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T R F

TRANSPORTATION RESEARCH FORUM

A Technology Assessment of Transportation Systems Design in Three Case Study Communities

by Dr. Lonnie E. Haefner, Lee Hutchins*, Don Lang*, Rob Meyer* and Bigan Yarjani**

ABSTRACT

THE OBJECTIVE of the research effort presented herein is 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. It develops an abstract technology assessment format, capable of generic evaluation over a hierarchy of city sizes, shapes, and modal transportation technology characteristics, using unit cost and impact data. Although not a part of the scope of work for this study, this could be accomplished with analytical techniques of factor analysis, cluster analysis, and using their result as an input for the evaluation approach of Markovian Decision theory, as employed in this research. Thus, the analyst is not required to know or explore the historical data characteristics of the region in depth. A research agency or public policy analyst is able 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

Introduction-Level of Abstract Use

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 its 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 will attempt 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 representative 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 attractions 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 has been formulated for use in this study.

Taxonomical Development

As stated previously, the analysis should be capable of extending over a

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

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 1 exhibits a description of transportation technologies suitable under the various regional parameters. Table 2 is a 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. At this point, appropriate generic regional unit data is available to be used in the evaluation model. The following sections will detail the methodological use of the evaluation model, and the demonstration of the three regions with different characteristics.

OVERVIEW OF EVALUATION MODELING APPROACH

Brief Review of Relevant Markovian Decision Theory Structure

This chapter reviews the significant elements of the evaluation modeling structure. The analysis and evaluation of the impact benefits and costs that will result from implementation of regional transportation technology alternatives can be undertaken by a Markovian decision theory approach.[1]

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:

TABLE 1

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 2

TRANSPORTATION TECHNOLOGY IMPACTS

		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

s(n) state at time interval n, n = 1, 2, . . .

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

The actual Markovian assumption has the following formulation:

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

where P is a probability measure.

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.

The next step in the modeling formulation is the development of k technology alternatives for future regional transportation activity. These k alternatives are formulated in conjunction with different assumptions affecting the region under study. These assumptions may relate to the potential for transportation service in the region, as well as the locale of possible sites available.

The state transition probabilities are the probabilities P_{ij} of a system in state i going to state j in the next time interval. Several assumptions are made with respect to the transition probabilities, in order to maintain accuracy, and remove some of the modeling complexity. These

FLOWCHART DESCRIPTION OF A MULTI-DIMENSIONAL TRANSPORTATION EVALUATION MODEL

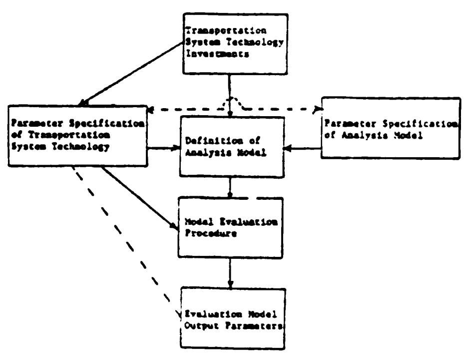

FIGURE 1

are: 1.) There is a finite set of states 1, 2, . . . N of the system which may be occupied at any time. 2.) The time interval spacing is assumed to be constant. 3.) P_{ij} measures are independent of time and therefore do not change with time.

There are two constraints on these probability measures:

First, for all i, j,

$$0 \leqslant P_{ij} \leqslant 1.$$

Second, the probabilities are normalized,

$$\sum_{j=1}^{N} P_{ij} = 1 \qquad i = 1, 2, \ldots N.$$

As a result, the matrix of the transition probabilities, N × N, is referred to as a stochastic matrix.

The stochastic inputs for this evaluation methodology consists of the single step transition probabilities for the Markov process. The determination of these probabalities are critical to the analysis, and reflect professional evaluation of the land use and transportation issues in both a general and region specific context. This versatility of the evaluation methodology enables the qualified user to readily assess the impacts of transportation technology alternatives as a function of the regional state parameters, either at a sketch planning level, or a detailed system analysis. In the first case, the user may specify the general size and spatial parameters of the city under consideration, formulate the transportation technology alternatives to be reviewed, then employ the Markovian evaluation methodology to assess them. The second case is similar, except that the growth states and transportation alternatives are specified in greater detail, as was done in NASA CR 152084.

CASE STUDIES

Introduction

As previously stated, a major objective of this research is to test the methodology presented previously in actual case study settings, incorporating realistic study scenarios, actual data, and relevant performance indicators. The following metropolitan areas were chosen to be tested as case study sites:

A. San Francisco Bay Area
B. St. Louis Metropolitan Area
C. Louisville, Kentucky

These metropolitan areas were chosen due to the research team's familiarity with their transportation policy activities, and their subjective feel for the decision makers' and actor groups' responses to public work investments which have significant socio-economic-environmental impacts. Further, each of these metropolitan areas represent N.S. cities with meaningful differences in size, population density, and spatial form, and complexity of regional transportation patterns. Each case study will be presented within a format of initially discussing the region's historic socio-economic and growth status, followed by generation of transportation technology alternatives to be evaluated. Subsequently, the modeling format will evaluate these options, using gross impact data and data gathered at the site, with conclusions being offered as to results, and efficacy of the evaluation approach.

A. SAN FRANCISCO BAY AREA

A Brief Review of the Profile of Future Bay Area Growth Projections

This section will discuss the future growth projections for the San Francisco Bay Area with respect to long run planning objectives and the associated land use, population, and economic forecasts of relevance to the research effort, and the structuring of related computational models with respect to growth. The PLUM (Projective Land Use Model) model was used by the Association of Bay Area Governments and the Metropolitan Transportation Commission to develop forecasts for the metropolitan area. Such model output has been used by the research team to structure the Markovian state space of the research evaluation models.

The PLUM Model is designed to yield projections of future zonal distribution of population, employment and urban land use within a region. The model is based on two fundamental concepts which were derived from the Lowry Model. The first concept involves a distinction between "basic" and "local serving" employment. The second concept involves the notion of an allocation function. The model iterates to a single forecast for the year desired based on a balancing between the projected location of the basic employment, the distribution of the local-serving employment, and the set of households associated with both employment categories. The output of the PLUM model is a set of projections of employment, population, and land use per zone of the region under study for a given target year. This model and its associated output on future growth states was used by the Association of Bay Area Governments (ABAG) and the Metropolitan Transportation Commission (MTC) in a joint study conducted in

1976-1977 and adopted by the ABAG Regional Planning Committee on March 2, 1977.

Development of Transportation Technology Alternatives

The transportation technology alternatives developed in this research for the Bay Area range from "status quo" to a high intensity STOL alternative. The following pages contain a listing description of the alternatives:

Alternative I — Status Quo

1. BART
2. Local buses
3. Express buses

Alternative II

1. BART
2. Local buses
3. Express buses
4. Car pool program

Alternative III

1. BART
2. Local buses
3. Express buses
4. Car pool program
5. Demand Responsive Transportation Service

Alternative IV

1. BART
2. Local buses
3. Express buses
4. Personal Rapid Transit

Alternative V

This alternative incorporates the high intensity STOL system in addition to those alternatives considered in status quo (Alternative I). High STOL operation in the Bay Area would include the following sites as STOL ports.

Major Airports—
- Oakland International
- San Francisco International

General Aviation Fields—
- Rhonert Park
- Napa County Airport
- Buchanan Field
- Livermore Municipal
- Gnoss Field

New Sites—
- Mill Valley
- San Francisco CBD - Transbay Terminal
- Fremont - BART Terminus
- Oakland - Jack London Square
- San Francisco CBD - World Trade Center - Barge

Obviously, this alternative relies significantly on new STOL port construction to supplement existing major airports and general aviation fields.

Alternative VI

In addition to those transport technologies considered in Alternative V, demand responsive transportation (one to many, many to one) will be incorporated in this alternative to furnish a better connection to the STOL ports. Thus, the alternative set is composed of:

1. BART
2. Local Bus
3. Express Buses
4. High STOL (sites as in Alternative V)
5. Demand Responsive Transportation

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 3, 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.

B. ST. LOUIS METROPOLITAN AREA

This section will utilize the evaluation approach to assess transportation technology alternatives for the St. Louis metropolitan region which have recognizable impacts on land use, growth, and economic issues.

Transportation Alternatives

The transportation alternatives were selected on the basis of current options under study in the metropolitan St. Louis comprehensive transportation study, and selective inclusion of transportation technological innovations and their relevant use with regard to size, population density and spatial form of the St. Louis Metropolitan area.

The **first alternative** represents the status quo.

The **second alternative** represents a program of highway improvements of a limited nature, including approximately 50 miles of new freeway construction, and 375 miles of improvements to existing major roadways. The total system would be composed of approximately 250 miles of freeways and 1300 miles of major arterials, totalling to 1550 miles of major roadway facilities. In addition, a transit component is included which consists of a proposed 100 mile set of rail rapid transit trunk lines, plus extension to three outlying activity centers with

TABLE 3

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 Dominiant	Low Growth Dominant	Medium Growth Dominant
1	6	6	6
2	6	6	5
3	5	5	6

appropriate feeder bus service throughout the region. The total transit system thus includes 151 miles of rail rapid transit, and a feeder bus system of 2716 route miles.

Alternative three includes the limited highway improvement plus the transit component of alternative two, in addition to a regional car-pooling program.

Alternative four includes the components of alternative three and a demand responsive transportation system.

Alternative five has two components. The first component is that set of options proposed for alternative three. The second component is a personal-rapid transit system for use in the downtown core.

Alternative six includes the limited highway improvements and the transit program described in alternative two, and the demand responsive transportation system, in addition to a STOL system which would spatially consist of three outlying STOL ports and a downtown port.

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 4. 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.

C. LOUISVILLE METROPOLITAN AREA CASE STUDY

Review of Regional Growth Profile

The Louisville Metropolitan Area case study consists of nine counties. The five counties of Clark, Floyd, Bullitt, Jefferson, and Oldham are considered within the metropolitan SMSA while Henry, Shelby, Spencer, and Trimble, the remaining four counties, are considered non metropolitan. The principal development activities have taken place in the three counties of Clark, Floyd, and Jefferson. Bullitt County has undergone significant pressures for development in recent years and may attract larger portions of the region's economic activity in the future. Further, such pressures are also developing with respect to Spencer and Oldham counties.

Here, the regional growth states reflected changes in distribution of region-

TABLE 4

ST. LOUIS CASE STUDY SUMMARY

State	Core Dominant Growth	Corridor Dominant Growth	Satellite Center Dominant Growth
Environmentally Sensitive Preference Scheme			
1	6	6	6
2	5	5	5
3	5	5	5
Development Oriented Preference Scheme			
1	5	5	5
2	5	5	5
3	5	5	5
Compromise Regional Preference Scheme			
1	5	5	6
2	5	5	5
3	5	5	5

al 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.

Development of Alternatives

The various transportation technology alternatives selected for analysis were based upon the existing short and long range transportation plans for the case study area, and consideration of the scope of work for this research effort. Alternative 1 can be generalized as a highway oriented alternative with several construction components. Alternative 2 places a greater emphasis on express bus routes and includes a Downtown People Mover (DPM). In a similar emphasis on transit systems, Alternative 3 emphasizes rail rapid transit improvements. Alternative 4 represents a mix of transportation technologies previously described.

The subsequent evaluation, summarized in Table 5 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.

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 in-

TABLE 5

LOUISVILLE CASE STUDY SUMMARY

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

vestments 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 inherent 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 vector.

FOOTNOTES

1 **Volume II, Development of Air Transportation Evaluation Processes**, Dr. Lonnie E. Haefner, prepared for Ames Research Center, National Aeronautics and Space Administration, August, 1975.

2 **Operations Research** by Frederick S. Hillier and Gerald J. Lieberman, Holden-Day, Inc. 1974.

3 Howard, Ronald A., **Dynamic Programming and Markov Processes**, M.I.T. Press, Cambridge, Mass., 1960.

4 Howard, Ibid.