(NASA-CR-152154-1) EXECUTIVE SUMMARY: N78-28988
BENEFIT-COST EVALUATION OF AN INTRA-REGIONAL
AIR SERVICE IN THE BAY AREA AND A TECHNOLOGY
ASSESSMENT OF TRANSPORTATION SYSTEM Unclas
INVESTMENTS Technical Report, 1 (Washington G3/83 27507

NASA CR-152154

EXECUTIVE SUMMARY:

BENEFIT-COST EVALUATION OF AN INTRA-REGIONAL AIR SERVICE IN THE BAY AREA

and

A TECHNOLOGY ASSESSMENT OF TRANSPORTATION SYSTEM INVESTMENTS

NASA Grant NSG-2170
Period of January 1, 1977 - March 31, 1978

Department of Civil Engineering
Washington University
St. Louis, Missouri 63130

March 31, 1978

Dr. Lonnie E. Haefner
Principal Investigator

EXECUTIVE SUMMARY:

BENEFIT-COST EVALUATION OF AN INTRA-REGIONAL AIR SERVICE IN THE BAY AREA

and

A TECHNOLOGY ASSESSMENT OF TRANSPORTATION SYSTEM INVESTMENTS

NASA Grant NSG-2170
Period of January 1, 1977 - March 31, 1978

Department of Civil Engineering
Washington University
St. Louis, Missouri 63130

March 31, 1978

Dr. Lonnie E. Haefner
Principal Investigator

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Introduction

This report summarizes the work completed during the period January 1, 1977 through March 31, 1978 on NASA Grant No. NSG-2170 "Benefit-Cost Evaluation of an Intra-Regional Air Service in the Bay Area." Two major research report objectives were achieved. The first half of the research effort concentrated on the benefits and costs that would result from an intra-regional air service operation in the San Francisco Bay Area.[1] The second half of the research effort addressed the development and documentation of a technology assessment tool capable of evaluating the suitability of transportation technology investment alternatives over a variety of city sizes, land-use patterns and socio-economic characteristics. The majority of this executive summary will review the intra-regional air service research conducted in the Bay Region, followed by a brief discussion of the research on technology assessment of transportation system investment alternatives.

BENEFIT-COST OF INTRA-REGIONAL AIR SERVICE IN THE BAY AREA

Essentially, the Benefit-Cost Evaluation of Intra-Regional Air Service in the Bay Area study utilizes an iterative statistical decision model to evaluate combinations of commuter airport sites and surface transportation facilities in conjunction with service by a given commuter aircraft type in light of Bay Area regional growth alternatives and peak and off-peak regional travel patterns. The model evaluates such transportation options with respect to criteria of airline profitability, public acceptance, and public and private non-user costs. In so doing, it incorporates information on modal split, peak and off-peak use of the air commuter fleet, terminal and airport costs, development costs and uses of land in proximity to the airport sites, regional population shifts, and induced zonal shifts in travel demand. The model is multimodal in its analytic capability, and performs exhaustive sensitivity analysis.

Markovian Decision Theory Structure

The analysis and evaluation of the benefits and costs that will result from intra-regional air service operation in the San Francisco Bay Area can be undertaken by a Markovian Decision Theory approach. This approach involves the formulation of a state space, delineation of transportation alternatives, state transition probabilities, and reward matrices for the system under study as illustrated in Figure 1.

In an analysis of an existing or proposed system from a Markovian framework, the basic concern lies with the trajectory of the process, i.e. the sequence of system states, rather than in the time interval between successive states (although this sequence of time intervals can also be considered a random variable). More directly, a system can be described in terms of its state transitions given discrete time intervals. The state variable descriptors, such as land use, population, and economic forecasts, themselves capture the dynamics of the system.

The basic assumption of a Markov process lies in its relationship between the successive states of the system. The notation for the formulation of the state space is:

$s(n)$ state at time interval n, $n = 1, 2, \ldots$

$i, j, k, \ldots m$ any sequence of states $1, 2, \ldots N$.

The actual Markovian assumption has the following formulation:

$$P\{s(n + 1) = j \mid s(n) = i, s(n-1) = k, \ldots s(0)=m\} = P\{s(n+1)=j \mid s(n)=i\}$$

where P is a probability measure.

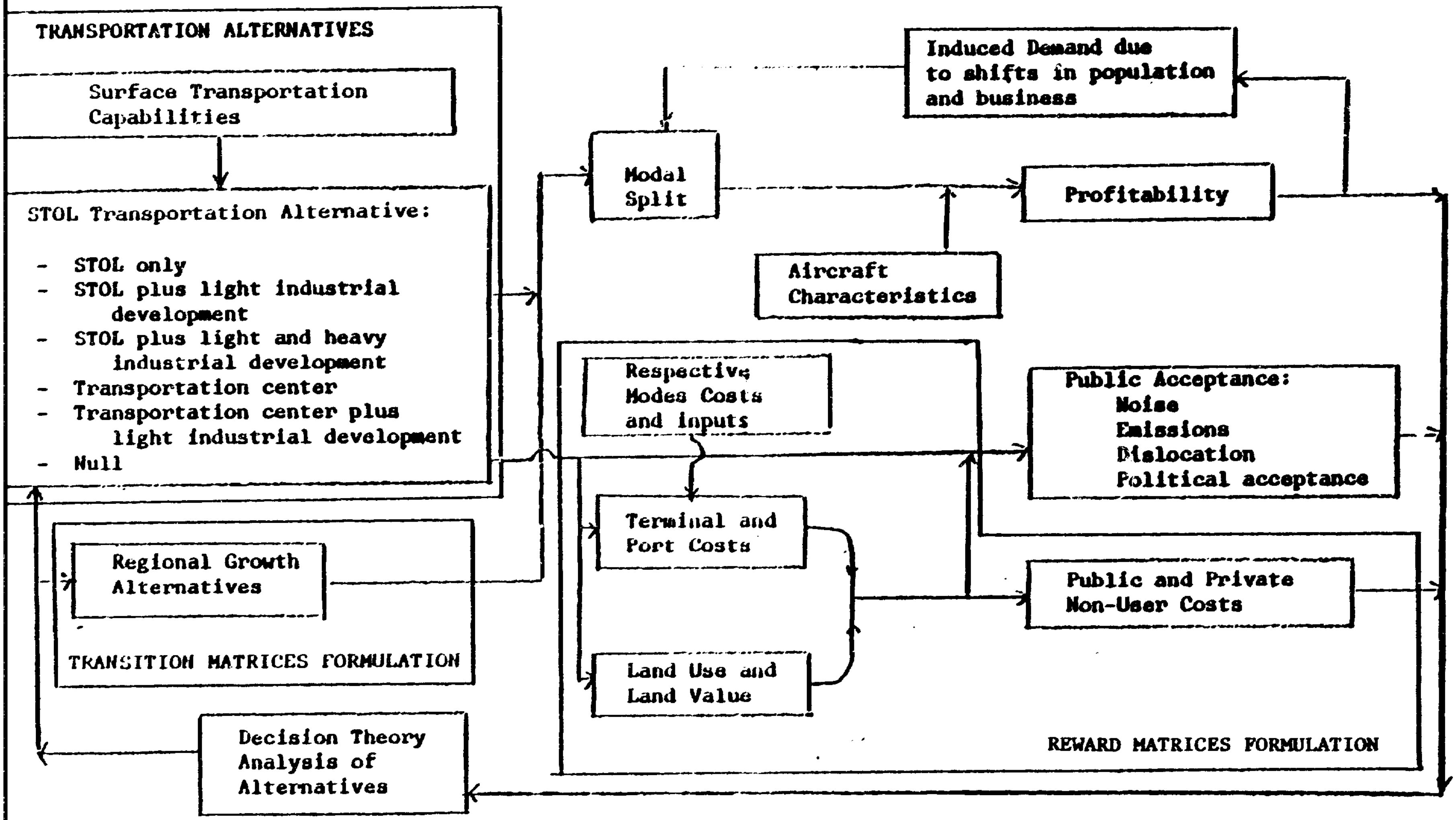

FIGURE 1

MARKOVIAN DECISION THEORY MODELLING STRUCTURE

The Markovian property is equivalent to the conditional probability of any future "event," given any past "event." In addition, the future state of the system is independent of the past events and depends upon only the present state of the process.[2] In essence, the system's being in state j at time n + 1 has only to do with the previous state i, and not all previous states of the system from time zero. For the postulated Markov Process previously defined, a significant assumption concerns the ergodic property. This property asserts that the final long run steady state probabilities are independent of the initial starting state.

Solution Technique

The Markovian solution maximizes the test quantity

$$q_i^k + \sum_{j=1}^{n} p_{ij}^k V_j \qquad i, j = 1, 2, 3 \qquad k = 1, 2, \ldots 4$$

where

q_i^k = the expected reward from the next stage transition, given the starting growth state i, for transportation alternative k,

p_{ij}^k = single step transition probabilities, growth state i to growth state j, for transportation alternative k,

V_j = relative total expected reward or relative value accruing to the system under the previous policy,

N = the maximum number of growth states, here N = 3,

For each growth state i, i = 1, 2, 3, the alternative k*, k = 1, 2, . . .4, is found, by comparison, which maximizes the test quantity and becomes the policy for growth state i.

The test quantity represents the selection criteria by which one alternative is considered optimal in relation to the other transportation alternatives for each land use system state. Symbolically this maximized test quantity, for each transition, arrays the alternative to be selected for each state based on a set of rewards and values relative to all alternatives. As such, this test quantity is not an absolute measure of benefits for the selected transportation alternatives.

However, one modification was established: due to the long lead time of constructing facilities within the planning horizon, it was presumed, for purposes of model computation, that the system chosen optimal through analysis would be held constant as to implementation policies of the chosen alternative over the planning horizon period. Thus there would be no "totally shelving the adopted plan" as is often done in the real world midway through a planning horizon, based on annual updates.

State Space Formulation

As stated previously. one of the principal advantages of the Markovian evaluation methodology is its capability to review various transportation alternatives in light of land use-growth state changes. This allows the execution of a search for the optimal transportation policy under uncertainty. The computational search format is initially developed by structuring the San Francisco Bay Area regional projections to correspond to growth states in the Markovian model. Such a corresponding structure appears below:

TABLE 1

GROWTH STATES FOR BAY AREA
(all data in 1000's)

S(n)		1975			1990			2000		
Growth States		Population	Occupied Housing	Labor Force	Population	Occupied Housing	Labor Force	Population	Occupied Housing	Labor Force
1	Base Case 1	4829.2	1768.2	2122.2	5621.9	2363.9	2652.8	6149.0	2657.8	2953.8
2	Base Case 2	4829.2	1768.2	2122.2	5283.7	2342.7	2561.6	5418.6	2506.6	2653.2
3	Base Case 3	4829.2	1768.2	2122.2	5452.8	2353.3	2607.2	5783.8	2582.2	2803.5

Demand Analysis Components

The estimation of person-trip travel demand for a new technology such as STOL requires a slightly different perspective than a travel demand analysis for more traditional modes. In the case study conducted on the San Francisco Bay Area, it was necessary to estimate those exisitng trips which could be attracted to the air mode.

The demand analysis was divided into two major parts. The first part concerns demand for airport feeder service, that is, the transport of residents and non-residents from various locations to one of the three regional air carrier airports or vice versa, (i.e., San Francisco International, Oakland International, and San Jose Municipal). The second part of the demand analysis addresses intra-regional daily commuting which concerns the journey-to-work for persons making reasonably long commuter trips.

Early in the research, a set of sixteen potential STOL service points was identified in consultation with NASA personnel.[3,4] As illustrated in Figure 2, these sites are geographically distributed over the entire Bay

ORIGINAL PAGE IS
OF POOR QUALITY

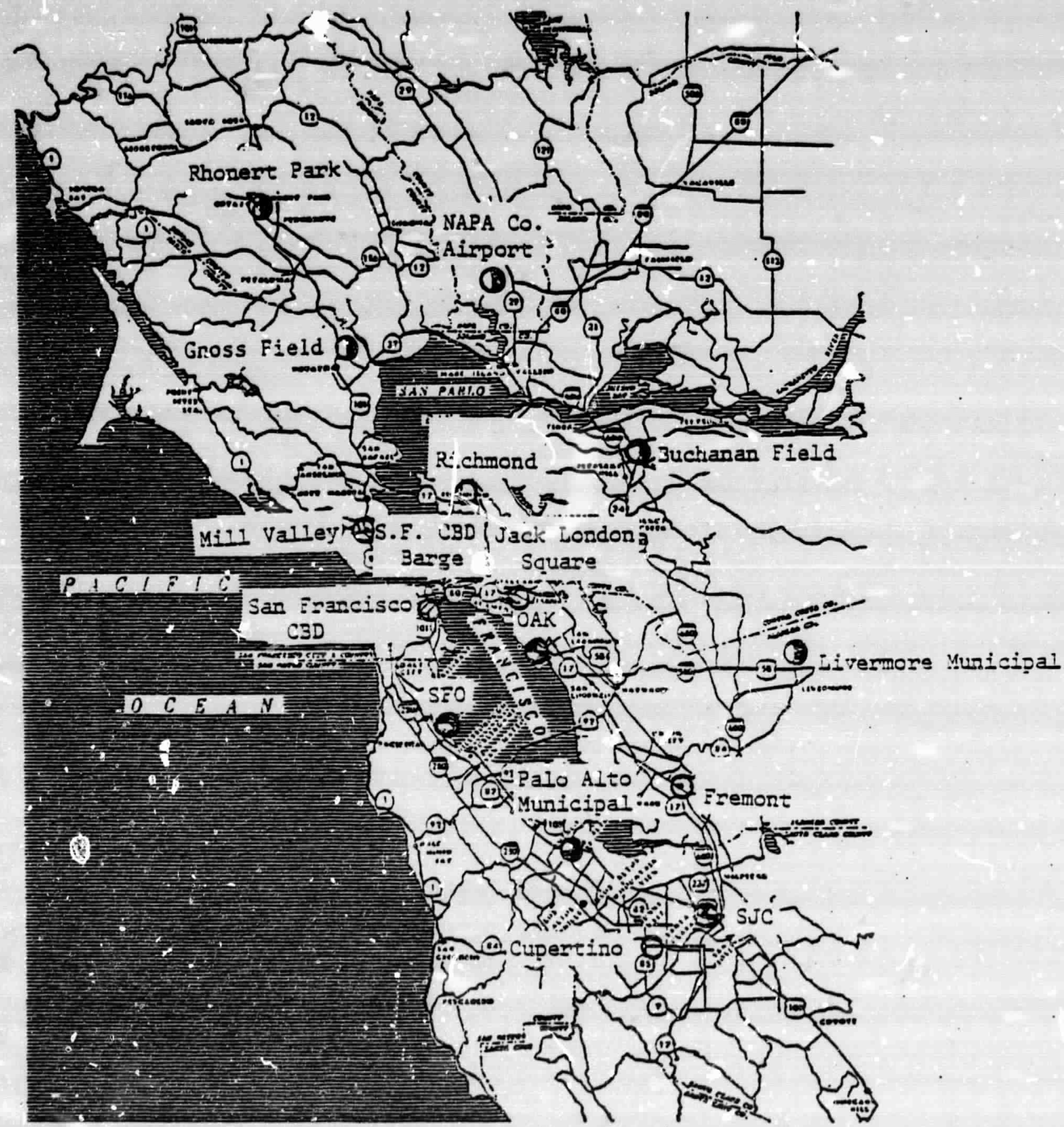

FIGURE 2

ORIGINAL SITES FOR DEMAND ANALYSIS

◕ Major Airports

◑ General Aviation Fields

Area. They include existing general aviation fields, the existing air carrier airports, and several new STOL sites (e.g. Transbay Terminal).

Results of Demand Analysis

As a result of the analysis it was determined that the sites in the North Bay area provide a significant number of trips to the Oakland and San Francisco CBD areas. In addition, the San Francisco International Airport is a focus of significant demand. As expected, these volumes include mostly airport feeder demand. Three of the South Bay Area sites (San Jose Municipal, Cupertino, and Palo Alto Municipal) failed to produce sufficient demand and were dropped from further consideration. Reasons for this result primarily from San Jose Municipal's position as a local serving air carrier airport for the airport feeder demand, and the relatively close proximity of work and residence for persons living in the South Bay Area. Similar reasons could be cited for the failure of the Richmond CBD site to be included. Its longest distance commuter patterns are well under 30 miles in trip length.

Transition Reward Matrices

The reward matrices for the states of the system reflect the benefits to the region in its transition from state i to j during the specified time interval. The reward matrix is specific to the individual transportation alternatives due to differing costs and beneficial impacts of employing a particular transportation alternative. Notationally we have:

$R^k = r^k_{ij}$ where $i, j = 1, 2, 3$

$k = 1, 2, \ldots 4$

Two alternate approaches were employed in arriving at the reward values, r^k_{ij}. These approaches are the value added approach and the value matrix approach.

Value Added Approach

The transition from state i to j will yield an alternation in dollar value of regional activity. A reasonable surrogate for regional value added is total income generated through addition of non-residential floor space. Thus, a reward matrix of shifts in regional value added due to the existence of different states and associated transportation alternatives could be developed. Therefore, based on the state characteristics, a crude approximate figure can be reached for the additional change in primary monetary effects on the region due to floor space that will be added in each of the states. The second component of r^k_{ij} is the capital cost of the transportation alternative, and evaluation of user savings and costs associated with this particular alternative.

The formulation of the reward matrices, R^k, for the value added approach consisted of combining the two components v_{ij} and c^k. Therefore, the element:

$$r^k_{ij} = v_{ij} - c^k$$

where:

v_{ij} = \$ value generated through change in non-residential construction

c^k = ten year average cost of alternative k.

i, j = 1, 2, 3, the regional growth states

k = 1, 2, . . .4, the transportation alternatives

Value Matrix Approach

The value matrix approach develops an alternative approach to r_{ij}^{k} formulation, to incorporate social and environmental concerns, along with regional economic wealth criteria in the analysis. Noise, air pollution, energy cost and regional value added related to the airport operations are the concern of many communities residing nearby. The above are each evaluated separately, than synthesized into a Markov Reward Matrix.

In the value matrix approach, first each alternative is ranked according to its attainment of a certain impact, i.e. capital cost, noise pollution, auto energy differentials, etc. Each alternative received a value of 1 through 4 depending on its position relative to the other alternatives under consideration.

Next, the impact factors are weighted for each state of the system. This is necessitated by the fact that certain impacts are of greater consequence for various system states.

Each transportation alternative is then given a score based on the rank value and associated weight. This score is determined by:

$$\text{score}_{i}\ k = \sum_{x=1}^{m} r^{k} w_{x}$$

where

i = system state, i = 1, 2, 3,

k = transportation alternative k = 1, 2, . . .4

r^{k} = rank value of that alternative

w_{x} = weight of that impact

x = number of impacts, x = 1, 2 . . .,5

The transportation alternatives were then ranked for the regional value added impact factor via considerations of the steady state transition probabilities and the commerical and industrial land development for each state. For each alternative, the regional value added is an expected value, defined by

$$E(rv^k) = \sum_{L=1}^{3} \pi_L^k \; (rv_i)$$

where

$E(rv^k)$ = expected regional value added

π_i^k = steady state probability, state i, alternative k

rv_i = regional value added, state i.

With the relevant transportation alternative rank and the impact factor weightings, values for the score $_i^k$ can be calculated for all weighting schemes. For example,

$$\text{score}_i^k = \text{score}_1^1$$

is the score for transportation alternative one, under the regional growth state 1.

Reward matrices R_{ij}^k are then calculated. Here r_{ij}^k is defined by:

$$r_{ij}^k = (\text{score}_j^k) - (\text{score}_i^k) \qquad i \neq j \, .$$

and by

$$r_{ij}^k = \text{score}_i^k \qquad i = j$$

with the terms as defined previously.

GROWTH STATE TRANSITION PROBABILITIES

The matrix of transition probabilities, P_{ij} is composed of the probabilities of the system, i.e., the region's land use pattern, currently in state i, moving to state j, the same or different land use patterns in the next transition. The determination of these probabilities are critical to the analysis, and reflect professional evaluation of the land use and transportation issues of the Bay area. For example, for $i = 1$, the Base Case I land use pattern and $j = 3$, the Base Case III land use pattern, p_{13} represents the probability there will be a change or shift in land use patterns from 1 to 3 over the next transition period. Also if $i = j = 1$, then P_{11} would indicate the probability the land use pattern would remain unchanged during this transition period.

Here, the transition time period is ten years, which reflects the time span required for land use patterns to develop recognizable shifts which have regional growth implications. Thus the P_{ij} matrix exists for each alternative and is a stochastic matrix. We have

$$P^k = p_{ij}^k$$

where $k = 1, 2, \ldots 4$ for the four alternatives under study and $i, j = 1, 2, 3$ for the three different growth states.

Computational Results

From this evaluation methodology incorporating Markovian decision theory, the output results take the form of a policy vector.[4] This vector is an ordered set of optimal transportation alternatives for each state of the system under study. These state specific alternatives will maximize the rewards accruing to the system given the current state, over the planning horizon.

Due to the two formulations of the reward matrices (R_{ij}^k), the value added and value matrix approaches, there are two separate policy vectors. Each vector represents the optimal alternative in light of the reward matrix formulation. These will now be presented and discussed.

Value Added Approach

The value added approach involved the quantification of transition reward matrices on the basis of the regional value added due to state transition and the cost of the transportation alternative. As stated in Chapter IV of the main report, the regional value added component was measured by an aggregate total of industrial and commercial land use increments for each growth state. The transportation alternative costs were arrived at via considerations of capital and operating costs and expected revenues. Using the value added approach reward matrix formulation, a sensitivity analysis across a variety of P_{ij} reflecting high, low, and medium growth subjective estimates of P_{ij}^k was then conducted.

The analysis of the results demonstrated that alternatives 4 and 3 (high STOL and low STOL) are selected to be the optimal solution over the three growth states, illustrating the potential that transportation needs of the region are not met with the existing transportation modes, and that high and low STOL could be valuable alternatives to complement the existing modes in Base Case 1 and Base Case 2 and 3, respectively.

Value Matrix Approach

The alternate reward matrix formulation involved the use of such social and environmental concerns intrinsically related to a selection of transportation strategies. As previously outlined, the reward matrices reflected such impacts, and the weighting of these impacts, that were critical to each transportation alternative over each state of the system.

The results of these analysis are, again, a policy vector specific to each system state. Again, a sensitivity analysis across a variety of P_{ij} reflecting high, low, and medium growth subjective estimates of P_{ij}^{k} was conducted.

Evaluation of the results of sensitivity analysis indicated that alternative 4 (high STOL) was selected to be optimal under the Development Oriented Preference Scheme for growth states 1 and 3. This is due to the fact that more development will require more mobility, and alternative 4 (high STOL) furnishes this mobility. For Growth state 2, continuation of existing development at a lower pace, the alternative 3 (low STOL) was chosen to be optimal.

In the medium growth compromised weighting scheme, alternative 4 (high STOL) is again selected as the one which will yield the maximum benefits for all three growth states over the planning horizon. This is apparently due to the mobility requirements associated with even a compromised development preference.

Summary of Computation

A regional analysis of transportation investments must be tied closely to desired or resultant land use and spatial arrangements of growth in the planning region. Modelling the regional air commuter transportation investments as a Markovian Decision Problem is a viable approach to their evaluation and growth state changes. Some subjectivity must be employed in the transition probability formulation. However, the professional planner's knowledge of the study area and land use-transportation interactions can yield logical transition matrices. Regional surrogates for system value are often extremely difficult to obtain. In light of the need for simple, computationally concise approaches which relate to critical issues of the region, such as environment vs. growth and economic wealth, the short cut value added and value matrices were employed.

The following section exhibits the preceding type of analysis at a more micro-scale, that of detailed evaluation of specific sites for STOL port operation within the community of Fremont, California.

Site Specific Model - Fremont Case Study

In addition to examining the modelling of regional air commuter transportation investments, the research effort also developed and tested two statistical decision theory models at the site specific level. These models yield an evaluation of specific sites within Fremont which fit the optimal policy of regional commuting for the region. It is appropriate at the outset of analysis to state that none of the sites under study in Fremont proved feasible as appropriate STOL port sites, except under very qualified conditions, As such, the objective of the remainder of this section will be to demonstrate the model usage at a site specific level.

Bayesian Decision Theory

The first model under development is the Bayesian Decision Theory approach. The feasibility of various STOL port locations are tested for sites within the City of Fremont. The advantage of a Bayesian model for STOL port site locational analysis is in the degree of flexibility and realism which it allows in the evaluation process.

The purpose of the Bayesian model is to determine the expected utility of developing a specific STOL site within a city such as Fremont. In classical Bayesian Decision Theory analysis, the decision-maker confronted with a complex system about which he has incomplete knowledge. As such, in the Bayesian scheme, the decision maker performs "experiments," i.e. feasibility studies to yield more information as to the site which should be chosen. Associated with each experiment, there is a study cost.

Such above experiments have a set of outcomes associated with them. The outcomes are descriptions of the results of the experiments. As a result of the information gained on the potential sites through the feasibility study experiments and outcomes, an action is indicated. Such actions represent various types of development that might appropriately take place given the site chosen and the outcome associated with the feasibility study.

The above actions are taken in the face of the possible end states which may obtain over the long run, which are known in a probabalistic sense. Hence, the gain or utility of a given action ultimately depend upon the actual states of the system subsequent to implementation activities.

Markovian Decision Theory

The second model explored and tested is the Markovian Decision Theory Decision approach articulated in previous sections at the regional level. Its use at the site level is essentially the same, with more detailed individual analysis of impacts and site phenomena likely to influence specific location decisions.

Conclusions

Upon examing the output from the Bayesian analysis and the Markovian analysis, it was concluded that STOL development within the community should not be recommended. Since a new STOL port would need to be constructed within the community and only 440 passengers per day are forecast to use STOL, a large capital outlay for STOL construction does not appear worthwhile.

It is appropriate to conclude with some discussion of results and issues raised during this Bay Area portion of the research effort:

In conclusion, we have demonstrated the following:

1.) The Regional Commuter Air Transportation problem for a metropolitan region, such as the Bay Area, can be modelled using a Markovian Decision Theory Approach, with appropriate historical inputs to the transition matrices, and incorporation of a variety of monetary and non-monetary components of costs and gains input to the reward matrix.

2.) The results of Chapters 6-8 with respect to the above show that medium or high STOL alternatives appear to offer optimal benefit levels, complementing the Bay Area regional transportation investments to date, and warrant consideration for further implementation, particularly in a complex commuting region such as the Bay Area.

3.) Likewise, the Bayesian and Markovian approaches are also viable evaluation modelling structures for analysis of specific STOL port sites, incorporating both private venture capital viewpoints, and public works and non-monetary community impact viewpoints.

4.) With respect to the above, use of the evaluation models for the case site of Fremont California produced minimal incentives for

ORIGINAL PAGE IS
OF POOR QUALITY

STOL Port siting in the community, due to low travel demand levels, and the dominance of highest and best use land values associated with Agricultural use throughout all areas of the city. Highly altered travel demand and highly focused associated external stimuli for industrial park development in the future could alter such results.

5.) Based on the use of the above approaches at the regional and site specific level in the Bay Region, with its expansive, sophisticated and complex regional travel characteristics, it is concluded that the models have proven themselves structurally functional to be considered transferable to other regions as general evaluation approaches. It should be pointed out again, as in previous volumes, the models closely approximate the real world decision process, and do require reasonable regional data travel inputs and historical analysis of transportation-land use trends in the region, ordering and structuring this information through the modelling format to yield a manageable decision framework and output.

A TECHNOLOGY ASSESSMENT OF TRANSPORTATION SYSTEM INVESTMENTS

The objective of the second half of the research effort, presented herein, was to develop and document a technology assessment tool capable of evaluating the suitability of transportation investment sets over a variety of city sizes, land-use patterns and socio-economic characteristics. The effort is a follow-on to previous detailed development of the analysis technique at the regional and site specific levels. This detailed development, summarized in previous pages, was performed over a 2 year period in the San Francisco Bay Region, under NASA Grant NSG-2170, and is documented in the final report Benefit-Cost Evaluation of an Intra-Regional Air Service in the Bay Area, December 28, 1977.

This effort differs significantly from the above, in that it develops an abstract technology assessment format, capable of generic evaluation over a heirarchy of city sizes, shapes, and modal transportation technology characterist[illegible] unit cost and impact data. Thus, the analyst is not required to know or explore the historical data characteristics of the region in-depth, as was performed in the previous NASA work. This enables a research agency or public policy analyst to rapidly examine sensitivities and boundaries of rational or optimal transportation investments. This examination may occur over a group of similar or different regions, and may draw significant conclusions about the mix of transportation technology investments most likely needed and capable of compatible operation.

Rationale for Technology Assessment

Technology assessment is a systems analysis approach to providing a conceptual framework, complete both in scope and time, for decisions with respect to appropriate utilization of various transportation technology sets and their combinations. Technology assessment permits the comparison of alternative strategies, and selection of the optimal technology alternative(s) in terms of total impact on a particular metropolitan region. Its use is intended to aid the research, planning, and political decision making process in becoming more effective in assuring that broad public and private interests are fully considered in the process of technological implementation, so as to maximize the contribution of the technology while minimizing its negative impact on society.

As such, the research effort attempted to develop and test a methodology in which:

a) a framework of analysis of the similarities and differences between metropolitan regions in the United States with respect to the characteristics relevant to their transportation needs is presented.

b) the optimal type or types of transportation technology which best meets the needs of various metropolitan regions in the United States can be readily identified.

It is important to be able to properly select the "sample set of urban areas" so as to include some minimum number of areas which are respresentative of all metropolitan areas for which the transportation technologies may be applicable. Although not a part of the scope of work for this study, factor analysis or cluster analysis are two methods which could be developed for identifying the latent dimensions of differentiation between metropolitan areas, classifying areas into relatively homogenous groups and identifying the most representative areas in each group.

In the process of selecting the transportation technologies suited for a particular metropolitan region, it is appropriate to consider the complete set of transportation modes and their relative attractiveness with regard to metropolitan size, population density and spatial form, and efficiency of operation in light of such parameters. The following section will detail the taxonomy development of the above which was formulated for use in this study.

Taxonomical Development

As stated previously, the analysis should be capable of extending over a broad array of regional sizes, types, and patterns, classified in an orderly manner. The classification developed herein is by regional size, cross-classified by spatial orientation as either being core dominant, corridor dominant, or satellite center. Table 2 exhibits a partial typical description of transportation technologies suitable under the various regional parameters. Table 3 is a partial compilation of unit impacts resulting per mile of investment in a particular transportation technology within a particular region-size, spatial-orientation classification. Thus, the user specifies a class or classes of regional sizes, and appropriate technology sets for such classes, and arrays the unit impacts of such technologies for a particular region.

TABLE 2

GENERAL CLASSIFICATION OF TRANSPORTATION TECHNOLOGIES

SIZE AND SPATIAL FORM

city size	Spatial Form	Transportation Alternatives I Railway Light Rail Transit	 I Railway Subway Rail Rapid Rail	 I Railway Commuter Rail	 II Bus Local Bus	 II Bus Express Bus	 III Highway Freeway	 III Highway Arterial
3 to 5 million	Core Dominant	—	✓	✓	✓	✓	✓	✓
	Corridor Dominant	—	✓	✓	✓	✓	✓	✓
	Satellite Centers	—	—	—	✓	✓	✓	✓
2 to 3 million	Core Dominant	—	✓	✓	✓	✓	✓	✓
	Corridor Dominant	—	✓	✓	✓	✓	✓	✓
	Satellite Centers	✓	✓	✓	✓	✓	✓	✓
1 to 2 million	Core Dominant	✓	✓	✓	✓	✓	✓	✓
	Corridor Dominant	✓	✓	✓	✓	✓	✓	✓
	Satellite Centers	✓	✓	✓	✓	✓	✓	✓

TABLE 3

TRANSPORTATION TECHNOLOGY IMPACTS

		I Railway		
		Light Rail	Rapid Rail	Commuter Rail
Operating Cost Per Mile		1.65 - 2.93 per car mile	1.01 - 2.79 per car mile	1.48 - 4.23 per car mile
Land Cost per mile	CBD Fringe Residential	mil- lion 2.22 1.44 1.28 per mile	mil- lion 2.22 1.44 1.28 per mile	mil- lion 2.22 1.44 1.28 per mile
Construction Cost Million per mile	At Grade	.3 - 1.6 M.P.M.	6.6 - 9.4 M.P.M.	6.6 - 9.4 M.P.M.
	Elevated	6.5 - 157 M.P.M.	13.2 - 18.6 M.P.M.	13.2 - 18.6 M.P.M.
	Cut & Cover downtown	-	35.8 - 71.4 M.P.M.	35.8 - 71.4 M.P.M.
	Cut & cover Fringe	-	16.3 - 31.6 M.P.M.	16.3 - 31.6 M.P.M.
Station cost million/ each	Subway	9.7 - 12.1 million	10.0 - 17.0 million ea.	15-25 million ea.
	at -grade	.2 million each	2.0 - 5.0 million ea.	5.0 - 8.0 million ea.
	elevated	0.7 - 2.6 million each	-	-
Rolling Stock Cost		$120,000 to $4.8,000	$125,000 to $350,000	$350,000 to $714,000

M.P.M. = million per mile

Case Study Results

The technology assessment was demonstrated in three specific case study examples. The metropolitan areas selected were chosen, in part, due to the research team's familiarity with these areas. Further, the cities which were selected indicated differences in size, population density, and spatial form as well as varied and complex regional transportation patterns. The metropolitan areas selected as case study sites are as follows:

1.) San Francisco Bay Area
2.) St. Louis Metropolitan Area
3.) Louisville, Kentucky

The San Francisco Bay Area technology assessment began with a thorough review of the ABAG and MTC regional land use and socio-economic planning and forecasting process through the PLUM Series 3 projections. These projections were used to postulate three feasible growth states of the region which reflected changes in magnitude and distribution of regional growth as a function of background assumptions. In total, three growth states were derived for use in the evaluation methodology.

The next step in preparation for the analysis was the delineation of appropriate transportation technology alternatives and associated reward matrices. These technology alternatives represented feasible mixes of technologies and covered a range of technical sophistication and complexity from BART-local bus to STOL/VTOL options. The subsequent impact analysis of the transportation technology alternatives lead to the reward matrix formulation. Various preference schemes were introduced in the weighting of impact matrices and transition probabilities to demonstrate the optimal solution's sensitivity to changes in input parameters, as well as to reflect the priorities different user or non-user groups may associate with the transportation technologies.

The output of the evaluation methodology is a policy vector which indicated the optimal transportation technology to be employed for each system state under the detailed input preference schemes. As can be seen in Table 4, Alternative 5 (BART, local bus, express bus, STOL) or 6 (Alternative 5 plus demand responsive transit) arise as optimal under the various growth state/preference schemes. This is due to their high level of service and advancement of beneficial impacts, such as reduced pollution, noise, etc.

TABLE 4

SAN FRANCISCO CASE STUDY SUMMARY

Environmentally Sensitive Preference Scheme

State	High Growth Dominant	Low Growth Dominant	Medium Growth Dominant
1	6	6	5
2	6	6	5
3	5	5	6

Development Oriented Preference Scheme

State	High Growth Dominant	Low Growth Dominant	Medium Growth Dominant
1	6	6	5
2	5	6	5
3	5	6	6

Compromise Regional Preference Scheme

State	High Growth Dominant	Low Growth Dominant	Medium Growth Dominant
1	6	6	6
2	6	6	5
3	5	5	6

The second case study performed was that of St. Louis, with a similar sequence of growth states, transportation technology alternatives, reward matrices, and stochastic inputs for use in the evaluation methodology. In this study, the state variables of population density, non-residential core floor space, non-residential corridor floor space, regional value added, and total personal income delineated three district states, reflecting core dominant, corridor dominant, or satellite center regional growth.

The transportation alternatives again were selected as a result of current technologies in use or under study in the region, and those suitable for relevant use in relation to the size, density, and distribution of regional growth in the St. Louis area. Upon the formation of the transportation technology alternatives, the associated reward and transition probability matrices were developed, again reflecting varied weighted impact and development preference schemes.

The use of the Markovian evaluation methodology once again presents the optimal transportation technology arrayed against the growth state as a function of input parameter preference schemes, as summarized in Table 5. Here, Alternatives 5 (limited highway improvement, rail rapid transit, regional car pooling, PRT) and 6 (limited highway, rail rapid transit, demand responsive transit, STOL) are optimal under the various schemes. This is often due to anticipated energy savings and minimized environmental impacts of these alternatives for the various growth state under respective preference schemes.

TABLE 5

ST. LOUIS CASE STUDY SUMMARY

Environmentally Sensitive Preference Scheme

State	Core Dominant Growth	Corridor Dominant Growth	Satellite Center Dominant Growth
1	6	6	6
2	5	5	5
3	5	5	5

Development Oriented Preference Scheme

State	Core Dominant Growth	Corridor Dominant Growth	Satellite Center Dominant Growth
1	5	5	5
2	5	5	5
3	5	5	5

Compromise Regional Preference Scheme

State	Core Dominant Growth	Corridor Dominant Growth	Satellite Center Dominant Growth
1	5	5	6
2	5	5	5
3	5	5	5

The final case study analysis undertaken was for the Louisville Area. Here, the regional growth states reflected changes in distribution of regional growth and did not address variations in magnitude of future growth as determinants of the regional growth states. Growth State 1 reflected a continuation of existing trends, state 2, a core dominant growth, and growth state 3, an acceleration of dispersed regional activity.

The next step was the preparation of the set of transportation technology alternatives reflecting existing regional preferences and feasible technologies for use suitable to the study area. Subsequently, the alternatives' impacts were delineated under two development preference schemes as well as the respective transition probabilities. Once again, the principal impacts of concern were those of capital cost, regional value added, energy cost, air pollution, and noise.

The subsequent evaluation, summarized in Table 6 once again detailed the state specific optimal transportation alternative under alternate preference schemes. As can be seen, Alternative 4 (highway improvements, downtown-people mover, demand responsive transit) or Alternative 3 (rail and bus transit improvement, DPM, DRT) are selected as optimal under either preference scheme for respective growth states, indicating a stable solution under variation in impact weighting.

TABLE 6

LOUISVILLE CASE STUDY SUMMARY

State	Environmentally Sensitive Preference Scheme	Development Oriented Preference Scheme
1	4	4
2	3	3
3	4	4

Conclusions

This research effort has seen the development of a methodology suitable for the assessment of transportation technology impacts in relation to the regional land use and growth configurations. Further, the Markovian decision formulation enables the qualified user to accurately measure and evaluate the impacts of alternative transportation investments under various regional growth formulations. For example, the methodology is suitable for the varied levels and intensities of development exhibited in the San Francisco case study yet also responsive to the land use orientations as seen as the Louisville case study. Further, the methodology is multimodal in its analytic capabilities as seen in the St. Louis case study as well as the other two.

The state space formulation inherant in the Markovian decision theory approach enables the user to adapt to the wide range of development patterns evident in urban areas across the U.S., yet capitalize on similarities which arise. The reward matrix formulation employed here enables the assessment of both user and non-user impacts associated with the transportation technology. These reward matrices derived from the technology impacts are responsive to the importance of the impact in each postulated regional growth state. Also the Markovian methodology presented herein enables the user to pursue straightforward and adequate sensitivity analyses over ranges of input variable values to test the stability of the policy vectors,