aluminum construction.
5. Improving efficiency of operation of energy conversion devices through improved information processing and control.
   Example:
   - Use of mini-computers in automobiles to monitor and adjust the engine for minimum fuel-consumption under all operating conditions.

### D.5.1 Decrease in Energy Loss Associated with Vehicle Motion

A significant fraction of the total energy expended by transportation vehicles is allocated to overcoming resistance to forward motion. For aircraft, the primary source of resistance is aerodynamic drag while for wheeled vehicles the resistance comes from both aerodynamic drag and rolling friction. Rolling friction results from friction in wheel bearings, inelastic flexing of the wheels/tires, and from contact with the surface over which the wheel is rolling (including some degree from sliding). There is also a certain amount of energy expended by motion- and vibration-damping devices, although this tends to be minimal.

### D.5.1.1 Aerodynamic Drag of Flight Vehicles

Since for an aircraft in steady flight the drag forces equal the engine thrust forces, it is clear that any reduction in drag will serve to conserve fuel. Depending upon the nomenclature used, the total aircraft drag is considered to be composed of two or three components. The induced drag is the penalty paid for the aerodynamic lift that supports the aircraft, whereas the profile drag and skin friction drag (sometimes called parasite drag) are the penalties associated with moving a body through a viscous fluid.

### D.5.1.2 Induced Drag

Induced drag can be decreased by increasing the effective aspect ratio of the wing. Because the air pressure on the lower surface of the wing is greater than on the upper surface, there tends to be a flow of air around the tip from the lower to the upper surface. Since the wing is moving forward, this flow results in a trailing vortex that consumes energy. This effect can be lessened by making the wing longer and narrower (increasing the aspect ratio). It can also be lessened by employing a winglet to help block the flow around the tip.

It has been estimated that the use of winglets offers a potential saving of 4% - 6% in fuel consumption. However, the decrease in drag is obtained at the expense of higher wing bending moments, which, in turn, tend to increase structural weight. According to conclusions drawn by the Douglas Aircraft Company (NASA CR-137923, 1976), there can be a net benefit from the use of winglets.

#### D.5.1.3 Supercritical Airfoil

There is a newly-developed airfoil shape that essentially increases drag-divergence Mach Number of a given wing relative to conventional shapes. This, in turn, can be translated into reduced wing structural weight, either by decreasing the required sweepback angle and/or increasing the allowable wing thickness. It is difficult to assess the potential benefit of this development because of the complexity of possible design tradeoffs. Only an overall design optimization study can determine the magnitude of the fuel-conservation potential of the supercritical airfoil for a particular aircraft of for a generic family of aircraft. For example, at a cruise Mach Number of 0.8, a 5% reduction in fuel consumption has been computed by changing to a supercritical airfoil in the DC-9 aircraft derivative.

#### D.5.1.4 Laminar Flow Control

By removing the boundary layer from the aerodynamic surfaces, skin friction drag can be reduced and laminar flow enhanced (which further reduces drag by delaying the onset of turbulent flow). This can be accomplished by suction of the boundary layer through holes or slots in the surfaces. Although drag reductions equivalent to 15% to 20% reduction in fuel consumption were achieved under laboratory conditions as long as 25 years ago, the concept has not been exploited because the problem of the holes becoming clogged with foreign matter has not yet been solved.

### D.5.2 Storage and Regeneration of Braking Energy

For vehicles that make frequent stops and starts, a significant fraction of the total propulsion energy is associated with the braking phase. With automobiles, this mechanical energy is converted to thermal energy by the brakes and is dissipated into the air. However, in the case of a subway, if the braking energy is dissipated to the air as thermal energy, an auxiliary cooling system must be installed to remove this heat from the subway tunnels. For this reason, and for the purpose of conserving energy, various techniques are being studied to "regenerate" the braking energy, that is, to conserve and re-use it.

With electric railways using a D-C feeder system, one way of accomplishing this is to feed the braking energy, in the form of D-C electrical current, back into the feeder system. It is estimated that currently 75% of the braking energy can be recycled, depending upon the "receptivity" of the feeder system, which is determined by the characteristics of the vehicle/feeder dynamics.

Another technological area that is being explored is that of storing the braking energy in a flywheel aboard the vehicle for use during subsequent acceleration. Studies to date indicate that flywheel storage and regeneration can be accomplished with approximately the same efficiency as the electrical regeneration. However, flywheels have the advantage of storing the energy aboard the vehicle, thus assuring a ready recipient of the regenerated energy (which might not occur in the previously described regeneration method) as well as providing a limited source of emergency propulsion energy in case the feeder line experiences a "blackout."

Electric automobiles may be able to extend their range significantly and conserve energy by use of a flywheel plus the necessary solid state electronic devices for regenerating braking energy. Although without a flywheel, braking energy could be channeled to the batteries for temporary storage, it would be required that they efficiently store the energy at the high rate at which it is produced in braking and that they recycle it efficiently. Currently, regeneration of braking energy for automobiles appears potentially more efficient with flywheel storage, but future technological developments in electro-chemical energy storage systmes might change this picture.

It should be noted that the recent achievement of efficient regeneration capability has as its basis recent technological accomplishments in the solid state electronic field that have made possible the efficient conversion of D-C voltage into multiphase, variable-voltage, variable-frequence A-C voltage at high power levels.

### D.5.3 Chemical Fuels and Their Energy Conversion Devices

In examining the potential impact of new technology in this area, with reference to the year 2030, it can be seen that the direction and impact of new technology is determined not only by technical improvements feeding the technology from the inside but also by changing conditions on the outside, such as changing availability of fuel and changing societal requirements such as those dealing with pollution.

As the supply of petroleum decreases in quantity and quality, we can expect that increasing technological efforts will be directed toward developing engines capable of utilizing fuels with "degraded" characteristics. Such efforts are already underway in the case of the aircraft turbojet engine, where it is desired to provide the capability of utilizing fuels with higher aromatic content than allowed by current specifications. However, this type of technological improvement is a response to a new need, rather than the exploitation of a new technological innovation. The merit of this new technology is not that it improves transportation system operation but that it tends to lower the rate of increase of fuel costs (English and Liu, 1977).

Alternative fuels such as liquid hydrogen, liquid methane, ethanol and methanol have been considered for various transportation systems. Of these, hydrogen fuel has perhaps had the most attention, its attractive features being its high energy per pound and the fact that the product of combustion is water. However, on the problem side is hydrogen's low density, the problems of dealing with cryogenic systems, and the unfavorable net energy analysis associated with hydrogen production and storage.

Aircraft design studies have indicated that hydrogen-fueled aircraft are technologically feasible but that high overall costs of using hydrogen fuel make the system more expensive, both in terms of total energy expended and in terms of monetary cost, than aircraft systems utilizing synthetic jet fuel produced from coal.

High-energy fuels for turbojet engines have been studied for many years. One of the more exotic was a boron-based fuel which provided the potential for decreasing aircraft gross weight (for equal range and payload) by approximately 40%. (Problems of cost, availability and net energy analysis, as well as technological problems, precluded its serious pursuit).

Methanol has a heat of combustion of 8,600 BTU/lb compared with 19,100 for gasoline (they have roughly the same density) and has been mixed with gasoline to form a fuel that has been burned in standard auto engines (with no adjustments). Ethanol has a heat of combustion of 11,500 BTU/lb and its weight is also suitable for use in ground transportation.

At the present time, there are technological problems with both methanol and ethanol in connection with their use for fuels for internal combustion engines and their cost is currently higher than gasoline. However, in competitioin with synthetic fuel from coal, methanol and/or ethanol (or chemical derivatives of these) can be expected to have an impact on some portion of the transportation fuel spectrum.

### D.5.4 Decreasing the Mass of the Vehicle Relative to Payload

It is well recognized that in the case of aircraft, there is great incentive to minimize non-payload weight; the value of one pound of weight saved during the design stage may be several hundred dollars. It was pointed out in Section D.5.1 that induced drag is the penalty paid for aerodynamic lift. It is, therefore, one of the parameters that couples changes in aircraft weight to changes in propulsion energy required. For example, improvements in aircraft structural weight efficiency are expected from new structural materials -- particularly filament-reinforced composites -- as well as from decreases in dynamic loads made possible by active control systems. However, other types of vehicles have not, in the past, fostered the same degree of incentive to minimize mass. The conventional railroad car is an example where the cost-versus-mass tradeoffs were very different from those of the aircraft, resulting in rather massive construction.

It is particularly important for future high speed vehicles employing levitation (such as air-cushion or magnetic) that structural technology developed for aircraft be tailored and exploited in their non-aircraft applications because of the important implications for energy expenditure and costs of the guideways.

D.5.5 Improving Information Systems for Control and Communication

The growing field of technology in solid state and electro-optical devices in the processing of information has potential for a very large impact on transportation systems of the future as discussed below.

D.5.5.1 Control and Management of Energy Conversion Systems

It can be expected that small, on-board computers or micro-processors will play a major role in monitoring and controlling the energy management of vehicles ranging from small automobiles to trains and aircraft. In autos, these devices would not only maximize efficiency of the propulsion system (electrical or internal-combustion) and manage energy regeneration under varying operating conditions, but would also interact with the driver in various ways to improve safety.

D.5.5.2 Control of Aircraft Dynamic Response

The control-configured aircraft is another conceptual advance in technology made possible by computer-based control-system technology. By providing active "artificial" aerodynamic stability, this concept allows the use of new aircraft configuations that are tailored to minimize aerodynamic drag and structural weight.

Active control systems also provide a decrease in flight loads for conventional configurations by means of gust-alleviation and lift-distribution control. It has been estimated that active control technology would allow structural weight reductions up to 14% (Grey, 1974).

D.5.5.3 Control of Movement (Guidance and Velocity) of Automobiles

Automatic pilots for aircraft have been used for many years. However, similar devices for automobiles have not been exploited -- undoubtedly due, in part, to the complexity of the problems that would have to be dealt with, as well as to the technical difficulties that would be encountered in obtaining the necessary information inputs.

It might be expected that at some future time, on-board microprocessors in automobiles could be linked to computer systems serving special throughways so that, while the automobile was traveling on the control highway link, its movement would be controlled in both position and velosity so as to obtain optimum traffic flow.

D.5.5.4 Use of Optical Information Transmission Systems

A serious problem encountered with the information transfer to and from an electric railway vehicle utilizing high-voltage feeder lines, together with pulse-width modulation inverter equipment, is the problem of electrical noise. The same problem exists with on-board information transfer. Electrical filtering and shielding provide only a partial solution. However, new applications of the technology of information transmission by optical means (fiber-optics and laser-beam transmission) can have a significant impact on the operation and safety of transportation vehicles, such as high-speed tracked vehicles, because optical transmission is not subject to electrical interference.

### D.5.6 Maximum Capacity of a Transportation System

For a given transportation system, as the demand grows increasingly large, it is inevitable that at some point in time the maximum passenger-carrying capacity, or freight-carrying capacity, will be reached -- even with all possible additions to the various system components and with maximum improvements in efficiency of operation.

Obviously, as this point is approached, it is necessary to have built the capability to phase in a new system to meet the increasing demand. But in order to do this, we must have previously completed the necessary planning, research, development, testing, engineering, etc., sufficiently far in advance of the time of need.

It is difficult to predict the maximum capacity of a system because, for any system, various actions can be taken along the way that will incrementally increase the capacity and thereby postpone the time at which the maximum point is reached. Some of these will be based on technology and innovations not yet in existence. Likewise, it is even more difficult to predict the year in which a given system will reach its maximum capability because the question of "when" introduces additional uncertainties into the picture. However, what we can predict is that there is a level, for every system as we know it today, at which the system will approach saturation. By studied analysis, it is possible to compute, for a set of conditions assumed to exist at a specified future time (together with assumed pathways leading from the present time to the future time), an estimate of maximum capacity and the date at which it will be reached.

The purpose of this section is to illustrate the factors involved in this type of endeavor and to illustrate how this approach can be used as a planning tool for new transportation systems.

In order to provide some feeling for the conditon of saturated payload-carrying capacities, a hypthetical example will be presented. Following this, a simple conceptual model is used to examine the question of system capacity and the basic factors that determine maximum capacity.

### D.5.6.1 Hypothetical Example

As an example to illustrate a situation in a single transportation link approaching saturation, consider the case of air transportation between two terminal points corresponding to the Los Angeles and San Francisco areas. For simplification, the airport and terminal facilities at each of the two areas are treated as a single aggregated unit.

The following assumptions are made regarding the characteristics of the system link and the passenger flow rate:

- air distance between terminal points: 547 air-kilometers
- number of passengers per aircraft: 400 passengers (this would correspond with an 80% load-factor on the 500 passenger Boeing 747-SR)
- the annual travel rate between these two terminal points: $10.4 \times 10^9$ passenger-kilometers per year
- the traffic: equal in the north and south directions.

*CASE I. Equal Distribution of Traffic Load Over 24 Hours*

Using the assumptions listed above, together with the assumption that traffic volume is evenly spread over the 24 hours of the day, we can calculate the corresponding number of vehicles landing plus take-offs at each terminal per hour:

$$\text{Vehicles/hour} = \frac{10.4 \times 10^9}{(24)(365)(547)(400)}$$

$= 5.4$ vehicle landings plus take-offs per hour at each terminal

This is equivalent to one Los Angeles/San Francisco-link vehicle landing or taking off every 11 minutes at each terminal. This corresponds to 4400 LA/SF-link passengers per hour continuously moving through each terminal.

*CASE II. Peaking Distribution*

If we now consider the more realistic situation wherein traffic flow is not uniform throughout the day and night, and if we apply a daily peaking factor of 1.5 (this would correspond to a situation of no traffic during 8 hours of the night, the total then being distributed evenly over the remaining 16 hours), the following traffic rates result:

| | |
|---|---|
| Aircraft per hour: | 8.2(1 aircraft landing or taking off every 7.3 minutes) |
| Passenger arrival/departure rate: | 400 passengers every 7.3 minutes or 3,280 passengers per hour |

Recall that this is traffic over only one link of the system -- that between Los Angeles and San Francisco. If, for example, we assume that this constitutes as much as 5% of the traffic at the LAX complex, the total traffic at LAX in our hypothetical example, during the spread-out peak period,would be something like 164 aircraft per hour, or one aircraft landing or taking off every 22 seconds, with a passenger flow through the terminal of approximately 32,780 passengers per hour, or 0.79 million passengers per 16 hour day.

It might be mentioned that the figure of $10.4 \times 10^9$ annual passenger kilometers was obtained by assuming a conservative average annual growth rate of 4% in air traffic between Los Angeles and San Francisco based on an estimated $1.15 \times 10^9$ air passenger kilometers in 1975 and allowing this growth to continue until the 2030 time frame. The 4% growth rate is considered a conservative estimate since the growth rate in 1977 for U.S. domestic passenger miles and revenue ton-miles of air freight was 14%.

### D.5.6.2 An Example of Growth and Capacity Limitation

As mentioned above, the problem of estimating "absolute" capacity is complex because of the many components involved through which the flow of passengers or freight must move -- components having different limitations and options for expansion when a particular one becomes the flow-rate-limiting bottleneck. As an illustrative example, the situation with the Los Angeles International Airport (LAX) and the Los Angeles area airport complex is useful to examine.

Currently, the "official" maximum capacity for LAX is set at 40 million passengers annuallly; in the year 1977, LAX handled 28.4 million passengers. The 40 million capacity figure is based not upon air space limitations but upon ground access limitations that will determine passenger flow-rate in the future even after planned improvements have been made. The present passenger flow-rate of 28.4 million severely taxes current ground-access facilities at peak periods and is beginning to cause an impact in the form of delays during non-peak hours as well. Because of this, it is planned to provide additional ground-access facilities at LAX in the near future.

With four parallel runways in combination with California's good weather, LAX is estimated to have a flow-rate potential, in terms of aircraft-handling capability, of nearly 80 million passengers annually. Therefore, it is clear that the limitation on maximum capacity lies in the ground-access portion of the passenger flow facilities.

It has been estimated by the Los Angeles Department of Airports that the maximum passenger flow-rate capbility for LAX (of 40 million) will be reached in 1985, at which time it is planned that the new 17,000-acre Palmdale Airport will begin operations. By the year 1995, it is forecast that with its four 13,000-foot runways plus two STOL runways, Palmdale Airport will be handling 12 million passengers annually.

Ontario Airport, which is a component of the Los Angeles area airport complex, currently handles 1.5 million passengers annually. However, the limitations on maximum capacity for Ontario Airport, which is estimated ultimately to be about 15 to 20 million passengers annually, is expected to be determined by air space limitations (because of the proximity of March and Norton Air Force Bases). As a means of expanding the current capacity of Ontario Airport, a new runway and new terminal-complex facilities are planned for construction.

In terms of the conceptual model discussed in Appendix C, it can be seen that the major source of increased capacity is that of providing additional conduits on the ground (primarily additional runways). However, in the case of Ontario Airport, when the airspace reaches saturation, the only way to further increase passenger flow rate will be to increase the module capacity. The criterion of minimum allowable headway was not a limiting factor for any of the above mentioned airports.

Based on the numbers presented above, together with similar estimates for other facilities in the Los Angeles area airport complex, we might estimate a maximum capacity on the order of 130 to 150 million passengers annually in the year 2030.

Based on the 4% exponential growth rate used in the previous example, it was estimated that in the year 2030 the number of passenger kilometers flown on the LA/SF-link would be $10.4 \times 10^9$ annually. Using this value to calculate the corresponding number of passengers passing through each terminal facility annually gives:

$$\frac{(10.4 \times 10^9)}{(574)} = \text{19 million LA/SF-link passengers annually per terminal.}$$

This level of need, for the LA/SF-link alone, amounts to about 14% of the total available airport capacity estimated for the year 2030 (discussed above). In order to make this 14% figure correspond with the current value of 5.21% (the current percentage of LAX area passengers who travel to the San Francisco area), we would require an airport capacity of 364 million annual passengers -- a capacity 2.7 times the currently estimated maximum capacity, in the year 2030.

It appears that this flow-rate cannot be handled realistically by presently planned expansions. Therefore, if the level of passenger flow-rate is really nearing the maximum capacity of the airport system complex, and if the demand for high speed transportation continues to grow, a great deal needs to be done prior to this date in order to provide the system that will furnish the additional needed capacity.

### D.5.6.3 Exponential Extrapolations

The above example demonstrates one of the possible pitfalls of exponential extrapolation. While in real systems there may be a portion of the growth cycle during which the growth is exponential, inevitably, one or more constraints begin to operate to tip the exponential curve towards the horizontal as it approaches some asymptotic value.

The point of this example is to show that even with anticipated expansions and construction of new facilities for handling air traffic, it is to be expected that at some date a saturation level will be approached. And it is evident that even before this point is reached, there will be manifested a demand for a new high-speed transportation system that will embody, or improve upon, the desirable characteristics of air travel -- both for passengers and freight.