A TIME-STAGED STRATEGIC APPROACH TO TRANSPORTATION SYSTEMS PLANNING

by

LANCE ARNOLD NEUMANN

B.S., Brown University
(1970)

Submitted in partial fulfillment
of the requirements for the degree of
Master of Science
at the
Massachusetts Institute of Technology

September 1972

Signature of Author

Department of Civil Engineering, July 14, 1972

Certified by

Thesis Supervisor

Accepted by

Chairman, Departmental Committee on Graduate Students of the Department of Civil Engineering

-1-
ABSTRACT

A TIME-STAGED STRATEGIC APPROACH TO TRANSPORTATION SYSTEMS PLANNING

by

LANCE ARNOLD NEUMANN

Submitted to the Department of Civil Engineering on July 14, 1972, in partial fulfillment of the requirements for the degree of Master of Science.

Typically, urban transportation studies have focused on target year networks and have adopted one of these target year systems as a master plan for improvements over the ensuing twenty year period. This thesis proposes a substantially different approach to system planning which focuses attention on the sequences of improvement which can occur over time. The time-staged strategic approach to developing an investment program can better address the issues of uncertainty, the role of time, scarce resources, and multiple objectives, and is more compatible with a planning process designed to be sensitive to community and environmental values. The research was done in cooperation with the California Division of Highways. The Division's present process is contrasted with the staging approach and an example application of the time-staging concepts to California is presented. A number of recommendations for improving the present process and procedures used to develop an investment program are included.

Thesis Supervisor: 
Wayne M. Pecknold

Title: 
Assistant Professor
ACKNOWLEDGEMENTS

This research was sponsored in part by the State of California, Business and Transportation Agency, Department of Public Works, Division of Highways. In addition, the author wishes to express his appreciation to M.I.T. and the U.S. Department of Health, Education, and Welfare for the support provided by a National Defense Education Act fellowship for the past two years.

The research was done in conjunction with the Transportation and Community Values Project directed by Marvin L. Manheim in the Urban Systems Laboratory at M.I.T.

Many thanks go to Wayne M. Pecknold who initially stimulated by interest in the area of investment planning and who has provided guidance and support throughout the effort.

Kirt Mead, Arlee Reno, and Frank Koppelman have provided many helpful comments and suggestions at all stages of this work. Particular thanks go to Mark Krejci who helped to develop the examples presented here and to Art Hall for providing the figures. Al Mailman has provided some much appreciated moral support.

In addition, thanks go to Mike Stephenson, Larry Wieman, Charles Whitmarsh, Tom Tamburri, Paul Talbot, Gene Knabel, Bill Bethel, and Frank Navarette of the California Business and Transportation Agency Department of Public Works and Division of Highways who have given freely of their time throughout the project.

Finally, thanks go to Bobbie Cochran and Dolores Rimpas who typed the thesis.
Disclaimer

The opinions and conclusions expressed or implied in this thesis are those of the author. They are not necessarily those of the California Division of Highways or the Federal Highway Administration.
# Table of Contents

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
<td>9</td>
</tr>
<tr>
<td>1.1</td>
<td>Objectives of Research</td>
<td>9</td>
</tr>
<tr>
<td>1.2</td>
<td>Project Scheduling Problem</td>
<td>12</td>
</tr>
<tr>
<td>1.3</td>
<td>Nature of Decision-Making Environment</td>
<td>19</td>
</tr>
<tr>
<td>2</td>
<td>System Planning in California</td>
<td>28</td>
</tr>
<tr>
<td>2.1</td>
<td>Institutional Framework</td>
<td>29</td>
</tr>
<tr>
<td>2.2</td>
<td>Needs and Allocation Process</td>
<td>32</td>
</tr>
<tr>
<td>2.2.1</td>
<td>Needs Process</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>A. Local Development Goals</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>B. Functional Classification</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>C. Level of Service Standards</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>D. Traffic Forecasts</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>E. Identification of Deficiencies</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>F. Calculation of Needs</td>
<td>39</td>
</tr>
<tr>
<td>2.2.2</td>
<td>Allocation of Funds</td>
<td>40</td>
</tr>
<tr>
<td>2.3</td>
<td>Development of the Investment Program</td>
<td>42</td>
</tr>
<tr>
<td>2.3.1</td>
<td>Priority Lists</td>
<td>42</td>
</tr>
<tr>
<td>2.3.2</td>
<td>Planning Program</td>
<td>46</td>
</tr>
<tr>
<td>2.3.3</td>
<td>Multi-Year Program Proposal</td>
<td>47</td>
</tr>
<tr>
<td>2.3.4</td>
<td>Multi-Year Financial Plan</td>
<td>51</td>
</tr>
<tr>
<td>2.4</td>
<td>Planning, Programming, and Budgeting System</td>
<td>51</td>
</tr>
<tr>
<td>2.4.1</td>
<td>Planning</td>
<td>53</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td></td>
<td>2.4.2 Programming</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>2.4.3 Budgeting</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>2.4.4 Effectiveness of P.P.B.S.</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>2.5 Findings and Problems with Present Programming Procedures</td>
<td>57</td>
</tr>
<tr>
<td>Chapter</td>
<td>3 A Time-Staged Strategic Approach</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>3.1 Developing Staging Strategies</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>3.2 Evaluating Staging Strategies</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>3.2.1 Alternative Approaches to Evaluation</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>3.3 Summary: A Comparison of the Time-Staging and Master Plan Approaches</td>
<td>94</td>
</tr>
<tr>
<td>Chapter</td>
<td>4 Application of Time-Staged Strategic Approach to California</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>4.1 Example of Time-Staging Approach</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>4.1.1 Introduction</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>4.1.2 Description of Santa Barbara Project</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>A. Project Background</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>B. Historical Summary</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td>C. Problems Highlighted by Crosstown Freeway Experience</td>
<td>113</td>
</tr>
<tr>
<td></td>
<td>4.1.3 Application of the Proposed Time-Staging Approach</td>
<td>114</td>
</tr>
<tr>
<td></td>
<td>A. Freeway Alternatives in the Santa Barbara Corridor</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>B. Relating Santa Barbara Corridor Decisions to the Rest of the District</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>C. Developing Time-Staging Strategies for the Santa Barbara Corridor</td>
<td>138</td>
</tr>
</tbody>
</table>
2.4.2 Programming ........................................... 53
2.4.3 Budgeting ............................................. 54
2.4.4 Effectiveness of P.P.B.S. ......................... 55

2.5 Findings and Problems with Present Programming Procedures ........................................... 57

Chapter 3 A Time-Staged Strategic Approach ......................... 70
3.1 Developing Staging Strategies ............................. 71
3.2 Evaluating Staging Strategies ............................ 84
3.2.1 Alternative Approaches to Evaluation ............. 87
3.3 Summary: A Comparison of the Time-Staging and Master Plan Approaches ......................... 94

Chapter 4 Application of Time-Staged Strategic Approach to California ........................................... 100
4.1 Example of Time-Staging Approach ...................... 100
4.1.1 Introduction ........................................... 100
4.1.2 Description of Santa Barbara Project ............. 102
   A. Project Background ................................... 102
   B. Historical Summary .................................. 108
   C. Problems Highlighted by Crosstown Freeway Experience ........................................... 113

4.1.3 Application of the Proposed Time-Staging Approach ........................................... 114
   A. Freeway Alternatives in the Santa Barbara Corridor ........................................... 115
   B. Relating Santa Barbara Corridor Decisions to the Rest of the District ............. 131
   C. Developing Time-Staging Strategies for the Santa Barbara Corridor ................ 138
<table>
<thead>
<tr>
<th>Section/Chapter</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2</td>
<td>Recommendations</td>
<td>144</td>
</tr>
<tr>
<td>4.2.1</td>
<td>Development of Planning Programs</td>
<td>145</td>
</tr>
<tr>
<td>4.2.2</td>
<td>Evaluation of Planning Programs</td>
<td>150</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>Summary, Conclusions, and Extensions</td>
<td>155</td>
</tr>
<tr>
<td>5.1</td>
<td>Summary and Conclusions</td>
<td>155</td>
</tr>
<tr>
<td>5.2</td>
<td>Extensions</td>
<td>159</td>
</tr>
<tr>
<td></td>
<td>Selected References</td>
<td>162</td>
</tr>
</tbody>
</table>
# List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Institutional Structure for Highway Planning in California</td>
</tr>
<tr>
<td>2.2</td>
<td>Fund Structure for California State Highway Fund</td>
</tr>
<tr>
<td>2.3</td>
<td>Highway Needs Process</td>
</tr>
<tr>
<td>2.4</td>
<td>Development of Planning Program</td>
</tr>
<tr>
<td>2.5</td>
<td>Highway Transportation Program Structure</td>
</tr>
<tr>
<td>3.1</td>
<td>Time-Staged Approach to System Planning</td>
</tr>
<tr>
<td>3.2</td>
<td>Programming Additions to Capacity on Three Links</td>
</tr>
<tr>
<td>3.3</td>
<td>Regional Staging Strategy</td>
</tr>
<tr>
<td>4.1</td>
<td>Santa Barbara Corridor</td>
</tr>
<tr>
<td>4.2</td>
<td>Allocation of Funds to Crosstown Project in Planning Program</td>
</tr>
<tr>
<td>4.3</td>
<td>Staging Strategy Based on Designing at Grade Alternative in the First Period</td>
</tr>
<tr>
<td>4.4</td>
<td>Undiscounted Benefits and Costs for Freeway Alternatives</td>
</tr>
<tr>
<td>4.5</td>
<td>Discounting Formulas</td>
</tr>
<tr>
<td>4.6</td>
<td>Pattern of Benefits and Costs Assumed for Freeway Alternatives</td>
</tr>
<tr>
<td>4.7</td>
<td>Sample Expected Value Calculation</td>
</tr>
<tr>
<td>4.8</td>
<td>Effect of Discount Rate on Net Present Value</td>
</tr>
<tr>
<td>4.9</td>
<td>Expected Value of Designing Freeway Alternatives</td>
</tr>
<tr>
<td>4.10</td>
<td>Substitution Programs for Crosstown Freeway</td>
</tr>
<tr>
<td>4.11</td>
<td>Staging Strategy Relating Santa Barbara Corridor Decision to Planning Program</td>
</tr>
<tr>
<td>4.12</td>
<td>Alternative Sequences of Improvement for Santa Barbara Corridor</td>
</tr>
</tbody>
</table>
Chapter 1
INTRODUCTION

1.1 OBJECTIVES OF THE RESEARCH

During the past two years, the Transportation and Community Values (TCV) research group at M.I.T. has been concerned with the incorporation of community and environmental factors into the highway planning process in cooperation with the California Business and Transportation Agency, Department of Public Works, Division of Highways.

Within this research effort, attention has been given to all phases of the planning process from statewide system planning to detailed project planning. The research to be reported in this thesis is one element of the work done in the area of statewide system planning--the planning of a network of urban freeways and expressways as well as other links of statewide significance. The work program for this research on system planning has been divided into four main categories:

1) overall process design
2) institutions
3) allocation
4) process and procedures used by the planning agency

The research in process design is part of an ongoing effort to specify a planning process which is responsive to interests at all political levels (state, metropolitan, and local)\(^1\). The second task

area has examined the institutional structure needed in California to support a process which requires representation of metropolitan as well as state and local interests in transportation decision-making. The third focus of the system planning research has been the process used to allocate the State Highway Funds and the biases and assumptions behind different allocation schemes. The fourth and final task area has focused in detail on a number of the functional activities of the Division of Highways in effort to determine how the current process and procedures used at the system planning level could be modified to facilitate the reflection of community and environmental factors early in the planning process. This fourth category included work on community interaction, development of alternatives, impact prediction, evaluation, and network analysis tools. The results of this research to date has been reported in Volume II of a series on the incorporation of community and environmental factors in highway planning.\(^1\)

The research to be reported in this thesis will be the results of the work done on the development of system planning alternatives. Specifically, the focus of this element of the system planning effort has been on the process and procedures used by the California Division of Highways to develop the Multi-Year Financial Plan (MYFP). The aim of this effort has been to explore how the Division\(^2\) might best allocate both its manpower and monetary resources to improve the State's

---


2 Although much of the research reported herein will be applicable to other states and highway departments, throughout this thesis, reference to the division or state will refer specifically to California.
transportation system over time.

The MYFP represents the way in which the Division expects to utilize its resources in the future to improve the service provided by the State Highway System. This includes funds allocated to capital improvements, safety, and maintenance programs, as well as general administration and planning. In light of the high percentage of funds spent on new construction, however, the real potential for improving California's highway investment decisions involves changing the present process for developing a new construction schedule. Therefore the discussion to follow will focus, for the most part, on improving the process used to develop the capital improvement program.

Section 1.2 will give an overview of this problem in more detail and define the focus of this research in terms of the project scheduling problem. Section 1.3 will then describe the nature of the decision-making environment in which investment programs in system planning must be developed for a highway department such as the California Division of Highways.

Chapter 2 then turns to examine in detail the present system planning process used by the California Division of Highways and in particular the procedures used to develop an investment program. The chapter will conclude with a summary of the research findings with respect to the

---

1At the present time, approximately 75% of the total budget is allocated to new highway construction and this program will probably continue to dominate the Division's MYFP in the future.
current planning process in California.

Chapter 3 presents in detail a time-staging approach which is more compatible with the nature of the decision-making environment than the more traditional master planning approach.

Given the existing problems with the Division and a new approach to planning presented in these two chapters, Chapter 4 then presents an example application of the time-staging concepts to actual projects in the Division's investment program. The example focuses on the Crosstown Freeway Project in the city of Santa Barbara. The chapter concludes with a series of recommendations made to the Division of Highways aimed at improving their investment planning process, both in terms of improved monetary and manpower resource allocation.

Finally, Chapter 5 presents a brief summary of the research results and the conclusions which can be drawn from this effort. In addition, a number of extensions for future research in this area are outlined.

1.2 THE PROJECT SCHEDULING PROBLEM

There are three major factors which any planning process designed to be sensitive to community values and environmental concerns must recognize. First, change is endemic in the society in which we live. Community goals and planning objectives, transportation needs, and the impact of transportation facilities on the environment all change over time and require new responses in the planning of transportation systems.

In California, as in other states, these changes have been reflected in increasing and more vocal opposition to urban highways, growing pressure to develop mode options other than private auto by opening the highway
trust funds (both national and state), and a renewed debate over the state's development goals and transportation requirements. The new "coastal zone" policy for highways, and the controversies generated by development plans for Mineral King Canyon and the Lake Tahoe area are representative of the increasing interest in the environment being voiced by public agencies and private groups.

While such changes should be responded to in any improvements to the transportation system, the second important factor which the planner must recognize is that public policy and investment decisions can strongly influence the patterns of change in a region. Though the long run interaction between the transportation system and the myriad social and economic forces is not well understood, there is much evidence to suggest that the transport system can encourage growth and development patterns that, in turn may place new requirements on that system. Hence, the "need" for transportation cannot be described in the abstract without consideration of the system proposed to meet that need.

Finally, the transportation planner must recognize that changes in values, demand for service, and the influence of transportation improvements on these changes cannot be predicted with certainty. In addition to uncertainty in demand and factors influencing demand (population growth, etc.), the resources to be available in the future to meet these demands are also subject to change.

Thus the planner must develop transportation options with the knowledge that present decisions must be based on an imperfect understanding of the future of the region. Unforeseen changes may require new responses
and adaptations which are impossible to fully evaluate at the present time.

Currently, the California Division of Highways is finding it difficult to accommodate these changes and accomplish their highway program. The Division is constrained by legislation to consider road improvements on the State Highway System. The majority of this system is also contained in the Freeway and Expressway System master plan.\(^1\) While this master plan is reviewed by the Division and legislature every four years, only minor additions and deletions to the system have occurred. A major problem now facing the Division is that many projects programmed for funding are not getting built on schedule or at all. Inflation, changing design standards, and new programs to compensate for adverse community and environmental impacts have all shrunk the highway dollar. In addition, however, many communities throughout the State are demanding a greater voice in making transportation decisions and questioning the need for many of the links in the present highway plan.

In fact, the Freeway and Expressway System originally proposed for completion in the mid-1970's will probably never be built in its entirety and certainly not on schedule. Had this been known or anticipated at the time of its completion, there may have been an intermediate system (in scale or length) that could have better served the state's transportation requirements in the 1970's. For example, instead of building major

\(^1\)Of 16,000 miles of roadway (or proposed roadway) in the State Highway System, about 13,000 miles are also included in the Freeway and Expressway System master plan which was originally defined by the Legislature in 1959.

-14-
freeways in rural portions of the state, more moderate upgrading might have occurred over a larger segment of the highway system. There is presently some discussion within the Division of the need to explore more thoroughly the opportunities for constructing "interim" improvements.

The problems currently facing the Division emphasize the need to critically reexamine the present system planning process. The planning of investments in a transportation system involves addressing a complex set of issues concerning the appropriate location, mode, scale, and timing of improvements. Though in practice, in California and other state highway agencies, these issues are often assumed to be independent and are addressed quite separately, in reality, each issue is strongly interrelated and they should be addressed simultaneously.

Over the past few years, the Division has moved in the direction of addressing these issues more directly by taking a number of innovative steps to improve their planning programs. These efforts have included a comprehensive look at the ever widening gap between resources and highway "needs", the use of escalation factors to account for inflationary trends in the economy, and most significantly, the implementation of a Planning, Programming, and Budgeting System.¹ The implementation of P.P.B.S. has provided a framework for the Division's activities, organized resource allocation in terms of purpose programs, and provided for a more explicit evaluation of the Division's performance. While all of these measures

represent a commitment to the judicious use of transportation funds, our research indicates that there are still additional opportunities to further improve California's investment decision-making.

As a first step to improve investment decision-making, there is a need to substantially revise the traditional concept of system planning to allow for more flexibility. California's system plans have identified facilities to be built over a period of more than 20 years, with the specific locations of these roads to be determined in route studies. Thus, there are significant time lags in implementation of transportation system alternatives. As stated by Manheim,

"Since it is now taking anywhere from 10-15 years to plan, design, and construct a new highway, the 'comprehensive freeway and expressway plan' for 1985 is not being implemented instantaneously, but as a series of stages. Meanwhile, the world continues to change: transportation planning takes place in a context of continuous change in demand, in technology and in goals.

Transportation planners therefore need to deal with strategies; each alternative strategy is composed of a sequence of actions staged over time. For example, consider a twenty-year comprehensive metropolitan plan. Such a transportation plan might be divided into five four-year stages. Each stage might consist of several actions—particular highway links, transit extensions, data collection activities, community decision points, etc. We can expect that by the end of the first four-year period, things will have changed. Demand patterns will have changed; new technologies will have been developed, or problems or advantages in existing technologies will have been uncovered; goals and aspirations will have changed; data collection activities will have produced new information. We will have learned more. Conditions will have changed and therefore, at the end of the first stage, the strategy consisting of a sequence of stages would be reviewed and possibly revised. If change has been relatively minor, the actions to be implemented in the following stages of the strategy may stay the same; more likely, however, the later stages of the plan will be revised because of the
changing world. To have an effective continuous planning process, we need to conceive of our transportation systems plan as a sequence of staged actions; at the conclusion of each stage, we must open the door again to review an analysis of what the succeeding stages must be, based upon new information and the results of the preceding stages.¹

The time-staging approach to be described in Chapter 3 of this thesis recognizes that significant decisions on a system plan are in reality going to be postponed until environmental impact, corridor, and initial route studies are underway or complete. The mode, scale, specific alignment, and indeed existence of a particular facility may be determined in later phases of planning. Time-staged system plans recognize the possibility of a number of outcomes from these later studies.

The role of system planning in the context of staged alternatives then is to skillfully anticipate the choice issues that must be resolved as planning continues, and devise tentative sequences of improvements based on potential outcomes from these choices. At the same time, it must be recognized that no amount of skill or effort will anticipate all the choice issues or recognize all the feasible alternatives. New options will be added at a later point in time while others will be dropped from consideration.

While the preparation of master plans has often only included demand and cost studies, the time-staging approach presented in Chapter 3 postulates that system plans can't be evaluated by these demand and cost studies.

alone. In fact, system planning should concentrate on the development of feasible alternatives on the basis of preliminary estimates of the ranges of community and environmental impacts, as well as from demand, cost, and revenue studies. The alternatives will then be more representative of the alternative that will actually be built and be continuously evaluated as the planning process continues.

As corridor and route studies begin, impact prediction, community interaction, revision of previous alternatives and development of new alternatives will shed light on system planning strategies. Decisions on particular modes, scale, alignment, or whether to continue studies will be made. Since staging strategies haven't identified one "optimal" network, as choices are negotiated, the decisions at the corridor and route planning levels will have to be reflected in system plans. Results of a particular corridor study may place constraints on the improvements in other corridors, and system planning will have to integrate different proposed corridor and project solutions to insure consistency.

It may be that as a corridor study or route planning proceeds there will be a need to recycle back to system planning (i.e., re-consideration of network effects due to corridor study information). Staged plans can minimize the effect of this recycling by considering this possibility explicitly when plans are initially formulated and by devising alternative assignments of resources which can adapt to delays and restudies.

The time-staging approach suggested in this thesis is therefore both decisive, by requiring action on first period plans, and realistic, by recognizing that it is neither desirable or necessary to make tentative decisions over a long time horizon. While leaving future decisions open
until more information is obtained, staging strategies take into account possible future options and events and are able to evaluate the most flexible direction for present decisions. Because a staging strategy must include decisions on both program selection (set of projects, network alternatives) and individual project development, it provides a convenient framework for relating the interaction between system and route levels. That is, strategies recognize that information acquired during more detailed route studies may affect both the schedule and improvements desirable in that location, and in turn, affect the desirability and timing of improvements in other locations.

The overall objective of this thesis is to illustrate how the concepts of time-staging, and especially time-staging in the face of uncertainty, can be applied in California. A staging approach can improve the investment decisions being made by the Division, increase the flexibility of the planning program, and provide a mechanism for internally allocating manpower resources more effectively.

Section 1.3 summarizes the critical issues that must be addressed in developing an investment program for transportation improvements. The discussion will focus on the nature of the decision-making environment for state transportation system planning in California.

1.3 NATURE OF THE DECISION MAKING ENVIRONMENT

Before discussing how investment plans should be developed, it is necessary to describe in more detail the characteristics of the decision-making environment in which choices will be made in California. Both the
decision-making process for implementing state system plans and the basic characteristics of transportation investments place requirements on an agency developing an investment program.

In particular there are five important factors that must be considered in developing an investment program for a state highway department such as California. These factors are:

1) time of implementation
2) sequencing dependencies
3) budget dependencies
4) multiple objectives, and,
5) uncertainty.

This section will discuss how each of these factors can influence investment decisions.

The first factor that must be examined in developing an investment program is the effect of implementation time. The implementation time of investments in a transportation system can have an important impact on the desirability of a particular improvement. Marglin has shown that for a single project the net benefits of the investment may vary significantly with time.\(^1\) If population is rising, the benefits from constructing a particular highway link may rise monotonically over time.

\(^1\)Marglin, Stephen, Approaches to Dynamic Investment Planning, Amsterdam: North Holland, 1963.
may be timing or sequencing dependencies among them. For example, first building a circumferential highway around a city and then major new arterials into the downtown area might have very different impacts on the city, and even the region, than first building the arterials. In general, because of the topography of the transportation network, there will be different network effects (i.e., changing flow patterns) depending on the sequence of improvements made to the existing system. Link interdependencies might require that specific subsets of highway additions be built simultaneously or sequentially. Such interdependencies could exist among a number of projects on one route segment where, unless the road connects two specific points, few benefits are realized. Similarly, two parallel links may be redundant and construction of one reduces the benefits from the other significantly. More importantly perhaps, in the long run, various sequences of investment may affect the magnitude as well as the pattern of flows differently and create a dependence between the timing of investments and future demand levels.

A third major factor that must be considered in the decision making environment is the budget constraint. Since resources are scarce there are budget dependencies between the scale of particular improvements, the number of investments funded in any budget period, and the time at which improvements can be implemented.\(^1\) In designing a particular improvement, a basic question is how large a facility should be built

\(^1\)This dependency will be specifically elaborated upon in more detail in the example given in Chapter 4.
today to provide improved service over a period of time. Economies of scale usually exist in transport investments making it cheaper to build a four-lane road all at once rather than initially building a two-lane facility and adding two lanes later. However, building the larger facility and providing excess capacity in the near term commits capital resources that might otherwise be used elsewhere. The decision to build large to exploit economies of scale must be considered in light of the cost associated with foregone investment opportunities in other locations. For example, an eight-lane facility built in two four-lane stages provides capital from the unbuilt four-lanes to be used productively until the extra four lanes are required.

Discussions with personnel in the California Division of Highways have indicated a desire to explore the possibility of reducing the scale and design standards of certain projects in order to allocate resources to other shorter range improvements. In developing an investment program, consideration must be given to the effects of reducing the scale of some improvements in order to either increase the scale of others, or to fund more improvements in a given time period. The best decision, considering the tradeoff between economies of scale and the opportunity cost of capital (in terms of the benefits lost by not funding other projects), will depend on California's tradeoff rate for immediate versus future costs and benefits (i.e., the discount rate), the magnitude of the economies of scale of highway projects, the expected future demands for the facility, and the community and environmental impacts of different
size facilities.

When improvements are scheduled for a number of budget periods, the budget constraint may make it desirable to delay some improvements and fund others earlier, or to change the scale of improvements scheduled in different periods.¹ Both the payoff from immediate construction and the loss associated with postponement must be examined before the most desirable investments for the present period can be identified. California's present process tends to schedule those investments yielding the largest return from immediate implementation without considering the effects of delaying some projects in order to fund others. This issue will be explored in more detail in the example application in Chapter 4.

A fourth factor which complicates the process of developing an investment plan in California, as in most states, is the fact that investments in the state transportation system will serve multiple objectives. In statewide system planning the Division is planning transportation improvements for groups at a number of political levels (state, metropolitan, local). Even within one particular jurisdictional level, a number of different interest groups will exist.

Since the transportation interests of the different "communities" may overlap or conflict, decisions about specific transportation proposals must be negotiated over time. In California, the existence of

¹Timing and budget dependencies are particularly crucial for the Division of Highways in light of the durability of transportation investments. Once implemented, a transportation facility improvement represents a long term fixed investment which can have significant future impacts. First, the resources required to plan and implement an improvement constrain future choices. Secondly, the impacts of the facility on the pattern and volume of flows as well as its physical and social environment will occur over a long time period.
local veto power over major road improvements, the emergence of metropolitan planning organizations, and much existing federal legislation all require that transportation proposals be subject to a bargaining process. Presently, cities and counties negotiate with the Division of Highways about the roads to be added and deleted to the state system and the location and design of particular projects.

As a result of this bargaining process, rarely, if ever, will a particular interest have its preferences systematically reflected in decisions. In general, compromises will be sought and achieved. An agency charged with developing alternative investment plans must provide choices around which negotiations can occur. This multiplicity of objectives implies that, in general, no simple set of measures can describe how alternative investment plans affect differentially the various interests or objectives involved.

Many problems have arisen in transportation planning when the benefits and costs (including the environmental and social impacts) of proposed improvements do not fall on the same groups. A regional network may provide many benefits to groups throughout the region, yet a particular link may have serious adverse impacts on one municipality or neighborhood. A number of different metropolitan systems may evolve out of the negotiations at the corridor and route level when both regional and local interests are represented in the decision-making process. System plans should be careful not to overly constrain the "solutions" which are sought in corridor and route studies, but should prepare in advance
for different regional options.

Very often it is hard to elicit community reaction to system plans, especially those which will be implemented over a long time period. Those groups most impacted by the transportation facilities are often not the ones whom the project will primarily benefit, and hence, simple benefit-cost evaluations must be ruled out. By increasing local input to system plans and seeking that input continually over time, it will be easier to tailor those plans to community values, while at the same time making it less likely that later project decisions will be confronted with adverse local reaction.

The fifth major element in the decision-making environment, that must be explicitly addressed, is the need to recognize uncertainty. Because of the resource constraints, long lead times for implementing transportation improvements, and the need to reconcile and negotiate with different interest groups, a system plan is implemented over a long time period. Generally, a series of decisions are made over time on different components of a plan. Corridors may be identified in which improvements are deemed desirable, alignments for different modes proposed, designs then considered on each alignment, and so on.

Because system plans are implemented over a lengthy time period, the Division of Highways must plan improvements to the transportation system in a region that may undergo considerable changes during the period for which plans are initially developed. Community goals and planning objectives, transportation needs, and the impact of transportation facilities
on the environment all change over time and require new responses in the planning of transportation facilities.

Also, the rate and content of the changes that may occur in all these factors can never be predicted with absolute certainty. Thus, proposed improvements in the transportation system over time must be developed with an imperfect understanding of the future. Depending on the magnitude of the uncertainty present, a specific sequence of transportation improvements may not be well suited to the full range of changes that may occur over the current planning horizon. Plans should be adaptable to a wide range of "futures" if significant uncertainties exist.

Naturally, as parts of the plan progress from system planning to more detailed project development phases, some of the uncertainties are reduced as more information is obtained. This information may suggest continued study, revision of alternatives, or even cancellation of a particular project. New information for different planning levels must be continually coordinated and reflected in the revision of plans. Rarely will the set of alternatives developed as a catalyst for negotiations remain the same over time. Rather, new or revised alternatives will emerge as negotiations proceed, and an agency must be prepared to continually update its plans. Thus, the implementation of a series of improvements to a transportation system over time requires a skillful allocation of manpower to the various planning and project development
activities.

In summary, the process of developing an investment program for transportation is a complex task requiring explicit recognition of the effects of time, scarce resources, multiple objectives, and uncertainty. The following chapters will describe both the problems identified with the California Division of Highways' current investment planning process, and a staging approach which can address these issues more systematically than the Division of Highways' present process.
Chapter 2

SYSTEM PLANNING IN CALIFORNIA

Having discussed in the previous chapter, the nature of the decision-making environment in state system planning in general and the issues that must be addressed in making transportation investment plans, this chapter will describe in some detail the process and procedures used by the California Division of Highways to develop an investment program. The objective of this chapter is to identify the current procedures and the problems with this process before the proposed revised process is presented in Chapter 3.

To date, state transportation system planning in California has been concerned, almost exclusively, with road improvements. Until very recently, the planning, operation and financing of transit was left entirely to local governments (cities and counties)\(^1\). This chapter, then, will focus on the planning efforts of the California Division of Highways and the procedures used by the Division to develop and implement their investment program for improving the state highway system.

The discussion will begin with brief descriptions of the institutional framework within which highway planning occurs in California and the needs and allocation process by which the state trust fund monies are split up among regions and municipalities. The process of developing

\(^1\)In 1971 the State legislature passed a sales tax on gas to provide funds for mass transit. Originally these funds were going to be allocated directly to the local governments. At present, the legislature is considering a proposal to create a State Department of Transportation which would combine the planning for highways and transit in one state agency.
an investment program will then be examined.

The chapter will conclude with a discussion of the research findings and the problems with the present investment planning approach used by the California Division of Highways.

The information contained in this chapter was obtained from an extensive series of interviews conducted during the summer of 1971 in the State of California. People in the State Business and Transportation Agency, Department of Public Works, and Division of Highways were contacted as well as a number of individuals in local planning agencies and civic organizations. The majority of the interviews were with people in the Division of Highways headquarters in Sacramento, but a number of discussions were held with people in the Division's district offices and other planning agencies in San Francisco, Los Angeles, and San Diego.

2.1 INSTITUTIONAL FRAMEWORK

The structure of the organizations presently involved in state system planning in California are shown in Figure 2.1. The Secretary of the Business and Transportation Agency (BTA) and the Director of Public Works (DPW) are both appointed by the governor.

The BTA's involvement in transportation planning has generally been confined to advising the governor on policy matters. Within the DPW the major operating agency is The Division of Highways. Over the past few years, however, more and more of the decision-making authority has been placed directly in the DPW rather than in the Division of Highways.

The Division of Highways is restricted by legislation to plan and
FIGURE 2.1-INSTITUTIONAL STRUCTURE FOR HIGHWAY PLANNING IN CALIFORNIA
implement improvements to roads in the state highway system. Of the approximately 16,000 miles of roads (or proposed roads) in the state highway system about 13,000 miles are also in the legislatively defined Freeway and Expressway System. The Freeway and Expressway System was originally defined in 1959 and at that time, represented a network of limited access roads (including Interstate links) to be constructed by the mid 1970's. It appears very doubtful now that the Freeway and Expressway system master plan will ever be completed and certainly not on schedule.

Section 256 of the State Highway Code requires a review of the master plan every four years and provides the mechanism by which additions and deletions to the system can be proposed. To date, however, the 256 reports have not resulted in significant changes in the original system though the 1972 report may propose deletions of a number of coastal routes.

In the past few years there has been a growing tendency for legislators to sponsor bills adding and deleting routes from the state system. Relieving local communities of a financial burden is generally the purpose of the additions by legislators, while projects generating strong local opposition result in the deletions. Despite this trend, the concept of the state F&E system has not been seriously questioned by the Division of Highways.

The legislature provided resources for the highway program by establishing a State Highway Fund with revenues obtained for the most
part from gas taxes and motor vehicle fees. The funding structure is shown in Figure 2.\textsuperscript{1} At present California receives back about seventy cents in federal aid reimbursement (for Interstate program, etc.) for every dollar contributed to the federal highway trust fund.

The administration of the State Highway Fund is carried out by the California Highway Commission whose six members are appointed by the governor to staggered terms. The Highway Commission allocates the fund to the state highway budget for each fiscal year. Though the state highway budget is included in the governor's budget, the legislature and governor have no authority over the fund until present law is changed. The legislature has placed constraints on the allocation of monies and these will be discussed in the next section.

The actual operations of Division of Highways are carried out in eleven highway planning districts. At the district level there is contact between the Division and other local planning agencies also involved in transportation. At the Division's headquarters in Sacramento, the district plans are reviewed, checked for compatibility with policy and procedural guidelines and combined to form the State's highway plan. The Division headquarters also acts as support staff to the districts and, in conjunction with the DPW director's office and Highway Commission, develops policy and procedures to be used by the districts.

2.2 NEEDS AND ALLOCATION PROCESS

This section will describe how each district determines its highway

\textsuperscript{1}The data in Figure 2.2 was taken from McKinsey and Co. Strengthening Management Processes report prepared for California Division of Highways, November 1968.
FIGURE 2.2-FUNDING STRUCTURE FOR CALIFORNIA
STATE HIGHWAY FUND

figures in millions of dollars
(1968-69)
"needs" and how the Highway Fund monies are allocated to districts and municipalities.

2.2.1 Needs Process

The needs process is used by each district to determine which links in the state highway system should be candidates for improvement over the next ten year period. Section 188.8 of the State Highway Code requires that a needs study be conducted every four years.

Figure 2.3 shows the present process for calculating needs. Essentially needs studies combine state and local development goals, traffic forecasts, and level of service standards to identify the location and size of needed improvements. Each step of the process shown in the figure will be discussed in turn.

A. Local Development Goals

The 1962 Highway Act requires that states cooperate with local jurisdictions in the highway planning process. The so-called "3C" process (continuing, coordinated, and comprehensive) evolved out of this legislation and resulted, at least on paper, with the inclusion of local representation in highway planning. To date, however, local participation in California has been rather narrowly defined and does not appear to have resulted in a planning process that is sensitive to the needs of metropolitan regions.

During highway needs studies, the primary local contacts have been the city and county engineering staffs. In most cases, the Division of Highways provides the technical staff and services for these studies with the local engineers providing the data for the transportation modelling
FIGURE 2.3-HIGHWAY NEEDS PROCESS
package. In the past, local land use plans have been quantified to provide the necessary data. Presently, a land use model is being developed for both San Francisco and San Diego to provide better input and coordination with the transportation model system.¹

Many people within the Division recognize that local contact in planning has been restricted to a narrow group who tend to support the Division's position. The justification given for the present policy is that city councils and county supervisor are local "representatives" and they in turn rely on the judgement of their engineering staffs for advice on transportation. Hence, the Division feels it is appropriate to work most closely with these staffs.

There is presently some discussion within the Division of obtaining broader statements of local goals through the use of sub-regional studies. It appears that sub-regional studies may simply be used to further dis-aggregate land use plans to get traffic flows for smaller networks. If this is the case, they will in all probability result in no new community interaction.

The trend to more comprehensive regional planning agencies may cause a significant change in the Division's relationship with the metropolitan regions in the state. At present the Metropolitan Transportation Commission in the Bay Area must approve all transportation plans except highways of "overriding" statewide significance. Similarly the County Planning

¹The University of California and the Division are cooperating to develop the PLUM model for these two urban areas.
Organization in San Diego may play an increasingly important role in determining the direction of transportation plans in that region.

B. **Functional Classification**

Functional classification is an attempt to define the purpose of each segment of the road system. Each road is classified by location (rural, urban) and function (freeway, major arterial, collector, etc.). The legislature uses the classification system as a basis for dividing financial responsibility for different portions of the road system among the state, counties, and municipalities. To date, functional classification has resulted in only minor changes to the Freeway and Expressway system. Functional classification is done in conjunction with a study of proposed deletions and additions to the state highway system required every four years by Section 256 of the State Highway Code.

Present law requires that both the functional classification study and the 256 report be approved by city councils and county supervisors. As previously described, most of the local input has been provided solely by municipal engineers. For these studies the Division provides the technical staff while the local engineers review the proposed recommendations. The municipal engineers are most concerned with the financial burden that any changes in the classification of roads or links in the state system may place on the local jurisdiction. Hence, deletions to the state system are often difficult to negotiate and in many cases the state continues maintenance support even when deletions occur.

C. **Level of Service Standards**

For the function classifications included in the state highway system,
level of service standards are defined. These standards represent the minimum levels of service that the Division feels are tolerable on the highway system. The standards are specified in terms of the speeds on links (i.e. for urban freeways, 40 m.p.h., and for rural, 60 m.p.h.) and design features (lane width, radii of curvature, etc.). Though recognizing that these standards cannot always be met or maintained, particularly in urban areas, the Division still uses them in the calculation of needs.

D. Traffic Forecasts

After quantifying local land use plans for input data, the Division uses the standard Bureau of Public Roads program package for trip generation, attraction, assignment, and distribution.\(^1\) Generation rates are calculated independent of any level of service variables. The forecasts are made for a target year and assignments assume all links in the system are in place and providing the standard level of service. The trips are assigned to the minimum travel time path with no capacity constraint. In effect, travel desire lines are created and limited access facilities receive the majority of trips. Diversion formulas are used to distribute percentages of the assignment to the best city street route and the second best freeway route. This is an inherent bias of the package and tends to favor freeway travel, a fact that may be true, but is handled only as an ad hoc approximation.

The major assumptions of such a modelling package, therefore, are that 1) demand is independent of the supply of transportation; 2) the

the whole system will be in place at the target year; and 3) links actually provide the state standard level of service.

E. Identification of Deficiencies

Once a traffic analysis has been done, the Division identifies deficiencies in the existing state highway system. A deficient link is one not providing the standard level of service assigned to it by functional classification.

Deficiencies are grouped by the time period in which the projected demand will exceed the capacity of the existing facility. Deficiencies labeled "now" are roads currently providing less than the standard level of service. Ten year deficiencies are roads where, assuming the projected demand materializes, the level of service will drop below the standard within the next ten years. Now, ten, and twenty year deficiencies are identified.

For unconstructed links in the highway master plan, a deficiency is assumed when the projected demand for the "corridor" in question justifies construction of a facility whose magnitude would place the link (according to functional classification) into the state highway system.

F. Calculation of Needs

Once deficient links have been identified, needs can be calculated by estimating the cost of improving the facility so that the level of service standard is met. The magnitude of a need is taken as the cost to correct the deficiency in the year in which it occurs (now, ten, or twenty) and have it provide the required level of service for a period.
of twenty years. Escalation factors are used for ten and twenty year needs to account for inflation of costs.

A congestion-free twenty year life for new facilities is recognized by the Division as unrealistic and some routes are "deficient" soon after construction. Strict devotion to the twenty year design standard would indicate that numerous 15-25 lane freeways are "needed" in L.A. now. However, reported needs of this magnitude are reduced to a maximum of twelve lanes.

Revenue estimates do not enter the needs calculation and are used only when priorities among needs are determined. Thus the need categories bear no relationship to when a new facility might actually get built. Now, ten, and twenty year needs in fact far exceed even the most optimistic revenue estimates for these time periods. Presently now needs are reported as totaling $8.1 billion; ten year needs are $14.2 billion, and 20 year needs $17.1 billion. In the 1971-72 fiscal year $525 million, or about seven percent of the now needs, were budgeted for new highway construction.\(^1\)

2.2.2 Allocation of Funds

The User Tax Fund monies are allocated both to the State Highway Fund and to counties and cities. The legislature determines the proportion of funds to be given directly to cities and counties for the maintenance of local roads. These funds are allocated on the basis of miles

of road, population, etc.

While the California Highway Commission administers the State Highway Fund, the legislature has placed a number of constraints on the allocation of these funds. These constraints are in the form of a North-South split, district minimums, and county minimums. The North-South split divides the entire budget and allocates sixty percent of the funds to the districts in the Southern half of the state and forty percent to the districts in the Northern half.

Within the North and South regions, the district minimums require that 70% of the funds be allocated on the basis of the relative needs of each of the state's eleven districts as reported in the Section 188.8 Needs study. Hence, if San Francisco accounted for 50% of the total North's needs, then at least 35% of the North portion of the budget would have to go to District 4. The district minimums are calculated on a four year basis so a district receiving less than its relative needs one year will have to be over-compensated at some point to make the four year total correct.

County minimums require that each county receive four million dollars over a four year period. Money spent on interstate construction does not count toward county minimums.

Theoretically, the state has 30% of the North-South totals to allocate as it sees fit within those regions. In fact the county minimums often reduce that flexibility substantially. In rural districts the district minimum is often exceeded not because needs are of higher
priority but because the sum of county minimums may exceed the district minimum for that region. The result is that roads that would be left alone in the Bay Area or Los Angeles are being widened in rural Imperial County. The flexibility of the 30% funds is further reduced by the interstate funding scheme. To take advantage of the 90%-10%, federal-state, funding, the state has committed itself to completion of the Interstate routes by the mid 1970's.

2.3 DEVELOPMENT OF THE INVESTMENT PROGRAM

Once the needs and revenue estimate for each district has been made, each district must prioritize the needs list and select the projects to be funded over the current planning horizon. This section will describe the process used to assign priorities and develop an investment program.

The process for developing the investment program is shown in Figure 2.4. The major steps in this process will now be discussed.

2.3.1 Priority Lists

The first step in the development of the planning program involves reordering the district needs study to reflect priorities. The needs list contains all projects deemed necessary in the next 20 years and lists them in the period in which they will become deficient (now, 10, 20). The priority list ranks the projects costing more than one million dollars (estimated right-of-way and construction costs) and shows the relative importance of the needs. The list contains only capital improvement projects (new construction).

Initially, the priority list is developed without regard to
FIGURE 2.4-DEVELOPMENT OF PLANNING PROGRAM

- N/S split
- District & County min
- Interstate Funding

8-12 one year revenue estimates for capital improvements

State Inputs - county min.
- links of statewide importance

District Inputs
- Needs Study
- Safety Improvement
- Sub-Standard Design

Priority List (20 years)

Revised Priority List (20 years)

Program Guidelines

Planning Program (8-12 years)
- projects grouped in priority order

Multi Year Financial Plan

Multi Year Program Proposal

District details first year of MYFP

Budget Guidelines

State Highway Budget

District Budget Request

DPW = Dept. of Public Works
CHC = Cal. Highway Commission
constraints such as total revenue, county minimums, or local political preferences. This first list is generated in the districts by considering the benefits from increased capacity (decrease in congestion) and the user safety benefits afforded by each project. The capacity adequacy, delay, and safety indices are used as proxies for these benefits.

1) Safety Index

The safety index is an attempt to estimate the benefits from accident reduction resulting from an improvement. The index itself is the ratio of dollars saved (through prevented accidents) to the capital investment cost (construction plus right-of-way) of the improvement. The costs of accidents are calculated from statistical data on existing and projected accident rates for three accident types of varying severity. These rates depend on facility type (number and width of lanes, etc.) and average daily traffic. Dollar cost figures are assumed for each accident type on rural and urban roads and an average cost calculated over a 20 year life.

2) Capacity Adequacy Index

The capacity adequacy index is an attempt to measure the "quality" of service provided by a facility. The index is the ratio of the service volume capacity to the present peak hour volume. Service volumes are defined by state levels of service for each road in functional classification.

3) Delay Index

The delay index represents an attempt to measure the benefits from the time savings afforded the user from an improvement. The
travel time savings are estimated from average daily traffic, average speed, and the length of the road segment. Congestion is treated as follows. If the service volume (i.e. free flow volume) for a road is 85,000 vehicles per day and the average daily traffic 90,000 vehicles per day, then 85,000 vehicles are assumed to travel at the standard level of service (55 m.p.h. for a freeway) and 5,000 get "congested" and travel at congestion speed (20 m.p.h. for a freeway). Assuming a twenty year life and a value of three cents per vehicle minute, the time savings are divided by the capital cost to yield the delay index.

Projects are ranked by using the sum (or weighted sum in several districts) of these indices as a proxy for the benefits per dollar cost from the investment. The indices are not discounted and thus represent the ratio of the aggregate undiscounted benefits to undiscounted capital cost assuming the project is built today.

Once the projects have been ranked by the user benefit indices a revised priority list is developed to reflect the constraints on the district's program. Interstate routes are now given high priority as a result of the 90%-10% federal-state funding ratio and other routes of "statewide" importance are shifted upward on the list. The county minimums are considered and priorities may change to insure that each county within the district has the specified amount of funds being spent in it. Usually the county minimum causes priority changes only in rural counties where lower priority projects must be moved up in the list. In addition, the district engineer will be aware of a legislator's pet projects and
projects with strong community support or opposition. Therefore, the revised priority list will reflect to some extent the political climate within the district as interpreted by the district engineer and his staff.

Though other than user benefits are considered in developing revised priorities, the lack of an explicit evaluation process makes it difficult to determine which factors are considered and the relative importance assigned to them. The only priority criteria which are systematically documented are the user benefit indices and any "subjective" factors considered are difficult to identify. The underlying assumption in the priority process has been that since the user is financing the system through the trust fund, user benefits are an appropriate criterion. One measure of effectiveness that evolved from this assumption was lane miles constructed per support budget dollar (planning, design, etc.).

2.3.2 Planning Program

The planning program groups sets of projects from the revised priority list in the year in which construction is expected to commence. The time horizon for the planning program varies from eight to twelve years. The last year of the plan remains the same for four years and then it is pushed out another four years. The ordering of projects over time in the planning program is equivalent to the revised priority ordering (highest priority projects in the first year, etc.). The planning program contains almost exclusively now needs.

The planning program is based on capital improvement target figures for each year in the plan. The targets represent the Division's estimate
for the revenues that will be available for capital expenditure over the 
next 8 to 12 years. The first three years of the planning program include 
all construction projects costing over $100,000 with the subsequent years 
containing only projects costing over $500.00.

It is during the development of the planning program that revenue 
estimates first come to bear on investment decision-making. Previous to 
this, projects were identified and designed in the needs process as 
though unlimited funds existed (i.e. a twenty year design standard was 
applied to each project identified as deficient). In applying the budget 
constraint, the Division places from the top of the revised priority list, 
as many projects as resources permit in the first year of the planning 
program. Naturally, the first few years of the planning program contain 
many projects for which right-of-way acquisition or construction was 
initiated in an earlier program.

2.3.3 Multi-Year Program Proposal (MYPP)

Adding other expenditures to the planning program produces a Multi-
Year Program Proposal. This Multi-Year Program Proposal represents an 
estimate of the entire budget for the district for the next six years. 
They include the first six years of the planning program plus all other 
district programs, such as maintenance, overhead, etc. Figure 2.5 
shows the program structure for the Department of Public Works as developed 
recently for their newly implemented Planning, Programming, and Budgeting 
system. Program guidelines are sent from Division headquarters and con-
sist of six one-year revenue estimates. These estimates include the
Figure 2.5 - Highway Transportation Program Structure
capital expenditure targets used in the planning program and another target for the rest of the district programs. The program guidelines and capital expenditure targets are given to the districts at the same time as the development of the planning program (new construction) and MYPP (all programs including new construction) occur concurrently.

The 1971 Annual Highway Planning report issued by the Division estimates that the new highway construction sub-program will receive 76.9 percent of the money budgeted to the highway transportation program.

Though the MYPP's represent stages in the construction of the Freeway and Expressway system, they are not considered in terms of an overall strategy for completion of that system. Conditionality rarely enters the MYPP since the assumption that the whole system will get built has simplified the choice of projects. If one project is delayed (by local community opposition or cost over-run), it is shelved and a "buildable" inventory project replaces it. If the inventory of projects is low and projects in the MYPP run into trouble, the district is faced with the possibility of losing funds to another district. District 4, in particular the Bay Area, is faced with this problem as they find it harder and harder to get freeway agreements.

The decision to stage construction of a particular road (4 lanes now, 4 lanes later) is made jointly by the district urban planning, design, and right-of-way departments. The issue is generally not one of uncertainty in demand, cost, or community acceptance, but one of limited
capital. Unable to fund construction of the larger facility the question arises whether to provide right-of-way now for later expansion; i.e., sunk capital now versus higher right-of-way costs five years from now.

District 4 did consider the conditionality issue with the proposed southern crossing of San Francisco Bay. The results of an upcoming referendum to determine the fate of the proposed bridge is in considerable doubt so two MYPP's have been developed. One contains the bridge and the other does not. The projects funded during the next fiscal year will be routes that are common to both plans. Once the outcome of the referendum is known, the appropriate MYPP will be followed.

Chapter 4 will discuss the benefits of this approach and a more general approach to obtain flexibility in planning programs.

At the present time, the district has some flexibility to shift projects in the MYPP, though interstate and major state routes are less subject to variation in scheduling than the other projects. In the first four years of the MYPP, the ability to make changes in the project schedules is severely reduced due to project development lead times and the need to meet district and county minimums. By the time a project is within four years of construction, right-of-way acquisition has begun making delays extremely costly.

Split financing allows the construction costs to be budgeted over a three-year period though actual construction may take longer. The right-of-way and project development costs (design, planning, etc.) are allocated in earlier budgets but are accounted for in the total project cost.
2.3.4 Multi-Year Financial Plan (MYFP)

Division headquarters reviews and revises the district MYPP's to insure compatibility between districts and compliance with State guidelines. The MYPP's are then combined into a Multi-Year Financial Plan (MYFP) which is submitted to the State Highway Commission for approval. After approval by the Commission, revenue estimates for the first year of the MYFP are updated to reflect any changes that have occurred since program guidelines were issued. The revised estimates in the form of budget guidelines are sent to the districts where programs are changed to conform to the new revenue figures. The districts then submit budget requests for the next fiscal year. The State Highway Budget is submitted to the Highway Commission which authorizes expenditures for the year by program.

2.4 PLANNING, PROGRAMMING, AND BUDGETING SYSTEM

This section will trace the development of the Division's new management tool, the planning, and budgeting system (PPBS). Each phase of PPBS and the effect the system has had on the Division's operation will be described.

In 1968, a report by the management consulting firm\(^1\), identified the following problems with the Division's performance attributed to growing external constraints and uncertainty in revenues and the applications:

1) greater percentage of total effort in negotiations and rework
2) short notice juggling of projects with few available alternatives
3) potential development of a large and vulnerable fund surplus.

The report went on to suggest that the Division's response to deal with these problems should:

1) improve program flexibility
2) tighten and clarify the construction program decision process
3) emphasize performance measures and improvement.

To aid in achieving these goals, the study recommended the implementation of a formal information system, PPBS. In September 1969, the Division of Highways created a four member team and an advisory committee to work with the consultants to develop a PPB system. At this point in time, the work of the implementation team is nearly done. The planning and programming activities are now being performed within the PPBS framework and a sample program budget was submitted to the Highway Commission in August 1971 along with the old style line item budget. During the current year, only a program budget will be submitted and implementation of the PPB system will be completed at that time.

The PPB system represents an attempt by the Division to structure its activities and information requirements in a management system. The system encompasses the formal flow of communication between the planning, programming, and budgeting functions and has three major objectives.

1) to involve top management in the formation of alternatives
   (planning program, MYPP)
2) define the Division's activities in terms of purpose oriented
programs (improvements, maintenance, etc.)

3) improve and extend the Division's evaluation efforts.

The PPB system will be discussed in terms of the activities included in each phase, and their timing and documentation.

2.4.1 Planning

The planning phase is a continuous activity which includes the needs, functional classification, and urban transportation studies as well as the Division's coordination efforts with other state, regional, and local planning agencies. Every four years, functional classification and needs studies are conducted along with the Section 256 study proposing additions and deletions to the Freeway and Expressway system. The planning activities also include formulating the Division's operating policies and issuing program guidelines which determine both the appropriate program mix and the expected revenues for each program. The major output of the planning phase is the Annual Highway Planning Report which defines program objectivities, identifies links of statewide importance, and reports the estimated twenty year needs and ten year revenue totals.

2.4.2 Programming

This phase schedules resources to programs and determines the actual program mix over the next six years. Actually the planning program forms the heart of the multi-year program proposal by providing the six-year, new construction program to which other district program totals are added. Programming activities occur over a thirteen-month period and the multi-year financial plan is the final document from this phase. The MYFP
represents the aggregation of all district programs approved by the California Highway Commission.

The rationale behind the program format is that by grouping the various activities of the Division by purpose, an improved allocation of resources and evaluation of accomplishments can follow. This appears to be a reasonable assumption if sub-programs under each general purpose program (see Figure 2.5) are weighed against each other when funds are allocated. Obviously new operating policies or safety measures can only go so far in providing alternatives to new construction. What really is needed for better allocation is a transit sub-program, a zoning policy and land use control sub-program, and probably other programs like these with broader perspectives. Such considerations, however, are outside the Division's authority and in their absence, the existing program structure is a reasonable definition by purpose.¹

2.4.3 Budgeting

The budgeting phase further details the first year of the MYFP for authorization of funds by program. The documents include the budget guidelines and State Highway Budget. By the time that budgeting occurs all the critical tradeoffs and decisions on program mix have been made. The budgeting process is merely the formal assignment and approval of funds to specific projects. Some readjustment of district MYPP's may occur during budgeting due to changes in revenue estimates or project

¹Presently, both the Division and the State Legislature are reviewing the institutional structure for California's transportation agencies. As previously mentioned, a new department of transportation may be formed as a result of this review and provide more flexibility in terms defining a more comprehensive state transportation program.
development lead times since issuance of the program guidelines occur ten months prior to the authorization of the final State Highway Budget.

2.4.4 Effectiveness of PPBS

The full impact of the PPB System cannot be evaluated for at least one more year when the budgeting and evaluation portions of the system have been fully implemented. This section will describe preliminary reaction to PPBS at both the state and district level and what the system has accomplished to date.

The first objective of the system was to involve top management in the development of alternatives. By requiring extensive formal reviews and communication (through guidelines) PPBS has provided a mechanism to accomplish this objective. It remains to be seen whether, or how, greater involvement of top management effects the decisions made. It is interesting to note that the PPB System has been tailored so that the final decisions are made by the Director of Public Works rather than the final decisions itself. The review authority of the Highway Commission is also extended from yearly budget approval to review of planning reports and the MYFP.

Response to the new system has been varied at both state and district levels. At the state level, many people feel that PPBS does in fact structure the Division's activities and clarify responsibility. Very few people contacted, however, felt the system would significantly effect the decision-making process or lead to better resource allocation. There is widespread feeling that the success of PPBS depends critically
on the benefit measures developed and the evaluation process.

However, the difficulty in obtaining measures of this sort that are consistent, equitable and satisfying to all groups (i.e. measuring or evaluating many social and environmental impacts, for example) is viewed as a major stumbling block for an effective PPB System.

At the district level, response to PPBS has ranged from skepticism about its potential for better resource allocation to a feeling that it would have no effect at all on the district. Many felt the new system was a burden as it required more extensive reporting and a reorganization of existing reports to a program format. Since PPBS is aimed at helping top management, its diluted effect and lukewarm reception in the districts is not surprising. However, the effectiveness of the system will suffer if the districts do not perceive what their role in accomplishing these objectives should be.

The new system orients the Division's activities toward purpose programs and requires a continuous evaluation process. Since true alternatives to highway construction can't be considered by the Division at the present time, one can only hope that the program orientation and evaluation lead at least to the development of more alternatives within the new construction sub-program.

One criticism we have found of the present PPB System is that it separates to too great an extent the planning and programming phases. Planning decides what should be done given the Division's objectives. Programming decides what will be done given the revenues available. The result is needs statements unrelated to revenues and a master network
that may never get built. The function of planning should be tied more closely to a realistic estimate of what the Division can accomplish. The question of what should be done and what is feasible are not independent, as we shall discuss in following sections.

These problems with present PPB system and other research findings with respect to the Division's current investment planning process and procedures will now be discussed in more detail in the following section.

2.5 FINDINGS AND PROBLEMS WITH PRESENT PROGRAMMING PROCEDURES

The previous sections have described the current system planning process in California and placed the development of an investment program in the context of the institutional structure and needs and allocation process. Many of the limitations of the master planning approach are reflected in the Division's present planning and programming process. This section will discuss our research findings and an assessment of the problems with current investment planning practice. The next two chapters, 3 and 4, will then demonstrate how a time-staged strategic approach can be implemented in the California Division of Highways to address more directly and effectively the critical issues in investment decision-making.

The major findings of our research can be divided into five categories:
1. Lack of systematic treatment of multiple objectives
2. Lack of explicit consideration of uncertainty
3. Need to relate project designs due to budget constraints
4. Need to improve procedures for evaluating the timing of investments
5. Need to display choice issues and reflect community values in the planning program.

Each of these problems will be discussed in detail.

1. Lack of systematic treatment of multiple objectives

The first major finding is concerned with the incorporation of multiple objectives early in system planning. The California Division of Highways has clearly recognized the multi-objective nature of transportation planning by articulating as its goal "to provide highway facilities which in their location and design, as well as in their transportation functions, reflect and support the environmental values and community planning objectives of the areas for which they are proposed."¹

However, only user benefits and capital costs have been systematically reflected in priority and revised priority lists to date. While it is true that priorities may be revised due to local support or opposition, environmental effects, or any of a number of "subjective" factors, such concerns are not brought to bear on programming decisions in any consistent and rigorous manner.

In addition, it is often difficult to determine what factors were

considered in choosing a particular program, how the different objectives were weighed, and what alternatives were available. In Planning Programs and Priority Lists only the P.P.B.S. user benefit indices are reported for every project, implying that the one objective explicitly considered is increasing the direct benefits to the user.

At later stages of project development, however, the Division does explicitly recognize the other objectives of the planning process such as compatibility with community and environmental values. Community and Environmental Factor Unit (CEFU) reports and Environmental Impact Statements provide a wide range of information for project evaluations. There are opportunities to bring many of the same considerations into priority lists and program evaluations.

By delaying a systematic examination of all objectives until more detailed project studies, the Division loses the opportunity of screening out undesirable alternatives early in the process and of reserving detailed studies for projects with a fair chance of being implemented. In the past, costly delays have resulted when a recycle of project development activities was necessary to consider new options.

2. Lack of explicit consideration of uncertainty

The second major finding is the lack of consideration of uncertainty in a consistent manner in system planning decisions. The Division of Highways has reported that spiraling costs, new design standards, and the vigorous concern being voiced for environmental and community interests have made it increasingly difficult to develop and implement
multi-year investment programs.¹ Costly delays and interruptions have occurred in District planning programs, especially in the urban areas of the state.

When projects are delayed or dropped from further study, substitution projects or programs must often be developed on relatively short notice to meet district or county minimums. Such "rush orders" make it difficult to allocate funds and professional skills effectively, especially in smaller districts where large pools of talent are not available. Often substitution projects are low priority and selected mainly for their potential for quick implementation.

The Division does recognize some uncertainties in the planning environment and in a number of instances, contingencies have been developed in the planning program. One example of this approach was described earlier; District 4, the proposed Southern Crossing of San Francisco Bay, has two Multi-Year Financial Plans; one containing the bridge, the other omitting it. Projects funded during the first year were those common to both plans, and thus provided some flexibility for subsequent decisions.

However, an explicit and systematic approach to considering uncertainty as a guide in the development of alternative plans and programs has not occurred. In particular, there are a number of uncertainties

which can significantly affect the Division's ability to implement a long range construction program, most notably, funding, community acceptance and impacts:

a) Funding. There are two dimensions to uncertainty associated with funding. First, the total amount of funds available for highways in the future is somewhat uncertain and subject to rather sudden fluctuations. Recently the legislature diverted the truck transportation tax and stopped advance acquisition funds for right-of-way. Recognition of a wider role for the Division of Highways has led to trust fund monies being used for replacement housing and environmental impact studies and the trend toward broader applications will probably continue. In addition, as the interstate program winds down, new federal funding patterns can be expected. At both the federal and state level, pressure to open funds dedicated to highways for multi-modal purposes has increased and may lead to changes in the distribution of transportation funding.

The second aspect of the uncertainty associated with funding concerns the distribution of funds between Districts and among improvements proposed in different locations within each District. This distributional uncertainty results from the inability to predict either improvement schedules or the final design of improvements when planning programs are developed. Indeed there may often be no improvement, or no improvement the Division is allowed to fund in some locations where corridor studies occur.

b) Community Acceptance. A second major uncertainty facing highway plans in California is the Division's ability to negotiate route
location and design (freeway) agreements. Local veto power is not likely to disappear soon even with the emergence of regional agencies like the Metropolitan Transportation Commission in the Bay Area or the County Planning Organization in San Diego. Highway projects will continue to be conditional on the success of a bargaining process at both the local and regional levels.

Because the system planning in urban areas must be done in conjunction with metropolitan agencies and local governments over which the Division has limited control, very often plans cannot specify with any certainty the mode, scale, location, or timing of transportation improvements until negotiations are well underway.

The rescinding of freeway agreements in Newport Beach and Hawthorne underscores the significance of the uncertainty associated with community acceptance by demonstrating that even the necessary agreements signed by a transient political administration are not a guarantee of sustained local approval.

c) Impacts. Finally, the impacts of transportation facilities on emerging development patterns, the environment, and different interest groups are not well understood and cannot be predicted with certainty.

First, there is uncertainty associated with the types of impacts which will occur from a proposed improvement. Often a more thorough assessment of the likely impacts must wait until detailed study has commenced. Therefore, decisions must be agreed upon before a thorough list of potential impacts has been developed.
Secondly, there is uncertainty associated with the future magnitude of impacts. Thus, costs, demand for transportation, and land use patterns in the future must be predicted to assess transportation proposals, but such predictions have a range of uncertainty associated with them. The possible ranges of impacts that might occur can substantially alter the desirability of a particular plan.

3. Need to Relate Project Designs Due to the Budget Constraint

The third major finding is concerned with budget constraints and their relation to project designs. Presently the Division's planning and programming activities take place in a sequential fashion. Functional classification, traffic analyses, and needs studies define what the Division would like to accomplish on the State's Freeway and Expressway system. Programming then determines, in light of budget and other constraints, what the Division presently expects to do over the next 8-12 years.

Division policy dictates that a project in the needs list be designed to provide adequate service (in terms of speed and safety standards) for a twenty year period. Adequate service levels are defined for each road type (i.e., freeway, expressway, etc.) in functional classification studies. For design purposes, replacement is assumed to occur in the year in which the existing facility operates at capacity. The Division illustrates this policy in describing the P.P.B. system:

For example an existing 2-lane section will have needs of four lanes in 1975, six lanes in 1985, and eight lanes in 1995. To satisfy 20-year design policy
eight lanes would be constructed in 1975.\textsuperscript{1}

Thus, projects in the needs studies are designed independently as if unlimited funds were available. When the budget constraints are applied these projects are generally taken in order off the revised priority list. Such a process ignores the fact that a budget constraint creates a dependence between all projects in an investment program.\textsuperscript{2} The Division loses an opportunity to explore what may well be better allocations of funds for improvements given the constraint on resources.

Thus, the top priority projects in the current needs lists may be the most desirable investment given the Division had unlimited resources and could meet all the needs. However, if all the "needed" projects can't be built, then programming must determine whether it is more cost effective to build as many projects in priority order as the budget allows or to spread those funds among some other projects or project designs which in sum provide more benefits over time. This is an especially critical question if uncertainty is present and only one of a number of objectives (i.e., increasing user benefits) is systematically reflected in priority lists.

\textsuperscript{1}California Division of Highways, "Planning, Programming, and Budgeting System", March 1970.

\textsuperscript{2}For a more complete discussion of project dependencies caused by the budget constraint, see Marglin, Stephen, Public Investment Criteria, Cambridge: M.I.T. Press, 1967, pp. 69-71.
Whenever planning and programming are done in a sequential manner, there is a danger that planning will define a system which is unobtainable in a time period considered and that programs will be biased toward constructing as much of this "ideal" system as possible without examining the benefits from more intermediate improvements which can be completed in entirety over the programming period.


The fourth finding is related to the need to recognize the dependence between projects due to the budget constraint and concerns the need to be able to compare investments with different implementation schedules. The Division has already begun to recognize the implications of this problem.

The rising costs of freeways, individually and cumulatively have the effect of stretching construction scheduling and postponing projects for many years. In some instances, highway improvement cannot be deferred until the ultimate improvement can be financed and a lesser interim improvement, that would improve service much earlier, would yield a higher benefit. 1

Two aspects of the timing problem must be dealt with more explicitly. First, the benefits and costs for a project are presently calculated for the twenty year period following the year in which the volume on the existing facility reaches capacity. However, the year in which a project is first needed is not necessarily related to the year that construction is programmed since needs far exceed revenues. As mentioned

earlier, the benefits and costs of a project may vary significantly with the time of implementation and the Division of Highways should recognize this fact explicitly by testing the sensitivity of programming decisions to different project schedules.

Secondly, to compare different sequences of investment over time it must be recognized that benefits and costs accruing next year are usually not of equal "value" as those same benefits and costs today. This results from the fact that money today can be invested and the principal and interest earned on an investment can then be applied to a future cost. Thus, future benefits and costs should be discounted and, for those benefits and costs which are quantifiable, an explicit discount rate can be used to compare different sequences of investment.

The use of a discount rate by the Division of Highways would not imply that the agency was free to invest highway fund monies in anything other than road improvements. Rather, use of a discount rate would recognize that the money for public investments is taxed away from the citizens of California and that there is an "opportunity" cost (in the form of lost investment opportunities) to the taxpayer whenever money is diverted to the private sector.

Presently, the Division of Highways' programming procedures implicitly assume a discount rate of zero and attempt to maximize the aggregate benefits (as defined by the P.P.B.S. indices) in each year of the Planning Program, subject to the constraints imposed by the revised priority process. Such a process does not adequately reflect the value
associated with the timing of different investments and may not result in a sequence of investments which provides the best improvement possible over time. The losses associated with delaying an improvement must be compared with the gains associated with being able to spend those resources on other improvements in the interim. By not discounting future benefits and costs, there is an inevitable bias toward constructing the ultimate improvement initially. This bias occurs because the potential benefits from the large improvement realized over a long time period are considered of equal weight as benefits from smaller improvements which are realized much earlier, which is clearly not necessarily true.

The need to discount future benefits and costs has been widely recognized in economic literature\(^1\) and has been applied successfully for investment planning in a number of sectors of the economy.\(^2\) The Division of Highways should adopt an explicit discount rate in order to make better investment decisions. Use of a discount rate is consistent with current engineering practice and professional planners in other fields have recognized the need to account for the public's time preference for receiving benefits and costs.

It should be mentioned that the use of a discount rate addresses a different investment planning issue than the use of escalation rates presently used by the Division of Highways to account for inflation.

---

\(^1\)Marglin, Op. cit.

Escalation rates account for the fact that a dollar next year will buy less than a dollar today if the economy is inflationary. Discount rates account for the fact that a dollar today is valued more than a dollar next year (regardless of whether inflation is present). A dollar today can be invested and yield a return over the next year and thus there is an opportunity cost to the taxpayer who is not indifferent about when taxes are levied or when benefits from public investments are received.

5. Need to Display Issues and Reflect Community Values in Planning Programs

The final major finding of our research is related to community values and choice issues. Presently, the Division commits itself to one project design and one set of projects too early in the planning process. As a result, a large amount of flexibility to adapt to changes as they occur is lost by closing many options prematurely.

Generally, a number of different improvements are possible to solve in varying degrees the transportation "problem" in a given location. The final choice will involve the tradeoff of many objectives and cannot be predicted before more detailed corridor or project studies are well underway. As a result, a recycle of planning and project development activities is often needed to examine alternative improvements after work on the initial project studied has proceeded to a very detailed level. In large districts these delays are particularly disruptive due to the complex nature of the projects and the time required to examine alternative improvements.
In addition, when choices are not developed in the Planning Program, it is difficult for groups outside the Division to get a sense of the range of options available over time and to express initial preferences or reservations about the courses of action open to them. Yet encouraging such interaction is critical if the objectives of the planning process include enhancement and support of local community and environmental values.

These five major problems summarize the findings of our research efforts in California in the area of system planning and the development of planning programs. Other related problems and findings have been described in a related research report.\footnote{Pecknold, Mead, Neumann, et al., \textit{Transportation Systems Planning and Community and Environmental Values}, Op. cit.} The remaining sections of this thesis will focus on the development of a time-staging approach to system planning and its application to the California planning environment. Chapter 3 will describe the time-staged strategic approach in detail and compare it to the current master planning approach in use in California and most other planning agencies. Chapter 4 then presents a case study application of this approach to Santa Barbara's Crosstown Freeway project in District 5.
Chapter 3

A TIME-STAGED STRATEGIC APPROACH

To develop effective investment programs, the planning process must recognize the nature of the decision-making environment in which choices will be made. The previous chapter described the principle limitations of the planning process used by the Division of Highways in dealing with the issues of multiple objectives, uncertainty, the role of time in investment plans, and scarce resources. The purpose of this chapter will be to present an approach to planning which explicitly recognizes the dynamic nature of improving the transportation system for a region and the inherent uncertainties associated with large scale durable investments.

With the time-staging approach, rather than focusing attention on alternative networks to be in place by some target year, emphasis will be placed on developing alternative sequences of decisions on proposed improvements staged over time. Time-staging has significant advantages over the more traditional master plan approach when one or more of the following elements is present:

1) one agency or decision maker does not have the authority to specify one sequence of investments for each project and corridor; rather, choices must be negotiated over time.

2) detailed studies of each project are required before feasibility is assured, and such studies cannot be completed for all projects before initial decisions are made.
3) there are uncertain "events" which may significantly
effect the desirability or feasibility of transportation
improvements.

If an agency responsible for planning and implementing transportation
improvements is faced by some combination of these elements, then it is
appropriate and desirable to develop investment plans which explicitly
recognize the alternative choices and uncertainties present.

The chapter will describe how time-staged investment strategies
can be developed at three planning levels. The evaluation of staging
strategies will then be discussed and the major differences between the
staging and master plan approaches will be presented.

3.1 DEVELOPING STAGING STRATEGIES

Historically, most of transportation studies carried out in the
U.S. in the last 20 years or so have developed only a few candidate
systems for a future target year and then chosen one of these plans to
be implemented over the time horizon considered.¹ In taking this
approach, attention is restricted to relatively few target year pro-
posals and once a choice has been made, further studies consider only a
limited list of projects.

An alternative approach to planning is to consider the planning
period as consisting of a number of stages, and to examine the sequences

¹The urban transportation studies done as a result of the 1962 Federal
Highway Act focused almost exclusively on evaluating systems to be
implemented by some target year. Usually if alternative networks were
even evaluated there were only minor differences among them.
of decisions on improvements that can occur over this series of stages. For example, rather than looking only at alternative 20 year target networks, first divide the period into four five-year stages and then consider the different sequences of decisions which can be time-staged over the 20 year period.

By time-staging actions on facility improvements, emphasis is placed on what choices are available over the planning time horizon, and how decisions at each stage to implement particular improvements affect the range of choices available in future stages. The different sequences can explicitly recognize uncertainty in both the objectives for, and impacts of transportation investments by providing for a number of outcomes from negotiations or impact studies. Thus, choosing among different sequences of decisions on facility improvements provides more flexibility for revising actions and objectives at each stage.

Given a particular sequence of decisions, a number of horizon year systems could evolve depending on the choices made in future stages. Initially, no particular "end state" need be identified as a target system. This represents a significant departure from the concept embodied in California's State Highway System. The critical choices, in this case, are the first stage decisions which commit the agency to particular facility implementations or studies. Decisions in the succeeding stages will depend on the results of decisions in the present stage and on the information gathered in the interim. The end states which are possible would be composites of the different actions that could be taken over time on facility improvements throughout the region.
Figure 3.1 illustrates the staging approach to planning. With time-staging a range of alternative improvement sequences over time are traced out. Initial decisions recognize explicitly the choices left open in the future and the range of future systems that may evolve from later decisions. In contrast, the master plan approach examines a number of potential final systems, chooses one, and then schedules improvements to implement that end state by the target year. Chicago, Boston and all other urban areas that came under the 3-C requirement have followed this approach. California, in its adoption of a legislatively defined State Highway System in 1959, has also, at least implicitly, adopted this approach.

A more elaborate example will illustrate the difference between these 2 approaches more precisely and define the concepts involved in the application of the time-staged approach to decision-making. Consider the problem of providing increased capacity between three cities (labelled city 1, 2, and 3 in figure 3.2) over the next 15 years. To simplify the example, assume the lengths of links A, B, C are equal and the agency's budget allows for the construction of four lanes (between any 2 city pairs) in each five year period.

The agency, on the basis of demand predictions over the next 15 years, determines that what appears today to be the "best" system in 15 years is 4 additional lanes on each link. One can imagine a number of ways to implement this target year system. Two are shown in the figure. While building four lanes on each link sequentially might be the most efficient way to build one target system, there may be better sequences over time to implement that system, or even better systems if demand predictions happen to change.
FIGURE 3.1 - TIME-STAGED APPROACH TO SYSTEM PLANNING
\[ \Theta \text{ = DIFFERENT LEVELS AND PATTERNS OF DEMAND} \]

**FIGURE 3.2 - PROGRAMMING ADDITIONS TO CAPACITY ON THREE LINKS**
By prematurely focusing on one future system, an agency may lose some of its flexibility to revise plans in the future. If four lanes were built on A initially and later demand predictions suggested the need for only two on A and six lanes on B, the option to revise the system would have already been closed. Similarly, by anticipating the construction of four lanes on B in the second five year period, the option to shift some or all construction activity in the second period to C would have been foreclosed if the necessary route and design studies on C were not conducted during the first period.

In fact, one cannot ignore the uncertainty associated with the demand predictions. There are a large number of ways capacity could be increased over time and several alternative systems that could evolve by the target year. The diagram in figure 3.2 is an attempt to present these options by tracing out only a few of the sequences available to the agency. Each first stage decision leads to a range of choices available in the succeeding stages. However, as decisions are made, the number of choices and systems which can evolve during the specified period decrease due to both the budget and time constraints.

In most cases, the agency not only has the option of immediate actions, particular transportation system changes, but also of deferring implementation of an action in order to acquire more information about the problem. For example, if there is a great deal of uncertainty about demand, it might be more efficient in the long run to delay construction of a new system for a period in order to collect sufficient information to reduce this uncertainty.
The staging approach then develops different strategies which consist of a first stage decision leading to a range of choices in following stages. Decisions in future stages are conditional on the impacts of previous decisions and the information gathered in the interim.

One strategy would be to construct 4 lanes on A in the first stage leading to a range of possible second and third stage decisions which, in turn, would depend on revised demand predictions available in future periods. A strategy represents a first period decision followed by a series of conditional future decisions. In this case the conditionality is a revised estimate of the magnitude and pattern of future traffic volumes. By recognizing explicitly the uncertainty associated with demand, the agency can examine the desirability of different first period decisions based on the responses available to it given the different levels and patterns of demand which may develop in the future.

The staging approach generally will result in different decisions than a master planning approach, depending of course on the range of choices and uncertainties considered. Staging also allows for more flexibility in responding to change by making future decisions conditional and displaying what studies need to be done before the next stage decisions can be made. In California, the growing opposition to urban freeways and the need to satisfy requirements of increasingly more stringent environmental legislation suggests that such flexibility may be very important in future investment programs.

Obviously, there are many other possible sequences of decisions which are not traced out in figure 3.2, particularly the choice to delay funding all projects in a given stage. In general, there will be a number of uncertainties present and a wide range of different sequences
of decisions possible over the planning horizon. Clearly an agency could never expect to provide for all the possible contingencies in developing staging strategies. As Manheim notes:

First, there is generally a large number of combinations of actions and events. Second, the probabilities at each stage are different, because information is acquired at different stages, and the information depends upon which actions were taken at earlier stages. Third, society's values with respect to transportation may change over time. Fourth, and perhaps most significant, to evaluate the alternatives at any stage may require running a complex simulation model, such as the urban transportation package (or other network equilibrium prediction models).¹

While the resources available for planning will restrict the number of sequences and uncertainties which can be considered, attention need not be limited to one sequence over time. Staging strategies cannot represent a statement of everything that may occur in the future, but can represent what appears today to be the major choices facing the decision making process.

Research has been ongoing to develop practical techniques for treating transportation planning as a sequential decision process in the face of uncertainty.² However, there will always be a limit on the number of strategies an agency will be able to examine. Thus, judgements will have to be made as to which uncertainties are most significant and what range of transportation options should be studied.

¹Manheim, Marvin, et.al., op. cit.

In practice, if an agency is planning a large number of projects in each stage, many of which are related only by a budget constraint, a description of the alternative sequences of investments in terms of regional staging strategies would be unnecessary. Rather, strategies could be developed for different portions of the investment program and related via the budget constraint.

Thus, if an agency was planning to increase the circumferential mobility around two cities in different parts of the region, separate time-staged strategies could be developed to increase the transportation service around each city over a number of years. The actual improvements funded in each area would have to be related since delaying investments in one city would allow larger or more rapid improvements in the other.

Relating all of this specifically to the California context, there are three levels at which staging strategies for transportation facilities in a region might be developed.

1) Project level: in this case, strategies would trace out alternative ways to improve transportation service in a specific location or alignment over time. The basic choice would be on the scale and timing of improvements. For example, the choices might be to build two lanes now and two later; four lanes now; or four lanes later.\(^1\) Staging construction would allow

---

\(^1\) Winfrey was one of the first to recognize the benefits of staging, although he limited his analysis to single links and considered staging only once the alternative was to be built, i.e. he ignored network effects, the no-build option, and multi-period staging. See Winfrey, Robley "Cost Comparison of Four-Lane vs. Stage Construction on Interstate Highways." Bulletin, Highway Research Board, National Academy of Sciences, Vol. 306, pp. 64-80 (1961).
expansion if future demand levels are high or delaying if demand is low or improvements in other locations are more urgent.

2) Corridor level: a corridor will be defined as a sub-area of the region in which project stagings cannot be considered separately because of project interdependencies. Corridor strategies might consider a number of projects which differ in location and mode as well as scale and timing. The example cited previously would represent a corridor strategy where the scale and timing of improvements on one link might effect the pattern of demand and hence the desirability of improvements on the other two links.

3) Regional level: at this level, a staging strategy would trace out how resources might be shifted among all the investments proposed in region. The essential tradeoff at this level will be the allocation of funds to different corridors or projects based on the possible outcomes of studies and decisions made for staging strategies at these other levels. For example, given high demand in all corridors being studied in the region, large improvements could be funded in some areas with no improvement in others, or intermediate improvements might be funded in all corridors.

Thus a corridor strategy may include a number of project strategies and within a region, several "independent" corridor and project strategies may be developed. When particular projects or corridors are funded for study, any of a number of improvement sequences could develop since a staging strategy represents alternative decisions that may occur over time. At the regional level, all strategies will be related by
the budget constraint on transportation improvements.

Figure 3.3 illustrates the idea of a regional level strategy. In each corridor, A and B in a region, different strategies for improving transportation service could be studied separately. The alternatives implemented in one corridor will not effect the desirability of alternatives in the other, except in terms of restricting the resources available for improvements there. At the regional level, staging strategies trace out the combinations of improvements that can be funded over time in both corridors.

By considering a range of possible outcomes from the studies in each corridor, regional strategies recognize the budget dependencies between strategies in each corridor without initially restricting the range of solutions studied in either. If only small improvements are acceptable to the communities in corridor B, then more major improvements could be funded in A. Likewise, if communities in both corridors wanted major improvements, then a compromise would have to be achieved with either intermediate improvements funded in both areas or all but minor improvements delayed in one of the corridors.

The steps involved in developing strategies at the project, corridor, and regional levels are basically the same and differ mainly in detail. Each component of the process of developing staging strategies will be reviewed as a series of steps.

1. Choose a time horizon: Staging strategies have a time dimension which specifies how far out in the future tentative alternatives will be developed. In choosing a particular time horizon there is a tradeoff between the ability to postulate future uncertainties and conditional
FIGURE 3.3-REGIONAL STAGING STRATEGY
decisions versus the information gained from assessing the long range consequences of present decisions. Often the interest rate on capital is used as a guide in determining at which point in the future dollar benefits and costs are insignificant. However, if one is dealing with multiple objectives, all of which aren't representable in dollar terms, the determination of a time horizon is somewhat arbitrary.

2. Choosing Decision cycles: The implementation of transportation improvements proceeds over time in stages as resources are periodically committed to projects. The time horizon of these stages define the length of time that choices are constrained and when new choices can be made. Generally, the budget cycle defines one periodic decision point. However, with large capital projects requiring right of way acquisition and new construction, a decision to build will constrain choices over several budget cycles. For the time dimension of the stages in a decision strategy, we will want to use the period for which choices are effectively constrained which may be longer than a yearly budget cycle. In general, decisions committing resources to construction will be more constraining than decisions to initiate or continue studies.

3. Identification of Uncertainties: Over the time horizon specified the key events which may effect programming decisions at each stage must be identified. Naturally there is a limit to the number of conditionals which a staging strategy can consider and a choice must be made as to which events will have the most disruptive effect if their occurrence is not explicitly anticipated and a contingency considered.

4. Develop different sequences of improvement: The final step in developing staging strategies involves the tracing out over time the
different sequences of decisions and events which may occur. If demand is uncertain, a number of sequences of improvements could be considered, each hypothesizing a different level or pattern of demand in the future. Similarly, if revenues were uncertain, sequences assuming a variety of funding levels could be developed.¹ The sequences of improvement developed should display the essential choice issues present. Naturally, one could not postulate every possible sequence imaginable; but, rather, attention must be limited to some subset of the sequences of improvement which are each representative of some range of the uncertainties present.

3.2 EVALUATION OF STAGING STRATEGIES

Evaluation is the process in which the staging strategies developed are compared with each other with respect to the objectives of the planning process. The comparison is then used by the decision making process to choose what is felt to be the best strategy or to redefine objectives and develop new strategies. The evaluation process has three requirements:

1. Periodicity

The strategic approach explicitly requires a periodic evaluation and monitoring process. At each stage, commitment is made only to the implementations and studies for the next period, recognizing the range of future choices that these decisions leave open. As time goes on,

¹Pecknold, op. cit. showed the effects of different sequences and the benefits of staging strategies for the single link case for uncertainty in demand levels.
decisions on subsequent stages will be based on the events that have occurred and a reassessment of relative probabilities of future events and decisions. Naturally, in future periods new strategies might be added based on information obtained during the previous stage. If planning was continuous, the time horizon of the strategies considered would be extended by one period each time a decision point was reached.

It is important to remember that each strategy is capable of reaching a number of end states (or one end state a number of ways). By implementing the first stage of a strategy, one has not identified an "optimal" construction program over time but rather the first stage of a range of possible programs which depend on the uncertain events anticipated in the future. Choices between this range of possible future programs will be decided upon in future periods.

2. Consideration of the Long Range Consequences of Present Decisions

While we have stated why it is inappropriate to make long range decisions on investments for transportation systems, the use of staging strategies does not imply a short run myopic approach to investment planning. Though final decisions must be made only on first period choices, such decisions, as we have seen, foreclose certain systems from being implemented over the time horizon. Thus an evaluation process must compare the alternative investment sequences left open and foreclosed by each strategy. The best decision in the first period is the first stage of that strategy which encompasses the range of alternative investment sequences best suited to meeting the objectives of the transportation planning process over the entire time horizon. The best first period
decisions will depend greatly on the range of alternatives developed and the uncertainties considered.

3. Consideration of Multiple Objectives

The third element of evaluation involves the multiple and often conflicting objectives for transportation improvements which must be included in the evaluation of alternative investment programs. Any process used to evaluate staging strategies to determine the appropriate first period decisions must recognize the multi-objective nature of the problem in the criteria it uses to compare different strategies. Evaluation must then display for the decision-making process what the critical tradeoffs are.

For the economic efficiency objective it is possible to partially quantify the benefits and costs involved. Strategies could then be compared by weighing the different outcomes of future decisions by the probability of their occurrence.

For other objectives, particularly equity, the evaluation of staging strategies should display how different decisions will impact each interest group affected. As staging strategies are developed, tentative information may be available on how some groups are likely to be affected. As much information as is available should be explicitly displayed, both to identify information requirements for later studies and to give an estimate of the range of impacts implied by the choices contained in different strategies.

Before discussing a suggested approach to evaluation, a number of alternative methods will be discussed. These approaches are not collectively exhaustive nor mutually exclusive. They can be used in
parallel and sometimes have been used simultaneously.

3.2.1 Alternative Approaches to Evaluation

A. Multi-Objective Planning in Water Resources

A large amount of work has been done in developing methods of planning multi-objective water resource systems. The objectives of water resource projects are most often to increase the net economic efficiency benefits accruing to the region in which a project is proposed and to the nation as a whole. National and regional accounting schemes have been developed for efficiency benefits and costs which can consider in theory the value of system inputs and outputs, negative and positive externalities, and the use of previously unemployed resources or creation of unemployed resources. Different investment programs are compared with respect to the net present value of benefits they yield to the nation and region. Then by weighing the value of national versus regional benefits, the decision maker can make a choice among programs.

For the water resource problem, then, the multi-objectives considered are generally quantifiable in dollar terms and a great deal of work has gone into developing schemes to measure the benefits and costs generated. In one case, the multi-objective approach has been used for an objective non-quantifiable in dollar terms.\(^1\)

\(^1\) In one study 'environmental quality' (measured in terms of acres of natural area preserved) was traded off with national income benefits. See Major, David C. "Multiple Objective Redesign of the Big Walnut Project" Water Resources Council - M.I.T. Cooperative Agreement, WRC - 69 - 3. April, 1970.
The ability to simulate water resource systems and formulate measurable objectives have aided in making the applications of multi-objective investment planning much more sophisticated in water resources than in other areas of the public sector.

B. Decision Analysis

A second approach to the evaluation of staging strategies is to use what has come to be known popularly as decision analysis. This approach is essentially the same as the staging decision tree approach described earlier. In theory, decision analysis is capable of handling multi-objectives and determining the best strategy given the decision makers' preferences between objectives.

The approach is to develop objectives and measures of effectiveness for each objective which we will refer to as evaluation criteria. While each criterion must be measurable there is no requirement that they be of commensurate units, hence dollars of cost, households displaced, and a scale of environmental quality from 0 to 10 could be included.

Associated with each possible action in the decision tree is a level for each criterion which describes the effect of that action with respect to each of the objectives. For the staging strategies depicted in figure 3.2, the actions were additions to the capacity of the three links. Each action had to be assessed in terms of its ability to provide transportation service in light of the uncertain demand levels which might occur in the future. Different actions would be considered given an estimate of the future demand level.

The preferences of the decision maker for combinations of the criteria at different levels are then encoded in a utility function.
A utility function is merely a scale on which the preference among alternative actions are measured in terms of the evaluation criteria. A utility function is the subjective preference of the decision maker for tradeoffs between evaluation criteria. Thus a project costing $100 and dislocating 3 families may be preferable to one costing $50 but dislocating 5 families. Naturally each criterion may have a time preference associated with it so ten dollars of cost today may not be of equal "utility" as ten dollars of cost next year. Hence there may be a discount rate associated with each criterion to express its change in worth to the decision maker over time.

If actions do not result deterministically in one performance level of evaluation criteria, then there are probabilities associated with the impacts of an action. These probabilities along with the probabilities of events which are independent of actions taken will be assessed as the information in the decision tree is collapsed over time to yield the best first period decision. This approach will be illustrated for the economic efficiency criterion in the following chapter.

The use of decision analysis to evaluate transportation investments has been treated in theory for single objectives\(^1\) and a few real world applications of the multi-objective approach have been tried to date.\(^2\)

---

\(^1\)Pecknold, op. cit.

C. Proposed Approach to Evaluating Staging Strategies

While in theory the type of evaluation required by a decision analysis approach will be implicit in any choice of first period stages the usefulness of a complete decision analysis approach depends greatly on the objectives of the planning process, the existence of appropriate evaluation criteria, the decision makers involved, and the decision making environment. As a result the evaluation process proposed in this thesis is less ambitious and more pragmatic than decision analysis. Before describing the proposed process we will discuss why the standard decision analysis approach was felt to be inappropriate.

First, the objectives of many transportation plans do not lend themselves to quantification. While scales or numerical proxies might be fabricated for almost any conceivable objective, the role of evaluation is to inform the decision makers of the critical and difficult choices involved and not to oversimplify these tradeoffs. If equity is considered, a decision maker must know not just the preference rankings of each group but how the alternatives affect them differentially. Secondly, if one agency does not have the authority to make final decisions, it is not appropriate to base evaluations on their subjectivite preference alone. In many instances, there are many parties to the final choices among transportation options. Conflicting values and goals will almost always be present and while in theory it is convenient to speak of a social welfare function (i.e. group utility function) operationally it would be impossible to obtain or use.

The above problems are compounded if the decision-making environment requires an open, understandable and communicative process. If a
continuous planning process must make a number of decisions on different projects in every period, each requiring a large amount of interaction and negotiation with various agencies and the general public then an evaluation process must be credible and understandable to each party involved.

In addition when choosing an evaluation process one must weigh the expertise and resources required for evaluation against the information it brings to the decision making process. At this point in time, this consideration alone might weigh heavily against a multi-objective decision analysis approach.

In light of the difficulties of using a decision analysis, the approach we propose for the evaluation of staging strategies hopefully can address the multiple and conflicting objectives involved in transportation planning and at the same time handle some of the dynamic aspects of investment programming.

We do propose, however, that the economic efficiency benefits and cost be evaluated using the technique of decision analysis. Many efficiency benefits and costs are in part quantifiable and have a common metric (dollars). One objective of programming ought to be the maximization of the expected net present value of efficiency benefits. This implies only that given two strategies which were neutral with respect to all other objectives the one offering higher expected net efficiency benefits would be a desirable choice. This does not imply that maximizing efficiency benefits is an appropriate decision rule given two strategies which were not neutral with respect to other objectives. It simply means that a comparison between strategies on efficiency criteria is desirable input to the decision making process.
By efficiency benefits we mean:
1) willingness to pay for system outputs. This is essentially user benefits and any increase in a region's economic activity due to increased transportation service.
2) willingness to pay for positive externalities. Giving access to a developers' land raises the value of that land and should be included.
3) utilization of unemployed resources.

By efficiency costs we mean:
1) cost of system inputs (i.e. planning, right of way, construction costs)
2) negative externalities - the cost of replacement housing, mitigating the effects of noise, etc. must be included.
3) creation of unemployed resources.

Naturally it is well known that many of the efficiency benefits and costs as we have described them are not easily quantified with a dollar amount. It is difficult to put a cost on air pollution or community disruption as well as benefits from regional economic growth. To date many transportation agencies have only considered average user benefits and capital costs. We are suggesting that all the efficiency benefits and costs that can be ascribed a dollar figure should be included in the decision analysis. Those categories which can be identified but not given a meaningful dollar value must be considered with the other objectives. By meaningful we imply a figure which all parties to the decision making process can agree on.

For the other objectives the evaluation process will want to do
basically the same things that is done in an analytic fashion with the efficiency objective,

1) **equity**: evaluation should identify who the users of the system most likely will be (thru traffic versus local, etc.) In addition it must identify over time how each program will affect user and non user groups. For the externalities considered in the efficiency objective a dollar cost from replacement housing was valued equal to a dollar construction cost. For the equity objective, the question of the income transfers implied by different programs must be addressed and hence the incidence of impacts on different groups and regions must be displayed by the evaluation process.

2) **Community Acceptance and Environmental Quality**

These objectives can be handled in a number of ways. One method already mentioned is to consider community acceptance and environmental quality as conditionalities in the staging strategies. That is, any benefit from a particular project is conditional on that project being acceptable to the communities it goes through and satisfying the intent of federal environmental policy.

Secondly, by encouraging participation from all interest groups in the development of transportation plans and programs and in the decision-making process one might screen out many unacceptable projects before programming strategies were developed.

The objectives as stated overlap and conflict. If the equity objective is met fully it may go a long way toward achieving community acceptability. The most "efficient" strategy may have undesirable
environmental effects requiring a tradeoff and compromise between objectives. The task of evaluation is to assess each strategy against each objective.

In addition the sensitivity of these assessments to the estimated probabilities in the strategy should be examined. If the desirability of a strategy with respect to an objective changes with a small change in the probability estimate, one would be wary of choosing the first stage of that strategy. Another value of such sensitivity analysis is that it might imply when a particular alternative program should be dropped from a strategy. That is if the probability of community acceptance for a project fell below 50% it might not be worth pursuing further, if there were many other alternative uses for funds with a high probability of acceptance.

The actual decision on what strategy to follow in the first period would have to result from a compromise between objectives. Since the first period decision will constrain future choices, one course of action could be to follow the most flexible strategy (i.e. the one leaving the widest range of choices open to future decisions). Alternatively one might want to maximize efficiency benefits subject to the constraints on equity, community acceptance, and environmental quality.

3.3 SUMMARY: A COMPARISON OF THE TIME STAGING AND THE MASTER PLAN APPROACHES

This chapter has described a time-staging approach to system planning which is substantially different both in concept and in application from the more traditional master plan approach. In this section, we will
attempt to summarize the key differences between the two approaches.

First, the master plan considers alternative plans as much as 20 to 30 years into the future and predicts the most likely or most desirable state of the region at that time and its corresponding transportation requirements. One end state is chosen and all elements of that plan over the interim 20 years are determined. Note that the end state is chosen independently of the possible sequences of investments required to proceed over time toward implementation of the target network. Often only future demand and cost predictions are examined in choosing a master plan, and estimates of the community and environmental impacts of the proposal are ignored completely. Ultimately, however, these impacts will determine to a large extent the desirability of any system.

In contrast, an approach has been described which considers a range of possible sequences of improvements based on the uncertainties present and choice issues to be resolved. Different sequences of decisions which may evolve toward a number of end states are then developed in terms of staging strategies. The strategic approach does not choose the best end state and then choose a sequence of implementations to reach it over time. Rather, the first stage of the best strategy is chosen and that strategy may lead to a number of sequences and end states.

Naturally both the master plan and conditional decision plan can be altered in future periods in response to changes. Neither irrevocably commits a region to one sequence of implementations over time. The two essential differences between the approaches are how initial decisions are made and the flexibility provided to revise the plan over time. Initial decisions with the master plan aim at one target year system. While
the master plan can be revised, many alternatives are foreclosed prematurely by focusing on one target network. The time-staged approach considers uncertainty and a number of improvement sequences over time when initial decisions are made. By anticipating the changes which may occur and a range of the choices available in the future, staging explicitly requires periodic evaluations and revisions.

The advantages of the master plan approach can be summarized as follows:

1) The master plan attempts to fix a network in the future. Very often communities want long range plans specified so that other planning and development efforts can be coordinated more easily with transportation plans. Also individuals want to know if transportation plans will affect their homes or businesses. A master plan may minimize the number of people who must live with the possibility that a proposed facility will take their property or affect them in some tangible way.

2) The master plan often represents merely a statement of desire, with little or no potential for complete implementation. As such, it is often relatively easy to obtain political endorsement for such plans. Such endorsement is not a commitment to action and often doesn't require examination of what can reasonable be expected to be accomplished.

3) Once an end state is chosen, subsequent studies need only consider a limited number of alternative improvements (i.e., links in the target network).

The disadvantages of the master plan approach, which severely limit
its usefulness today are:

1) The master plan ignores the dynamic nature of planning and the fact that desirable end states are not independent of the sequence of improvements chosen to implement them over time.

2) Uncertainty is not explicitly considered. Initial decisions often assume completion of the master plan and are partially justified by that assumption. The impacts of changes which may alter the desirability or feasibility of the end state are not considered.

3) The alternative improvements considered are constrained to one list of investments. Thus, a wide range of alternative improvements and sequences of improvements are not kept open or opened early enough to respond effectively to change.

4) Once a master plan is developed an agency often develops a psychological commitment to the plan and begins to interpret as its mission the implementation of that specific plan rather than a continual search for imaginative solutions to transportation problems.

In contrast, we have described a time-staging approach which recognizes the dynamic nature of transportation planning. The advantages of this approach are:

1) By explicitly considering uncertainty and anticipating changes, time-staging allows decisions to be made in light of the choices they leave open and foreclose in the future.

2) Staging strategies develop alternative sequences of improvements and do not choose one "best" end state or sequence. At each
stage choices are provided and the plan has more flexibility to respond to change. Thus staging allows for a more effective allocation of planning resources and provides better alternatives when changes occur.

3) Another consequence of leaving choices open is that staging requires periodic re-evaluation and the agency does not become committed to implementing one "system".

4) Staging strategies allow the major choice issues to be represented over time, enhancing the chances for dealing with both short and long run decisions in an interactive planning process.

The major disadvantages of the staging approach may limit the extent to which it is applied, but in our opinion, they do not outweigh the potential benefits from utilizing the staging concepts. These disadvantages should be recognized, however, and are the following:

1) There are a large number of potential alternatives and uncertainties and hence to be operational, one must limit alternatives to a representative sub-set which illustrates the important choices and which considers the most significant uncertainties present.

2) The strategic approach requires more resources for planning and evaluation in order to obtain the desired flexibility. In particular, it may be difficult to collapse information over time to identify the best strategy in light of the multiple objectives present.

3) Some communities may not like to be forced to live with uncertainty. It is desirable to display the uncertainties
present and choices available, but if a community opts for a fixed plan over time, staging strategies may only be useful in showing the costs of such a choice in terms of lost flexibility.

4) Though alternative sequences of improvements can highlight the choices facing a region, there are difficult display and communication problems with the strategic approach if very many alternatives, uncertainties, or planning periods are considered. With this discussion of the time-staging approach, the following chapter will illustrate the time-staged approach in an example based on the Santa Barbara Crosstown Freeway project in District 5.
Chapter 4

APPLICATION OF THE TIME-STAGED STRATEGIC APPROACH TO CALIFORNIA

This chapter will present an example of the time-staging approach with actual projects included in the Division of Highways' investment program. The example will be followed by the recommendations made to Division of Highways for improving their investment planning process.

4.1 EXAMPLE OF THE STAGING APPROACH APPLIED IN CALIFORNIA

4.1.1 Introduction

In order to illustrate the basic concepts involved in time-staged decision making presented in the previous section, some time was spent in California gathering the information needed to generate a staging example based on projects actually being considered in the State's planning program. The focal point for this example is the Crosstown Freeway project in the city of Santa Barbara.

The Division's experience with the Crosstown project highlights many of the limitations of the present process for developing an investment program which the staging concepts can help to address more directly. The example considers the issues involved in the management of both monetary and manpower resources at two levels of the planning process:

1. The Corridor Level: At the corridor level the focus will be on how the transportation service into and through the downtown section of
Santa Barbara could be improved. The proposed Crosstown Freeway and its alternatives will be considered with particular attention given to how the Division could explicitly consider the uncertainty on the outcome of negotiations with the city and stage decisions on different sequences of improvement over time for the Santa Barbara corridor.

2. District Level: At this level, the emphasis will be on relating the improvements planned for the Santa Barbara corridor to the rest of District 5's Planning Program. The emphasis in this case will be on how resources should be allocated to projects in light of the ongoing negotiations with the city of Santa Barbara.

To illustrate the application of the staging concepts, three examples will be presented using the corridor and district levels. The first example will focus in detail on the corridor level, and the second will deal primarily with the district level. A third example will then be used to more thoroughly integrate the issues which must be addressed at each level and describe a more realistic application of staging to the Crosstown project. Data from reports issued by the Division have been used to the extent possible. However, it is to be emphasized at this point that a number of assumptions had to be made in developing the examples and the results are meant more to be illustrative of the application of the staging ideas, rather than a recommendation for specific transportation improvements in the Santa Barbara area.

The fact that the Crosstown project has been controversial and well publicized offers both advantages and disadvantages as an example for the staging ideas. On the one hand, because it is a well-known project, many people in the Division of Highways are familiar with the Crosstown Freeway and recognize many of the problems that this example proposes to address.
On the other hand, there is a danger that the results of the example may be interpreted as having very limited applicability because of some of the unique characteristics of the Santa Barbara case.

The example will identify what appear to be the unique features of the Santa Barbara project while at the same time generalizing those results which apply to a much wider range of problems facing the Division's planning process in all Districts. A later section will discuss particular examples in other Districts which might be appropriate for the application of time-staged decision making.

The information used to generate this example was obtained for the most part from interviews with various people in Sacramento in CEFU, Project Studies, Urban Planning, and Programs and Evaluation. In addition, numerous project reports, impact studies, planning programs, and memoranda relating to the project were reviewed. Unfortunately, the development of the case study came too late in the research effort for us to have any extensive contact with the people currently closest to the project in District 5.

4.1.2 Description of Santa Barbara Project

A. Project Background:

The Crosstown Freeway project in the city of Santa Barbara has been concerned with improving the transportation service into and through the City. In particular, the proposed Crosstown Freeway will upgrade the existing four lane downtown section of State Route 101 to freeway standards. Presently the downtown section has four signalized intersections and is one of the few remaining segments of Route 101
which is not at freeway or expressway standards.

Santa Barbara, a scenic coastal city, has traditionally placed a high value on aesthetics. The existing alignment of Route 101 forms a border between the beach and recreational area and the main business district. Figure 4.1 shows a map of the area and the location of alternatives for the Crosstown Freeway and for two of the proposed by-pass routes. During the past seventeen years the controversy surrounding the Crosstown project has been focused principally on the design and location of the freeway. While many different interest groups within the City have felt some improvements are desirable, a number of non-freeway alternatives have been proposed and recently a group of citizens opposing any further improvements on the downtown highway system has emerged. Over the years the City Council has steadfastly refused to accept a facility design felt to be detrimental to the City's visual and recreational assets. What began in 1954 as a one mile project with cost estimates around 10 million dollars is presently a 2.7 mile project with cost estimates ranging from 38 to 55 million dollars.¹

For the most part, the City has favored either a completely depressed freeway or a partially depressed, landscaped alternative. At first, the Division opposed all depressed alternatives because of their high

¹The length of project increased when new designs or route locations were proposed which involved longer segments of the downtown section of Route 101 than the Division of Highways originally proposed for improvements. Inflation, new design standards, and the increased length of the project were the primary factors contributing to the increase in cost.
cost and proposed a viaduct design and a number of at-grade alternatives. Subsequently, a ground water study concluded that a depressed freeway on the existing alignment was unacceptable based on envirnomental grounds. As each impasse was reached, new alternatives were studied and compromises sought.

Early in 1972, the Division and the City Council agreed on a route location on the existing alignment combining an at-grade freeway alternative and the Southern Pacific Railroad tracks on one right of way. A freeway agreement must still be signed and at this writing, it remains unclear whether or not the controversy surrounding the Crosstown project will be resolved in the near future.

As a result of the difficulty with developing an acceptable improvement for the Santa Barbara corridor, the District 5 planning program has experienced a large amount of project schedule slippage and reordering of project priorities. Since 1965, the anticipated start of construction for the Crosstown project has been pushed back six times and forward once. Figure 4.2 shows these slippages and the resources programmed for the project during this period. The 1972 Planning Program shows a construction start for the Santa Barbara project in the 1978-79 fiscal year.

Such fluctuations in Planning Program schedules has made it difficult for the District to effectively allocate its resources. The Crosstown project represents a large part of the southern half of district 5's budget. When the project was continually postponed, augmentation projects had to be found so that both the District 5 and the Santa Barbara County minimums could be met. Over the years, it has become more and more difficult to find interim projects to substitute for the Crosstown freeway. Some of these interim projects, advanced for early right-of-way acquisition
<table>
<thead>
<tr>
<th>YEAR</th>
<th>67-68</th>
<th>68-69</th>
<th>69-70</th>
<th>70-71</th>
<th>71-72</th>
<th>72-73</th>
<th>73-74</th>
<th>74-75</th>
<th>75-76</th>
<th>76-77</th>
<th>77-78</th>
<th>78-79</th>
<th>79-80</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965</td>
<td>*350</td>
<td>1000</td>
<td>200</td>
<td>50</td>
<td>8300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1966</td>
<td>100</td>
<td>1000</td>
<td>450</td>
<td>50</td>
<td>8300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1967</td>
<td>800</td>
<td>600</td>
<td>200</td>
<td>110</td>
<td>50</td>
<td>3600</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1968</td>
<td>1800</td>
<td>3980</td>
<td>4330</td>
<td>2840</td>
<td></td>
<td>8920</td>
<td>2500</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1969</td>
<td></td>
<td>2300</td>
<td>2200</td>
<td>3600</td>
<td>3225</td>
<td></td>
<td>120</td>
<td>3500</td>
<td>4550</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1970</td>
<td></td>
<td>2600</td>
<td>3300</td>
<td>3015</td>
<td>2865</td>
<td></td>
<td>120</td>
<td>1500</td>
<td>5200</td>
<td>6995</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1971</td>
<td></td>
<td>5870</td>
<td>6330</td>
<td>8845</td>
<td></td>
<td></td>
<td>6200</td>
<td>8425</td>
<td>9525</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1972</td>
<td></td>
<td>1200</td>
<td>5300</td>
<td>6000</td>
<td>6671</td>
<td></td>
<td>2000</td>
<td>240</td>
<td>10,200</td>
<td>12,980</td>
<td>8740</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* R/W CONSTR. IN 1000'S OF DOLLARS

PROJECT LIMITS
1965-1967 FROM POST MILE 13.0 TO POST MILE 14.0
1968-1970 " " 13.0 " " 14.8
1971-1972 " " 12.2 " " 14.8

FIGURE 4.2 - ALLOCATION OF FUNDS TO CROSSTOWN PROJECT IN PLANNING PROGRAM (1965 - 1972)
and construction, have also run into delays and controversy during the necessary negotiations with the communities involved.¹ Many of the substitute projects are of relatively low priority and are only funded to meet the legislated minimums.

The Division of Highways headquarters requested that two planning programs be submitted for the 1972 Multi-Year Financial Plan. One program was to assume the Crosstown project would continue to be delayed and the other was to be based on the Crosstown being built. The District reported in its 1972 Multi-Year Program Proposal that, because many of the projects that might serve as substitutes for the Crosstown had not been fully tested for local consensus, it was difficult to develop a dual planning program beyond the third year. After the third year, it was felt that a substitution list would have to assume one of the many forms that local acceptance might take.

One additional problem in District 5 is that effective allocation of manpower resources has suffered as a result of the delays to the Crosstown project. When a project is pushed ahead and scheduled for early right-of-way acquisition the Right-of-Way Department must shift people to this new project and rush to meet a new deadline. Because District 5 is a relatively small district it does not have a great deal of flexibility

¹ A proposed upgrading of a rural section of Route 1 in Santa Barbara County (project #88 in the 1972 District 5 Planning Program) came under attack by environmental groups after it's scheduling was pushed forward to serve as a substitution project for the Crosstown. In 1968, no funds were scheduled for this project until after 1977-78. In 1969, it was pushed up with funding to begin in 1971-72. Presently, construction for project #88 is to begin in 1976-77.
in reassigning personnel and moving projects ahead on short notice.

The following section summarizes the Division of Highways' experience with the Crosstown project and outlines the events leading up to the project's current status.

B. Historical Summary

1954 Original studies were begun to upgrade the existing expressway to full freeway standards initially on a four lane basis with provision for an ultimate six lane facility.

October, 1959 Project report was submitted proposing twin viaducts for the Crosstown Freeway.

December, 1960 A public hearing on the proposed project was held by the Division culminating several years of study and numerous meetings with city officials, the Chamber of Commerce, and citizen groups. Four alternatives, all along the existing alignment, were discussed: an at-grade facility with cross streets over the freeway; an at-grade facility with cross streets under the freeway; the viaduct; and a depressed freeway.

March, 1961 The City Council endorsed a report from the Architectural Board of Review's State Division of Highways Committee which recommended an elevated freeway. Members of the board were appointed by the mayor.

February, 1962 The Citizens Crosstown Freeway Committee notified the California Highway Commission that they favored a depressed freeway.
February, 1962  The City Council held a hearing to consider a freeway agreement for the Division's proposed elevated alternative. No vote was taken and the Council asked that the Division study in detail a plan presented by Clark Sargeant for a landscaped, covered, depressed road.

August, 1962  The City Council continued its consideration of the Crosstown project indefinitely to allow the Division time for further study.

September, 1962  The City Planning Commission endorsed the Sargeant plan in principle and disapproved of the elevated freeway.

July, 1964  The City Council adopted the Eisner General Plan which favored a depressed freeway and passed a motion opposing an elevated freeway.

June, 1965  The Division of Highways presented a summary of the studies to date to the City Council and the public. Three basic alternatives were discussed in detail; the elevated plan, the depressed plan, and the covered depressed plan. The Council was presented with a freeway agreement on the basis of the elevated plan.

September, 1965  A motion to execute the freeway agreement was defeated by City Council by a 5-2 vote.

November, 1965  A motion to execute the freeway agreement was defeated by a 4-2 vote. The Council requested the Division to reconsider its findings and submit a freeway plan consistent
with General Plan.

August, 1967 The City Council requested that the Division investigate a parkway concept for the Crosstown Freeway with provision for 8 lanes.

December, 1967 The Division submitted a report comparing the original viaduct plan with 5 "parkway" plans. Division approved of the parkway concept and allocated $800,000 for right-of-way acquisition in the 1968-69 fiscal year budget.

October, 1968 The City Council approved and authorized a special freeway plan study by the consulting firm of Daniel, Mann, Johnson, and Menhenhall to be jointly financed by the City and State.

April, 1969 The consultant's report was submitted and recommended that the freeway be fully depressed through the crosstown area along the existing alignment.

April, 1969 The City Council unanimously accepted and approved the consultant's study.

July, 1969 The District reiterated their position that a fully depressed alternative cannot be justified because of the cost. The fact that there may be adverse environmental impacts on the ground water was also cited.

October, 1969 The Mayor of Santa Barbara and the Division discussed the possibility of combining the freeway and railroad on one alignment.

February, 1970 The Division held a design public hearing covering 5 plans, elevated; landscaped fill, railroad and freeway
on landscaped fill; partially depressed; and fully depressed.

March, 1970 A ground water study was prepared by Glenn Brown, consulting geologist. The study concluded that a fully depressed alternative along the existing alignment would cause serious ground water depletion and salt water intrusion. The report also noted there was a possibility of constructing a depressed alternative north of the existing alignment without adverse effects on the ground water. More studies were required to judge the feasibility of a northerly route between Haley and Cota Streets.

August, 1970 The Division reported that the depressed design alternatives were unacceptable because of the high cost with no apparent offsetting community benefits. The City Council then requested that the Division study further the feasibility of a new alignment for the depressed alternative between Haley and Cota Streets.

November, 1970 The Division submitted a feasibility study of the depressed alternative along the Haley-Cota alignment. While the report concluded that the plan would avoid the ground water problems of earlier depressed plans and cost considerably less, the Haley-Cota alignment would result in substantially more dislocation of residents and businesses.

December, 1970 The Highway Commission authorized opening of studies to consider route relocation along the Haley-Cota line.
December, 1970  The City Council requested that the Division make additional studies on the feasibility for a freeway running at-grade and parallel to the existing railroad right-of-way.

January, 1971  The Highway Commission extended route location studies to consider an alignment parallel to the railroad.

September, 1971  The Division held its third public hearing and discussed six alternatives including the realignments between Haley and Cota Streets and parallel to the railroad. The meeting was exceptionally well attended and public reaction varied. Suggestions for a by-pass route, new search for in-town alternatives (including multi-mode), and no improvement at all were received.

October, 1971  A series of four sessions of the Crosstown Freeway forum were held by Santa Barbara City College to present a digest of the project to local citizens. At the end of the forum the Citizen's Planning Association submitted a report to the City Council opposing all alternatives.

November, 1971  The City Council passed a motion of intent to enter into a route agreement for the plan combining an at-grade greeway and the railroad along the existing alingment. The vote was 6-1.

December, 1971  The Director of Public Works recommended that the Highway Commission adopt the freeway routing supported by the City Council.
December, 1971 The Division asked for additional comments from city for the Highway Commission's consideration when they deliberated a route adoption. The city voted 5-2 that they had no further input. The vote signified some weakening of the Council's feeling toward the alternative as the previous motion had passed by a 6-1 margin.

January, 1972 The Highway Commission passed a resolution of intent to adopt the existing alignment as the route for the Crosstown Freeway.

C. Problems Highlighted by Crosstown Freeway Experience

This review of the history of the Crosstown Freeway project identifies some of the issues at the corridor and District level which the proposed time-staging approach will be able to address. The major problems with the development of the project to date have been:

1) A premature commitment was made to a particular improvement (freeway on existing alignment) and design (elevated or at-grade). The Division has been unable to successfully negotiate a freeway agreement over a prolonged period, despite what appears to be fairly widespread agreement that some improvement is desirable. The city administration and public have been determined not to settle on a particular improvement or design until after an extensive and thorough search of alternatives. Outside consultants were used to investigate an alternative which the city felt the Division had examined superficially.
2) There was a lack of exploration of opportunities to improve service over time. No significant improvements have occurred in the Santa Barbara corridor during the past 17 years while negotiations on the freeway have been conducted. The cost of the studies done on the Crosstown project has exceeded $800,000 and there may have been some improvements that could have occurred over this period even while negotiations on a freeway continued.

3) The delays associated with the Crosstown project have disrupted the Districts' programming efforts and have made it difficult to predict project schedules or make long-run programming decisions with any certainty. These delays have made it necessary to find substitution projects in order to meet the District and county minimums. Often these substitution projects have been relatively low priority improvements in rural parts of the District. In a number of instances, substitution projects have also been delayed, compounding the difficulties involved in shifting resources among projects and making it difficult to allocate manpower resources effectively to be able to meet rush schedules.

4.1.3 Application of the Proposed Time-Staging Approach

This section will present three examples to illustrate the basic concepts of time-staging and discuss how a staging approach could be applied in California to address the problems identified with the present programming process. The first example will consider only freeway alterna-
tives in the Santa Barbara corridor and how uncertainty can affect decisions at this level. The second example will relate the decisions on a freeway alternative in the Santa Barbara corridor to the rest of the district planning program, looking at both uncertainty and the budget constraint. The last example will consider a wider and more realistic range of alternatives in the Santa Barbara corridor and discuss how decisions on these alternatives must be related to the rest of the district planning program.

A. Freeway Alternatives in the Santa Barbara Corridor

The first example will consider just freeway alternatives for Route 101 in the Santa Barbara corridor. The example will attempt to illustrate:

1) the concept and application of a staging strategy and conditional decisions in a real world highway planning environment such as that offered in the state of California

2) how uncertainty can be explicitly considered in making programming decisions

3) how decisions might change if uncertainty is considered and actually accounted for.

It will be assumed that the Division is only looking at freeway alternatives to the crosstown route and for the time being, we will not relate the decision on the course of action pursued in Santa Barbara to the rest of the District planning program. Furthermore, we will restrict our attention to only three of the designs for the Crosstown Freeway documented in the Final Environmental Impact Statement in order to simplify the discussion. The three designs chosen were the depressed alternative on the Haley-Cota alignment, the elevated landscaped fill
alternative on the existing alignment, and the at-grade alternative combined with relocating the Southern Pacific tracks along the existing Route 101 alignment. Figure 4.1 shows both the alignments referred to above.

The decision to be considered in developing staging strategies is which alternative should be advanced to final design in order to present a request for a freeway agreement to the city. We will assume there are only enough manpower resources to do final design on one of the three alternatives.

The probability of obtaining an agreement will depend on the alternative chosen. Figure 4.3 shows a staging strategy based on the decision to do final design on the at-grade alternative. By the second period, if the community accepted the design and signed a freeway agreement, right-of-way acquisition could begin with construction taking place in the third period.

On the other hand, if the proposed alternative was unacceptable to the community, the Division would have to redesign the at-grade alternative or do final design on another alternative in the second period. Then, depending on whether or not the community accepted the new design in the third period, right-of-way acquisition could begin or a new design would again be needed.

Thus, assuming only freeway alternatives were available and that the Division would continue to choose to redesign rather than drop all studies if no freeway agreement was obtained, Figure 4.3 represents the choices available over a span of three planning periods. A similar staging
FIGURE 4.3- STAGING STRATEGY BASED ON DESIGNING AT GRADE ALTERNATIVE IN THE FIRST PERIOD

AC ACCEPTABLE TO COMMUNITY
UC UNACCEPTABLE TO COMMUNITY
R.O.W. RIGHT OF ACQUISITION
strategy could be developed assuming the first period decision was to
design the depressed or elevated alternatives.

Once a first period decision was made, future decisions would be
conditional on both the previous decision to design a particular
alternative and whether or not the design presented to the community
was acceptable. A staging strategy then is represented by a first period
decision and a series of conditional future decisions which represent
the choices left open over the current planning horizon. The desirability
of a particular first period decision would depend, to some extent, on the
choices left open and the magnitude of the uncertainties present.

Let us now examine how uncertainty could be explicitly considered
in the allocation of resources and how decisions might be affected as a
result. To do this, we will restrict our attention for the moment to the
effect of uncertainty on the relative economic efficiency of the three
designs.

The cost figures for right-of-way and construction were taken from
the Environmental Impact Statement. The economic efficiency benefits were
calculated from the Planning, Programming, Budgetary System (P.P.B.S.)
indices reported for the project in the 1972 Planning Program. The benefits
for all three designs were assumed identical since each provides the same
improvement in service. The undiscounted benefits and costs are shown in
Figure 4.4

Since all the benefits and costs don't occur in the first year the
project is funded, the distribution of these costs and benefits over time
must be determined. Once this distribution is obtained, the net present
value of each alternative can be calculated. Figure 4.5 shows the
-118-
SAFETY INDEX = 53%
DELAY INDEX = 240%

TOTAL UNDISCOUNTED BENEFITS = $109,000,000 FOR ALL ALTERNATIVES

<table>
<thead>
<tr>
<th>ALTERNATIVE</th>
<th>R.O.W. COSTS*</th>
<th>CONSTRUCTION COSTS*</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEPRESSED</td>
<td>20.1</td>
<td>29.2</td>
<td>49.3</td>
</tr>
<tr>
<td>ELEVATED</td>
<td>16.9</td>
<td>20.8</td>
<td>37.7</td>
</tr>
<tr>
<td>AT GRADE</td>
<td>18.1</td>
<td>22.2</td>
<td>40.3</td>
</tr>
</tbody>
</table>

* IN MILLIONS OF DOLLARS

FIGURE 4.4 - UNDISCOUNTED BENEFITS AND COSTS FOR FREEWAY ALTERNATIVES
FOR A SINGLE AMOUNT

\[ P = \frac{A}{(1 + r)^t} \]

WHERE:

\( A \): FUTURE BENEFIT OR COST

\( P \): PRESENT VALUE OF FUTURE BENEFIT OR COST \( A \)

\( r \): DISCOUNT RATE

\( t \): NUMBER OF YEARS TO REALIZATION OF BENEFIT OR COST \( A \)

FOR A SERIES OF BENEFITS AND COSTS

\[ P = \sum \frac{B_t - C_t}{(1+r)^t} \]

WHERE:

\( P \): NET PRESENT VALUE

\( B_t \): BENEFITS ACCRUEING IN YEAR \( t \)

\( C_t \): COSTS ACCRUEING IN YEAR \( t \)

\( r \): DISCOUNT RATE

FIGURE 4.5 - DISCOUNTING FORMULAS
discounting formulas for calculating both the present value of a single future cost or benefit and the net present value of a series of costs and benefits.

The distribution of costs and benefits over time was assumed to be as follows: right-of-way costs spread evenly over the first four years, construction costs occurring uniformly over the following four years, and the benefits accruing uniformly over a twenty year period after construction. This pattern of benefits and costs is shown in figure 4.6. Using a five percent discount rate and assuming right-of-way acquisition begins in the present year, the net present value of each design was calculated and these are shown in figure 4.6.\footnote{The net present value represents the net economic benefits as defined by the Safety and Delay indices given right-of-way acquisition begins in the present year.}

Naturally the discount rate chosen to evaluate the economic efficiency benefits and costs represents an important public policy decision. Discounting has been discussed in Chapter 2. While it is not appropriate to get into an extended discussion on discount rates here, it should be noted that the rate chosen represents the taxpayer's "opportunity" cost for investing in transportation versus some other investment opportunity. A five percent rate might represent a minimum opportunity cost since it is approximately the return available on a savings account. The net present values of the alternatives for a range of discount rates are shown in figure 4.7
SAFETY & DELAY BENEFITS

4 YEARS 4 YEARS 20 YEARS

R.O.W. COSTS CONSTRUCTION COSTS

ALTERNATIVE  NET PRESENT VALUE*

DEPRESSED  6.60
ELEVATED  14.3
AT GRADE  16.4

* MILLIONS OF DOLLARS

FIGURE 4.6 - PATTERN OF BENEFITS AND COSTS ASSUMED FOR FREeway ALTERNATIVES
## NET PRESENT VALUES *

<table>
<thead>
<tr>
<th>ALTERNATIVE</th>
<th>4%</th>
<th>5%</th>
<th>6%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEPRESSED</td>
<td>11.3</td>
<td>6.6</td>
<td>1.7</td>
<td>-10.1</td>
</tr>
<tr>
<td>ELEVATED</td>
<td>18.5</td>
<td>14.3</td>
<td>8.3</td>
<td>-3.0</td>
</tr>
<tr>
<td>AT GRADE</td>
<td>20.7</td>
<td>16.4</td>
<td>10.3</td>
<td>-4.5</td>
</tr>
</tbody>
</table>

* MILLIONS OF DOLLARS

**FIGURE 4.7 - EFFECT OF DISCOUNT RATE ON NET PRESENT VALUE**
Both the magnitude and the distribution of the costs and benefits for the freeway alternatives were assumed to remain constant over time. In calculating the net present value of freeway alternatives it was assumed that right-of-way acquisition began in the present year. If the start of right-of-way acquisition was delayed for four years, the net present value of the freeway alternatives would be the amounts shown in figure 4.6 but discounted back four more years.

The net present value gives a measure of the net economic efficiency benefits of an alternative given that implementation begins at some specified time. In describing the staging strategies based on doing final design on one of the alternatives during the first four years, however, explicit recognition was given to the fact that the implementation time was uncertain. To account for uncertainly then, the economic value of an alternative must be weighted by the probability of obtaining community acceptance for that design for any particular period.

Given the staging strategy shown previously in figure 4.3, one could estimate the probability that the design of the at-grade freeway would be acceptable or unacceptable to the community at the beginning of the second four year period. Likewise, if the at-grade was unacceptable, one could estimate the probability that designs on any of the three alternatives could be acceptable at the start of the third four-year period.

---

1 The assumption of constant benefits and costs independent of implementation time was made due to the lack of data available at the time the example was developed. In general, one would not expect benefits and costs to be independent of time due to factors like inflation and demand shifts.
Once probability estimates are made, an "expected" net present value can be calculated for a staging strategy. Figure 4.8 shows this calculation for a simple example. The benefits and costs associated with the two possible outcomes of the negotiations with the community are weighted by the estimated probability of their occurrence and then discounted.

The benefits and costs associated with not obtaining acceptance in the fourth year are, in fact, the discounted expected value of the decision made in the second period as shown in figure 4.8. In this case the second period decision would be to either redesign the at-grade or design one of the other two alternatives. It is assumed that the second period decision with the largest expected value would be chosen in figure 4.8.

To calculate the expected value of a staging strategy, one must work backward through the decision tree calculating the expected value at each decision point, assuming you have reached this point in the tree, and discounting back until an expect net present value is obtained for each possible first period decision.¹ This backward search procedure is necessary since one can't evaluate the actions in the last period until the history of actions and uncertain events up to that period is known.

Thus one assumes a history of actions and events leading up to the last period and then calculates the expected value over all possible

¹As assumption made in estimating probabilities and calculating expected values is that if uncertainty is large enough to affect decisions then it is more appropriate to estimate probabilities than to ignore the uncertainty altogether. For a more in-depth discussion both of this approach to decision making (referred to as Bayesian Decision Theory) and the calculation of expected values for a decision tree see Raiffa, Howard. Decision Analysis: Introductory Lectures on Choices Under Uncertainty, Reading Mass.: Addison-Wesley (1968).
EXPECTED NET PRESENT VALUE = \frac{P_1(B_1-C_1) + P_2(B_2-C_2)}{(1 + r)^4}

WHERE

r: DISCOUNT RATE

P_1: ESTIMATED PROBABILITY THAT DESIGN IS ACCEPTABLE TO COMMUNITY

P_2: ESTIMATED PROBABILITY THAT DESIGN IS UNACCEPTABLE TO COMMUNITY

B_1-C_1: PRESENT VALUE IN YEAR 4 OF OBTAINING ACCEPTANCE

B_2-C_2: EXPECTED PRESENT VALUE IN YEAR 4 OF NOT OBTAINING ACCEPTANCE

B_2-C_2 = \frac{P_3(B_3-C_3) + P_4(B_4-C_4)}{(1 + r)^4}

FIGURE 4.8 - SAMPLE EXPECTED VALUE CALCULATION
outcomes for each action at that time. The best decision for this point in time is then chosen as that action yielding the highest expected value. For example, we could assume that the at-grade freeway was designed and unacceptable to the communities in the first two periods. In the last period then final design could be done on any of the three alternatives and an expected value for each can then be calculated.

Once the expected values for alternative actions in the last period is known one can weigh the best action given an outcome of community negotiations by the probability of that outcome. For each event the best action for each possible outcome is weighted by the probability of that outcome and added together. These weighted sums then form the terminal expected values for the previous period actions and procedure continues over each period until an expected net present value is obtained for each first period decision.

Using the benefits and costs described previously, and the staging strategies developed as a result of doing final design on one of the three alternatives in the first period, the expected value of each strategy was calculated for a range of probability estimates. One example is shown in figure 4.9. Here the probability of the community accepting the depressed alternative was assumed to be 100% and for the elevated and at-grade alternative, 20% and 30% respectively.

The values shown at the end of the third period were obtained by assuming that if the community remained opposed to the alternative presented, after the third period no further studies would take place. The $2.86 million net benefit shown for the decision to redesign the
<table>
<thead>
<tr>
<th>Expected net present value</th>
<th>R.O.W.* for Elevated</th>
<th>R.O.W. for Elevated</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.72 Design At Grade 8.08</td>
<td>14.3 R.O.W. for At Grade</td>
<td>14.3 R.O.W. for At Grade</td>
</tr>
<tr>
<td>6.60 Design Depressed 6.60</td>
<td>5.42 Design Depressed 6.60</td>
<td>5.42 Design Depressed 6.60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Construct Elevated</th>
<th>Construct At Grade</th>
<th>Construct Depressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.42 Design Depressed 6.60</td>
<td>5.42 Design Depressed 6.60</td>
<td>5.42 Design Depressed 6.60</td>
</tr>
</tbody>
</table>

*AC - Acceptable to Community
UC - Unacceptable to Community
ROW - Right of Way Acquisition

Figures are expected net benefits in millions of dollars
discount rate = 5%

FIGURE 4.9 - EXPECTED VALUE OF DESIGNING FREEWAY ALTERNATIVES
at-grade in the third period then, represents the 30% probability of the community accepting the design times the net present value at that time of right-of-way acquisition commencing (14.3 million dollars), plus the 70% probability of no acceptance with a return of zero (since studies are assumed to be dropped).

For the probabilities assumed in the figure, the strategy with the highest expected economic return is to design the at-grade alternative, the second branch of the tree in figure. 4.9. If the community rejects the proposal in the second period, to redesign the at-grade facility and, if rejected again, to design the depressed in the third period. In reality, of course, the range of decisions in later stages as well as the probability estimates may also change.¹

The strategies shown were tested with a variety of different probability estimates each time assuming less than a 50% probability of acceptance for the at-grade and the elevated alternatives and more than a 50% probability of acceptance for the depressed alternative. In all cases, the decision to design the at-grade alternative in the first period had the highest expected net present value while the second and third

1 It should be noted that expected value is not the only criterion which might be considered in evaluating a staging strategy with respect to economic efficiency. Very often individuals and agencies exhibit risk adverse behavior and do not act to maximize expected value but rather some decreasing function of expected value as the size of the investment being considered increases. That is, one might be willing to pay 50¢ for a 50-50 change at 0 or $1, but not be willing to pay $500 for a 50-50 change at 0 or $1000, even though $500 is the expected value of such a lottery. For an agency, such as the Division of Highways, which
periodic decisions changed as the probabilities shifted.

Naturally, the expected new economic efficiency benefits is not the only criterion to be considered just as the present P.P.B.S. indices are not the sole consideration in placing projects in the Planning Program now. Accounting for uncertainty with respect to a quantitative criterion can be accomplished in the formal manner shown for economic efficiency. However, it is only illustrative of how considering uncertainty may effect decisions. In this case, the preservation of the visual connection between beach and downtown provided by the depressed alternative had to be weighted against its greater impact on the relocation of homes and business establishments.

The essential point of the example is that by considering uncertainty before committing resources to an alternative, one must examine the relative likelihood of obtaining acceptance or significant delays occurring before acceptance is achieved. One cannot eliminate the depressed alternative because of the ten million dollar cost differential without examining its probability of acceptance (or earlier acceptance) relative to other alternatives under consideration.

The conclusion reached from the above example is that the Division's assessment of alternatives on the basis of an economic efficiency criterion alone was correct, given all freeway alternatives were acceptable.

---

1is making a large number of investment decisions, there is some opportunity to pool risks, (i.e., balancing investments with low probability of success against those with a high probability) and use of expected value may be appropriate in such a case. However, the example is intended to show that considering uncertainty can affect decisions and not to imply the Division should maximize expected value. For a discussion of risk adversion see Raiffa, Howard Op.cit.; and deNeufville, Richard and Stafford, Joseph. Systems Analysis for Engineers and Managers. New York: McGraw-Hill (1971).
and could have been constructed at one time. However, the alternatives had different probabilities of acceptance and thus different schedules for implementation. In evaluating proposed improvements, one cannot simply compare statically the impacts of each alternative as the Division did, but must examine how the uncertainty and timing of different improvements may effect their desirability. The Division assumed the cost differential eliminated the depressed alternative, yet there has been no improvement for 17 years and the lead time till completion of any Crosstown freeway is still probably at least eight years away.¹ In some cases, it may be desirable to construct a more costly facility in order to realize the benefits earlier.

Naturally the probability estimates assumed in examining the effect of uncertainty may not have been the estimates or range of estimates that District personnel would have made. The key point is that the range of uncertainty present can affect the desirability of a particular decision whether the uncertainty is related to community acceptance, funding or demand levels, or some other possible future impact. If the uncertainty is deemed significant enough to affect decisions, some estimate of its magnitude and assessment of its effect should be made explicitly.

B. Relating Santa Barbara Corridor Decisions to the Rest of the District

This example will extend the previous one by relating decisions on the freeway alternatives in Santa Barbara to the rest of the district

¹ The Final Environmental Impact Statement reports that a 1980 completion date for the Crosstown is an optimistic estimate.
planning program. The example will illustrate how the desirability of improvements in the Santa Barbara corridor may be affected by improvements being considered elsewhere in the district.

Two types of relationships which may exist among different improvements considered in a planning program have been discussed in previous sections. First, within a given area there may be network effects (i.e., changes in traffic patterns or volume) which create dependencies among the schedules of a number of proposed improvements and which weren't considered in the first example. In the case of the Santa Barbara corridor, a number of improvements on Route 101 outside the Crosstown section are contingent on a freeway being built. Unless the crosstown freeway is constructed these improvements will also not be constructed.

The second and more general type of relationship between improvements is that due to the budget constraint. With scarce resources a decision on a particular improvement must be made in light of the alternative uses available for those resources. Thus, a decision to construct a freeway in Santa Barbara restricts a large amount of funds and manpower from being used elsewhere.

In California, this relationship among projects due to the budget constraint has two dimensions due to the existence of budget minimums as

---

1The 1972 Multi-Year Financial Plan reports that a number of sections of Route 101 scheduled for up-grading from expressway to freeway standards are contingent on the Crosstown. The contingent projects are identified as project numbers 95, 96, and 98-101.
well as maximums. In past years in District 5 when the Crosstown freeway was delayed, substitution projects were needed to meet the District and county minimums. The effect of the minimums was to constrain the geographic area in which substitution projects could be developed.

In the current Planning Program, the District 5 minimum will be met by funding projects outside the Santa Barbara corridor. If the Crosstown freeway is accepted by the city, it will be funded over and above the minimum. Such an arrangement may reduce the problems associated with the allocation of manpower to different projects in District 5, but does not eliminate the dependence between projects due to the budget constraint. In this case, the Division would have to examine the alternative uses of funds in other Districts as well as in District 5 if the Crosstown continues to be delayed.

Before the adverse environmental impact of a depressed alternative on the existing alignment was uncovered by a ground water study, the Division had ruled it out as too costly. Before making such as assessment, one must consider both the uncertainty associated with the community accepting a particular design and the alternative uses for the funds if the Santa Barbara project is delayed.

The difference between this example and the previous one is that now we will assume that if the Crosstown freeway is delayed, District 5 would have to spend some funds on one or more substitution projects just to meet the district minimum. Furthermore, the assumption will again be made that the only improvement alternatives in the Santa Barbara corridor are the three freeway designs (at-grade, elevated, and depressed) considered earlier.
Given these assumptions, two hypothetical substitution programs were developed from projects identified in the 1972 Multi Year Financial Plan as candidate substitution projects if the crosstown is delayed. Figure 4.10 shows the projects included in the substitution packages along with their net present value, calculated in the manner described earlier with the exception that right-of-way and construction costs were assumed to be spread out evenly over a four year period. The fact that the net present value is negative only confirms the Division's judgement that many of the substitution projects are low priority improvements whose schedules had been pushed forward prematurely just to meet the district and county minimums. The magnitudes and distributions of the benefits and costs were again assumed to be constant over time.

Figure 4.11 represents how the decision in the Santa Barbara corridor to design a freeway alternative is related to the District Planning Program. The decision to design a particular freeway alternative can again result in one of two outcomes. If the community accepts the design, right-of-way acquisition can begin in the second period, followed by construction in the third. If the design is unacceptable, a substitution program must be funded in the second period and a decision made to redesign the alternative rejected or design one of the other two freeway options.

By evaluating the strategies considered previously (in figure 4.9), but with the requirement now that a substitution program be funded if a design was unacceptable in a given period, the strategy with the highest expected net present value has changed from designing the at-grade alternative initially to designing the depressed freeway. The strategy of designing the depressed freeway in the first period continued to have
### PROGRAM # 1

<table>
<thead>
<tr>
<th>PROJECT NUMBER*</th>
<th>NET PRESENT VALUE*</th>
</tr>
</thead>
<tbody>
<tr>
<td>57 EARLY R.O.W. ON RT 41</td>
<td>2.6</td>
</tr>
<tr>
<td>58 &quot; &quot; &quot; &quot;</td>
<td>-4.4</td>
</tr>
<tr>
<td>59 &quot; &quot; &quot; &quot;</td>
<td>-3.9</td>
</tr>
<tr>
<td>61 &quot; &quot; &quot; &quot;</td>
<td>-3.4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>-9.1</td>
</tr>
</tbody>
</table>

### PROGRAM # 2

<table>
<thead>
<tr>
<th>PROJECT NUMBER</th>
<th>NET PRESENT VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>88 NEW ALIGNMENT FOR FREEWAY, RT 1</td>
<td>-3.5</td>
</tr>
<tr>
<td>96 2 ADDITIONAL LAMES RT 101</td>
<td>3.3</td>
</tr>
<tr>
<td>98 &quot; &quot; &quot; &quot; &quot;</td>
<td>-3.0</td>
</tr>
<tr>
<td>99 &quot; &quot; &quot; &quot; &quot;</td>
<td>-6.4</td>
</tr>
<tr>
<td>101 &quot; &quot; &quot; &quot; &quot;</td>
<td>-.10</td>
</tr>
<tr>
<td>TOTAL</td>
<td>-9.7</td>
</tr>
</tbody>
</table>

* PROJECT NUMBERS ARE THOSE GIVEN IN 1972 PLANNING PROGRAM
FIGURES ARE IN MILLIONS OF DOLLARS

**FIGURE 4.10 - SUBSTITUTION PROGRAMS FOR CROSSTOWN FREEWAY**

-135-
STUDY FWY

AC SUBSTITUTION PROJ.

STUDY FWY

AC ROW FWY

STUDY FWY

AC = ACCEPTABLE TO COMMUNITY

UC = UNACCEPTABLE TO COMMUNITY

ROW = RIGHT OF WAY ACQUISITION

PERIOD 1 PERIOD 2 PERIOD 3

FIGURE 4.11 - STAGING STRATEGY RELATING SANTA BARBARA CORRIDOR DECISION TO PLANNING PROGRAM
the highest expected net present value even when the probability of acceptance on the other alternatives increased to 50%. The implication is that the higher probability that the community will not accept the at-grade or elevated design, coupled with the need to fund premature substitution projects if the freeway is delayed, suggests that designing the depressed alternative may be a better decision with respect to increasing the expected economic efficiency from the entire planning program.

In the first example, by not considering the alternative uses of the funds available if the freeway was delayed, designing the at-grade facility in the first period yielded the largest expected net present value. By relating the decision in Santa Barbara to the rest of the Planning Program, designing the depressed freeway resulted in the largest expected value.

Again, the example is illustrative of the effects of considering uncertainty and recognizing budget dependencies. This is not to suggest that expected economic efficiency is the only criterion that need be examined or that the substitution programs considered were necessarily packages that the Division would have funded as we have stated earlier.

What must be recognized, however, is that it is extremely important to relate the design and timing of improvements in different locations at the time the district planning program is developed. If only low priority (however defined) projects are available as alternative investments, the Division should examine the relative desirability of sinking more money into a corridor where improvements are needed now, rather than delaying improvements there and funding projects not likely to provide major benefits till some time in the future.

-137-
Naturally, in another case, it may be desirable to fund smaller improvements in a particular corridor in order to be able to fund needed improvements in other corridors sooner. The actual decision will depend on the estimated probabilities of acceptance, the benefit and cost measures, etc., and how these change over time. What the strategic approach provides is a framework to help in making the kinds of tradeoffs required in an efficient and effective manner.

C. Developing Time-Staging Strategies for the Santa Barbara Corridor

The first example looked only at freeway alternatives in the Santa Barbara corridor and illustrated the concept of a staging strategy and how explicit consideration of uncertainty may affect programming decisions. The second example then illustrated the dependence between decisions on the freeway alternatives in Santa Barbara and the rest of the district planning program created solely by the existence of a budget constraint.

Let us now summarize the essential elements of the strategic approach and how it can help the Division allocate both its resources and manpower by considering a more realistic application of time-staging in the Santa Barbara corridor in a general discussion of alternatives. Essentially this example will attempt to describe how a staging approach can and ought to be applied in studying potential transportation improvements in corridors like Santa Barbara in the future. The first step in applying the staging concepts in a corridor is to consider initially a range of alternative improvement sequences over time. There are two reasons for the desirability of examining a range of choices available in a corridor over time. First, it allows both the Division and the communities
affected to see the choices that are available. The Division's role can then be viewed more credibly as helping communities evaluate and make decisions on transportation improvements rather than as an organization pushing a particular facility.

Secondly, by looking at choices over time, the Division is in a better position to respond to changes whether they be changes in funding availability for improvements in a particular area, community values, or population and demand predictions.

The two examples presented so far have only considered freeway alternatives in the crosstown area. During the course of negotiations and studies in Santa Barbara, a wide range of proposed alternative improvements from the "do nothing" alternative to by-pass routes have also been suggested and considered.

In figure 4.12, a number of different potential improvement sequences are traced out. The freeway alternative represents any of the routes and designs through the crosstown section. The local improvement alternative refers to any of the improvements discussed in the Final Environmental Impact Statement such as adding lanes to the existing Route 101 but not designed to freeway standards. The by-pass alternatives represent any improvement increasing service around the downtown area and would not necessarily need to be to freeway standards. The "other alternative" represents the improvements funded elsewhere in the District or state if no improvements were funded in Santa Barbara.

To follow a particular sequence of improvements over time would require that both community acceptance be obtained for, and the Division be willing to fund, each improvement. In the case of the Santa Barbara
Figure 4.12 - Alternative Sequences of Improvement for Santa Barbara Corridor
crosstown project, the Division initially assumed that the sequence to be followed would be the one shown at the top of the figure. The Division expected to build a crosstown freeway which would provide sufficient service improvements into and through the city for a number of years during which time "other alternatives" (e.g. improvements in other parts of the district would occur.

The sequence that has been followed to date is represented at the very bottom of the figure. During the past 17 years no improvements have occurred in the Santa Barbara corridor while the funds that might have been spent there if the Division and city had reached agreement were spent in other parts of the district or state.

In fact there were a number of sequences of improvements over time that could have occurred. By initially examining a range of the choices that could be made over time, a more effective allocation of manpower and fiscal resources should occur for the Division, and more importantly, an effective decision from the community's viewpoint be achieved.

Given a large amount of uncertainty over the community accepting a freeway or uncertainty over future demand, it may have been desirable to fund local improvements while deferring a decision on a crosstown freeway or a by-pass route. By recognizing uncertainty and considering alternatives, choices can be negotiated over time without causing a major disruption of programming activities. If a decision was made to delay all improvements in the Santa Barbara corridor, future options can be kept open by continuing studies on a range of alternatives.

-141-
Naturally, any improvement funded in Santa Barbara must be related to the rest of the improvements being considered in the Planning Program. As we have seen in an earlier example, the Division's willingness to fund an improvement depends to some extent on the alternative uses for those funds. By recognizing that different improvement sequences may develop in a given area, the Division can anticipate various patterns of funds allocated to improvements in different locations. This allows the Division to prepare more desirable substitution projects. If only low priority alternatives exist, the Division must then determine if more funds should be made available for improvements in locations where improvements are desirable but in which agreement has not been reached. Similarly, if projects are needed in a large number of locations, consideration should be given to decreasing the scale of improvements to be able to fund others sooner.

4.1.4 Other Applications of Time-Staging in California

The use of the Santa Barbara Crosstown project to illustrate the concepts involved in time-staging was not to suggest that its use be restricted to a very small number of "trouble spots". Hindsight was obviously valuable in suggesting how the Santa Barbara studies might have proceeded and what alternatives to the Crosstown Freeway were available.

Any location is potentially a trouble spot if the affected communities do not believe the range of alternatives available to them has been fully explored. The broad application of a time-staging approach will allow the Division to both recognize and leave open some of the choices available and at the same time restore more continuity to their investment scheduling.
Any area in which major improvements could potentially occur should be considered as a candidate for the development of time-staged strategies.

At the District level, explicit strategies for alternative use of funds based on the different outcomes of corridor or project negotiations should be considered. The fact that in the past, District 5 needed substitution projects to meet the district minimum when the Crosstown project was delayed, underscored the need to always relate the design and timing of different improvements at the District level as a result of scarce resources.

It should be emphasized that a number of these staging concepts have been applied by the Division of Highways to some degree already. For example, the Division has on various occasions staged the construction of a facility over time (adding two lanes now with the expectation of adding two more later). We suggest such staging is always a major policy option which should consider not just the present availability of funds for a larger facility, but also the uncertainty over demand, future funding levels, or the reluctance of a community to accept a major improvement immediately.

Secondly, in some areas, the Division has developed alternative planning programs in light of a particular uncertainty. The uncertain outcome of the referendum for the proposed Southern Crossing in District 4 and the uncertainty over the designation of a route for Interstate 15 in District 8 resulted in alternative planning programs. The use of staging does not result in a choice among different lists of projects such as were developed in these instances nor does it imply commitment of the larger amounts of resources that the development of different programs implies. By staging decisions, explicit recognition is given to the fact
that different systems or investment programs may evolve out of the choices for improvements available over time in the locations in which studies are occurring.

The closest application of staging to date has been the request that Districts identify which projects in the first years of the planning program are likely to be delayed because of litigation resulting from state and federal environmental policy acts. The districts will estimate the probability of such delays for each project and develop substitution projects where deemed appropriate. The approach we are suggesting would consider an even wider range of conditionalities than in this case and recognize choices over time for the improvements in a given location as well as choices that exist for funding improvements in different locations.

The following section will summarize our recommendations for the wider application of time staging by the Division of Highways.

4.2 RECOMMENDATIONS

Our recommendations for developing staging strategies within the District planning program are aimed at addressing the findings and problems identified in section 2.5 of this report; and thereby increasing the flexibility of the Division's planning and programming process. Staging strategies explicitly recognize uncertainty and the dynamic nature of investment planning and provide the framework for considering community and environmental objectives early in the process during programming. By displaying alternatives and critical choices over the time period of programs, staging strategies aid in encouraging interaction with outside groups, and help improve the management of manpower and the
allocation of capital resources.

4.2.1 Development of Planning Programs

The Division should adopt an explicit strategy of staged decision-making within District Planning Programs. To accomplish this, the Division would have to take the following steps:

1. Identify significant uncertainties. To be in a position to anticipate changes and develop alternatives, the Division should explicitly identify those factors which by changing in the future could have a significant effect on transportation plans.

The importance of considering different uncertainties will vary depending on the character of the region and the improvements proposed. If the feasibility or desirability of proposed plans does not change markedly for a wide range of factors, then the uncertainty need not be considered. It appears to us that in most cases, given California's present environment, the uncertainty associated with community acceptance, funding levels, and impacts should be considered explicitly when large projects are planned.

The uncertainties examined should be described explicitly in the Planning Program.

2. Develop Time-Staged Strategies Within District Planning Programs

The Division should develop a number of sets and sequences of improvements as contingencies for the different ranges of the uncertainties considered and to illustrate the range of
choices open to improve transportation in a particular region. Rather than developing one list of projects to be implemented over an 8-12 year period the Division can examine what different sequences of choices on improvements can be staged over time.

Specifically, the Division should consider how choices can be staged over four year periods within the Planning Program. A four year period seems appropriate since the flexibility of developing alternatives in the planning program may be quite limited within the first four years. This results from the legislative minimums which are calculated on a four year basis and the need to continue funding projects for which right-of-way acquisition or construction has begun. However, even after a tentative program has been decided upon for the first four years, options can be displayed within the Planning Program for the fourth through eighth years and the eighth through twelfth years.

The development of staging strategies is not simply a technique to improve the evaluation of an 8-12 year Planning Program which then schedules the one "best" sequence of investments over time. Rather, staging strategies allow future options to be explicitly left open while at the same time requiring decisions on first period actions. Because of lead time requirements, to keep future options open, it will be necessary to perform studies on sets of contingent projects, some of which will later be dropped from consideration.
Hence, to be able to choose to begin implementation of one of two improvements four years from now would require studies on both in the interim. Premature elimination of alternatives reduces the choices available in the future.

Legal commitments (freeway agreements), manpower constraints, lead time requirements and legislative minimums will always limit to some extent the ability to develop and keep open different choices in the future. Given the resources required to develop staging strategies, the size of districts, and the number of projects in the planning programs of the larger urban districts, the application of the approach may have to be limited to the larger projects or most significant corridors under study, but this should not be a major constraint of applying the approach.

One of the major recommendations therefore is that staging strategies be developed to provide alternatives for some projects and groups of projects over time for 3 levels of planning:

a) **Project Level**: The Division should develop alternative sequences of improvements over time rather than concentrating on one proposed design before that commitment needs to be made. One possible application might be to consider staging additions to capacity over time rather than attempting to build the ultimate improvement initially.

b) **Corridor Level**: In corridors or sub-areas in which a transportation problem has been identified, the Division
should develop staging strategies which consider a wide range of alternative improvement sequences varying in mode, scale, location, and timing. The development of alternatives should be guided by the uncertainties considered and the objectives of the proposed improvements. Thus, alternative strategies would not necessarily be just different orderings of the present priority lists. Strategies should be tailored specifically to different ranges of the uncertainties present and should highlight the tradeoffs between conflicting objectives. The present priority list might provide alternatives which emphasized direct user benefits or support and encouragement for one potential future development pattern. Other alternatives should emphasize other community or environmental values, or different potential development patterns.

Naturally, in developing strategies in any one corridor or sub-area one must consider the project interdependencies present. This involves identifying how the mode, location, scale or timing of one project affects or constrains the same characteristics of other projects both in the corridor or sub-area and in other areas of the District.

c) **District Level:** Within a district, staging strategies might be developed around a number of projects and corridors. Rather than displaying a list of projects to be implemented,

---

1The recent Transportation Corridor Study policy provides for the study of non-highway alternatives.
where strategies had been developed, the planning program would show the series of choices to be made over time and the uncertainties on which the outcome of those choices hinged.

The number of project or corridor strategies in a district would depend on the manpower available and the type of improvements proposed. In Los Angeles, each proposed freeway link or some groups of them in the same area would justify the use of staging strategies.

The scope of the strategies developed within a District might vary also depending on the size of the corridor. In District 8 the development of the Interstate 15 link on one of its alternate alignments would represent a situation where a staging strategy ought to be considered, yet the magnitude of the project suggests that only proposals for major facilities be included (i.e. the Interstate itself and its proposed feeder and intersections with other large facilities). In District 5, the proposed Santa Barbara Crosstown Freeway could form the basis for a staging strategy that included different freeway and non-freeway alternatives in a much smaller area.

At the District level, a staging strategy would essentially be concerned with the different possible allocations of funds to project and corridor strategies over time. A range of outcomes on the decisions in each staging strategy would be possible and would affect the location and size of improvements the Division could fund.

In developing the district planning program, different
combinations of the outcomes of the negotiations and other uncertainties considered for each project and corridor will have to be anticipated. If the improvements decided upon in each strategy for the next period are likely to exceed the budget constraint, some improvements would have to be delayed or lesser improvements accepted for some projects or corridors. On the other hand, if an excess of funds was likely to occur, new project or corridor studies would need to be initiated. By anticipating different distributions of funds an orderly allocation to projects and corridors could occur.

4.4.2 Evaluation of Planning Programs

Evaluation procedures should be adjusted to reflect community and environmental factors directly and increase coordination between project and network planning.


The Division need only be strongly committed to projects funded for initial right-of-way acquisition in the next year[1] and these choices should reflect the perceived condition-alities and alternatives being considered in the Planning Program. The desirability of a facility should be weighed

[1]This means there is a strong commitment to complete a project once right-of-way acquisition has begun. Thus, in each year, the Division will be obligated to projects for which right-of-way is initiated and other projects for which right-of-way or construction began in previous years.
by the estimated probability of getting community acceptance or other factors affecting its "value".

To evaluate the first four years of a proposed planning program (i.e., the period for which it is difficult to maintain much flexibility), the Division must consider the options left open and foreclosed by the investments scheduled for the first four years. Once a decision on the best schedule for the first four years has been made, the Planning Program should explicitly display the choices which are left open and the conditionalities presently considered.

As more information is gathered about the uncertainties considered, alternatives in the succeeding four-year period can be re-evaluated and augmented. As development of a particular improvement progresses, new community and environmental factors may arise which dictate the need for revision of the options for a specific project or corridor. Such revision might also effect other improvements in the planning program as a result of budget or timing dependencies.

2. Discount Rates Should Be Used To Evaluate Economic Impacts.

Presently the evaluation of the economic efficiency of Planning Programs is based on a benefit-cost ratio (defined by the P.P.B.S. indices) which measures aggregate user benefits per dollar cost. To make investment choices over time the Division should not be indifferent to various distributions of the same total benefits and costs over time. Similarly, the Division should not be indifferent between
projects or programs which could yield the same benefit and
cost streams but had different probabilities of successful
implementation.

In evaluating alternative staging strategies with respect
to economic efficiency (i.e., user benefits and implementation
costs) discount rates should be used. If discount rates
are not used, there is an inevitable bias toward projects
producing the largest aggregate benefits irrespective of the
time required for implementation. Often a combination of
smaller projects will have less net benefits but be easier
to implement and hence yield the benefit sooner.

A fair comparison of two investments with respect to
economic efficiency requires a common metric (i.e., net
present value of benefits). Economists in general and engineers
in water resources have accepted net present value as the
appropriate economic efficiency measure. To maintain credibil-
ity with the planning profession it is desirable that the
Division also adopt this criterion. Where conditionalities
have been considered and probability estimates made, the
appropriate measure would be the expected net present value
or a formula recognizing risk aversion as discussed in section
4.1.


In evaluating proposed improvements, the Division should
recognize the dependence between the design of different
improvements that exists due to the budget constraint. The
appropriate level of funding and timing for a specific project must be determined in light of the alternative uses for those resources.

Attention must also be given to how the timing of each improvement affects the desirability of that improvement and others being planned. The benefits accruing from projects may vary with their times of implementation, and different sequences of the same improvements may yield different benefits over time, depending on the magnitude and patterns of demand.

4. Make Explicit Evaluations of Planning Programs for Criteria Other Than Economic Efficiency.

The Division should explicitly document and make available reports on how alternatives in the planning program compare with respect to community acceptability, environmental values, and equity. This would require a preliminary assessment of the impacts on users, non-users, local traffic, through traffic, etc.

Such an evaluation also implies that comments and input to the development of alternative improvements and their evaluation be encouraged and solicited from outside the Division. The more public the process is allowed to be, the easier it will be to coordinate community and transportation development plans. In addition, the broader and more systematic evaluations of planning programs are, the less chance there will be that later project studies and negotiations will uncover information that causes costly delays in the districts'
network improvement schedule and that makes effective allocation of manpower resources difficult.
Chapter 5

SUMMARY, CONCLUSIONS AND EXTENSIONS

5.1 SUMMARY AND CONCLUSIONS

This research represents part of a larger effort that focused on a number of different elements of the system planning process used by the California Division of Highways. The major purpose of this particular study was to examine the investment planning process in a state highway agency and determine how that process could be improved to more explicitly recognize community and environmental values.

Specifically, the concept of time-staged decision making was tested to see if such an approach might be more compatible with the nature of the decision-making environment for system planning. As described in the first chapter, this environment required that a number of issues involving the role of time, scarce resources, multiple objectives, and uncertainty be addressed explicitly by the planning process. Both the master plan and time-staging approaches were examined to determine their strengths and weaknesses in dealing with these issues.

Based on the work presented here, several conclusions can be drawn. It seems clear from our review of the procedures used currently by the Division of Highways, that there are a number of serious weaknesses with the present approach to investment planning. First, there is a need for the Division to critically examine both the role of time and scarce resources in developing an investment program. Our recommendations to
explicitly recognize both the interdependence of project designs due to a budget constraint and the need to discount future benefits and costs were aimed at these deficiencies. These recommendations would be appropriate for improving investment decisions regardless of whether the planning process was guided by a master plan or a time-staging philosophy.

Secondly, and perhaps more importantly, the Division of Highways' current approach suffers severely in its ability to deal with the issues of multiple objectives, uncertainty, and the role of time in a broader sense than that implied by using a discount rate. The limitations of the Division procedures for dealing with these issues stem directly from the fact that California, like most state highway agencies, uses basically one master plan approach to system planning.

While the master plan approach focuses attention on a target year network, the decision-making process for implementing system plans occurs, in reality, in a series of stages over time. In each stage a number of decisions are made which commit resources to various project development phases (i.e., impact and route location studies as well as right-of-way acquisition and construction) and these choices must be negotiated with the groups affected by the decisions. In California, local veto power over highway construction ensures that cities and counties will be represented in the decision process. In light of the multiple objectives for transportation improvements, however, it is necessary for the Division to also recognize less well-defined "interests" in the negotiations.

The master plan is limited in its ability to address these issues due to the emphasis it places on target year networks rather than the sequences of improvements over time to implement those system plans. By focusing on
on a target network the master plan ignores the fact that choices on components of that plan must be negotiated over time and that many interest groups which are not involved in choosing a target system will be involved in later negotiations on each component of that network. In fact, many outcomes may develop from these negotiations and many systems may evolve over time. By focusing on one target network, master planning prematurely restricts the alternative improvements which are studied and often impedes the negotiation process by ignoring the full range of choices which are available.

While the master plan chosen may be the best transportation system for some target year based on predictions of the "state of the world" at that time, system planning is a continuous process which is concerned with improving transportation service for a region over time. Thus what really is sought is the best sequence of improvements over time not the best "end state" for some future year.

A more serious limitation stemming from the master plan philosophy is the fact that the inherent uncertainty associated with community values; cost, demand and revenue predictions; and the impacts of transportation facilities are ignored. When changes do occur, the master plan can be revised to some extent, but much flexibility is lost when changes are not anticipated and alternative courses of action are not considered initially.

To address the basic weaknesses in the master planning approach it was necessary to substantially revise the more traditional view of system planning. A time-staging approach has been proposed which develops alternative sequences of improvement over time in light of both the uncertainties present and choices available. Such an approach explicitly recognizes
the dynamic nature of planning and that both changes in the planning
environment and the results of negotiations with affected interests may
result in a number of systems over time.

Specifically, based on the research reported here, it has been
recommended that the California Division of Highways develop staging
strategies at three different levels. While the concept of a staging
strategy is the same at the project, corridor, and regional level, the
issues addressed and type of alternatives considered vary from level to
level.

The uses of staging strategies at three different levels will allow the
Division to provide more flexibility in system plans and recognize
explicitly the range of choices left open or foreclosed by a particular
first stage decision. The recommendations on the development of staging
strategies represent steps that the Division could begin to implement
immediately. Naturally, the extent to which the time-staging approach can
be applied is limited in terms of the number of alternatives and uncertain-
ties which can be considered. The key point is that a highway agency
involved in a continuing planning process need not restrict its attention
to one target network. Even with the present level of resources committed
to planning activities, the Division of Highways could examine a number of
uncertainties and sequences of improvement. It appears in the case of
California and the uncertainties present there, that it may be desirable
to commit even more resources to planning activities to further increase
the flexibility of system plans.

In summary, the development of a transportation investment program
is inherently a dynamic process. The decision making environment for
transportation improvement requires considerations of a wide range of alternative sequences of investment and explicit recognition of uncertainty. The actual development of specific designs occurs in a number of steps over time with a progressively more detailed and comprehensive assessment of the impacts of the proposal. At the same time, the nature of transportation improvements and the reality of scarce resources constrain to some extent the ability of the planner to develop alternatives and require that an assessment of the long-range impacts of present decisions be made.

The time-staging approach to developing system plans can address these critical issues in investment planning more directly than the master plan approach. We feel that the application of the staging approach in California will result in more desirable planning programs put together in less haste, more able to adapt to change, and containing "better" project and corridor improvement alternatives over time.

5.2 EXTENSIONS

This research has described both the advantages of time-staging approach to investment planning and the initial steps which need to be taken to begin to implement the approach in the California Division of Highways. The work has also served to point out several directions in which future research efforts in transportation investment planning is needed. A number of these directions for future work will be discussed briefly in this section.

In the short term, research is needed to provide further examples of the application of time-staging to actual investment programs being considered by a planning agency to demonstrate the desirability of the
approach under a wide variety of conditions. In particular, there is a need to demonstrate how different sequences of investment may provide different benefits over time. The examples presented in this work discussed the issues related to implementation time and timing interdependencies (network effects) but further efforts should explore the magnitude and importance of these effects.

In addition, there is a need to test the sensitivity of highway investment decisions to the ranges of uncertainty present in the planning environment. In the examples considered in the Santa Barbara corridor the significant uncertainty involved community acceptance of a facility design. In many cases both in California and in other states there will be significant uncertainty associated with funding, demand levels, and the impacts of proposed facilities. There is a need to examine how investment decisions might change if these uncertainties were explicitly considered when plans were formulated or reviewed.

In the long run, research needs to be done to more thoroughly design an overall time-staging approach for statewide system planning. By presenting the basic concepts in time-staged decision making, describing the levels at which strategies can be developed, and by recommending a number of steps that can be implemented immediately, the present work represents a first step toward this end. Further work is needed however to tie the development of time-staged investment programs to the allocation process by which funds are divided either to geographic regions or projects. The tradeoffs that a state must make between planning regions or districts have not been directly addressed in this research.

Also, given the number of alternative actions and uncertainties which
a typical state highway or transportation agency might consider, work must be done relating the philosophy and general approach of time-staged planning to the analytical techniques available for handling dynamic investment formulations in the face of uncertainty. While much emphasis to date has been made of developing analytic techniques, a pragmatic view must be taken in determining the appropriate role for such techniques in a continuous planning process. Essentially, it must be determined when the necessary assumptions can be made to apply different analytic tools and how the results of these applications can be used to screen or partially evaluate investment strategies.

One final area of future research which needs to be examined is the question of the evaluation process to be used in transportation system planning. While several alternative approaches to evaluation have been discussed, only the basic requirements of an improved evaluation process have been detailed in this effort. Much more work is needed to design an effective approach to evaluation for system planning which can recognize uncertainty, multiple objectives, community participation, and a large number of alternatives over time.¹

¹Work on developing an evaluation method sensitive to community and environmental values and issues of equity is ongoing. Cohen, Harry, "The Evaluation of Public Investment Alternatives" Ph.D. dissertation in process, Department of Civil Engineering, M.I.T.
Selected References:


7. _____, Key Decision Points by Director's Office in the P.P.B. System, April 1971.

8. _____, "Final Environmental Impact Statement for the Proposed Freeway Development of Route 101 in the City of Santa Barbara Between Salinas Street and Carrillo Street", December 1971.


Note: A thorough review of the literature on time-staging can be found in Pecknold, op. cit. Chapter 2.