HIGHWAY RESEARCH RECORD

Number 180

Transportation System Analysis and Evaluation of Alternate Plans

9 Reports

Subject Area

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Washington, D.C., 1967

Publication 1511

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Foreword

The papers in this RECORD represent, for the most part, a portion of the increasing literature in the rapidly developing field of systems analysis. Various analytical techniques and concepts are proposed by the respective authors for the development and evaluation of alternate transportation plans and their impacts. The various proposals presented here have been applied in settings ranging from specific urban areas to regional environments to developing countries. Although the specific techniques of systems analysis and evaluation that are proposed cover a rather wide range of geographical and political environments, the real significance of the papers is their overall attention to the needs of linking sound engineering economy to the development of socioeconomic goals and objectives. Collectively, they contribute further insight into the decision-making process.

Wilson points out the positive results from local plan review and joint state-local plan endorsement in Wisconsin as a result of Highway Commission involvement in "701" planning for communities of less than 50,000 population.

In the series of papers that follow, transportation system analysis is approached from somewhat differing, yet interrelated, viewpoints. Pikarsky, for example, discusses the methodology used to evaluated alternative alignments for the Crosstown Expressway in Chicago and outlines three specific areas around which evaluative criteria were developed: traffic and engineering aspects, impact on existing communities, and potential land-use improvements. Hill questions the efficacy of traditional cost-benefit methodology and proposes an alternative method described as goal-achievement analysis. Balkus discusses the relationship of six sketch plans prepared for the New York region and a population of over 30 million, with special focus on the implications that such plans would have on the transportation network. The paper by Jessiman, Brand, Tumminia, and Brussee presents a technique or framework that attempts to treat all pertinent factors in the evaluation of transportation improvements through defining objectives, evaluating the way each alternative meets each objective, and selection of the best alternative. The authors extend the technique to the consideration of an entire system of projects.

Putman discusses design conceptualization and implementation of a model system for forecasting and evaluating the indirect impact of alternative transportation systems in the Northeast Corridor Project.

Niebur focuses on the preliminary engineering economy analysis of five alternative urban transportation systems formulated and structured in the Seattle area. Three methods of engineering economy analysis were used in the Seattle study: the total annual cost method, the benefit-cost method and the rate of return method.

Shaner argues that the traditional methods of road evaluation employed in advanced economies cannot be universally applied in developing countries. The author offers an alternative set of procedures that incorporates concepts of economic development.

Contents

Policy and Procedure Review: State Highway Commission Liaison With "701" Planning in Wisconsin

BRUCE B. WILSON, Land Planning Supervisor, State Highway Commission of Wisconsin

•THE federal planning assistance program got under way in Wisconsin in September of 1959 when planning consultants started work on a comprehensive development plan for a community of some 14,000 population. As of July 1966, no less than 110 federally-aided local and county plans had been completed or initiated in Wisconsin. This activity is commonly referred to as "701" planning in reference to Section 701 of the U. S. Housing Act of 1954, as amended, which generally authorizes ⅔ federal matching funds for such planning activity in accordance with policies and procedures developed by the U. S. Department of Housing and Urban Development. Transportation studies partly financed with HPR funds, state planning activity, multi-county regional studies and special studies have also received federal "701" funds in Wisconsin. These latter programs, because of their size and complexity, receive the bulk of attention from highway agencies and researchers. This paper is concerned rather with the "701" planning assistance provided via state planning agencies to communities or groups of adjacent communities of less than 50,000 population and counties without regard to population.

The stated purpose of federal "701" aid is, "to assist state and local governments in solving planning problems resulting from the increasing concentration of population in metropolitan and other urban areas, including smaller communities; to facilitate comprehensive planning for urban development, including coordinated transportation systems, on a continuing basis by such governments; and to encourage such governments to establish and improve planning staffs" (1).

The 110 federally-aided planning assistance programs in Wisconsin can be described as varied in terms of geographic location, population size, level of government, and type of planning staff. Table 1 illustrates the distribution. Almost half of the local planning programs fall in the 1,000-4,999 population size group. Consultants have been retained for two-thirds of all local planning programs. While 22 private firms have participated in local planning assistance in Wisconsin, state records indicate 70 percent of consultant programs are being handled by seven firms carrying five or more programs each. Plan preparation by the state and other public staff has been limited to programs for communities of less than 10,000 population. Consultants also dominate the county planning programs, being responsible for all but one of the six county programs in the state.

All but a very few of the 110 "701" plans in Wisconsin have discussed or will discuss in some measure the location and function of state highways as coordinated with land use and community facilities plans. Clearly the State Highway Commission of Wisconsin should be and in fact has been involved in these local planning efforts. The purpose of this paper is to review and evaluate the first three years of the Commission's participation in such programs, from August 1963 to August 1966.

Throughout the paper the term "Planning Section" refers to the Urban and Advance Planning Section of the Planning and Research Division of the State Highway Commission of Wisconsin (see Fig. 1). "District Engineer" means engineer-in-charge of one

Paper sponsored by Committee on Organization and Administration and presented at the 46th Annual Meeting.

TABLE 1

"701" PLANNING ASSISTANCE PROGRAMS IN WISCONSIN AS OF JULY 1966

Population Size Group	Local Programs by Staff Type				County Programs by Staff Type		
	Consultant	State	Other[a]	Total	Consultant	State	Total
0-999	4	9	1	14			
1,000-4,999	26	19	1	46			
5,000-9,999	18	3	1	22			
10,000-24,999	15			15	3		3
25,000-50,000	7			7			
Over 50,000 (counties only)					2	1	3
Totals	70	31	3	104	5	1	6

[a]County Park and Planning Commission (2); City Planning Commission (1).

of the nine district offices of the Highway Commission; "state planning agency" refers to the Planning Division of the Wisconsin Department of Resource Development.

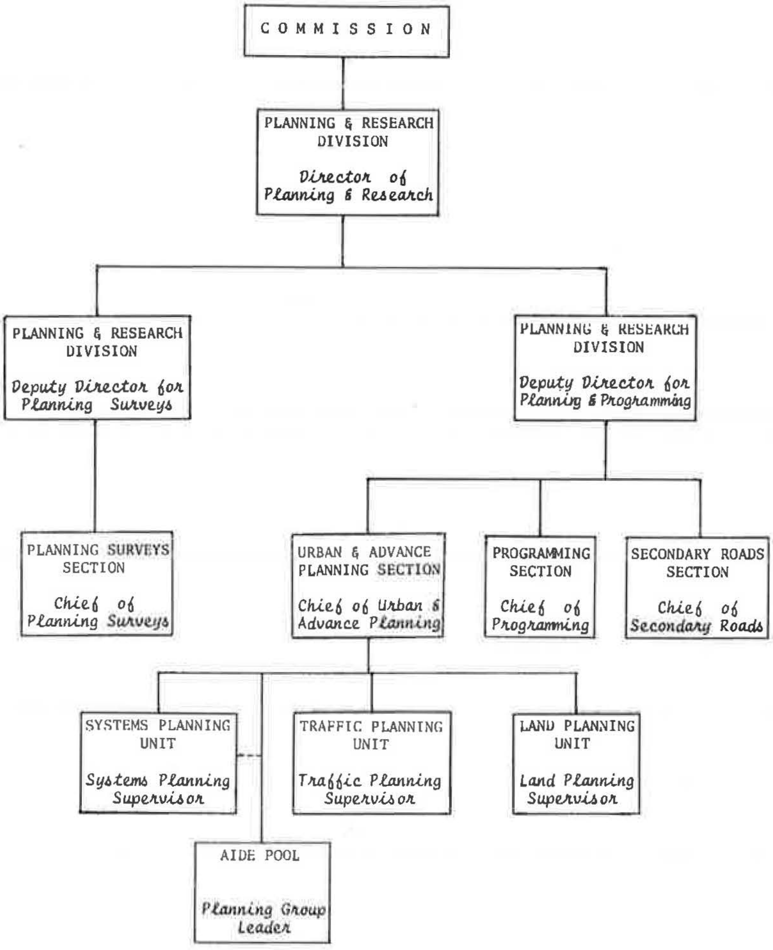

Figure 1. Wisconsin State Highway Commission Planning and Research Division.

TABLE 2

"701" PLANNING WORK STARTS IN WISCONSIN

Year	No. of Work Starts	Cumulative Work Starts
1959	3	3
1960	5	8
1961	11	19
1962	11	30
1963	27	57
1964	15	72
1965	18	90
1966 (as of July)	20 (incl. 11 pending)	110

NEED FOR HIGHWAY COMMISSION INVOLVEMENT ESTABLISHED

"701" planning acitivity in Wisconsin started in 1959 with three programs and increased to a peak of 27 "new starts" in 1963 (Table 2). District Engineers began to be concerned when the first completed plans were brought to them by local units with questions as to whether proposed state route changes or improvements were feasible. One of the earliest plans generated considerable departmental correspondence by proposing a complete system of circumferential highways which seemingly could only be implemented by State Highway Commission action. The only available estimate of "bypassable" traffic was derived by the consultant from an external O-D study in another city of comparable size. State highway corridor planning in the area had not been completed. The Highway Commission was placed in the unenviable position of needing a comprehensive answer to local questions when no such answer was available. Even more fundamental, the community and the Highway Commission were simply not speaking the same language. A communications gap needed to be filled.

In August of 1960, D. F. Haist was appointed Chief of the Highway Commission's newly created Urban Planning and Development Section (now Urban and Advance Planning Section). One of the first jobs of the Planning Section was to make an evaluation of local highway planning in Wisconsin as a basis on which to proceed with the necessary state-local coordination. The results of an intensive formal inquiry and evaluation were published in two years (2).

The study confirmed the lack of communication between the Highway Commission and local units of government in local highway planning. Local units were simply not too concerned with the need for quantitative analysis, which is the everyday job of the Highway Commission engineer. On the other hand, the Highway Commission had not clearly and publicly expressed its long-range goals and objectives in terms of a highway facilities plan, thereby leaving the door open for local intuitive planning.

The study recommendations can be summarized as follows:

1. State and federal construction aids in urban areas over 5,000 population should be conditioned upon preparation of documented local comprehensive plans.
2. The State Highway Commission should offer limited planning assistance to insure the incorporation of regional planning needs and the preparation of technically sound and workable plans. The establishment of regional needs implies the preparation of a documented statewide long-range highway system plan by the State Highway Commission. State highway plan refinement should permit maximum use of local implementation devices. Quantitative study in local planning programs requires a team approach with the State Highway Commission represented.
3. Local plans should receive mutual adoption by the local planning commission, the local legislative body, and the State Highway Commission.
4. Adjustment of Federal-Aid systems should comply with local plans prepared and adopted as above.
5. Continuing assistance by District Highway Commission personnel is required upon plan completion.

INITIATION OF HIGHWAY COMMISSION ACTIVITY

The Highway Commission's first step was to develop central and district office staff to meet the urban planning job ahead. By March 1963, Systems Planning, Traffic Planning, and Land Planning Units had been staffed in the central office Planning Section and at least one engineer in each district was assigned urban planning responsibilities though in some cases this duty was part-time.

By this time the Planning Section was making frequent contact with the state planning agency in regard to procedural requirements which could be incorporated into the production of local plans so that they would conform more closely to what was reasonable and feasible in view of overall state highway needs and financing priorities. In early 1963, the state planning agency started work on the first "701" plan to be prepared by their staff, which was in addition to their continuing responsibility to administer plans prepared by private consultants. In response to the Planning Section's desire for coordination, working arrangements began to be formulated for direct Highway Commission participation in all "701" studies.

The Highway Commission with the review of the state planning agency issued its first policy memorandum on coordination with comprehensive community planning in August 1963. The policy memorandum outlined Planning Section responsibilities to supervise both the Commission's review of plans prepared by consultants and Commission participation in the formulation of plans prepared by state planning agency staff. The memorandum called for Commission activity in (a) the review of contracts, (b) the furnishing of data and advice, (c) the review and recommendation of planning proposals, and (d) the review of final plans.

The idea of contract review was adapted to our needs from an Illinois Highway Department procedure and, at the Planning Section's prompting, was backed up by a letter from the state planning director to eligible planning consultants. The letter required the Highway Commission to be contacted by consultants prior to finalization of local work programs. While the theme of the Highway Commission's policy statement was planning assistance and review, it was recognized initially that without some responsibility to guide, the usefulness of review would be limited.

To support the proposed review function, the Planning Section staff developed a plan review manual. A preliminary draft was distributed to district offices in September 1963. Taking into account the experience of other midwestern State Highway Departments, the manual was developed around a series of 88 questions designed to test the organization, research, analysis, plan development, and implementation phases of the local planning program. It was stressed that the review process should take place concurrently with the planning effort rather than await plan completion. The manual also contains procedures for and conditions of Highway Commission endorsement of local plans.

For those planning efforts undertaken directly by the state planning staff, district-central office Highway Commission personnel were to participate by providing (a) traffic volume data and projections, (b) determination of capacity, (c) data on existing or programmed area highway projects, and (d) recommendations for and an evaluation of the proposed transportation plan. In turn, at appropriate times, the state planning agency was to furnish to the Planning Section a population forecast and other socioeconomic projections and their probable distribution in the future land use plan.

Other steps taken by the Highway Commission to gear up for the planning assistance and review job centered on the task of training the district urban planning personnel. The training effort included the following:

1. An on-the-job training program was initiated in the central office using the Madison Area Transportation Study.
2. Personnel were sent to Northwestern University's two-week class in city planning for highway engineers.
3. Two 2-day discussion conferences were held with representatives of the state planning agency participating.
4. A lending library of planning texts was developed.
5. A coding index of planning topics was established and used for distributing a fairly constant flow of background materials.
6. Personnel were sent to the BPR Traffic Forecasting and Assignment course as frequently as positions were available.

POSITIVE RESULTS OF HIGHWAY COMMISSION INVOLVEMENT

After three years of joint effort by many persons to get the system in working order, and in spite of the many problems encountered, substantial progress has been made toward the achievement of Highway Commission objectives, as evidenced by the following:

1. As of August 1966, 29 of 49 completed plans by consultants (about 60%) had received comprehensive reviews by district personnel. Comprehensive review of plans completed prior to early 1963 has been given second priority to concurrent review of 38 additional consultant plans now under way. Reviews are not considered complete until a summary statement is on file in the central office proposing how the district can and cannot work with the community in implementing the plan. In other words, the Highway Commission is preparing to answer those local questions before they are asked.

2. As of August 1966, two consultant plans had been formally endorsed by the State Highway Commission. The plans for the two cities of some 8,000 and 33,000 population both include potential reroutings of state trunk highways which were defined by a combination of consultant-local initiative and Highway Commission technical guidance. Since August 1966, two additional plans for cities of some 5,000 and 11,000 population have been endorsed by the Highway Commission.

Local pressure to depart from the plans has been noticeably diminished in both cases by the process of mutual plan adoption. In one case the Highway Commission refused to endorse the plan until a local issue was resolved. The desire for state-federal aid overcame the local disagreement. (Currently, two potential endorsements are being held in abeyance in similar situations.) In the other case of endorsement, pressure arose after mutual adoption but was quieted quickly when it was recognized as a step backward in state-local cooperation. The Highway Commission is proceeding to implement recommended relocations in one plan and is studying a plan to comprehensively adjust local Federal-Aid systems in accordance with the other. It should be noted finally that the Highway Commission did not actively solicit local requests for endorsement until early 1966 when completion of the overall state highway plan was imminent.

3. District-central office Highway Commission personnel have worked with the state planning staff to complete nine comprehensive plans for communities of less than 5,000 population. All but one of these plans (for a community which is not on a state trunk highway) have involved the joint consideration of highway-land use relationships by the two staffs. Proposals have been developed for potential route reservation, access control, and land use regulation which will affect the operation of the future state highway system. The Commission staff has been given sufficient latitude in report review so that the position on future highways can be carefully stated in the final reports. This becomes particularly important when state highway corridor planning has not been finalized in the vicinity of the particular community. Such state agency coordination has been a primary objective of local plans prepared by the state planning staff. Twenty-three additional planning programs of this type have been initiated, including three for cities over 5,000 population.

4. A positive result related to No. 3 above is that the good working relationship with the state planning agency staff has brought the planning and engineering disciplines closer together through the direct exposure to each other's assumptions and plan development criteria in state-prepared plans. In turn, this process of education has promoted a more realistic state agency review of plans prepared by consultants.

5. Of primary importance to the Highway Commission has been the good working relationship established between district urban planning personnel and local planning commissions in "701" planning. In many instances, involvement in local meetings by district personnel has resulted in beneficial use of highway data and better understanding of regional highway needs by local planning agencies. A partial listing of planning services provided to local planning efforts by the Commission includes (a) adjusting the local traffic counting program to better serve "701" planning needs; (b) providing copies of right-of-way plats; (c) providing readily available aerial photography and contour mapping; (d) providing information on design standards and cost data; (e) giving advice on the local use of traffic control devices, channelization, one-way streets, etc.; and (f) explaining long-range Highway Commission planning as expressed in the recently adopted functional highway plan.

TABLE 3

MINIMUM TRAVEL HABIT STUDY REQUIREMENTS

Population Size Group	External Information Requirement			Internal Information Requirement		
	Roadside Interview	License Plate	Post Card	Home Interview	Telephone Survey	Internal Cordon
0-999	—	—	—	—	—	—
1,000-4,999	P-1	P-1	P-1	—	—	—
5,000-9,999	P-2	P-2	P-2	P-1	P-1	P-1
10,000-24,999	M	—	—	P-2	P-2	P-2
25,000-50,000	M	—	—	M	—	—

Key:

— = No Requirement
P-1 = Possible Requirement (if appropriate)
P-2 = Possible Requirement (some survey required)
M = Minimum Requirement

Note: The exercise of "P's" is dependent upon individual community characteristics, such as total approaching volume exceeding 4,000 ADT, and considerations of the community's economic function, internal street system, and barriers to traffic flow.

The benefits of this working relationship are two-way. Urban planning personnel have reported learning something new and important for future highway planning from local plan review in each district—factors such as proposals for local land development, local desires concerning service from regional routes, and local street extension plans. This information is put to real use when the Highway Commission wants to investigate new highway locations near the community.

It can be stated generally that since the Highway Commission initiated its formal policy of coordination with local planning in August 1963, district urban planning personnel have actively participated in the formulation of arterial highway proposals in most if not all local planning programs. There have been differences of opinion but the team approach is resulting in the preparation of many plans which the Commission would be willing to endorse if requested.

6. Involvement in local planning commission meetings has basic administrative benefits as well. Through written reports submitted by district urban planning personnel, the central office Planning Section can keep up-to-date on local planning throughout the state. The meeting reports are also valuable as (a) background information for preparing formal plan endorsements, (b) a source for reporting current reactions on planning programs to the state planning agency, (c) a means of informing central office design and right-of-way personnel of pertinent local information, and (d) a source document for reconstructing Commission involvement in a local planning program at any later date.

As a conclusion to the positive results of Highway Commission involvement in local "701" planning it can be stated that this program has brought the Commission and communities closer together and improved the communications gap which once existed. The Commission's first uncertain reactions to the "701" program have been replaced by the attitude that this program is an integral part of overall highway planning effort.

PROBLEMS ENCOUNTERED IN HIGHWAY COMMISSION INVOLVEMENT

Positive results such as those listed can serve as a comforting reminder that an agency is on the right track, but the continuing improvement of agency policy requires a close look at problem areas as well. The following problem areas are arranged in the approximate order of occurrence in the planning process.

1. Some consultants have reacted unfavorably to Highway Commission review of their local work programs. The primary conflict is the additional program cost re-

quired to meet Highway Commission desires for more quantitative and comprehensive studies of transportation needs. As an initial goal, for example, the Planning Section set up the suggested guidelines for O-D surveys given in Table 3. Considering the typical costs of early "701" plans in Wisconsin and the requirement of the consultants to undertake balanced planning programs, the guidelines for communities between 5,000 and 25,000 population became particularly unpalatable.

A Planning Section study of contract costs in October 1963 indicated a typical cost of $12,500 for a plan for a Wisconsin community of 5,000 population. About 10 percent of total contract cost seems to be the guideline for transportation analysis in the small community plans. Ten percent of $12,500 might finance a one- or two-station external survey, assuming current Commission costs, and even then would leave little monies for other aspects of transportation analysis. Consultant concern is most evident from smaller planning firms with limited traffic survey, analysis, and forecasting experience; this would be more costly to them because it requires extensive preparation and research.

2. The Highway Commission has had to overcome some concern by the state planning agency that it might be encroaching on their established responsibility of negotiating contracts with consultants for "701" planning work. It was evident that the well-developed working relationship with the state planning agency might be jeopardized by continued insistence on a critical review of contract details. We were, after all, to a certain degree participating in the "701" planning process at the invitation of the state planning agency. A compromise was finally reached whereby copies of signed contracts were available to us to aid in plan review.

3. A corollary to the problems in contract review was the occasional tardiness of the Highway Commission's invitation into the local planning process. In the opinion of the author, involvement at the data-gathering stage is too late. There have been cases of consultants attacking the wrong highway planning problems, doing unnecessary traffic analysis, and ending up with a plan that satisfies neither the local community nor the Highway Commission. In one case, the Highway Commission was seeking a consensus at the local level on refined highway locations, but found instead an unnecessary concentration on establishing corridor traffic desires which had previously been estimated by the Commission. In other cases where regional transportation studies were pending, detailed local transportation studies might simply have been deferred. In still others the Commission might have recommended special studies related to the most pressing area needs. There have been, of course, many cases where the Highway Commission and the consultant's staff have collaborated in work directed toward the salient problems.

4. Being very familiar with highway planning data, district-central office staff have occasionally overestimated the clarity of such data to consultants and local planning commissions. One consultant, for example, misinterpreted a proposed drainage-way on a right-of-way plat to be a future roadway. Traffic data, assignments and capacities can also be misinterpreted unless they are carefully explained by Highway Commission traffic engineers. The various ways that traffic counts must be factored, the ways that assignments must be adjusted, and new capacity concepts are all subjects for local education.

5. It has been the position of the Highway Commission that it should not be alone in endorsing a local plan; the plan must first be adopted by the plan commission (as provided by state statute) and endorsed by the local legislative body (usually by resolution). One of the unexpected problems encountered in local plan review has been the hesitancy of some local units of government to adopt and endorse their own plans. This formal acceptance is often withheld because the benefit is not apparent to local units of government, or because the community is split on acceptance of one or more plan elements. This delay in local plan acceptance has required that some urgently needed highway improvements be made prior to plan endorsement. This action in itself eliminates some of the enticement to mutual plan adoption. In other words, the local unit already has part of what it wants. This should happen less frequently as plan adoption becomes a more accepted practice in Wisconsin.

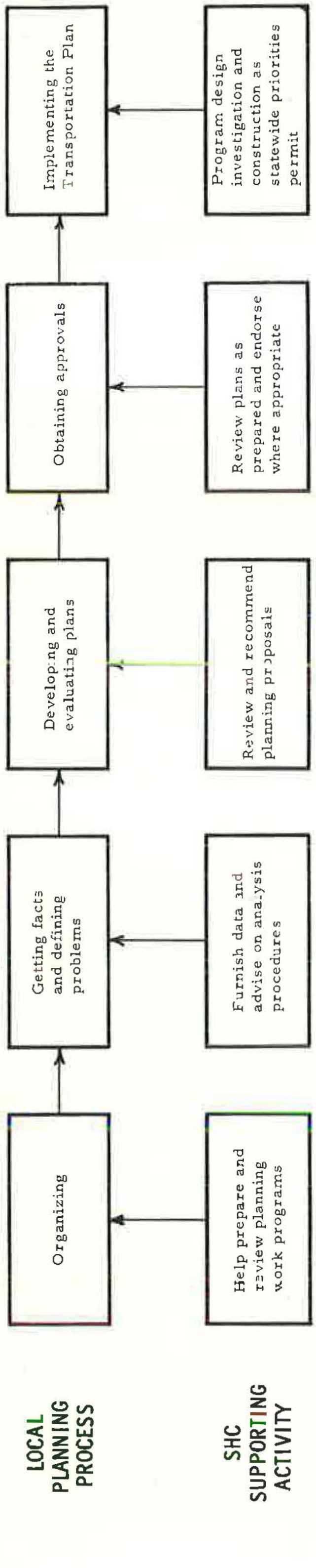

Figure 2. State-local planning cooperation.

Since Highway Commission adoption of a state highway plan has been imminent for several months, the Planning Section has been actively promoting local adoption and endorsement of plans and subsequent requests for Highway Commission endorsement. This promotion effort has included letters to localities from district offices when there seemed to be a reasonable chance for mutual plan adoption. The responses show a definite interest by many communities once they are approached directly.

SOME SUGGESTED POLICY MODIFICATIONS

Brand-new approaches to liaison with "701" planning are not required in Wisconsin. However, some modifications to a basically workable policy are suggested.

Local planning assistance must be offered by the Highway Commission prior to the contract-writing stage. Simply stated, the Commission needs to get in on the initial problem definition stage (Fig. 2). A good start has been made recently in conjunction with revised procedures of the state planning agency. That agency is now attempting to guide the preparation of general work programs for communities before the community talks to consultants. As a result of recent discussions with the state planning staff, the Highway Commission is now being asked to help define local transportation planning needs. The Planning Section of course relies on the district offices for initial recommendations based on their local knowledge. Initially a few reports of "no problems" were received, but now some rather long and interesting memos describe in detail the need to work out particular highway location and protection problems with the community involved. Every effort should be made to inject these real problem issues into the local planning process, even if pertinent Highway Commission planning is still in its preliminary stages. The alternative to this is the risk of promoting planning programs which attack vague and unreal problems of little importance to anyone.

With problem areas generally defined, the process of contract review also becomes more meaningful. Concentration on isolated contract detail can be replaced by concern with overall contract conformance to planning needs. If expensive traffic analysis is required, it can be more readily justified when related to problem issues. On the other hand, the Planning Section needs to develop more refined criteria for determining if a consultant should be required to prepare any traffic forecast at all. Local problems may simply not be directly related to traffic volume but rather to such items as circulation pattern, parking, traffic mix, access to major routes, and neighborhood disruption. Finally, it is believed that increased Highway Commission involvement prior to the contract writing stage as described could preclude the need for involvement in contract negotiation itself.

A valuable service can be performed for "701" planning by providing local planning programs with traffic forecasts available in the Planning Section. This is now being done to an increasing degree. Just as local population forecasts should be expected to be compatible with state and regional forecasts supplied by the state planning staff, so should local traffic forecasts be expected to be compatible with the statewide assignments being developed as part of the state highway plan effort. The requirements for expensive traffic forecasting by consultants on local routes should be carefully evaluated in all cases. This suggestion can only be achieved through earlier involvement in local planning programs.

There is a need for the Planning and Research Division to make available guidelines to consultants and communities for the use of highway planning data available in the central and district offices. Enough experience has been gained in working with communities to begin to formalize recommendations for local use of such data. Specifically, it is recommended that a publication be prepared on the multiple use of highway planning data. This will aid efforts to get the Highway Commission and local communities talking the same language on the subject of highway planning.

Increasing use can be made of recent products of the state highway planning program to strengthen and support local planning. Already the meaning of the various elements of the functional system plan for local planning is being realized by the state planning agency, consultants, and others. There is general recognition that the highest type of arterial is planned to serve the longest trips with highest mobility, while increasing amounts of land access may be provided by successively lower types of arterials. The Commission's freeway-expressway plan, based on the functional plan and future traffic volume, is generally indicative of the need for future relief routes or bypasses and should permit a general estimate of right-of-way widths required. In short, local plans can be and are now being prepared within a framework of established regional needs.

However, all of the preceding is not enough to achieve detailed state-local plan coordination. Potential opportunities exist for preserving future highway right-of-way, planning access arrangements properly related to future local street systems, developing guidelines for land development adjacent to arterials and intersecting roads, etc. Such coordination will require accelerating refinement of the initial functional highway plan in some areas. High priority should be given to preliminary design investigations to finalize centerline locations where opportunities for coordination with local planning exist. A recent step forward has been the preparation of a statewide priority plan for preliminary design investigations which take into account the need to reserve highway right-of-way in rapidly developing urban fringe areas.

If the initial "701" planning investment is to bring about lasting state-local coordination, the Commission must increase its efforts to stimulate continued local planning and volunteer to participate with the community in this activity. One-time cooperation in plan implementation will not be enough; contact must be maintained for plan reevaluation purposes. Commission endorsement letters of local plans specifically call for plan updating within five years. The Commission now has a plan of its own to review and update, which will require local reaction and feedback. One district urban planning supervisor recently visited all communities in his district having completed plans and questioned their current status. This example should be followed in the other districts. Commission personnel could sit on local technical coordinating committees which would meet at appropriate intervals. The basic steps in Figure 2 could be repeated on a selective, limited basis. Whatever the solution, the valuable state-local interaction stimulated by the "701" program should be maintained.

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Principles of Transport Systems Analysis

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Nine principles for the analysis of transportation systems are presented. The primary purpose of these principles is to identify the common threads underlying a great variety of seemingly disparate transportation problems, and so to stimulate the development of a "transportation science." The principles are equally applicable to urban transportation, megalopolitan transportation, developing country transportation, and strategic mobility.

The first five principles pertain to the scope of the system—the components of a transportation system, the modes and movements in a system which must be considered, and the nature of a transportation system as a particular form of "market." The second group of four principles pertains to the problems of analysis—the spectrum of potentially available transportation and non-transportation options, the objectives of transportation, and the relevant impacts.

To illustrate these principles, the paper concludes with a discussion of their application to two specific problems, urban transportation and strategic mobility.

•THE purpose of this paper is to present for discussion a set of principles for transport systems analysis. The accumulated experience of analysts, planners, and researchers working on many different transportation problems has yielded observations and insights which are applicable to a large number of such problems. These insights lead to new ways of looking at transportation systems problems. The principles proposed here have been developed in an attempt to summarize these insights and emphasize their generality.

The primary purpose of the principles is to identify the common threads underlying a great variety of seemingly disparate transportation problems, and so to stimulate the development of a "transportation science." A secondary purpose is normative—it is hoped that the principles will be useful as guidelines for analysis and will serve as a checklist for preventing the simplest yet most grievous analysis errors. However, like all generalities, these principles cannot be more than tests and guides; the realities of analysis are such that the analyst will always need to judge for himself what approximations and compromises may be necessary in the context of a specific problem. The principles can never be adhered to rigidly, but are objectives of analysis; whenever they are deliberately violated, the analyst should clearly so state.

The principles presented here should be considered tentative. Of course, they reflect the biases and experiences of the author. Through wide discussion and through testing against new transportation problems, they will be refined and amplified over time.

The principles themselves fall into two major groups. The first set, Principles I through V, identifies the system of concern—what must be incorporated in an analysis of a transportation system, and what significant interactions within that system must be considered. The second set, Principles VI through IX, considers the problem of analysis—what options or alternatives are potentially open to the analyst, and what factors must be considered in reaching a decision. The principles are summarized in Figure 1.

Paper sponsored by Committee on Transportation System Evaluation and presented at the 46th Annual Meeting.

GROUP A. THE SYSTEM

Principle I. The basic components of a transportation system are:
a. the persons and things being transported;
b. the vehicles in which they are conveyed;
c. the networks of links and nodes through which the vehicles move.

Principle II. All movements through the transportation system must be considered.

Principle III. Movements must be considered from their initial origin to their final destination.

Principle IV. All modes of transportation must be considered.

Principle V. A transportation system is a particular form of "market," in which supply and demand reach equilibrium within the constraining channels of the transportation network. Specifically:
a. a number of level-of-service variables are necessary to define the interaction between supply and demand;
b. the volume, composition, and time dependency of the demand for transportation depend upon the level of service at which transportation is supplied;
c. the level of service supplied by a transportation system depends (for given resource inputs) upon the volume, composition, and time variation of demand;
d. determining the level of service at which supply and demand are in equilibrium in a particular context is usually computationally difficult, because of the complexity of the transportation network and of the transportation demands.

GROUP B. THE ANALYSIS PROBLEM

Principle VI. The spectrum of potentially available transportation options includes decisions about:
a. routing and time schedule for a particular trip or shipment;
b. system operations, including routing and scheduling of vehicles, pricing, and types of service offered;
c. changes in non-fixed resources, such as vehicle characteristics and availabilities, and procurement of new equipment;
d. changes in fixed facilities, such as link and node characteristics, and network structure;
e. introduction of basically new transportation technologies, including vehicles, fixed facilities, and operating policies.

Principle VII. Transportation is not an end in itself.

Principle VIII. There are a variety of transportation-related options available; particularly important are those which can influence directly or indirectly the demand for transportation.

Principle IX. There is a spectrum of direct and indirect impacts of transportation relevant to the choice among alternative systems and policies.

Figure 1. Principles of transport systems analysis.

The principles are enunciated with a spectrum of transportation system contexts in mind. These include: (a) urban transportation—the problem of providing integrated multi-mode transportation systems (with highway, mass transit, rail, and other modes) to meet the evolving needs of a metropolitan area; (b) megalopolitan transportation—the problem of providing high-speed transportation among the cities of a highly urbanized region; (c) developing-country transportation—the problem of determining appropriate investments in transportation facilities to best achieve overall socioeconomic development objectives; and (d) strategic mobility—the problem of determining the most efficient set of transportation capabilities to best achieve national strategic objectives through rapid deployment of military forces. Transportation analysts have been involved in analyzing problems in each of these contexts, and can expect to confront an even broader range of transportation system problems in the future.

After presenting the proposed principles, their application to two specific contexts, urban transportation and strategic mobility, is discussed. These examples will demonstrate, it is hoped, the applicability and utility of the principles to any transportation systems problem.

THE PRINCIPLES

Principle I

The basic components of a transportation system are (a) the persons and things being transported; (b) the vehicles in which they are conveyed; and (c) the networks through which the vehicles move.

The purpose of this principle is to establish what we mean by a "transportation system." One level of description is the pattern of flows of persons and things through the system. These flows are constrained by the channels of the network, but for many kinds of analyses we may conceivably ignore the description of the physical facilities and simply show the patterns of flow, as, for example, in the pattern of grain flows across the United States, or of work trips in a metropolitan area.[1]

[1]Edward L. Ullman, American Commodity Flow, Univ. of Washington Press, Seattle, 1957; Walter Isard, Methods of Regional Analysis, Ch. 5, MIT Press, New York, 1960; Chicago Area Transportation Study, Final Reports, Vol. 1-3.

Vehicles are the containers which provide the interface between the items being transported and the fixed facilities of the network, such as the roadway. In such modes as rail, highway, and air, the vehicles are obvious, and the distinction of vehicles from other facilities is highly relevant for analysis. In such modes as pipelines or conveyor transportation, or movement of pedestrians on foot, while there is no vehicle as such, there is still some kind of interface between the goods and fixed facilities.

Networks consist of nodes and of links connecting various pairs of nodes. Each link corresponds to a specific transportation channel. Links may be well defined, such as rail lines, highways, controlled airways, or sidewalks, or may be relatively diffuse, as in uncontrolled air or sea travel, or off-the-road vehicles. Some nodes may be interchange points between links of the same mode, such as highway interchanges or rail yards. Other nodes may be interchange points between links of different modes, as a rail, bus, or airline terminal typically is. The paths of vehicles in a network are through a succession of links and nodes.

This principle has several important implications for analysis. First, our primary concern is with the things being transported. Second, the consideration of networks emphasizes that vehicles interact over space and time, competing for the limited capacities of the links and nodes, and flowing through the networks in a variety of interacting paths. These implications are expanded in Principles II through V.

Principle II

All movements through the transportation system must be considered. The resources in the transportation system are used for the transport of a variety of persons and things. Changes in the movements of one set of items through the system will, in general, impact upon the movements of others. For example, design of transportation terminals for air, rail, and other modes must consider the flows of baggage and other freight, as well as passengers; urban transportation planners must consider the patterns of goods movements throughout a metropolitan area, not just person trips, and must consider trips for purposes of shopping and recreation, not just trips to and from work. Identification of the full spectrum of persons and things potentially or actually moving through a particular transportation system is an important task.

Principle III

Movements must be considered from their initial origin to their final destination. To study adequately the flows through the transportation system, the analyst must trace the full history of each class of trips. One example is intercity air travel, where attention has been focused on the air leg between airports, with the result that little consideration has been given to the problem of getting the traveler to the airport from his initial origin, and from the airport to his final destination. Another example is the rapid growth of containerization, and particularly container ships, due partly to recognition of this principle. Besides increasing utilization of the ships and other vehicles, containerization also achieves more effective service for the customer over the full origin-to-destination movement of the commodity.

More attention to this principle is essential to increased effectiveness of the transportation system. Clearly, more important than the speed of one particular mode or link is the performance of the transportation system as a whole in carrying the movement from initial origin to final destination. In particular, this principle focuses attention on the interface between modes—the interchange nodes and their characteristics. In the sequence of modes between origin and destination, increasing the speed of one mode may not reduce the total trip time significantly if the speeds of other modes are low or the interchange functions are inefficient.

Principle IV

All modes of transportation must be considered. In order to analyze movements from origin to destination, we must include in the transportation system under study all modes actually or potentially utilized by the full set of movements. Thus, if our problem

Time

total trip time
reliability—subjective estimate of variance in trip time
time spent at transfer points
frequency of service
schedule times

Cost (to user)

direct transportation charges
other direct operating costs (loading, documentation, etc.)
indirect costs (warehousing, interest, insurance, etc.)

Safety

probability of fatality (or destruction of cargo)
probability distribution of accident types (shock vibration, damage, etc.)

Comfort and Convenience

number of changes of vehicle
physical comfort
psychological comfort (status, privacy, etc.)
other amenities (baggage handling, ticketing, etc.)
enjoyment of trip
aesthetic experiences

Figure 2. Level-of-service variables.

deals with intercity air travel, we must include not only the inter-airport leg, but also the ground transportation distribution system within both the origin and destination metropolitan areas, and the flows within the air terminals themselves.

Obviously, the conception of "mode" here is very broad. The various modes will include the full range of technologies, from air, rail, highway and water, to pipeline, conveyor, and pedestrian, and whatever variants and new technologies may potentially be applicable.

Principle V

A transportation system is a particular form of "market," in which supply and demand reach equilibrium within the constraining channels of the transportation network. Specifically: (a) a number of "level of service" variables are necessary to define the interaction between supply and demand; (b) the volume, composition, and time dependency of the demand for transportation depend upon the level of service at which transportation is supplied; (c) the level of service supplied by a transportation system depends (for given resource inputs) upon the volume, composition, and time variation of demand; and (d) determining the level of service at which supply and demand are in equilibrium in a particular context is usually computationally difficult because of the complexity of the transportation network and of the transportation demands. This principle identifies a major source of difficulty in transportation systems analysis, namely, the peculiar characteristics of the market for transportation. It has long been recognized in some areas of transportation[2] that predicting the flows in a transportation system is a problem in the prediction of the equilibrium between supply and demand. However, the simple textbook examples, such as the "cobweb" computation for determining this equilibrium,[3] are far from the complex realities of the transportation market.[4]

Whereas, in simple economic theory supply and demand are given as functions of a single variable, "price," in transportation the equivalent variable is in general multi-dimensional. The supply of and demand for transportation depend upon a number of characteristics of the transportation service provided, not just direct price in dollars. A sample of these "level-of-service" variables is shown in Figure 2. Generally, users of transportation in making their decisions consider several characteristics. An air traveler considers not only cost and expected travel time, but also safety, comfort, and possible variations in travel time. Automobile drivers may often pay higher tolls to save time, or may take longer, more scenic routes for greater driving enjoyment.

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[2] For example, Haskel Benishay and Gilbert R. Whitaker, Jr., An Empirical Study of Transportation Supply and Demand Relationships, Papers Fourth Annual Meeting, Transportation Research Forum; or, Ralph E. Rechel, Issues in Pricing Metropolitan Area Passenger Service—Public and Private, op.cit.; and many others.

[3] See, for example, William J. Baumol, Economic Theory and Operations Analysis, Prentice Hall, Englewood Cliffs, 1965.

[4] For a discussion of some aspects of these computational difficulties, see Alan Hershdorfer, Predicting the Equilibrium of Supply and Demand: Location Theory and Transportation Flow Models, Papers Seventh Annual Meeting, Transportation Research Forum, 1966.

Because of the spatial characteristics of transportation, demand is also spatially distributed. Further, the magnitude and composition of that demand will vary over time as well as over space. For example, consider the variation in intercity air travel demand among the following cases: Monday morning on a normal workday, eight o'clock on a Saturday night, or the Wednesday before Thanksgiving at a major U. S. airport.

Similarly, the level of service at which transportation is provided will vary spatially and over time; level of service responds to demand in a highly complex way because of the many interactions among flows in their movements over the transportation network. The interactions of autos in an urban road network during rush hours are a good example. In such a saturated and unstable system, a minor bottleneck quickly cascades over the system, causing breakdowns in service over a wide area.

In recent years, increasing attention has been paid to the problem of predicting the equilibrium flows in multi-mode transportation networks.[5] Approaches range from the purely predictive to the prescriptive. The "traffic assignment" techniques of urban transportation planning[6] attempt to predict the equilibrium distribution of flows resulting when each traveler is free to make his own decision about his path through the multi-mode network. On the other hand, such techniques as linear programming, Ford-Fulkerson network flow theory and scheduling algorithms attempt to prescribe the flows so as to achieve some type of overall "optimum."[7] Aside from the problems of obtaining functional representations for demand and supply, the problem of predicting equilibrium still remains a difficult one, in spite of these advances.

Principle VI

The spectrum of transportation options potentially available includes decisions about: (a) routing and time schedule for a particular trip or shipment; (b) system operations, including routing and scheduling of vehicles, pricing, and types of service offered; (c) changes in non-fixed resources, such as vehicle characteristics and availabilities, and procurement of new equipment; (d) changes in fixed facilities, such as link and node characteristics, and network structure; and (e) introduction of basically new transportation technologies, including vehicles, fixed facilities, and operating policies. By this principle, we attempt to summarize the range and variety of transportation options open to decision-makers in various contexts. The individual traveler or potential shipper sees the transportation system as essentially fixed; by and large, he can only choose his own particular routing and time schedule through the system. In the area of operating policies and decisions, the carriers have the options of establishing the routings and schedules of the vehicles, pricing, and a variety of other factors such as meals, cleanliness, handling procedures, and reliability which determine the level of service available to the user of transportation, including time, cost, comfort, and other characteristics. (These carrier options are of course often subject to regulatory or other institutional constraints.) The next level of options adds the additional dimension of vehicle procurement—options about what types, numbers and availabilities of vehicles there will be in the system. Purchase of new equipment, modification of old equipment, repositioning (basing) or leasing options fall under this general heading.

Beyond the level of vehicles, there are the options of changes in the structure and characteristics of the network—additions of new links or abandonment of old ones; changes in the operating characteristics of links, such as highway widening or resurfacing, signalization of a rail line, or dredging of a river; and changes in the basic structure of the network, such as adding a subway system to a metropolitan area, or implementing the Interstate and Defense Highway System nationwide, or assigning a new type of carrier operating rights in a certain market. Finally, the broadest set of options relaxes everything, and allows the introduction of basically new transportation technologies—new vehicles, new networks, new operating policies, etc., such as the

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[5] Hershdorfer, op. cit.

[6] Brian V. Martin, Frederick W. Memmott, and A. J. Bone, Future Demand for Urban Travel, MIT Press, Cambridge, 1966; Brian V. Martin and Marvin L. Manheim, A Research Program for Comparison of Traffic Assignment Techniques, Highway Research Record 88, 1965, pp. 69-84.

[7] Hershdorfer, op. cit.; L. R. Ford and D. R. Fulkerson, Flows in Networks, Princeton Univ. Press, 1962.

new technologies being investigated for the high-speed ground transport system in the Northeast Corridor of the United States.[8]

The objective in voicing this principle is to prevent the analyst from unduly constraining his analysis to a restricted set of options. However, the full set of options will rarely be open to one single agency or organization. Then too, types of options differ in the time frame in which they can be implemented; specific trip decisions can be implemented rapidly, but network changes and the introduction of a new technology may take years to accomplish. Still, it is up to the analyst to insure that the potential options are explored and pointed out to the relevant decision makers. For example, consider a shipper, who will ordinarily choose among a number of available routings together with their associated time and other level-of-service characteristics. He has the option of negotiating new rates, or, over the longer run, attempting to develop in coordination with a carrier new equipment more suited to his traffic.

Principle VII

Transportation is not an end in itself. This principle emphasizes that the ultimate objective in providing transportation is to fulfill some broader public or private objectives. The cliché that transportation adds "place utility" to an object expresses this. The broader objectives of transportation may be to stimulate economic development, to channel the growth of a metropolitan region, to bring goods to the market, or to deliver military forces where they can be an effective instrument of national policy.

Principle VIII

There are a variety of transportation-related options available; particularly important are those which can influence directly or indirectly the demand for transportation. As soon as it is recognized that transportation is not an end in itself, then clearly transportation decisions must be accomplished in concert with decisions in a variety of transportation-related areas. In particular, many types of non-transportation decisions will have significant effects on the demand for transportation. For instance, the distribution of demand over space, over time, and by type of transportation service desired, will be affected by national economic policies, in the case of the demand for freight movements; by influences on differential regional growth, in the case of intercity air travel; by staggering of work hours, and land use controls such as zoning and the provision of public utilities, in the case of metropolitan commuter transportation; and by distribution and inventory policies, in the case of military and industrial logistics systems.

The degree of influence which the transportation analyst can exert over such non-transportation variables may vary widely. However, the analyst must clearly recognize the existence of such variables, and must carefully explore their potential use in the context of his particular transportation problem.

Principle IX

There is a spectrum of direct and indirect impact of transportation relevant to the choice among alternative systems and policies. Clearly, as a consequence of Principle VII, impacts beyond the bounds of the transportation system must be considered.

The spectrum of impacts of transportation can be broken down into dollar-valued and non-dollar-valued, and further broken down by their incidence among different groups or elements in society. One useful set of distinctions is:

1. dollar costs
    a. capital investments in vehicles and fixed facilities
    b. dollar-valued operating costs
    c. dollar-valued changes in costs borne by users of the transportation system (shippers and travelers)

[8] Edward Ward, Prospective New Technologies, Papers Seventh Annual Meeting, Transportation Research Forum, 1966.

2. non-dollar-valued costs
   a. borne by the users of the system—aspects of level of service variables other than dollar-valued
   b. impacts on non-users of the system

ILLUSTRATION OF THE PRINCIPLES

We will now briefly illustrate the application of these principles to two specific transportation systems problems.

Example I: Urban Transportation

The last 15 years have seen a major growth, not only in the transportation facilities of urban areas, but also in the outlook and frame of reference of those professionals charged with planning urban transportation systems. The evolution of urban transportation planning has brought about a major stimulus to the development of a comprehensive transportation system approach. The following discussion illustrates the role of the principles in this problem area.

In metropolitan transportation, the frame of reference historically has shifted from a concern solely with highways to integrated planning for highways, arterial streets, and rapid transit systems. The complete metropolitan area transportation system (Principle I) includes the intra-urban modes, such as highway, arterial, and local streets, buses, commuter rail and rapid transit, and also the interfaces with inter-urban modes, such as rail, air, and bus. The movements through the system are both people and goods (Principle II). Person trips of interest are primarily commuting trips between home and work, but recreational and shopping trips are also significant. Except for relatively minor consideration of truck traffic, metropolitan area transportation planning on the whole has been deficient in considering goods movements within the urban area, and the intra-urban distribution function for inter-urban goods movements by rail, truck or air has received little attention. For that matter, little special attention has been paid to the intra-urban trip of the inter-urban traveler, from airport or train station to office or home, for example.

With respect to highway and rapid transit, there has been some consideration of the total origin-to-destination trip (Principle III). Again, it is primarily on the intra-urban legs of intercity trips that this principle has been violated. In most current studies, all currently available modes of transportation are being considered, including rail commuter, highway, subway, and bus, though sometimes the option of express bus on separate right-of-way is not evaluated (Principle IV). In the Northeast Corridor (but not to my knowledge in any metropolitan area study), attention is being given to basically new technologies, such as VSTOL.[9]

The major development in urban transportation planning in the last decade has been the development of techniques for computing the equilibrium between supply and demand (Principle V). These are structured in a way which leads to some significant computational and conceptual difficulties, but the sequence of steps involved—trip generation, calculation of zonal interchange volumes, modal split, and traffic assignment—is well developed[10] and institutionalized, perhaps too institutionalized. The level-of-service variables used are commonly out-of-pocket costs including tolls and parking charges, travel time door-to-door, and some measure of "comfort and convenience."

The metropolitan transportation studies have focused primarily on options with regard to changes in networks—more particularly, stimulated by legislative requirements, highway network changes of significant magnitude (Principle VI). Relatively little attention has been given to links of other modes, except mass transit, or to the inter-modal interchanges or terminals. Some consideration has been given to options

[9] See, for example, Robert Simpson, Future Short-Haul Air Transportation in the Northeast Corridor, Papers Seventh Annual Meeting, Transportation Research Forum, 1966.

[10] Martin, Memmott and Bone, op. cit.; Hershdorfer, op. cit.

of new technologies, though not much, and almost no attention to changes in the characteristics of the existing automotive vehicles (though minor changes in both mass transit and rail commuter vehicles have been addressed and implemented). No attempt has been made to explore ways of controlling the routes taken by private autos or the times at which they travel; occasionally pricing, to the extent of tolls and parking charges, has been investigated.

For many years, much verbal attention has been paid to the idea that transportation is only one instrument of metropolitan planning[11] and that the objectives of transportation planning are to contribute to the guiding of metropolitan growth in desired directions (Principle VII). In practice, however, there is some question as to the actual extent to which this philosophy has been implemented. More often than not, independent projections of land use development are used to define the needs for a transportation system, and no explicit attempt is made to test transportation system plans to choose that one which steers growth in the desired direction (Exceptions: Penn-Jersey, Southeastern Wisconsin). Although staggering of work hours and segregation of traffic, including prohibitions of vehicles from key central areas, have been discussed, in general they have not been put forward and analyzed as transportation-related options (Principle VIII). However, some studies have addressed possible uses of land use controls (zoning) and provision of public utilities (sewer, water, electricity) as ways of shaping demand through channeling metropolitan growth.

In evaluating transportation alternatives, there has been a strong emphasis on cost-benefit analysis. This has encouraged analysts to address only those impacts of a proposed system which could be relatively easily transcribed into dollar equivalents for decision-making. With just a few exceptions,[12] the difficult, non-dollar-valued impacts, such as disruption of neighborhoods, have been left out of the transportation planning calculation with the result that the issues have become part of the political arena (Principle IX).

To summarize, in urban transportation planning, we do see some adherence to the principles. Furthermore, by applying these principles, we get an indication of possible gaps in the way current analyses are being accomplished.

Example II: Strategic Mobility[13]

The basic problem in "strategic mobility" is to deploy large military forces to selected areas of the world as rapidly as necessary to achieve strategic objectives. At first glance, the strategic mobility problem would seem to be totally different from that of urban transportation. Yet they are both transportation systems problems and so the principles apply.

In strategic mobility, the transportation system is potentially the entire worldwide transportation system, including military and nonmilitary vehicles and networks, all modes—air, sea, rail, highway, etc., and in the United States as well as around the world (Principle I). The movements through the system which must be considered in

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11 William W. Nash, Roland B. Greeley, and Marvin L. Manheim, Interdependence of Transportation and Land Use Planning, Staff report to the U.S. Bureau of Public Roads, Joint Center for Urban Studies of MIT and Harvard, Cambridge, 1960; John R. Meyer, John F. Kain, and Martin Wohl, The Urban Transportation Problem, Harvard Univ. Press, Cambridge, 1965.

12 William W. Nash and Jerrold R. Voss, Analyzing the Socio-Economic Impacts of Urban Highways, HRB Bull. 268, 1960, pp. 80-94; Marvin G. Cline, Urban Freeways and Social Structure: Some Problems and Proposals, Highway Research Record 2, 1963, pp. 12-20; Donald Appleyard, Kevin Lynch, and John Meyer, View From the Road, Highway Research Record 2, 1963, pp. 21-30, also published by MIT Press, 1964.

13 Marvin L. Manheim, An Overview of Strategic Mobility and Its Implications for the Design of Analysis Systems, paper presented to the NATO Advisory Panel on Operations Research Conference on the Analysis of Military Transportation Systems, Oxford, England, July 1966; Lawrence E. Lynn, The Analysis of Strategic Mobility Problems, Papers Seventh Annual Meeting, Transportation Research Forum, 1966.

analysis (Principle II) are the troop units being deployed, including personnel and equipment; individual personnel enroute to or from the various theaters; and supplies and equipment to support the deployed forces after arrival, and to support forces already stationed around the world.

For the majority of elements to be transported in a rapid deployment, the initial origin is a home station in the United States and the destination a location in the objective theater (Principle III). While the airlift and sealift phases of these worldwide moves have received much attention in analyses, the phases of movements through the United States and other surface transportation systems have not been adequately studied. This historical fragmentation of concern is only now being overcome by a "from-origin-to-destination" approach, with due consideration of all potential modes (Principle IV).

The market aspects of strategic mobility are much more subtle than in urban transportation (Principle V). Here there is no set of independent consumers, creating through their aggregate behavior a demand function for transportation. Rather, in current practice, a theater commander or other strategic planner will formulate his requirements for movements of troops and supplies at a fixed level; that is, demand is set exogenously. The problem of the transportation analyst, then, is restricted to simply determining whether available resources are sufficient to deliver the movement requirements by the specified times. However, in practice, when the theater commander who submitted the plan finds that there are insufficient mobility resources to meet his requirements, or that there is excess capability potentially available to him, he will in fact go back and reformulate the movement requirements. Thus, the basic idea of finding an equilibrium is present, except that the demand is moved up and down by the deliberate actions of the theater commander, not by uncontrolled aggregate behavior. In this case, the level-of-service variables are predominantly (a) time of arrival in theater relative to time required (in accordance with the desired strategic response), and (b) the time it takes to marry up all the components of the fighting force (when personnel and equipment travel separately).

The spectrum of transportation options in strategic mobility is indeed wide (Principle VI). In the time frame of current operations, the vehicles and networks are fixed, and the problem is to achieve the most effective utilization of the given transportation resources to deploy the force. Over longer time frames, there are options about procurement of new vehicles, assignment of vehicles geographically and by command jurisdiction; and the introduction of new technologies such as the C-5 heavy-lift aircraft or the Fast Deployment Logistic Ship.[14]

Clearly, in strategic mobility, transportation is not an end in itself (Principle VII). The objective is an appropriate and adequate response to real or threatened aggression through rapid deployment of an effective fighting force. Transportation is obviously secondary to considerations of strategy and of national policy.

The transportation-related options (Principle VIII) include, first and foremost, the nature of the strategic response, as expressed in the requirements for movement—the forces, equipment, and supplies to be deployed, together with the origins, destinations, and desired times of arrival at the destination for each element. In addition, there are other options which directly affect the demand for transportation resources; for example, the option of prepositioning equipment and supplies overseas, or of changing the readiness of units to be deployed so that they can become available for movement at earlier times, or of redesigning the equipment to be transported to improve its transportability.

The relevant impacts of alternative strategic transportation plans are relatively obvious (Principle IX). First of all, there are the dollar costs—the costs of having men and vehicles available on a standby basis to provide support to a deployment, as well as the costs of operating them during a deployment. The dollar-valued revenues are the savings in using these vehicles for peacetime logistic support of the armed forces overseas. The non-dollar-valued costs are the many aspects of military effec-

[14]Lynn, op. cit.; Ernst Frankel, Planning the Design, Production and Operation of an Integrated Ship System, loc. cit.; Franz A. P. Frisch and W. Donald Weir, Analysis of Mission and Design Concepts for a Logistics Ship, loc. cit.

tiveness—buildup rate of forces in the theater, ability of the units to become an effective fighting force (as affected by length of time in transit, time available for training before departure, and marry-up with equipment), flexibility, reliability and vulnerability of the deployment plan.

CONCLUSIONS

We have presented several principles of transport systems analysis. We argue that these principles express guidelines or checklists which every transportation analyst should observe, to help prevent the most obvious types of errors in any problem of transportation systems analysis. To demonstrate the applicability of these principles, we showed their relevance in the context of two major transportation problems of current interest, urban transportation and strategic mobility.

Undoubtedly, these statements of principles require further clarification, testing, and modification. The author looks forward to spirited discourse about these principles, as part of a common effort to evolve a solid foundation for transportation science.

ACKNOWLEDGMENTS

The author gratefully acknowledges the constructive comments on an earlier draft of this paper by A. Scheffer Lang and Siegfried M. Breuning, while retaining full responsibility for all statements made herein.

A Method for the Evaluation of Transportation Plans

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The paper questions the efficacy of traditional cost-benefit analysis for the evaluation of transportation plans designed to serve a broad set of objectives. Cost-benefit analysis was designed for the evaluation of plans in terms of a single objective—economic efficiency. An alternative method of evaluation, known as goal-achievement analysis, is proposed and described. Plans are examined in terms of the entire set of objectives in a single system. Goals are defined operationally and goal achievement is measured in units which are relevant to the particular objectives. The relative effectiveness of alternative plans in achieving the set of desired objectives is determined by applying a weighting system to objectives and to the subgroups, sectors, locations and activities affected.

•IN RECENT years it has frequently been emphasized that plans for transportation improvements should reflect broad community objectives. Cost-benefit analysis has been increasingly employed in the evaluation of alternative transportation plans. How effective is traditional cost-benefit analysis for the evaluation of plans in terms of their probable achievement of a broad array of community objectives?

Cost-benefit analysis, after all, was developed as a technique for examining plans with respect to their achievement of the single objective of economic efficiency (8). This objective may be broadly defined as the maximization of net project or system contribution to the regional income or national income. Thus, in a manner analogous to the profit-maximizing firm, a public agency in pursuit of economic efficiency should allocate its resources in such a manner that the most "profitable" projects are executed. Traditional cost-benefit analysis requires the translation of both the costs and the benefits of a transportation improvement into monetary terms. Some of these costs and benefits are determined in market prices while others are imputed as if they were subject to market transactions. However, some costs and benefits known as intangibles are outside the scope of the market and cannot be priced in monetary terms.

Although lip service is paid to the consideration of intangibles, they do not really enter into the analysis. The net result is that the effects of investments which can be measured in monetary terms (whether imputed or derived from the market) are implicitly treated as being the most important effects, if only because they can be measured in this way. In fact the intangible costs and benefits may be as significant for the community under consideration. Furthermore, the expression of some costs and benefits in monetary terms and the restriction of the evaluation process to an economic analysis may lead to a deficient decision since the essence of particular costs and benefits may be lost through their conversion into monetary terms. Economic efficiency can perhaps be measured more precisely than other objectives, but this does not entitle it to an honored status. In the words of Tillo Kuhn, an important theorist in the economics of transportation (5), "Urban objectives have several dimensions—cultural, political, ethical, aesthetic, economic. To pursue only one dimension would indeed lead to a suboptimum from the total point of view."

Paper sponsored by Committee on Transportation System Evaluation and presented at the 46th Annual Meeting.

THE GOALS-ACHIEVEMENT MATRIX

How might a large array of transportation objectives be considered in a single system? This paper demonstrates how the problem may be handled by goals-achievement analysis. For the purposes of the paper we shall assume that those community objectives that are affected by a proposed transportation improvement have been identified and that the relative weights attached to these objectives by the community have been established. We shall further assume that alternative plans designed to serve these objectives have been prepared. The next step, therefore, is the comparison of the plans in order to determine which plan best realizes the objectives of the community.

The Hierarchy of Goals

Let us first outline a hierarchical goal system and identify that level of goals within it which primarily concerns us. In this discussion we shall use goal as the generic term and define it as "an end to which a planned course of action is directed." Goals may involve getting something the actor does not have or giving up something the actor does have. The goals of planned action may be categorized on the basis of specificity as ideals, objectives and policies.

An ideal is like a horizon allowing for indefinite progression in its direction but always receding. Ideals are characteristically of intrinsic value and are prized in themselves. Typical ideals are equality, freedom, justice.

An objective denotes a goal which has instrumental value in that it is believed to lead to another valued goal rather than having intrinsic value in itself. Objectives are defined operationally so that either the existence or nonexistence of a desired state or the degree of achievement of this state can be established. A qualitatively defined objective is one which, following the execution of a course of action, is either obtained or not. A quantitatively defined objective is one which is obtained in varying degree. The extent to which such an outcome is obtained can be measured. Typical objectives of transportation plans, for instance, are increase of accessibility, increase of safety, etc. An objective may be either instrumental in the achievement of an ideal or instrumental in the achievement of another higher objective, which, directly or indirectly, is instrumental in the achievement of an ideal.

A policy is the specification in concrete details of ways and means for the attainment of planned objectives. Policies may refer to specifications of practice, physical facilities, fiscal arrangements, legislative proposals, etc.

For the purposes of the goals-achievement matrix, goals should, as far as possible, be defined operationally, i.e., they should be expressed as objectives. In this way the degree of achievement of the various objectives can be measured directly from the costs and benefits that have been identified. Thus, the ideal of increased economic welfare can be defined in terms of objectives relating to the rate of increase or the absolute increase of the gross national product or the gross regional product. Similarly, the ideal of a healthy environment can be expressed in terms of objectives such as reduction in air pollution, reduction in the rate of accidents, etc.

Requisites

There is another category of values which are not specific goals of plans but which enable the planner and decision-maker to set guidelines. Requisites set limits to objectives and the policies by which objectives may be realized. They enter into consideration primarily at the time that the alternate plans are generated and developed, i.e., before the plans are evaluated in terms of the desired goals. Requisites indicate the necessary conditions which must be satisfied in order that the plans will not be rejected. However, they do not provide a sufficient basis for the acceptance of plans. The satisfaction of both a set of objectives and a set of requisites is necessary and sufficient for a plan to be acceptable.

Typical requisites are feasibility, immediacy and interdependence. By feasibility we mean, is the plan capable of being executed? Do existing fiscal, legal, political and social conditions facilitate the execution of the plan? Immediacy refers to the priority to be assigned to the execution of the planned facility and its various components, given the existing political and social conditions. Interdependence refers to significant interaction between the sector under consideration and any other sector. For instance, when planning transportation facilities, the interaction between these facilities and the nature, magnitude, intensity and location of the activities served by the transportation route or system is a primary consideration.

Constraints are a particular type of requisite. The achievement of specified levels of particular objectives may serve as constraints on the acceptability of alternative plans irrespective of the weight of these objectives in the total array of objectives. Thus, the maintenance of air pollution below specified levels may serve as a constraint on the choice of alternative transportation plans even though the reduction of air pollution, expressed as an open-ended objective, may not be highly valued by the community.

Before proceeding, it is necessary to define some additional terms. A consequence is a change in a given situation caused by a course of action or a policy. Consequences which are positively valued in terms of a given end are benefits; consequences which are negatively valued in terms of a given end are costs.

Procedure

The procedure which we employ is as follows: Given (a) the ordering of the goals of a community, and (b) a determination of alternative courses of action designed to achieve these goals, we must identify that course of action which best serves the community's goals. The evaluation of the alternative courses of action requires a determination for each alternative of whether or not the benefits, measured against the total array of ends, outweigh the costs, measured in terms of the total array of ends.

The only weighting introduced into the analysis is that which reflects the community's valuation of the various objectives. The weights are applied irrespective of the units in which the achievement of the objectives is measured. However, the weighting may also reflect the incidence of goal achievement since the extent of achievement of particular objectives may be considered more important for some groups of people than for others.

Incidence—It is therefore necessary to identify those sections of the public, considered by income group, occupation, location or any other preferred criterion, that are affected by the consequences of a course of action, since inevitably the consequences are unlikely to affect uniformly all sections of the public served. The incidence of the favorable and unfavorable consequences accruing to sections of the public should, of course, be taken into consideration by the decision-makers. This information is extremely important if charges and compensation payments are employed in order to implement a planning proposal. It is also necessary to have this information available in order to predict the reaction of the existing institutional power structure to the planning proposals. Therefore the principle should be firmly established that those sections of the community to which the costs and benefits accrue should be identified.

Uncertainty—Any rational determination requires the evaluation of anticipated consequences while allowing for the possibility of unanticipated consequences. The validity of the evaluation is, of course, strengthened by the increase of knowledge of anticipated consequences and the minimization of unanticipated consequences. Uncertainty concerning anticipated consequences is best treated by probability formulation. In general, a range of possible outcomes is preferable to the prediction of a unique outcome. To simplify the computation the following procedure may be used. If an outcome would be substantially affected by a particular contingency, e.g., technological innovation, a supplementary comparison of alternative courses of action can be made in terms of this modification. In general, allowance for uncertainty should be made indirectly by use of conservative estimates, requirement of safety margins, continual feedback and adjustment and a risk component in the discount rate. Estimates made at low discount rates are highly sensitive to variations in the estimate of future events. Higher discount rates lead to less sensitivity to such variations.

Time Preference—The time dimension of costs and benefits deserves mention at this point. Costs and benefits occurring in different time periods are not of equal weight. One cannot fully describe the costs and benefits of alternative courses of action without saying when they are to be incurred. This aspect has received considerable attention in the literature (6, 8) and will not be discussed in detail in this paper. The essence of the problem is, how are benefits and costs occurring at different times to be valued? Are benefits and costs accruing to the present generation more highly valued than costs and benefits accruing to future generations? The future is not usually valued as highly as the present, and a discount rate for future consequences is applied. The rate of discount reflects the opportunity costs of deferred consumption (or of social time preferences) applied to annual costs and benefits over time reduced to present values. Monetary costs and benefits lend themselves easily to the application of discount rates. Tangible nonmonetary costs and benefits may, in an analogous manner, be discounted for those time periods when they are less valuable and the worth of different time paths may be compared. Alternatively, and this procedure holds for the intangibles as well, it may be best to show what can be achieved in different periods and leave the comparison to the judgment of the decision-makers.

Costs and Benefits in the Goals-Achievement Matrix

In this analysis, costs and benefits are always defined in terms of goal achievement. Thus benefits represent progress toward the desired objectives while costs represent retrogression from desired objectives. Where the goal can be and is defined in terms of quantitative units, the costs and benefits are defined in terms of the same units. Where no quantitative units are applicable, benefits indicate progress toward the qualitative states that the objective describes while costs indicate retrogression from these objectives. For the same objective, costs and benefits are always defined in terms of the same units if the objective can be expressed in quantitative terms. Thus, if a benfit of x units accrues, it can be nullified by a cost of x units, provided both costs and benefits apply to the same objective. This interpretation of costs and benefits differs markedly from the traditional conception of costs and benefits. In general, costs have traditionally been defined as the value of goods and services used for the establishment, maintenance and operation of the project. Benefits are the value of immediate products, or services, resulting from the courses of action for which the costs were incurred. Thus in the proposed formulation costs may or may not be resources of land, labor or capital (as project costs are usually thought of)—this is dependent on the definition of the goal. The same applies to benefits.

The following, then, is the final product for every plan. The set of goals is known and the relative value to be attached to each goal is established. The objectives are defined operationally rather than in abstract terms. The consequences of each alternative course of action are determined for each objective. The incidence of the benefits and costs of each course of action measured in terms of the achievement of the goal is established for each goal. The relative weight to be attached to each group is also established.

The conceptual product of the analysis is given in Table 1. In the table, α, β, γ... are the descriptions of the goals. Each goal has a weight 1, 2, 3 ... as previously determined. Various groups a, b, c, d, e ... are identified as affected by the course of action. These groups may be combined in any meaningful manner in order to indicate the differential incidence of costs and benefits. A relative weight is determined for each group, either for each goal individually or all goals together.

The letters A, B ... are the costs and benefits which may be defined in monetary or nonmonetary units or in terms of qualitative states.

Costs and benefits are recorded for each objective according to the parties that are affected. A dash (–) in a cell implies that no cost or benefit that is related to that objective would accrue to that party if that plan were effectuated. A particular party may suffer both costs and benefits with respect to a particular objective. Thus, the reduction of noise may be a relevant objective of a plan for improved transportation facilities. A particular location may simultaneously experience a decrease of noise from one

TABLE 1

CONCEPTUAL PRODUCT OF ANALYSIS

Goal description		α		β		γ		δ	
Relative value		2		3		5		4	
Incidence		Costs	Ben.	Costs	Ben.	Costs	Ben.	Costs	Ben.
Groups Affected	Relative Weight								
Group a	1	A	D	E	–		N	Q	R
Group b	3	H		–	R		–	S	T
Group c	1	L	J	–	S	M	–	V	W
Group d	2	–		} T	–		–	–	–
Group e	1	–	K		U		P	–	–
		Σ	Σ			Σ	Σ		

source, e.g., as a result of the proposed diversion of heavy automobile traffic from that location, and an increase of noise from another source, e.g., from a new transit route proposed for that area.

For certain of the goals Σ indicates that summation of the costs and benefits is meaningful and useful. The total costs and benefits with respect to that goal can then be compared. This will be the case when all the costs and benefits are expressed in quantitative units. When this is not the case, i.e., for the intangibles, the costs and benefits and their incidence are best stated as explicitly as possible and then left to the judgment of the decision-makers. It is most unlikely that all the costs and benefits of all the goals can be expressed in the same units. In this rare case—which may occur when only one or two goals are valued by the community—it may be possible to arrive at a grand cost-benefit summation. However, this is highly unlikely.

For each plan, the product of the analysis is a table similar to Table 1. As was mentioned earlier, in the face of uncertainty, a range of costs and benefits is preferable to the prediction of unique outcome. Thus the letters A, B ... should not be considered as a single value but rather as a range of values.

Relative Weights in the Goals-Achievement Matrix

The key to decision-making by means of goals-achievement analysis is the weighting of objectives, activities, locations, groups or sectors in urban areas. It is possible to arrive at a unique conclusion by applying relative weights. How might these weights be determined? One or another of the following methods might be employed:

1. The decision-makers may be asked to weigh objectives and their relative importance for particular activities, locations, or groups in the urban area.
2. A general referendum may be employed to elicit community valuation of objectives.
3. A sample of persons in affected groups may be interviewed concerning their relative valuation of objectives (7).
4. The community power structure may be identified and its views on the weighting of objectives and their incidence can be elicited (1).
5. Well-publicized public hearings devoted to community goal formulation and valuation can be held (9).
6. The pattern of previous allocations of public investments may be analyzed in order to determine the goal priorities implicit in previous decisions on the allocation of resources (11).

The determination of community objectives and their relative valuation by the community is no easy task and requires considerable research. However, each of the procedures mentioned above either has been successfully performed (for typical examples see the studies referred to) or could be performed. It may be desirable to reinforce the determination and valuation of community objectives by one method with an independent determination by another technique.

Even if the relative valuation of objectives has not been empirically determined, the effect of changes in weights on the relative desirability of alternative plans may be usefully explored (4). Different sets of weights might be assumed and the effect of particular weights on the choice of the preferred plan can be determined. The effect of incremental changes in relative weights can also be examined. In this way the decision-maker can be helped if his subjective valuation approximates one of the sets of weights employed.

This, then, is the overall framework that is proposed. We now shift our attention to the evaluation of plans for improvements in urban transportation systems. The first step is the identification of the types of goals which might be furthered or might be thwarted by transportation improvements. In the next section we outline a hierarchy of goals that might be considered in planning a transportation system. The list of goals which follows is derived intuitively and is intended to be illustrative and not exhaustive.

A TRANSPORTATION GOAL HIERARCHY

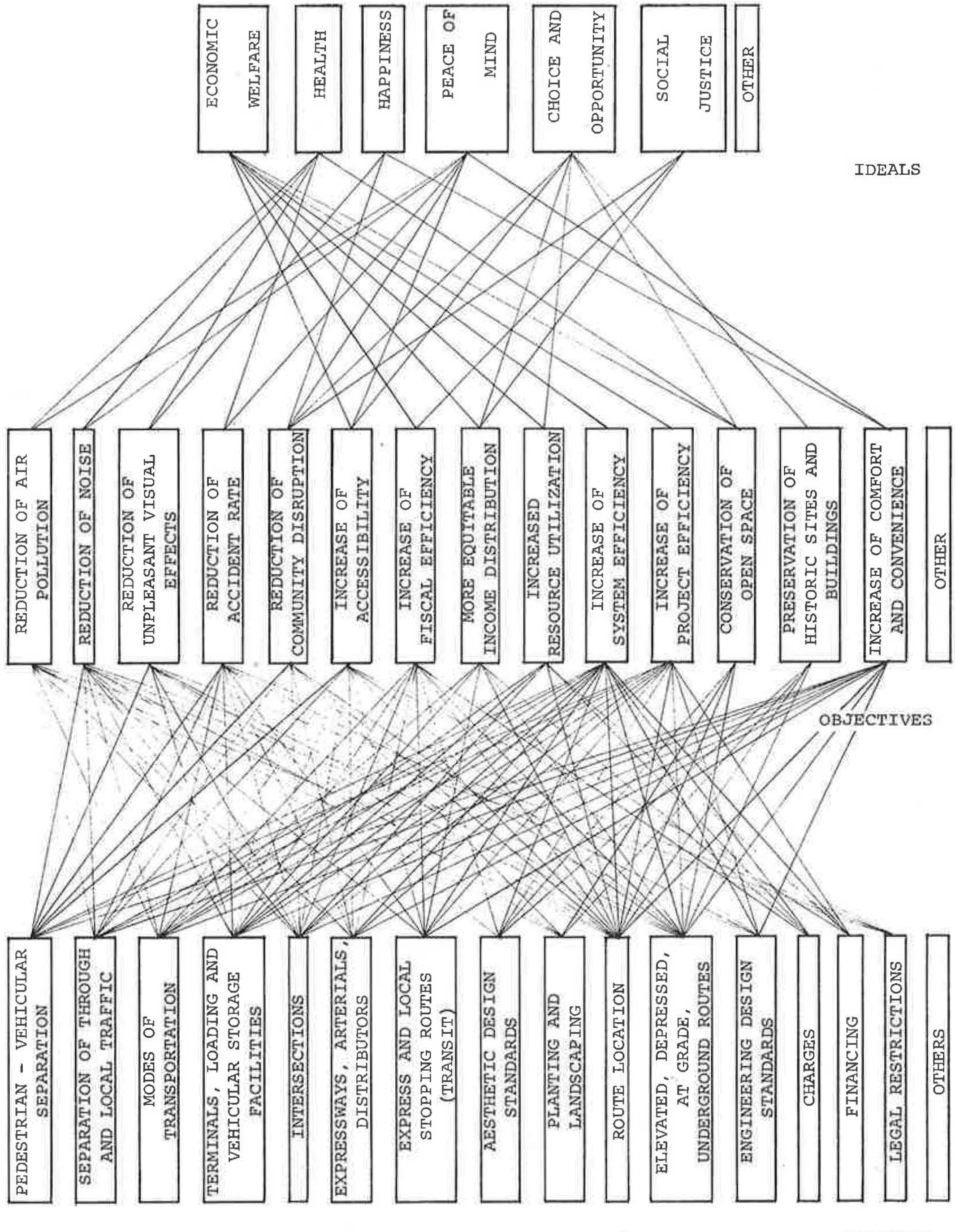
Listed here is a typical set of ideals, objectives, policies and constraints which are relevant for planning improvements in the transportation system.

1. Ideals: increase economic welfare; improve health and safety levels; increase happiness; increase peace of mind (serenity); increase choice and opportunity (freedom); increase social justice; other.
2. Objectives: reduce air pollution; reduce noise; reduce unpleasant visual effects; reduce the rate of accidents; reduce the disruption of existing communities; increase accessibilities; increase fiscal efficiency; achieve a more equitable income distribution; increase resource utilization; improve system efficiency; improve project efficiency; maintain open space; preserve historic sites and buildings; increase comfort and convenience; other.
3. Policies related to: pedestrian-vehicular separation; separation of through and local traffic; modes of transportation; terminals, loading and parking facilities; intersections; expressways, arterials and distributor streets; express and local stopping routes; aesthetic design standards; planting and landscaping; route location; elevated, depressed, at grade, or underground rail routes; engineering design standards; charges; financing; legal regulations; other factors.
4. Requisites: feasibility; immediacy; interdependence.

Diagrammatic Representation of Relationship

Figure 1 shows the relationship between the sets of policies, objectives, and ideals diagrammatically. Lines are drawn linking particular types of policies to particular ideals. At the foot of the diagram are listed the requisites which enter into consideration when the various alternative plans are generated.

The policies are represented as inputs intended to achieve the set of objectives, while the objectives are represented as a set of inputs for the achievement of a set of ideals. The relationship between each type of policy and each objective is considered in turn. Thus, a line joining a policy and an objective means that the particular policy affects the achievement of the particular objective. For instance, the modes of transportation used affect the objective of the reduction of air pollution. It must be stressed that a link between policy and objective does not represent a judgment about the degree of relationship that exists between objectives and policies. It simply states that the type of policy has an effect on the achievement of the objective, and, in turn, that the objective has an effect on the achievement of the ideal. If there is no line, no relationship exists between policy and objective. Thus pedestrian-vehicular separation has no effect on the achievement of a more equitable income distribution and the objective of increase of accessibility has no effect on peace of mind.



REQUISITES: FEASIBILITY IMMEDIACY INTERACTION

Figure 1. Transportation goal flow chart.

Analysis of Goal Achievement

Let us now turn our attention to the objectives, the intermediate level in the goal hierarchy. The extent of achievement of these objectives is analyzed in the goal-achievement matrix. We focus the analysis on the objectives because they are expressed in measurable terms. The objectives are classified in the following according to whether they primarily affect the users of transportation facilities, the immediate environment of transportation routes or the entire urbanized area. A number of these objectives could be classified in more than one category but each objective is listed under that category for which it appears to be most significant.

1. Objectives mainly affecting the users of transportation facilities: (a) increase of accessibility; (b) reduction of the accident rate; (c) increase of comfort and convenience.
2. Objectives mainly affecting the immediate environment of the transportation route: (a) reduction of noise; (b) reduction of unpleasant visual effects; (c) reduction of community disruption; (d) increase of project efficiency; (e) maintenance of open space; (f) preservation of historic sites and buildings.
3. Objectives mainly affecting the entire urbanized area: (a) increase of system efficiency; (b) increase of fiscal efficiency; (c) increase of resource utilization; (d) achieve the desired income distribution; (e) reduction of air pollution.

We now define and propose measures for measuring the extent of achievement of three of the objectives. Limits of space do not permit a detailed treatment of measures of the achievement of all the objectives listed above. For detailed treatment of all the objectives, readers are advised to see the study on which this paper is based (4). In it, the analysis is not restricted only to proposed measures and definitions. The implications of transportation improvements are also explored for each objective. Alternative transportation policies for enhancing the achievement of the objectives are postulated, and the determinants of the relative importance of particular objectives in particular environments are also discussed.

In this paper, definitions and measures are proposed for the following objectives (note that one objective from each of the categories has been chosen for this treatment): reduction of the accident rate, reduction of community disruption, and reduction of air pollution. We shall now consider each objective in turn.

Reduction of the Rate of Accidents Occurring on the Transportation System—Accidents are defined as mishaps on the transportation system causing damage to vehicles and/or to property and/or bodily injuries and/or death. The objective of reducing the accident rate might be measured by determining the probable costs that would result from accidents that would occur if various alternative transportation plans were executed. The following accident costs might be measured: property damage, damage to vehicles, temporary or permanent incapacity, administrative and legal costs, medical costs, personal cost of injury (pain and suffering), and death.

Of these costs, the following can unequivocally be expressed in monetary terms: property damage (this refers to property, other than vehicles, which may or may not be part of the transportation system); damage to vehicles; administrative and legal costs (the administrative costs refer to those accruing to the public authority as a result of the accident, legal costs are the public and private legal costs resulting from the accident); and medical costs.

The use of monetary measures to determine the cost of temporary or permanent disablement has been subject to some question. Nevertheless, the expression of the cost in monetary terms can be justified in that it reflects loss of output (and hence income) due to disability. This can be determined by estimating the future loss of output of those disabled, given a normal expectation of working life discounted to present-day values.

The use of monetary measures to determine accident costs has been severely questioned in the cases of (a) pain and suffering caused by injuries, and (b) death. The average compensation for pain and suffering of various types of injuries, from insurance policies, or as ratified by the judgments of courts of law, can serve as a basis for determining the monetary costs of pain and suffering.

The determination of the monetary value of a human life that has been lost as a result of an accident is a much more complex problem. The cost of a human life could be measured in one of the following ways (10): (a) the cost of a life—the cost technically necessary to save a life; (b) the price of a life—the expenditure that a community is, in practice, willing to make in order to save a life; (c) compensation for death—the cash award or compensatory payments to near relatives; (d) the cost of a man—the aggregate expenditures on consumption, investment and public service which are devoted to him; (e) the product of a man—the crude value of his production (his contribution to gross national product); and (f) the loss of a man—the loss that a death imposes on the community. Any, or all, of these measures could be employed but, as with compensation for pain and suffering, it may be contended that the entire cost is not recorded since "there is no market for human life, health and grief" (6).

Furthermore, some of these measures are misleading. For instance, the monetary value of a man may be taken to be his product, i.e., his expected output over his lifetime minus his expected consumption of goods and services. Thus, a retired man would have a negative cost for the community. Yet, the community regards the death of a retired man in a road accident as a loss. This is clearly inconsistent. If compensation is used as the value of a human life, then the accident cost of an injury may be higher than the accident cost of a death. A person who is injured in an accident may claim for medical expenses, for pain and suffering, and for loss of potential earnings. If a person is killed, his next of kin may claim for their financial interest in his potential earnings, but no one claims for the lost life. The actual money that the community is ready to spend in order to save life varies widely and depends mainly on the amount of public sentiment that is aroused by the way it is lost. For instance, if 10 people are killed in an air crash, a full inquiry may take place, but if 100 people are killed on the highways, it may be accepted as a matter of course. Or, if a child is missing, no expense is spared in an effort to save its life, but the same amount of money may not be readily spent on road improvements in order to prevent accidents which may take two (unknown) children's lives every year.

In spite of these objections, it might be advisable to choose a monetary scale of value for a human life and for injuries based on one or more of the given criteria (2). However, in order that perspective not be lost, it is advisable to include a simple statement of the expected number of injuries and fatalities that will probably occur on a transportation system as a result of a proposed transportation improvement.

Probable accident costs can thus be expessed in one of three ways:

1. All costs could be expressed in money terms.

2. The following costs could be expressed in money terms—property damage, vehicle damage, medical costs, administrative and legal costs. The other costs (incapacity, pain and suffering, and death) could be expressed in terms of the number of injuries (by type) and the number of fatalities that would probably occur.

3. All costs could be expressed monetarily. However, these could be supplemented by a statement of the expected number of injuries (by type of injury) and the expected number of fatalities.

Reduction of Community Disruption—This goal refers to the direct effects on communities immediately adjacent to the proposed transportation improvements resulting from the location of the route. Two such effects are evident: (a) the displacement of residential, commerical, industrial and institutional buildings by the proposed route; and (b) the boundary effects of the transportation route. Let us consider these effects in turn.

The Displacement of Residences and Other Buildings—Inevitably, when a new transportation route is chosen in a built-up area, some activities have to be displaced. The objective might be to reduce the number of households, firms and institutions that are displaced. Even though the displaced residents and businessmen may be compensated and relocated elsewhere, the financial compensation may not be equivalent to the actual money loss. In addition, there are psychological costs resulting from relocation which are seldom subject to compensation.

The older the resident or businessman displaced, the greater the financial and psychological difficulties are likely to be, particularly if the person displaced has been in the neighborhood for a long period. The older residents' involuntary departure from a neighborhood and adjustment to a new environment is inevitably more difficult than that of younger residents. If a business brings marginal profits, and this is likely to be the case in old neighborhoods where small businesses may supplement retirement incomes, it is likely to be wiped out if it is displaced. Similarly, the older the employee of a displaced business, the more difficulty he can expect to meet in finding new employment. Furthermore, if some of the residents, businessmen or employees belong to groups which suffer from discrimination in housing, business locations or opportunities for employment, they are likely to face more difficulties than others who are displaced. Therefore, priority should be given to those who are best able to adjust to displacement.

The Boundary Effects of a Transportation Route—These effects might be positive or negative. On the one hand, the new route might reinforce boundaries between two neighborhoods. It might separate two conflicting land uses, e.g., medium to heavy industry and residential or commerical districts. It may also set up barriers in a once-homogeneous community, thereby dividing what may be a school district, a congregational district, or an effectively integrated neighborhood (leading once more to the segregation of ethnic groups).

In the measurement of the reduction of community disruption, again let us consider (a) the displacement of households, firms and institutions; and (b) the boundary effects of the transportation route.

The Displacement of Households, Firms and Institutions—Two parallel measures are here proposed: (a) the number of displaced households, firms, institutions and employees classified according to various demographic variables; and (b) financial costs accruing to these groups as a result of relocation. The following groups of persons who would be displaced are analyzed in terms of the measures: landowners; residential occupiers, both tenants and owner-occupiers; businesses, both proprietors and employers; and institutions, both employers and employees.

The following data are gathered and considered according to the above categories:

1. Landowners
   Demographic data—(a) number of landowners displaced; (b) amount of land absorbed and type and amount of land uses displaced.
   Financial data—net loss or gain of landowners = financial compensation for property taken minus net revenues foregone.
2. Residential occupiers
   Tenants
   Demographic data—number of households classified by size of household, age of head of household, race, income, group and duration of occupancy.
   Financial data—(a) difference between existing contract rents and expected contract rents; (b) disturbance costs, i.e., compensation minus costs of moving.
   Owner-occupiers
   Demographic data—number of households classified by size of household, age of head of household, race, income group and duration of occupancy.
   Financial data—(a) difference between compensation and replacement costs; (b) disturbance costs, i.e., compensation minus costs of moving.
3. Businesses
   Proprietors
   Demographic data—number of businesses, classified by type, age of business, age of proprietor; number of businesses likely to be wiped out.
   Financial data—(a) for businesses likely to be wiped out, difference between net profit (over time) and compensation; (b) for businesses likely to continue elsewhere, difference between expected income loss while developing new clientele and compensation; (c) disturbance costs, i.e., compensation minus costs of moving.
   Employees

Demographic data—number of employees classified by occupation, age, race, number of years of employment in same occupation.
Financial data—(a) additional travel time and additional out-of-pocket expenses; (b) expected change in income (including expected drop in income of probable unemployed).

4. Institutions
Employers
Demographic data—number and types of institutions.
Financial data—disturbance costs, i.e., compensation minus costs of moving.
Employees (Data same as for employees of businesses displaced.)

The Boundary Effects of the Transportation Route—The probable boundary effects of a transportation route can be measured in the following ways.

1. Land-use analysis—The existing and proposed land uses and the alternative route locations are examined and the following questions are asked: (a) Does the proposed route cut across districts with similar land uses on both sides of the route? (b) Can the route serve as a boundary for conflicting land uses?
2. Trip origin and destination analysis—The origins and destinations of short trips from and to locations in the vicinity of the proposed route are examined in order to determine that route which crosses the least number of origin-destination lines.
3. Market and service area analysis—The market areas of businesses and service areas of various community services (schools, libraries, churches, etc.) in the vicinity of the route are determined. The question is then asked: Which of the alternative routes proposed disturbs the market areas and the service areas least?

Reduction of Air Pollution Caused by the Transportation System—Air pollution is defined as the presence of foreign matter (particulates and gases) in the air at levels of concentration which are considered objectionable, i.e., the pollutants affect man's well-being or interfere with the use and enjoyment of his environment. Although there is no universal agreement on the proportion of foreign matter which has to be present in the air for it to be considered polluted, some cities have instituted standards.[1] While a limit exists to the proportion of foreign matter in the air that man can tolerate in any environment, different environments might tolerate different levels of air pollution. For instance, higher concentrations of foreign matter may be acceptable in the air of industrial areas than in residential areas, or in areas where schools and hospitals are located.

A transportation system may cause air pollution in the following ways:

1. Emission from the exhausts and carburetors of gasoline or diesel-operated automotive vehicles.
2. The gases, smoke and soot produced by coal-burning steam locomotives. While this source is not significant in the United States, it is a major source of air pollution in Britain and other countries.
3. When transit units are driven by electric power, an additional load is put on the electric power supply. This demand gives rise to some air pollution regardless of whether power is derived from oil or coal.

The emission from automobile exhausts is by far the most significant "contribution" of the transportation system to air pollution in the United States. Estimation of the pollutants produced by automotive vehicles is based on the number and type of vehicles used, the number of vehicle miles traveled and the quantity of fuels consumed. Air pollution from automotive sources is not restricted to exhaust emissions. A considerable amount of fuel evaporates during the marketing operation and evaporation from

[1]"The level at which Los Angeles sounds a first alert, meaning that certain air-polluting activities must cease, is 0.50 parts per million. It considers 'adverse' a reading 0.15 parts per million for 1 hour—enough to cause eye irritation, impair visibility and damage vegetation." Quoted by Sen. Abraham Ribicoff in Hearings Before a Special Subcommittee on Air and Water Pollution of the Committee of Public Works, U.S. Senate, 88th Congress, Sept. 9, 10, 11, 1963, p. 45.

fuel tanks and carburetors accounts for a considerable proportion of the fuel used by automotive vehicles.

Techniques for the measurement of air pollution have been fairly well developed. Most large cities have several strategically located sampling stations. The measurement of pollution at different locations and at different times is at least as important for considering the effects of transportation improvements as the determination of the average pollution level.

The level of air pollution may be established by determining the amount of air pollutants of various types per unit volume of air. In any area, existing air pollution levels may be measured. By means of a continuously operating system of surface wind observing stations, it is now possible to draw reasonable inferences as to the frequency of weather conditions in an "airshed" which would be conducive to high air pollution levels (3). If information is available on local air flows and their variation in time, it is possible to develop hourly maps showing existing airflow patterns over specific areas. Data on precipitation as well as data on the amount of sunshine received diurnally and seasonally are easily obtained. On this basis, it is possible to predict regional air pollution dilution capacities.

The information on existing regional air pollution and on regional air pollution dilution capacity is considered together with various land use and demographic data. By considering the existing and proposed land use plans together with predicted population growth and density, predicted automobile ownership and consequent traffic flows as well as the information on existing air pollution and regional air pollution dilution capacity, it is possible to determine whether air pollution from transportation sources is likely to be a serious problem.

Let us now consider local air pollution. At this scale the planner examines the relative importance of the reduction of air pollution in the planning of transportation projects, e.g., a new link in a street network or in a transit system. Among the environmental conditions that must be considered are the general characteristics of the airshed and both the direction of the prevailing winds in the area and local wind patterns. The topography might create local winds. It is important to know not only the direction of the prevailing winds and local windflow pattern, but also the likely direction of dispersion of stationary air masses.

The next step is the estimation of expected levels of air pollution in the vicinity of the transportation improvement. The transportation plan spells out the proposed route. The expected volume of vehicles at various times of the day, the quality of the route (i.e., whether limited access, arterials, etc.), the number and nature of intersections, transit and bus stops, etc. With this information, it is possible to compute the expected amount of pollutants emanating from the planned facilities by time of day. The estimate of expected local air pollution and regional air pollution together with the information on environmental conditions enables the analyst to plot a map of expected air pollution levels at various locations alongside the proposed transportation route.

The next step is the review of existing and proposed land uses in the areas adjacent to the transportation route. For each of these land uses, acceptable thresholds of air pollution can be established. Standards can be instituted which relate the amount of air pollutants per unit volume of air which are acceptable for various types of activities at various densities without requiring public intervention to reduce levels of air pollution. Expected levels of air pollution at various locations can then be compared with acceptable levels of air pollution for the various activities at the various locations.

CONCLUSION

We have described the general framework for the analysis of multiple objectives and we have postulated a set of transportation objectives that might be treated within the framework. While the method proposed calls for an extremely complex task, the conceptual framework is recommended as a basis for rational decision-making. The method of evaluation has been demonstrated as workable in the comparison of alternative plans for Cambridge, England (4).

By determining how various objectives will be affected by proposed plans, the goals-achievement matrix can determine the extent to which certain specified standards are being met. Is the transportation plan likely to meet minimum accessibility requirements and minimum standards of comfort and convenience? Are levels of air pollution and noise likely to exceed specified standards? Is the fatal accident rate within prescribed acceptable limits? These are the types of questions that the goals-achievement matrix is designed to answer. It can also determine the costs of meeting specified standards in terms of the achievement of other "open-ended" objectives which would have to be forfeited. Different plans have different trade-offs between the achievement of objectives and standards, and these can be compared.

The application of the goals-achievement matrix requires the weighting of objectives and their incidence. As has been demonstrated in the comparison of the Cambridge plans (4), it is possible to arrive at a definite conclusion by the application of relative weights. The goals-achievement matrix is obviously of limited usefulness if weights cannot be objectively determined. The further development of methods for the determination of weights is thus of first priority for the successful application of the goals-achievement matrix.

We have proposed a set of measures for determining the extent of achievement of three of the objectives. Measures for the other objectives can be determined in a similar manner (4). It should be noted that while the costs and benefits relating to some of the objectives (e.g., accessibility, accident reduction, project or system efficiency) are incorporated into present-day evaluation procedures, others are usually treated as "intangibles" and omitted from consideration. We have shown how certain intangible effects such as community disruption and air pollution may be measured. By means of goals-achievement analysis and the application of relative weights, many of the intangible effects can be measured and considered simultaneously with costs and benefits relating to more tangible effects.

Because this approach to evaluation is new, much of the data necessary for the analysis is not readily available in most urban areas. The absence of data is part of a vicious circle. Because transportation planners have not focused on the types of questions here proposed, the data have not been sought. However, data for the types of measures of objectives that have been described can be obtained. The task is not easy, but if successful should prove worthwhile.

Perhaps it will never be possible or advisable to include, at least quantitatively, all of the relevant costs and benefits. However, we can hope to measure more consequences of courses of action than were considered in the past, and we can measure others more accurately than in the past, making final evaluation easier.

The task is undoubtedly complex. But the complexity of the task is no excuse for abandoning the attempt. The comparison of alternative courses of action with respect to the goals in view and the identification and measurement of the costs and benefits of these courses of action with regard to the achievement of all relevant community goals is proposed as the "rational" way to approach the evaluation of alternative transportation plans.

ACKNOWLEDGMENTS

The study on which this paper is based was supported by the Regional Science Research Institute under a grant from the National Institutes of Health for research into Comprehensive Programming of Public Facilities. The costs of production of the paper were borne by the Department of City and Regional Planning, University of North Carolina under a Public Health Service training grant from the Division of Environmental Health Services, National Institutes of Health.

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Comprehensive Planning for the Chicago Crosstown Expressway

MILTON PIKARSKY, Commissioner of Public Works, City of Chicago

•IN THE SPAN of 20 years, beginning in 1946, more than 112 miles of limited-access motor expressways have been planned, designed and constructed through densely populated areas of Chicago and the suburbs immediately adjacent. In addition to the network of freeways, more than 100 miles of tollways were placed in service during the same period. The total cost of these improvements stands at approximately $1.25 billion (1).

This accomplishment is not the subject of my paper. Other major metropolitan areas of the world have exceeded our program in both mileage constructed and moneys spent during the same period of time. But, mileages and moneys, or, for that matter, traffic demands, geometrics, or any other isolated considerations, are not necessarily the most significant yardsticks in evaluating either the scale of the accomplishment or the worth to the community of an expressway construction program, particularly in a densely populated area.

There are many factors which must be weighed in order to evaluate an expressway system—sociological as well as engineering considerations. The time for such evaluations is in the planning stages and this is the subject of my remarks: to relate an approach to planning which has evolved in Chicago out of the experience of the last 20 years—an approach that was employed from the beginning in preliminary studies leading to our current recommendation for construction of a circumferential, or crosstown, expressway in Chicago at a cost of approximately $500 million. I am told that our method is unique in that we are the first public works planning body in the United States to systematically mobilize and coordinate the various disciplines of sociology and engineering to arrive at our recommendation.

Chicago is situated on the western shore near the lower end of Lake Michigan, southernmost of the Great Lakes. The French Jesuits, Marquette and Joliet, were the first Europeans to visit the area in 1673 and they were quick to grasp the strategic importance of the area. In their journal they made note of the "Chicago Portage," a low divide between the waters of Lake Michigan and those of the Des Plaines River, used by the Indians as a canoe route between the two waterways.

This confluence of two great waterway systems is precisely why the City of Chicago is where it is. It also is the underlying reason for the growth of the city as a principal communications center.

Today, Chicago is the center of a great and growing metropolitan region. It is still a major communications center; a hub of air, rail, truck, marine and electronic traffic.

But now there is a difference; Chicago has outgrown her early role of "shipping clerk" to the nation—a convenient transfer point between major markets—and has become the heart of a viable complex of broadly diversified industrial, financial, agricultural, commercial, natural and human resources—increasingly important as both producer and user of an even larger share of the nation's goods and services.

In short, we now have a growing megalopolis extending across political boundaries of city, county and state, but still centered on the central city and taking shape from the historic radial routes of communication flanked by industrial development dividing the area into wedge-shaped and segmented residential neighborhoods of varying ethnic and economic composition, and characterized by high concentration of low-income population in old and deteriorating neighborhoods near the hub.

Paper sponsored by Committee on Transportation System Evaluation and presented at the 46th Annual Meeting.

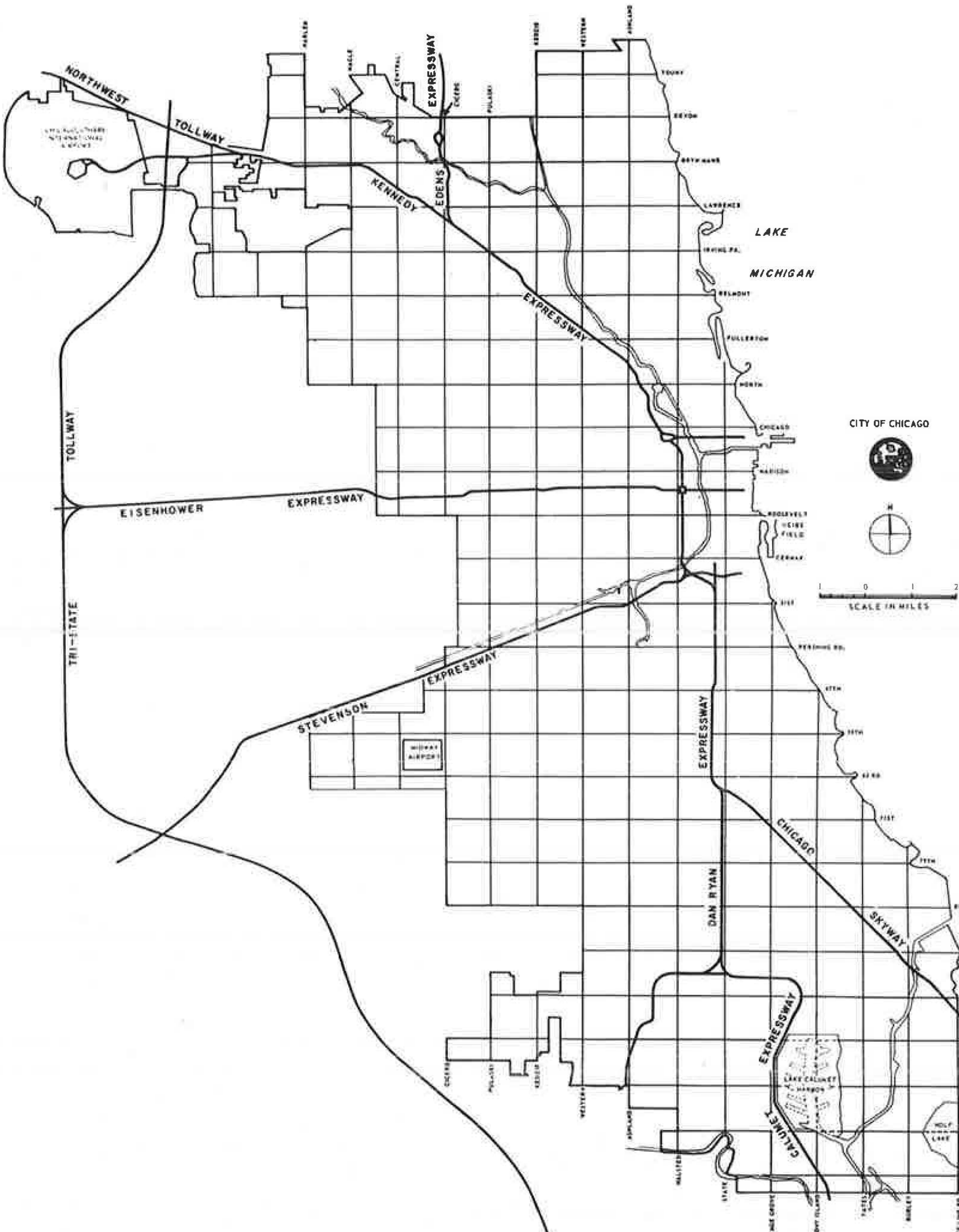

Figure 1. Federal Interstate System in the Chicago area.

This essentially radial pattern (Fig. 1) has been retraced once more by construction of the expressways since the war. This is the scene for the planning of a crosstown expressway, the subject of this paper.

Planning must be comprehensive, but no comprehensive plan can be final. Thus, at the end of World War II, when manpower and materials became available, and Chicago at last set out to cope with the rising flood of motor traffic, all of the superhighway planning done before the war had been rendered largely obsolescent. Old plans were exhaustively reviewed, and extensive new studies were carried out, leading to completion in 1946 of a new comprehensive plan for an expressway system as part of the General Plan for the City of Chicago prepared by the Chicago Plan Commission. This plan called for the system of radial express routes which has since been constructed.

A Crosstown Expressway on the west side of Chicago to connect the various arms of the radial system was a part of this Comprehensive Expressway Plan of 1946. The route was also recommended in the final report of the Chicago Area Transportation Study (CATS) released in 1962 (2), and endorsed in 1963 as part of the Interstate System (3) to serve as a bypass of the central business district. Finally, the proposed route was incorporated into the Basic Policies for the Comprehensive Plan for Chicago published in 1964 (4).

Despite these repeated studies and reaffirmations of the need for a crosstown route, there was no foregone conclusion, at the start of the final studies in November 1963, to determine whether a crosstown route should be constructed, and if so, to recommend an alignment to best serve the interests of the whole community. The objective was to achieve a harmonious balance between transportation goals and other community impacts and goals. A Transportation Advisory Group was formed to conduct the study and make the recommendation.

The scope of the group's planning approach was pretty well defined in an instructional memorandum on the subject of Urban Transportation Planning from the U. S. Department of Commerce (5) which said in part:

> It is declared to be in the national interest to encourage and promote the development of transportation systems embracing various modes of transport in a manner that will serve the States and local communities efficiently and effectively. To accomplish this objective the Secretary [of Commerce] shall cooperate with the States ... in the development of long-range highway plans and programs which are properly coordinated with plans for improvements in other affected forms of transportation and which are formulated with due consideration to their probable effect on the future development of urban areas ....

The memorandum concluded with a warning that, after July 1, 1965, no project in any urban area of more than 50,000 population would be approved for Federal participation funds under the Interstate Highway Aid program unless the project was "... based on a continuing comprehensive transportation planning process .... "

But, we must not allow our broadened definition of the planning responsibility to lead us into aimless and prolonged excursions into the almost infinite avenues of inquiry open to us. Time was of the essence. The existing Federal Aid Interstate Highway Act (6) requires that any state requesting approval to construct an individual segment of the Interstate System must demonstrate the ability to complete the segment by October 1, 1972, in order to be eligible for 90 percent Federal participation. Without Federal aid, the Crosstown Expressway would not be built. I should mention that two bills are now pending, either of which, if enacted, would extend the completion date.

Obviously, it was necessary to carefully define our objectives and methods in advance. But first, it was necessary to re-examine the basic proposition: Was a Crosstown route needed at all?

Chicago has made much progress in improving its transportation system, but, because of the city's ever-increasing activity, a continuous effort is required. More than 100,000 persons are added to the Chicago region each year (7, p. 1). Annually, some 20 square miles of vacant land are converted to a more intensive use. The pressure on transportation facilities is further increased by additional travel requirements in the daily life of the people.

Economic forecasts indicate that ownership and use of automobiles will rise at a faster rate than population growth. In fact, vehicle registration will increase about twice as fast as population during the next 15 years. By 1980, the Chicago

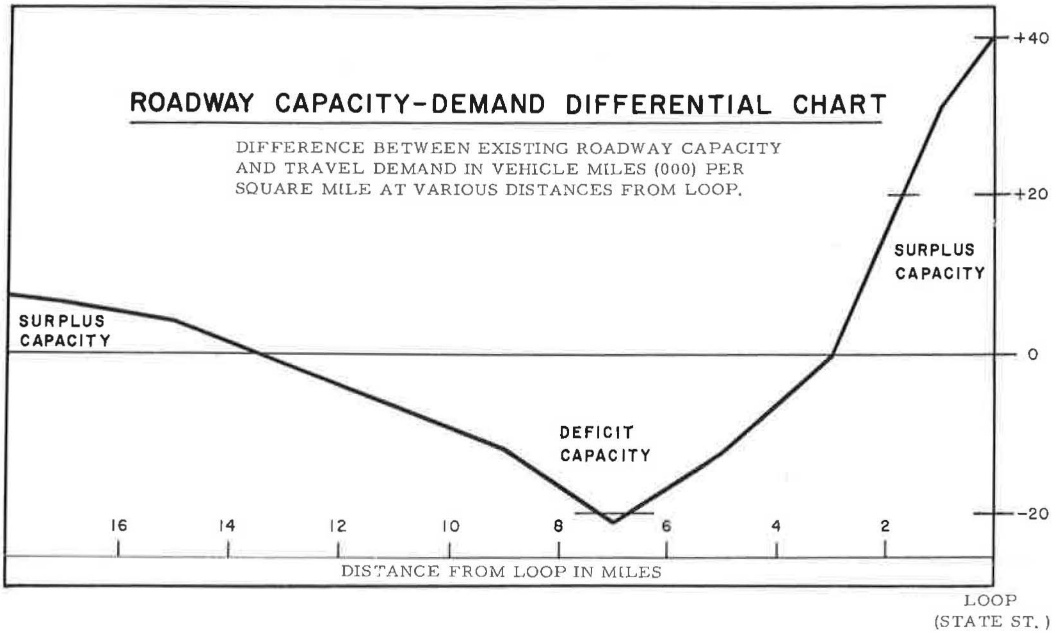

Figure 2. Results of roadway capacity survey.

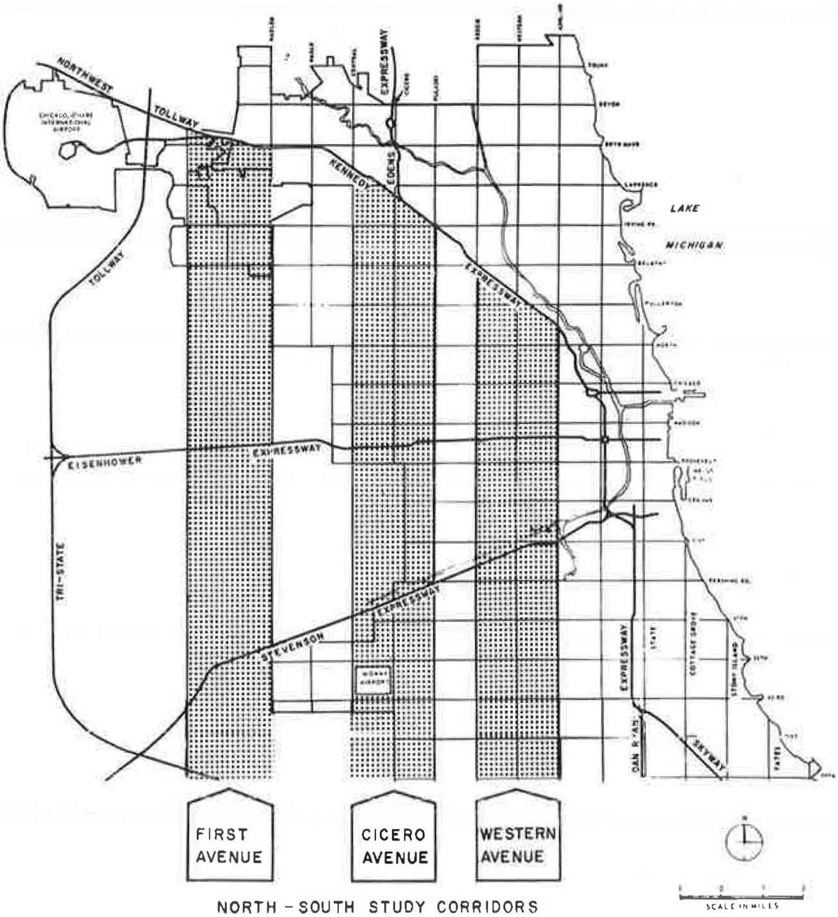

Figure 3. Crosstown Expressway study corridors with existing expressway system.

Metropolitan Area will have a population of about 8 million people who will own more than 3 million motor vehicles (8, p. 13).

Traffic congestion in certain areas has been relieved by construction of new expressways. Studies show that an expressway removed about half of the daily vehicle travel miles from the surrounding arterial street system (9).

Chicago's existing radial system of expressways is oriented to the central business district, but the portion of daily trips in the metropolitan area directed to the Loop is steadily diminishing. Since 1939, the traffic-attracting power of the CBD has remained stable while that of the metropolitan region has steadily grown. The trips to the CBD now constitute less than 10 percent of the total, and this is expected to dwindle to about 5 percent by 1980 (8, p. 45). Chicago's traffic problems are moving outward from the CBD at a faster rate than ever before.

A survey of existing facilities determined that the deficiency in roadway capacity related to present travel demands, as shown in Figure 2, was not at the CBD but was located in a wide belt starting about 3 miles from the Loop and extending outward over densely built-up parts of the region to a distance of about 10 to 13 miles from the Loop, with the greatest deficiency at about 7 miles (7, p. 84).

Having thus located the area of street capacity deficiency, the fundamentals of Creighton's Theory for Optimum Spacing of Expressways (10) were applied to establish three main north-south traffic corridors (Fig. 3) and one east-west corridor for more intensive study.

By superimposing the roadway deficiency chart (Fig. 4) we saw that roadway capacity was relatively not critical within the Western Avenue corridor. Moreover, this corridor would intersect the Kennedy and other radial expressway routes in the areas of their greatest traffic demands and would aggravate congestion without prior improvements to the west.

The First Avenue corridor, at approximately the 11-mile mark, was well out on the western slope of the deficit area. Also, the proximity to the Illinois Tollway, opened to traffic in December 1958, would ineffectuate the full potential usage of an expressway along this corridor until future traffic demands are realized.

The Cicero corridor clearly was in the area of greatest street deficiency. Included in the corridor were Central, Laramie, Cicero and Kostner Avenues and Pulaski Road; all were heavily traveled arterials with capacity inadequate to meet present demands. The Cicero corridor was equidistant between the hub of the radial expressway routes and the Illinois Tollway bypass route in the western environs of the city. Because of its location, an expressway in this corridor could connect directly to the Edens Expressway in the vicinity of the existing Edens-Kennedy junction. It also would provide a direct connection between O'Hare and Midway, the city's two principal airports.

Of the three north-south corridors, the Cicero corridor clearly emerged as the area for first priority investigation. Because of the location of the Stevenson Expressway, only one critical corridor in the east-west direction, centered along 71st Street, warranted detailed study at this time.

Alternatives to an expressway were also reviewed: improvement of existing arterial streets, removal of parking, signaling changes, and one-way street systems, to name several. It was concluded that only the proposed expressway could provide the needed capacity to reduce traffic on local and arterial streets, relieve congestion on the existing radial expressway routes, cut excessive travel time and costs, reduce accidents and produce economic benefits for the communities involved and the entire city which would be in harmony with the comprehensive plans for the future development of the region.

We were then ready to select the best alignment in the study area. To isolate the factors involved in determining the alignment for the Crosstown Expressway, three different viewpoints were identified: (a) engineering aspects, (b) impact upon the existing communities, and (c) potential land use improvements.

The engineering aspects category include criteria for considering all technical and economic requirements of the expressway facility itself in its primary purpose of moving people and goods more safely, rapidly and efficiently, and evaluating alternative alignments to other transportation facilities.

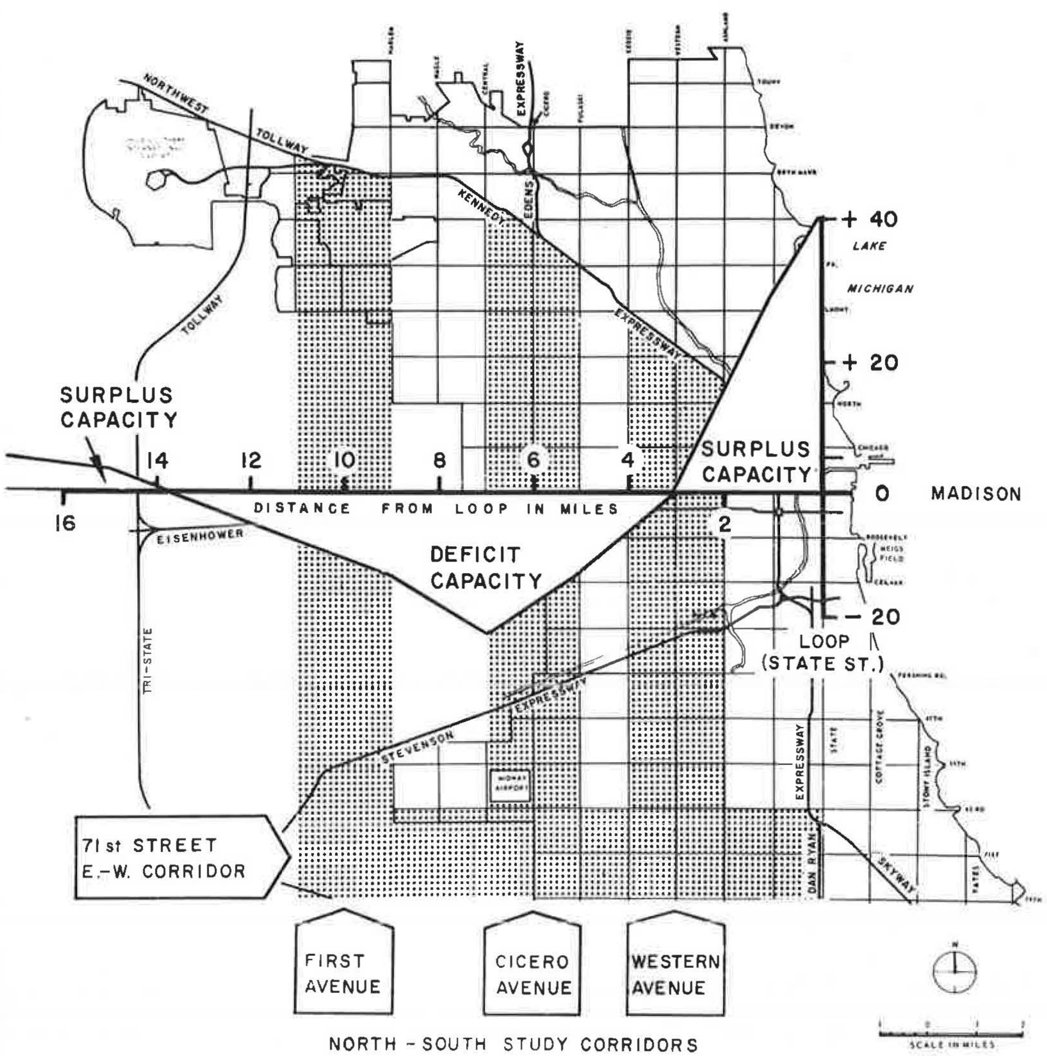

Figure 4. Crosstown Expressway study corridors with roadway capacity-demand differential chart superimposed.

The impact upon existing communities category analyzed community groups on ethnic, religious and political bases and considered the number of people and business establishments that would be directly dislocated by the alternative alignments. This study element considered such factors as the displacement of schools, churches, and parks and the splitting of school, fire, police and other special districts. The distinction between the highly neighborhood-oriented grocery or drug store and the used-car lot, or the small specialty plant employing neighborhood people also was of great concern.

The third category, potential land use improvements, explored opportunities presented by the alternative alignments as a possible catalyst for achieving desirable objectives—a means of linking the community as it is to an image of what it might ideally be. Chicago's basic policy requires that "Transportation facilities should be used as positive factors in improving Chicago's communities and in establishing the future form of the City."

TABLE 1

ANALYSIS PROCESS

Analysis Level	Engineering Aspects	Impact on Communities	Land Use Improvements
General—Broadest context evaluation	Independent Study	Independent Study	Independent Study
Separate evaluations compared at conclusion and least promising alignments eliminated			
Intermediate—Narrowed field of analysis	Independent Study	Independent Study	Independent Study
Ends with second comparison of evaluations of basic routes and variations, further eliminations			
Detailed—Final study to conclusion	Final comparison of separate evaluations to determine alignment best satisfying all three viewpoints		

These three categories, or viewpoints, constituted the framework of our study. Each of the three had its own set of objectives and criteria, and each was to be treated separately in analysis because, while often complementary or overlapping, they would sometimes conflict.

Having established this framework for the study, the technical committee then related it to a process of analysis. Because the study group was to consider "all possibilities," the method of analysis would function as a deductive process of elimination. To accomplish this process, three levels of analysis were established—general, intermediate and detailed (Table 1).

At the general level of analysis, all proposed alignments in the crosstown study corridor were to be considered in the broadest context with respect to the city as a whole and the communities involved. The purpose of the general level analysis was to consider all possible alignments in the study corridor with respect to the three points of view, in order to determine which alignments were to be given more detailed study.

The intermediate level of analysis might be compared with the second power of magnification in a microscope. The field was narrowed to encompass only those alignments surviving the first screening, but these now were to be brought into sharper focus for more detailed analysis.

At the level of detailed analysis, maximum magnification was to be applied to the alignment or alignments still under consideration Modifications would be considered involving analysis by parcel and structure for sections of the route, if not the entire alignment, until, hopefully, one alignment would emerge which best satisfied all requirements in all categories of analysis. In that case, the accumulated data would then be assembled into a recommendation.

While relative values or weights were given to the individual criteria in each of the three categories with respect to one another, alignments were to be rated with respect to each category separately. Thus, if one alignment emerged as the best in all three categories, it obviously would be the best solution. If, however, there were a great disparity, which could not be resolved by any reasonable modification of any of the alignments under consideration, then the decision would become a matter of policy, beyond the province of the technical committee, but influenced by the evaluations of the participating professional disciplines.

Following this approach, it remained only to list the specific factors to be considered in each of the three categories of basic consideration. Because each category was to be strictly self-sufficient and separate from the others, there was no effort to standardize language, study disciplines, or relative weight of the factors, except within each category.

The engineering aspects category established 16 primary factors or criteria for consideration and assigned a relative weight or value to each (Table 2).

TABLE 2

TRAFFIC AND ENGINEERING ASPECTS

Criteria	Levels of Analysis		
	General	Intermediate	Detailed
BPR requirements	X		
Aesthetics	X		
Benefit-cost ratio			X
Control points	X	X	X
Construction costs			X
Maintenance costs			X
Preliminary costs	X	X	
Right-of-way costs			X
Directness of route	X		
Future expressway plans	X		
Geometrics and operational	X	X	X
Highway and railroad structures		X	X
Other modes of transportation	X	X	X
Right-of-way negotiation		X	
Traffic	X	X	X
Utilities		X	X
Totals	9	8	10

Similarly, criteria were established for the impact on existing communities category (Table 3). The criteria, of course, were carefully defined and methods of scoring and assigning relative weights were explained. Twenty basic criteria were set for this category. It must be noted that within these basic criteria, many "public acceptability" standards were considered.

TABLE 3

IMPACT ON EXISTING COMMUNITIES

Criteria	Levels of Analysis		
	General	Intermediate	Detailed
Inventory of buildings and condition			
Residential	X	X	X
Number of units	X	X	X
Industrial	X	X	X
Commercial	X	X	X
Retail			X
Non-retail			X
Vacancies			X
Mixed-use structures			X
Community facilities inventory	X		X
Property values and taxes		X	X
Community areas	X	X	
School district boundaries	X	X	
Parish boundaries	X	X	
Housing characteristics		X	
Population characteristics		X	
Number of industrial employees		X	X
Number of major employers		X	X
Number of commercial employees		X	
Potential areas for urban renewal	X	X	X
Totals	9	14	13

TABLE 4

POTENTIAL LAND USE IMPROVEMENTS

Criteria	Levels of Analysis		
	General	Intermediate	Detailed
With respect to announced land use objectives, evaluate the positive or negative values of the alignment as an influence for:			
Effecting desired land use changes	X		
Separating non-compatible land uses	X		
Improving service to major traffic generators	X		
Minimizing through traffic on residential streets	X		
Contributing aesthetically to area	X		
Facilitating other public improvements	X		
Achieving specific land use objectives:			
Residential		X	
Industrial		X	
Commercial		X	
Complementing other transportation	X		
Complementing other development programs		X	
Affecting environmental factors (noise, vibration, light, aesthetics, pollution):			
As elevated highway			X
As depressed hightay			X
Requiring related adjustments			X
Totals	7	4	3

The 16 basic criteria for the potential land use improvement category were related to "announced" land use objectives (Table 4). The reference for this was the "Basic Policies for the Comprehensive Plan of Chicago" (4).

Seven possible north-south alignments and four east-west alignments were considered in the crosstown study area (Fig. 5). When this total of seven basic alternative alignments was investigated certain modifications were introduced. For example, the Belt Railroad alignment C was considered both as a 6-lane expressway with a minimum of interchanges, and as an 8-lane facility.

TABLE 5

ENGINEERING ASPECTS ANALYSIS—SAMPLE RATING CHART

Weight	Criteria	Rating									
		High					Low				
		10	9	8	7	6	5	4	3	2	1
9	BPR requirements	90									
8	Future expressway plans					48					
7	Control points				49						
6	Geometrics and operational features			48							
5	Traffic							20			
4	Other modes of transportation	40									
3	Preliminary cost			24							
2	Directness of route			16							
1	Aesthetics				7						

Rating = 38 (50 is highest possible, 5.0 is lowest possible), computed as follows:
90 + 48 + 49 + 48 + 20 + 40 + 24 + 16 + 7 = 342 ÷ 9 = 38

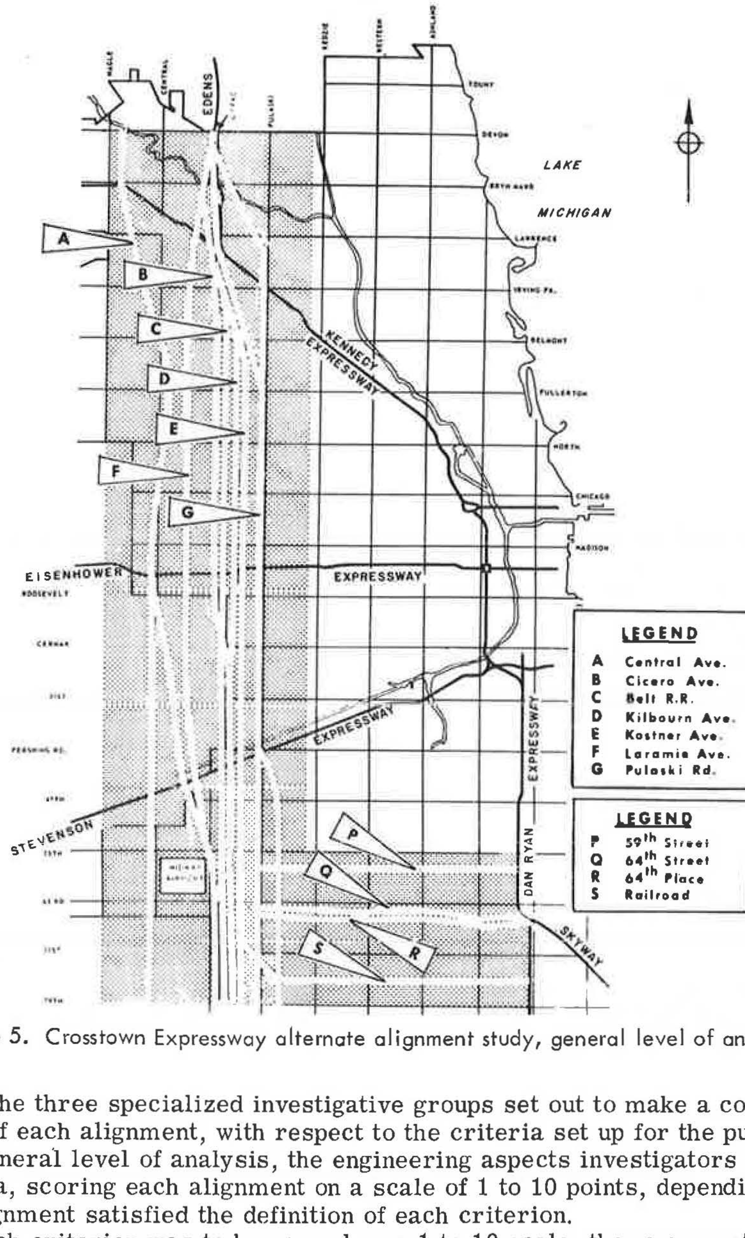

Figure 5. Crosstown Expressway alternate alignment study, general level of analysis.

Each of the three specialized investigative groups set out to make a comparative evaluation of each alignment, with respect to the criteria set up for the purpose.

At the general level of analysis, the engineering aspects investigators considered nine criteria, scoring each alignment on a scale of 1 to 10 points, depending on how well the alignment satisfied the definition of each criterion.

While each criterion was to be scored on a 1 to 10 scale, they were not given equal weight in the evaluation (Table 5). Each criterion was weighted differently and the rating of the alignment then became the sum of the criteria scores multiplied by their assigned weight and reduced to an average. In this example, for instance, the rating was 38.

Thus, each of the alternative alignments was given a rating with respect to the criteria for the engineering aspects category (Table 6). Concurrently, and in a similar manner, but entirely independently, each of the other two specialized professional groups examined the sociological, economic, and city planning factors in their respective categories of impact on existing communities and potential land use improvement.

Finally, the findings of the three groups were brought together and compared. If we were hoping for a decisive consensus in favor of a single alignment at the general level of analysis, we were disappointed (Fig. 6). Several routes received acceptable

TABLE 6

ENGINEERING ASPECTS RATING CHART

General Level of Analysis, North-South Alignment Alternatives

Weight	Criteria	Alignments							
		A	B	C_6	C_8	D	E	F	G
9	BPR requirements	90	90	90	90	90	90	90	90
8	Future expressway plans	40	80	72	72	72	64	64	48
7	Control points	63	56	42	42	35	56	56	49
6	Geometrics and operational features	60	54	36	48	36	48	60	54
5	Traffic	45	50	30	45	35	45	45	45
4	Other modes of transportation	40	32	28	28	24	36	40	32
3	Preliminary cost	6	30	3	3	12	18	18	30
2	Directness of route	2	20	20	20	20	18	18	16
1	Aesthetics	10	9	5	5	6	9	10	10
	Rating	40	47	36	39	37	43	44	42

Legend:
A = Central Ave. C = Belt R. R. E = Kostner Ave. G = Pulaski Rd.
B = Cicero Ave. D = Kilbourn Ave. F = Laramie Ave.

ratings in all three categories. Routes A, F, and G were eliminated from further consideration because of serious shortcomings, particularly in the impact and land use categories. Routes D and E were not considered worthy of further study as separate alternatives, but a composite D-E proposal was deemed worth further attention to

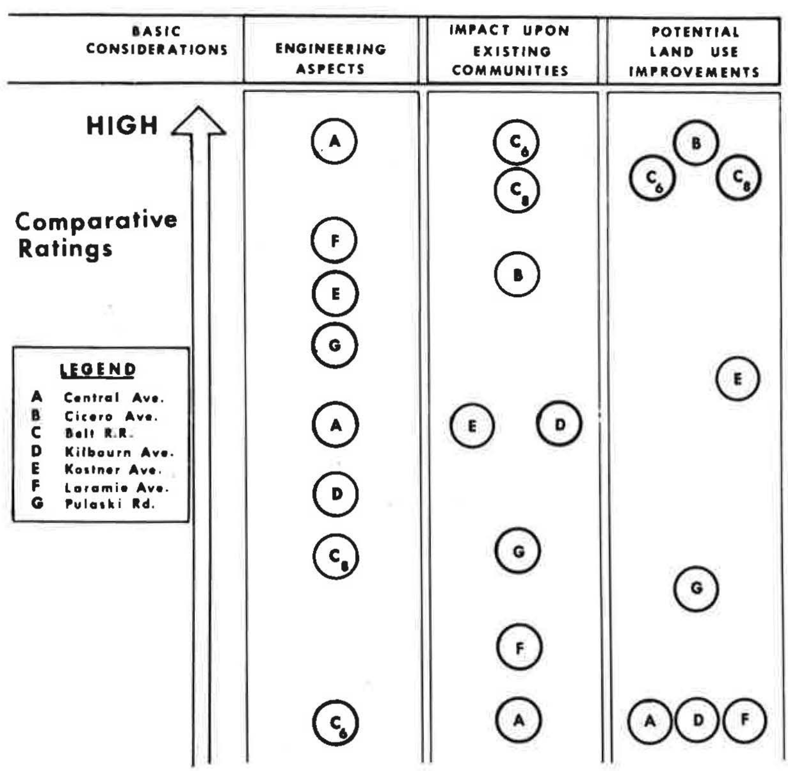

Figure 6. Crosstown Expressway study evaluation chart: General level of analysis, north-south alignment alternatives.

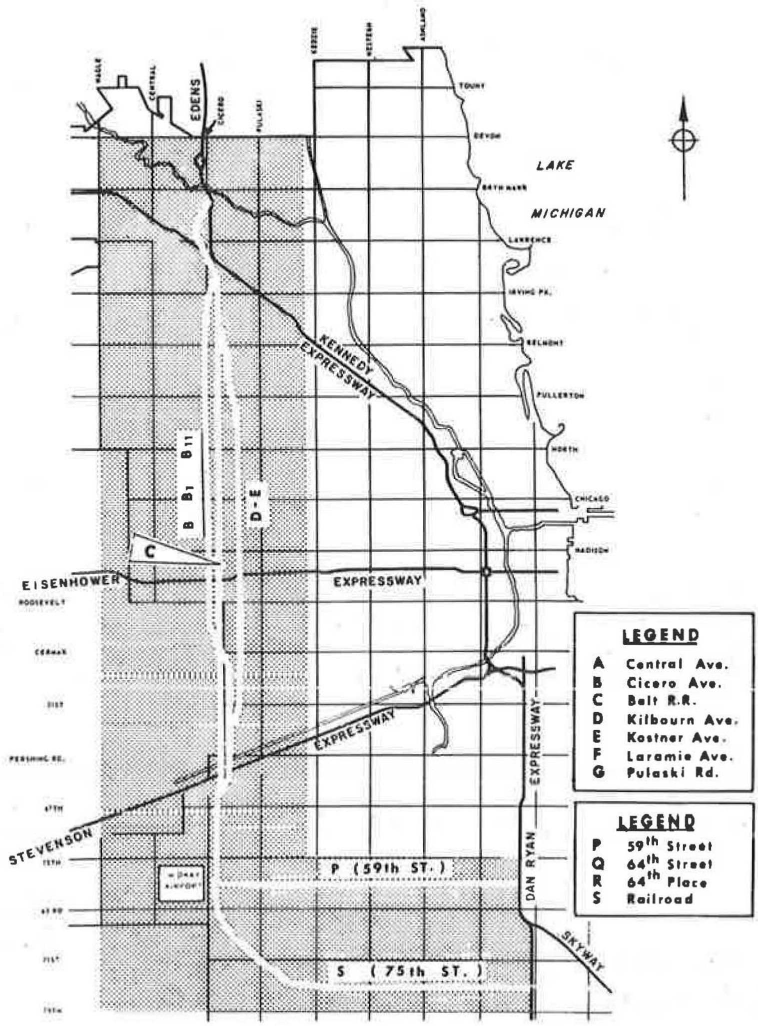

Figure 7. Crosstown Expressway alternate alignment study, intermediate level of analysis.

determine whether unfavorable features of each could be eliminated by combining the best characteristics of both.

In this manner, the study advanced to the second level of analysis with three basic north-south alignments, and variations to be considered for the Cicero Avenue B alignment (Fig. 7). These were designated as alignment B along the west side of Cicero, variation B-II on the east side, and variation B-I centered on the avenue.

At the intermediate level, new criteria were introduced in each area of investigation and some of the criteria examined during the general level of analysis were given more detailed study. Finally, the three independent evaluations again were brought together.

Still, there was no decisive result (Fig. 8); the engineering discipline again rated the B alignment highest, with the D-E and C alignments less desirable but satisfactory. The community impact group widened its preference for the C alignment over the others, and the land use study still rated B and C highly with a slight preference for B.

One result of this level of analysis was that the D-E compromise alignment was eliminated because of its poor rating in the community impact and potential land use categories.

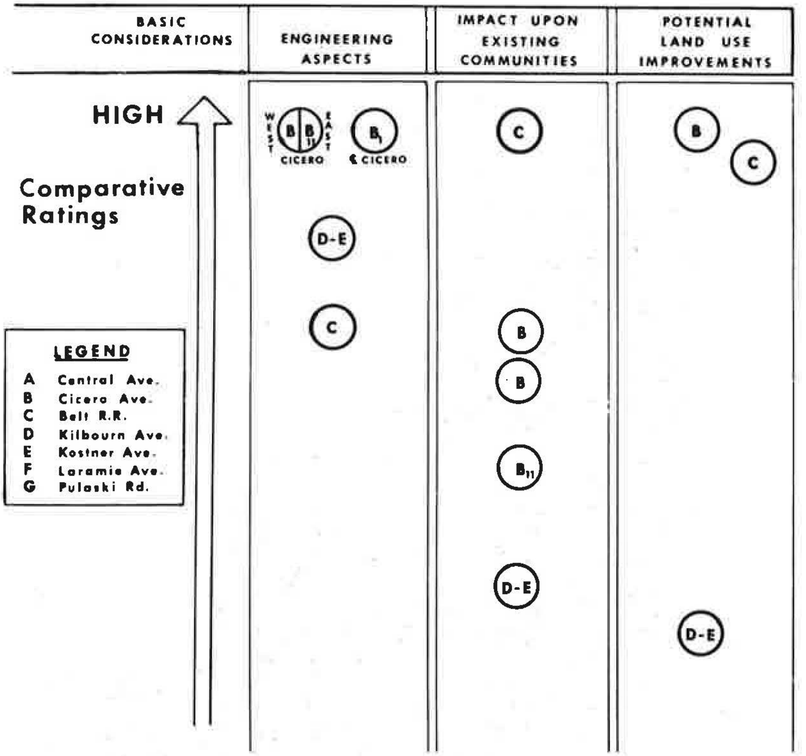

Figure 8. Crosstown Expressway study evaluation chart: Intermediate level of analysis, north-south alignment alternatives.

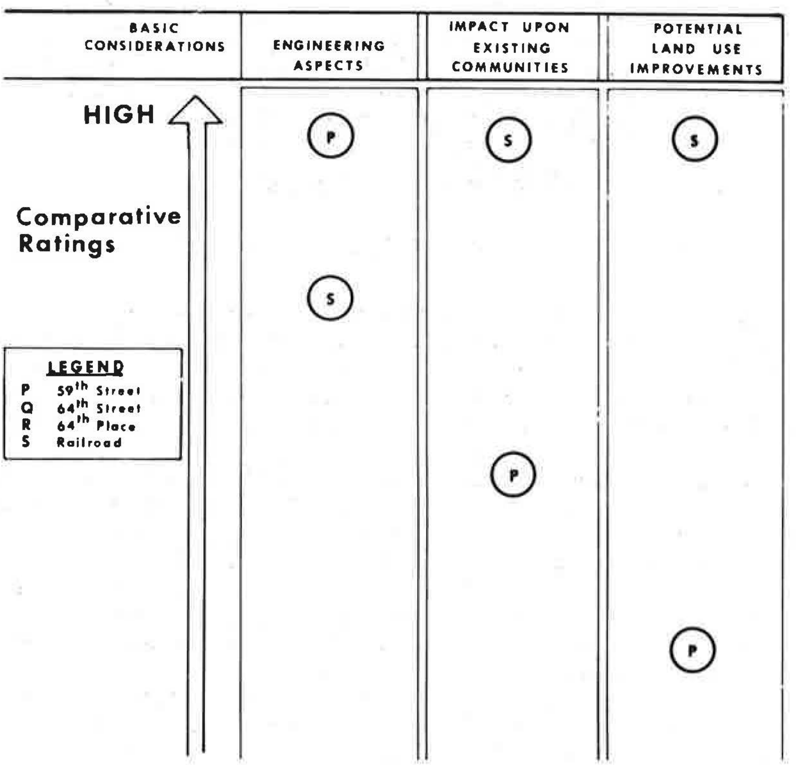

Figure 9. Crosstown Expressway study evaluation chart: Intermediate level of analysis, east-west alignment alternatives.

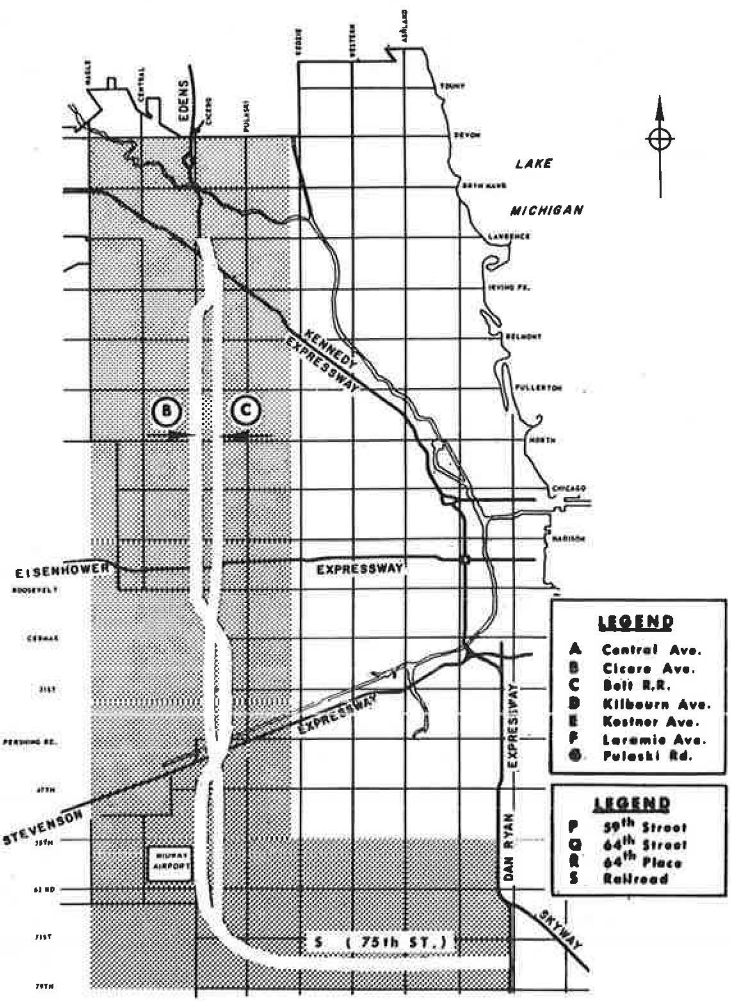

Figure 10. Crosstown Expressway alternate alignment study, detailed level of analysis.

A similar result was reflected for the east-west alternatives (Fig. 9). Engineering studies rated the 59th Street alignment as best, but also rated the S alignment as being acceptable. In the other two categories, however, the 75th Street S alignment emerged as the decisive choice, and the P alignment was rated as being unacceptable. At this point, the decision was made for the 75th Street S alignment, subject only to detailed studies and variations to be made in the design stage.

Going into the detailed level of analysis, two alternatives for the north-south alignment still remained under consideration (Fig. 10). They were the B alignment on Cicero Avenue and the C alignment along the Belt Line Railroad—both 8-lane facilities. The Cicero alignment was proposed principally as an 8-lane depressed highway, while the C alignment would be constructed as an 8-lane facility elevated on structure for much of its length on air rights to be obtained from the railroad.

It is important to note, however, that in the southern sector much of both alignments had similar engineering and impact characteristics.

At the conclusion of the detailed analysis, the evaluation chart closely resembled the one at the previous level of analysis, but with one significant change (Fig. 11). The B alignment remained the more desirable route from the traffic and engineering viewpoint, but the C alignment was established as adequate to satisfy the engineering

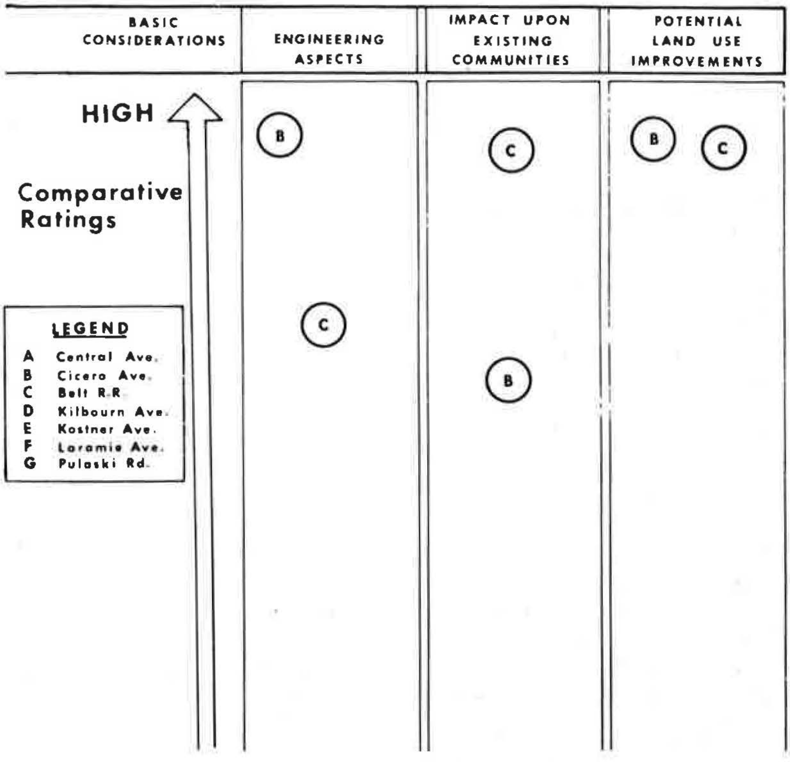

Figure 11. Crosstown Expressway study evaluation chart: Detailed level of analysis, north-south alignment alternatives.

requirements. Moreover, both alignments were shown to have user benefit-cost ratios greater than 1.0. In the potential land use category, the C alignment had climbed to a position of virtual equality with B at the top of the scale. And, decisively, in the community impact study, C emerged as the clear preference, while B dropped out of the acceptable range.

Thus, a decision was reached. The Belt Railroad alignment C became the preferred choice of the Crosstown Expressway task force, and the formal recommendation was made.

The complete documentation of the study fills volumes. Table 7 is a brief digest of only a few of the factors on which selection of the Belt Railroad alignment C was made, and provides comparative data only on the two alignments which remained in contention through the detailed level of analysis. The Cicero B alignment is equal or superior to the selected alignment in several respects. However, a cursory study of the data shown here will reveal the basis for choice of the Belt Railroad alignment.

It is noted that the two were rated virtually on a par with respect to accommodation of traffic demands, travel time economies, safety, service to adjoining communities, potential land use development, future transportation plans, reduction of traffic on parallel streets, effect on other modes of transportation, BPR requirements, and compliance with basic plan of Chicago.

In the cost factors at the top of the table, the Cicero alignment shows a lower estimated construction cost—$276 million vs $467 million—and a lower annual maintenance cost than the Belt Railroad alignment. Both of these advantages for the Cicero route stem principally from the fact, as shown farther down in the tabulation, that it would be on structure for a distance of only approximately 4 miles, compared with the 13 miles of elevated highway in the Belt Railroad alignment. Significantly, these factors are more than offset by the obvious advantages of the Belt Railroad alignment with respect to right-of-way cost, annual tax loss and effect on utilities.

TABLE 7

COMPARISON OF CICERO AND BELT RAILROAD ALIGNMENTS

Factors	Cicero	Belt Railroad
Estimated right-of-way cost	$121,643,000	$ 58,201,000
Estimated construction cost	276,371,000	467,611,000
Estimated annual maintenance cost	1,595,000	3,374,000
Estimated annual tax loss	2,973,000	1,491,000
Effect on utilities	49,000,000	23,000,000
Residential structures affected	2165	670
Dwelling units affected	4220	840
Industrial structures affected	200	140
Commercial structures affected	588	110
Employees affected	5670	7180
Miscellaneous structures affected	250	11
Community facilities affected	20	1
Communities disrupted	20	0
Mileage on structure	4	13
Mileage on embankment	4	3
Mileage depressed	12	6
Aesthetics	Better for landscaping	Less residential proximity preferred
Access between communities, continuity of streets		

The alignments were rated as equal with respect to:

Accommodation of traffic demands, travel time economies, safety, service to adjoining communities, potential land use development, future transportation plans, reduction of traffic on parallel streets, effect on other modes of transportation, BPR requirements, and compliance with basic policies plan for Chicago

The next block of factors in the table reveals the areas of investigation which clearly compelled selection of the Belt Railroad alignment: only 670 residential structures affected vs 2,165; 840 dwelling units vs 4,220 on the Cicero alignment; 140 industrial structures vs 200; 110 commercial structures vs 588 for the Cicero route; only 1 community facility displaced vs 20 on the other alignment. Finally, and most significantly, the Cicero alignment would seriously disrupt 20 well-defined communities; the Belt Railroad route would not disrupt any.

These are but a few of the factors which made selection of the Belt Railroad alignment inevitable. This, I believe, reveals the real value of the planning approach we have discussed. If engineering considerations, alone, had prevailed in making the decision, the Cicero alignment would have been selected. The fact that it was not selected does not represent a denial of the validity of the engineering evaluations; rather, it represents a comprehensive and objective evaluation of all factors bearing on the problem. And, don't overlook the fact that the Belt Railroad alignment does satisfy all requirements in the traffic and engineering category.

We who share the direct responsibility for the decision-making processes are bound, in good conscience, to strive for a proper balance in achieving transportation goals which are in harmony with other community objectives. We are concerned about losses to small businesses, disruption of neighborhoods, the relocation of people, and the removal of property from the tax rolls. We are equally conscious of the opportunities a new highway affords to attract new industries, stimulate commercial activity, remove blight and upgrade neighborhoods—advantages beyond the obvious ones of increased safety, comfort and relief of traffic congestion.

This is the contribution of the Chicago planning approach. If it is a unique contribution, it is because it introduces a systematic and objective method of analyzing and evaluating the many diverse factors of social, economic, psychological, fiscal and political considerations—each area of study conducted independently of the others, and each according to its own professional disciplines. It is a methodology which documents the thoroughness and objectivity of every step in reaching its conclusions.

Significant policy changes are emerging from the U. S. Bureau of Public Roads. Recognition of the need for a coordinated solution of the urban highway problem is now being advocated. It is the author's hope that the Chicago Crosstown Expressway study stimulated discussion within the Bureau of Public Roads and that this paper will similarly stimulate other evaluations which will add to our knowledge in relating the complex and variable factors involved in urban transportation planning in a sensible, systematic way.

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Transportation Implications of Alternative Sketch Plans

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Six sketch plans prepared by the planning division for a region of 30 million population were evaluated for transportation implications. The aim was to gain insight into the form of transportation network which, according to the present means of travel, would correspond to each development sketch. The study also compares the resource commitments required for the several plans. Of the planning variables employed to construct the sketch plan alternatives, the distribution of population densities served as the measure of variation among the alternative plans. Trip generation and segregation by transportation modes were estimated on the basis of the prevailing patterns in this and other regions. Travel costs for this analysis were adapted from other studies.

Results indicate the relative growth of mass transit and auto modes of travel in terms of the 1960 volumes, and also provide an indication as to how the variation in travel might influence the resource allocation between the two modes of transportation. The value of this study lies primarily in the uniform application of travel generation criteria to a set of different population distribution schemes. The uniform evaluation was accomplished by transforming characteristics of the sketch plan communities into mathematical models.

Sketch plans represent development concepts, and the objective of this undertaking is to open vistas for speculation on the course of future urbanization trends. This analysis provides the first approximation of transportation implications for the analyzed development schemes. It also suggests the succeeding steps that could be taken to narrow the gap between sketch plan ideas and workable alternatives.

•THE six sketch plans which were analyzed in this report represent three basic patterns of regional growth: (a) decentralized—under minimum of development control; (b) new-town concept; and (c) the concentration of future population in a few large urban units. Each of the three patterns were presented in two variants differing in the number of units and in the intensity of development.

Figure 1 shows the sketch plans. The circles represent the relative size and the number of communities. The original sketch plans were composed of residential, commercial, industrial, governmental, and park land units. Each unit represented a land area of one square mile. The following factors were considered in developing the sketch plans (1):

(1) Geographic division of major socioeconomic systems (core vs remainder of region); (2) activity center locations within major urban systems; (3) population distribution by major geographic areas; (4) household composition distribution by core and remainder systems; and (5) open space pattern throughout the region.

Paper sponsored by Committee on Transportation System Evaluation and presented at the 46th Annual Meeting.

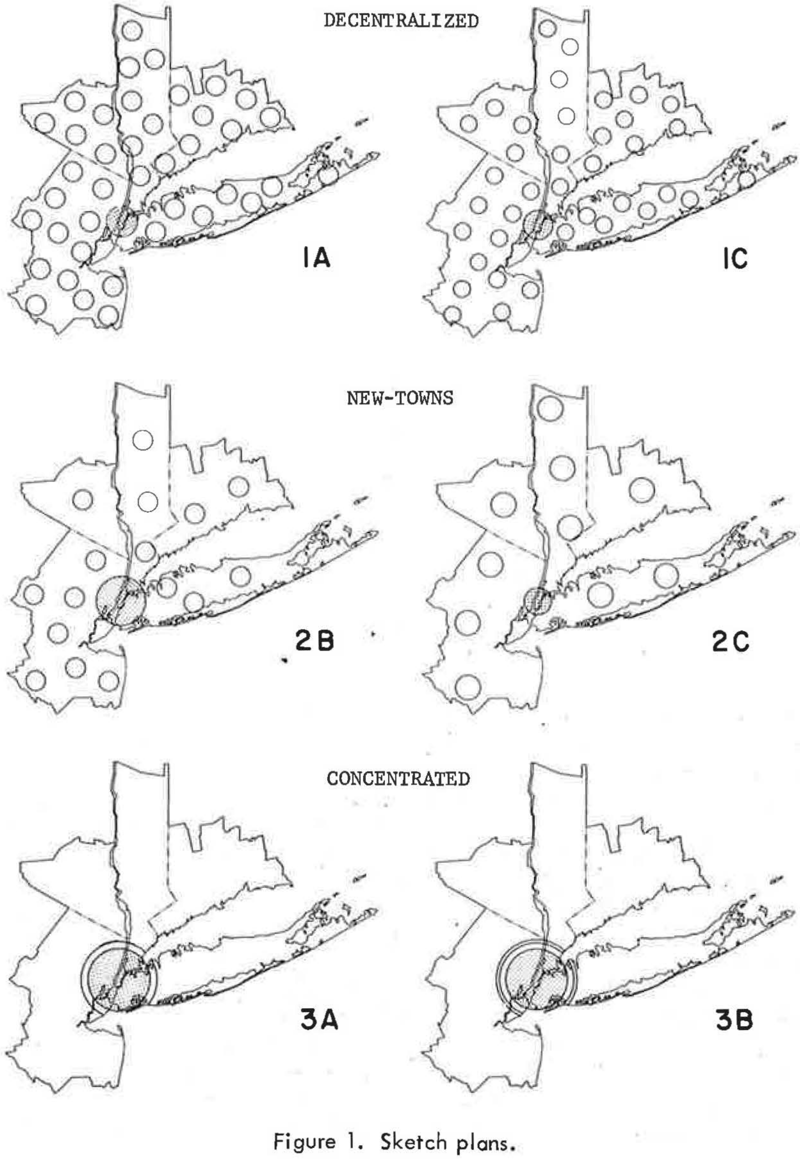


Figure 1. Sketch plans.

Table 1 summarizes the basic sketch plan quantification data which served as input for the travel implication analysis. The basic difference between the two "decentralized" sketches (Fig. 1) can be seen in the area of land allotted for residential purposes. Nearly equal populations of the two metropolitan community groups are allocated drastically different areas of residential land. The average density of metropolitan communities in sketch 1A amounts to 2,810 persons per square mile, and in sketch 1C, to 3,870.

As to the "new town" sketches, the average population density of the core area of sketch 2C is considerably higher than that of sketch 2B. Densities of the metropolitan communities for this development pattern vary only moderately.

Of the two "concentrated" schemes, the average core density of sketch 3A is somewhat higher than of sketch 3B. Density of the surrounding communities, however, differs considerably.

Certain elements are common for all the schemes. All sketches are designed to accommodate the estimated future population of 30 million. An equal amount of jobs

TABLE 1

POPULATION DISTRIBUTION

Pattern	Sketch	Part of Region	Number of Units	Population (000)	Res. Land Area (sq mi)	Avg. Resid. Density (000) Per Sq Mi
Decentralized		Core	1	10,000	533	18.75
	1A	Met. Area	40	20,000	7,120	2.81
		Total	41	30,000	7,653	3.92
		Core	1	11,000	435	25.30
	1C	Met. Area	38	19,000	4,902	3.87
		Total	39	30,000	5,337	5.63
New Towns		Core	1	14,000	1,184	11.80
	2B	Met. Area	16	16,000	3,328	4.81
		Total	17	30,000	4,512	6.65
		Core	1	10,000	410	24.40
	2C	Met. Area	10	20,000	3,190	6.28
		Total	11	30,000	3,600	8.33
Concentrated		Core	1	26,000	2,026	12.82
	3A	Met. Area	1	4,000	1,123	3.56
		Total	2	30,000	3,149	9.53
		Core	1	22,000	2,077	10.60
	3B	Met. Area	2	8,000	1,190	6.72
		Total	3	30,000	3,267	9.20

was distributed among communities in all sketches. This was done on the basis of the prevailing ratios among the several employment classes. The current composition of household sizes was projected for the region's future population.

The several sketches embody density variations in the core areas and in metropolitan communities. This was accomplished by either changing the size and the number of communities or by increasing or decreasing the area of open land. Combinations of these provided a spectrum of population distribution patterns for the region.

It is common knowledge that lower densities produce more trips and that high densities utilize mass transportation to a greater degree for routine travel. In the planning process, nonetheless, it is of interest to know the relative change in travel patterns and the degree of change associated with different population distribution patterns for a given future region's population. Further travel implications become apparent by weighing the relative cost of travel under different regional development schemes.

From the basic premises of population distribution, this analysis reveals the travel implications with respect to the intensity of trip generation and to different utilization of auto and mass transport modes. It also demonstrates these implications in terms of costs.

FINDINGS

Travel implications for the six sketch plans were determined in two steps. The first step deals with travel characteristics. The trip-making potential for the six sketches was established, and the estimated volumes were expressed in terms relative to population increase.

In the second step, communities which indicated propensity to support public means of transportation were fitted with mass transit systems. Travel costs for these systems were evaluated beforehand. Ultimately, this analysis step established the extent of resources needed for travel purposes under each development scheme.

Travel Characteristics

Two aspects of travel characteristics were evaluated: the propensity for making trips and the relative utilization of transportation modes. Subsequently, the resulting

TABLE 2

TRIP-MAKING CHARACTERISTICS–INCREASE ABOVE 1960 VOLUMES[a]

Pattern	Sketch	Part of Region	Region Total		Mass Transit		Auto	
			Trips Per Day (000)	Increase (%)	Trips Per Day (000)	Increase (%)	Trips Per Day (000)	Increase (%)
Decentralized		Core	18,815		9,168		9,647	
	1A	Met. Area	58,800		–		58,800	
		Total	77,615	122	9,168	0	68,447	163
		Core	18,206		10,031		8,175	
	1C	Met. Area	53,504		–		53,504	
		Total	71,710	105	10,031	11	61,679	137
New Towns		Core	31,829		12,137		19,692	
	2B	Met. Area	44,074		9,728		34,336	
		Total	75,903	117	21,865	143	54,028	108
		Core	16,803		9,211		7,592	
	2C	Met. Area	53,030		13,910		39,120	
		Total	69,833	100	23,121	157	46,712	80
Concentrated		Core	55,923		23,178		32,745	
	3A	Met. Area	11,442		–		11,442	
		Total	67,365	92	23,178	158	44,187	70
		Core	51,915		18,613		33,302	
	3B	Met. Area	21,029		5,778		15,251	
		Total	72,944	108	24,391	171	48,553	87

[a]1960 volumes: mass transit, 9 million; auto, 26 million; total, 35 million.

travel characteristics of the six plans were compared to the projected population growth. (The 1960 population of 17 million was projected to reach the 30 million mark in the year 2010, an increase of 77 percent.)

As indicated by Table 2, the region's future trip-making propensity exceeds the population increase for all sketches. Sketch 3A generates the lowest trip volume and sketch 1A the highest. This could have been expected, judging from average population densities shown in Table 1; lower densities tend to produce more trips.

However, sketch 2B, with the average regional population density of 6,650, produced more trips than sketch 1C, with a population density of 5,630. This condition was brought about by the considerably lower densities in the core city of sketch 2B. Trip generation rates vary little in the high-density range, but this variation becomes significant at low densities. Thus, in comparison with sketch 1C, the lower trip generation rate of the 2B metropolitan area failed to offset the high trip production rate of the core city.

The following summary further reveals the trip generation characteristics of the six sketches:

Development Pattern	Development Variants (trips in 000)	
Decentralized	1A–77,615	1C–71,710
New towns	2B–75,703	2C–69,833
Concentrated	3B–72,944	3A–67,365

It can be seen that the trip generation potential between the two development variants of each development pattern varies more than between the comparable variants of the three development patterns. That is, the differences between sketches 1A and 1C, 2B and 2C, and 3B and 3A, are larger than between 1A, 2B and 3B, and 1C, 2C and 3A.

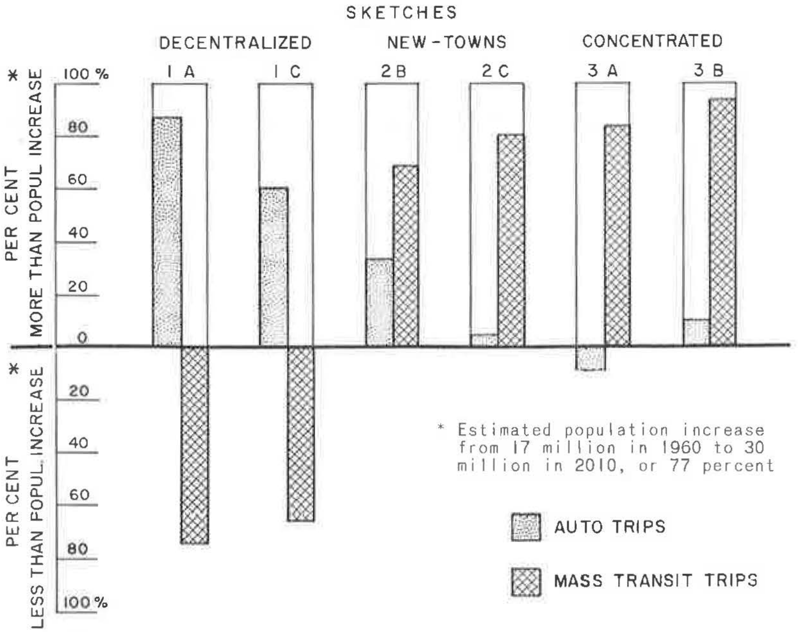


Figure 2. Travel growth by mode.

The data in Tables 1 and 2 and the above summary lead to a conclusion that the variation in trip generation potential of the six development sketches is influenced not so much by densities of the core area, but by percentages of the region's population that are expected to reside in metropolitan communities and by the average density of these urban units.

The sketches indicate a pronounced variation in the utilization of auto and mass transit modes of travel, as shown in Table 2. The increase of mass transit trips above 1960 volumes for sketch 1A equals zero, while auto trips for this scheme increase by 163 percent; for sketch 3B the mass transit trips grow 171 percent, but auto trips increase only 87 percent. The region's population for both sketches increases 77 percent.

According to the findings, mass transit facilities for sketch 1A will operate in the year 2010 at the same patronage level as at the present. Evidently the population growth under this development scheme would be accommodated in the region's outer areas where most of the travel would be done in autos. Concentrated development (sketches 3A and 3B) in this respect represents the other extreme. Here the mass transit travel would grow at more than double the rate of the region's population increase while auto usage would trail the population growth in the case of 3A and only slightly exceed it in the case of 3B.

Figure 2 shows the increase in the usage of auto and mass transit modes of travel as related to the population growth. At the extremes, in sketch 1A the population growth would expand only auto travel. In sketch 3B, the auto travel would grow in proportion to the population, but mass transit would exceed this growth by 94 percent. The radically different picture of travel habits in the extreme development schemes implies a profound variance in the two urbanization concepts. Other sketches represent the intermediate conditions.

This drastic variation in the utilization of auto and mass transit modes of travel appears to be one of the most important issues requiring reconciliation with other urbanization problems in weighing future development policies. The obviously different means of travel in the six development schemes also implies different policy orientations toward housing, parking, distribution of jobs, and other urban development programs.

Figure 2 suggests travel implications extending beyond the issues of transportation. Some of these implications are discussed in the following.

For sketches 1A and 1C the public policy would provide for the growing demands of auto travel. New developments and redevelopment projects of existing urban areas would be auto-travel oriented, providing suitable access and parking facilities. Auto travel is space demanding. Therefore, for a proper accommodation of all urban elements, either the densities of the present urbanized areas would be reduced, or advanced technology would generate development forms which are unknown at the present. Mass transit under these development sketches would gradually be giving ground to auto travel—a condition which exists at the present.

Sketch 2B should be looked upon as the product of a conscious public policy favoring a balanced transportation system. This sketch presupposes that a balanced transportation is possible and feasible. All urban development policies under this scheme would be guided by concepts designed to sustain the planned modes of travel.

Sketches 2C, 3A, and 3B indicate a strong bias favoring mass transit. Either through specific development policies or through consciously designed transportation regimes the urban development forms would be public-transport oriented. These sketches suggest a complete reversal of the present transportation policy to one in favor of mass transit. The rate of auto travel per person in the year 2010 would remain at about the same level as at the present.

These sketch groups suggest three radically different pictures of future urban forms. Presuming that the urban development forms and transportation services ultimately must attain a functional integration, the above sketch groups imply three different forms of urban travel, as well as three different forms of urban living. The individual image of these forms is left to be created in the minds of the readers.

The Cost of Travel

The last column of Table 3 shows the estimated annual travel cost for each sketch. These costs include investments in facilities as well as operating expenditures, and are given in 1963 dollars.

Since daily travel expenditures claim a sizable part of a household's disposable income, the aggregate regional expenditures for this purpose are large, ranging from $15.48 billion for sketch 3A to $17.29 billion for sketch 1A. These figures include all public and private outlays for the transportation function.

The main body of these expenditures remains relatively stable under similar conditions of development at a given time. Only a fraction of it can be altered by the rationalization of environment, i.e., optimization of choices and maximization of benefits. Consequently, the difference of $1.81 billion between the two extreme travel costs of sketches 3A and 1A does not seem to be impressive. Nonetheless, it amounts to about half of New York City's annual operating budget and more than three times the city's capital improvement budget. Should further analysis embrace all major regional functions, even under these conditions the total savings that could be arrived at through the optimization of separate functions most likely would not amount to more than two or three billion dollars annually. Proper reinvestment of these moneys, however, could have profound effects on the region's well-being. Thus the differences among the total travel costs of the six development schemes in the economic sense are significant and meaningful. The impact of the economies in travel could be considerable by freeing substantial resources for other improvements of the general urban plant.

Figures showing the daily travel expenditures for the different sketch plans in Table 3 follow, to a degree, the pattern of trip-making characteristics. The size, the arrangement of mass transit facilities, and the effect of population density on the cost of auto travel, however, influence these expenditures for each sketch plan differently. Daily travel expenditures, therefore, are not entirely proportional to the number of trips.

Viewing the daily expenditures as resources which are being withdrawn from the population's income and put into the development and operation of transportation facilities, the resource allocation picture for the different development schemes is shown in Figure 3. This analysis was concerned not with the effects of population growth, but

TABLE 3

RELATIVE COST OF TRAVEL AND EXPENDITURE INCREASE ABOVE 1960 VOLUMES[a]

Pattern	Sketch	Part of Region	Number of Units	Region Total		Mass Transit		Auto		Total Annual Cost $ (billions)
				Daily Expenditure $(000)	Increase (%)	Daily Expenditure $(000)	Increase (%)	Daily Expenditure $(000)	Increase (%)	
Decentralized		Core	1	12,446		3,367		8,779		4.54
	1A	Met. Area	40	34,986		—		34,986		12.75
		Total	41	47,432	118	3,367	0	43,765	140	17.29
		Core	1	12,596		4,012		8,584		4.60
	1C	Met. Area	38	31,835		—		31,834		11.60
		Total	39	44,431	104	4,012	11	40,419	122	16.20
New Towns		Core	1	20,018		4,355		15,163		7.30
	2B	Met. Area	16	25,037		3,405		21,632		9.11
		Total	17	45,055	107	8,260	129	36,795	102	16.41
		Core	1	11,656		3,384		7,972		4.25
	2C	Met. Area	10	32,275		6,260		26,015		11.77
		Total	11	43,931	102	9,344	176	33,987	87	16.02
Concentrated		Core	1	35,631		9,271		26,360		13.00
	3A	Met. Area	1	6,808		—		6,808		2.48
		Total	2	42,439	95	9,271	158	33,168	82	15.48
		Core	1	31,922		7,445		24,477		11.61
	3B	Met. Area	2	13,031		2,389		10,142		4.76
		Total	3	44,953	106	10,334	187	34,619	88	16.37

[a]1960 estimated daily expenditures (in millions): mass transit, $3.6; auto, $18.2; total, $21.8.

with the travel implications of the different schemes designed to accommodate this growth. Therefore, in Figure 3, as in Figure 2, the diagram shows the relative magnitudes by which the daily expenditures for the two modes of transportation exceed the population increase, or lag behind it.

In the dispersed development (sketches 1A and 1C), mass transit would be alloted about the same amount of resources as at the present. Resource allocation for this mode would not be affected by the population growth. The investments in auto travel, instead, would exceed the present rate, reaching 140 percent above the present in the year 2010.

At another extreme, the resources put in mass transit for sketch 3B would outpace the rate of population increase by more than twice, reaching the 187 percent level in 2010. Resource allocation to auto travel in this scheme would increase at the rate of population growth, exceeding it by only 11 percent in 2010.

Figure 3 thus suggests the direction which would be followed by the decision-making process in the allocation of resources for transportation under conditions of the six development schemes. The figures presuppose the present amenity level of travel for all sketches. Depending upon which of the two factors is regarded as cause and which as effect, one can look upon Figure 3 as an indication for channeling the resources to achieve the desired development characteristics, or, from another point of view, Figure 3 indicates the corresponding travel modes for the six regional development patterns established by means other than the transportation regime.

ESTIMATION OF TRAVEL CHARACTERISTICS

Sketch plan communities were constructed from one-mile squares representing several classes of land development. Residential land uses were shown in four density ranges, the highest 72,800 persons per square mile and the lowest 350. The number of such density squares for each sketch plan was determined by planners according to a preconceived idea of the region's development trend. Each sketch consists of a core

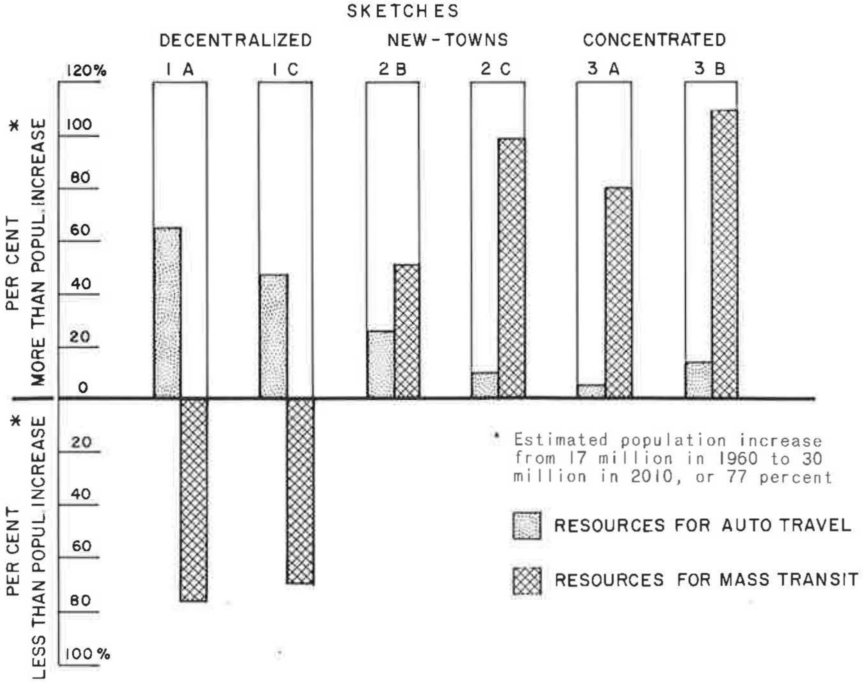


Figure 3. Change in resource allocation for travel by mode.

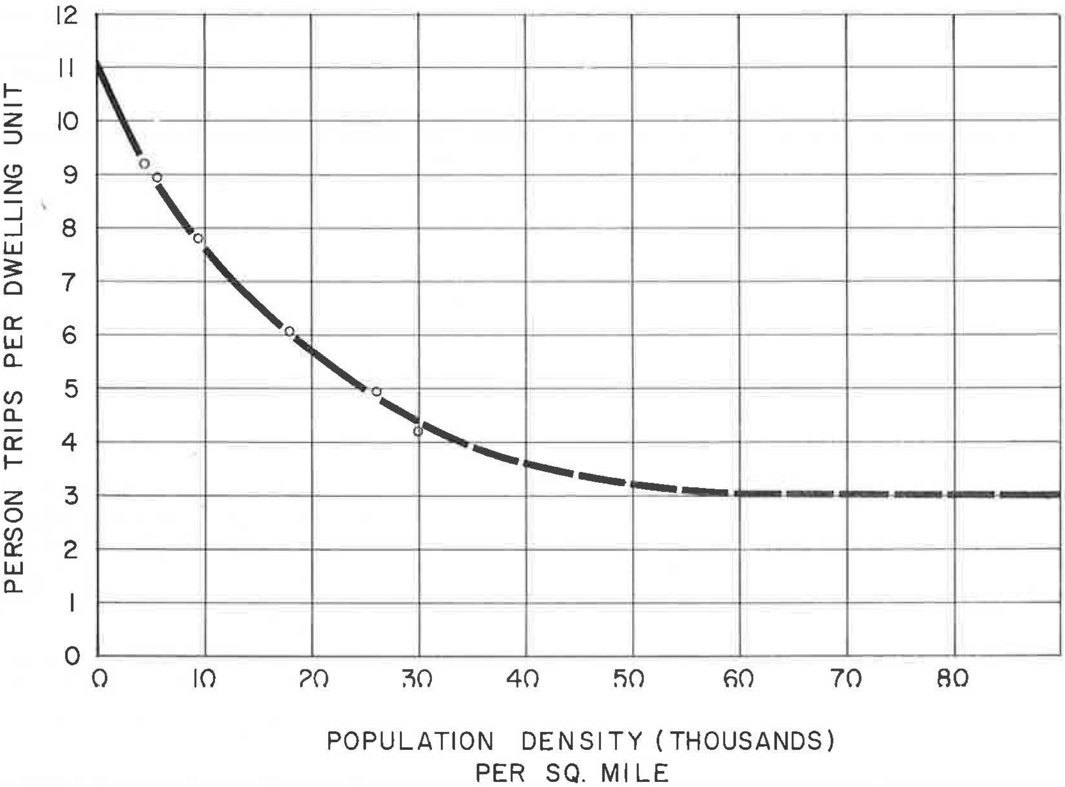


Figure 4. Trip generation rates.

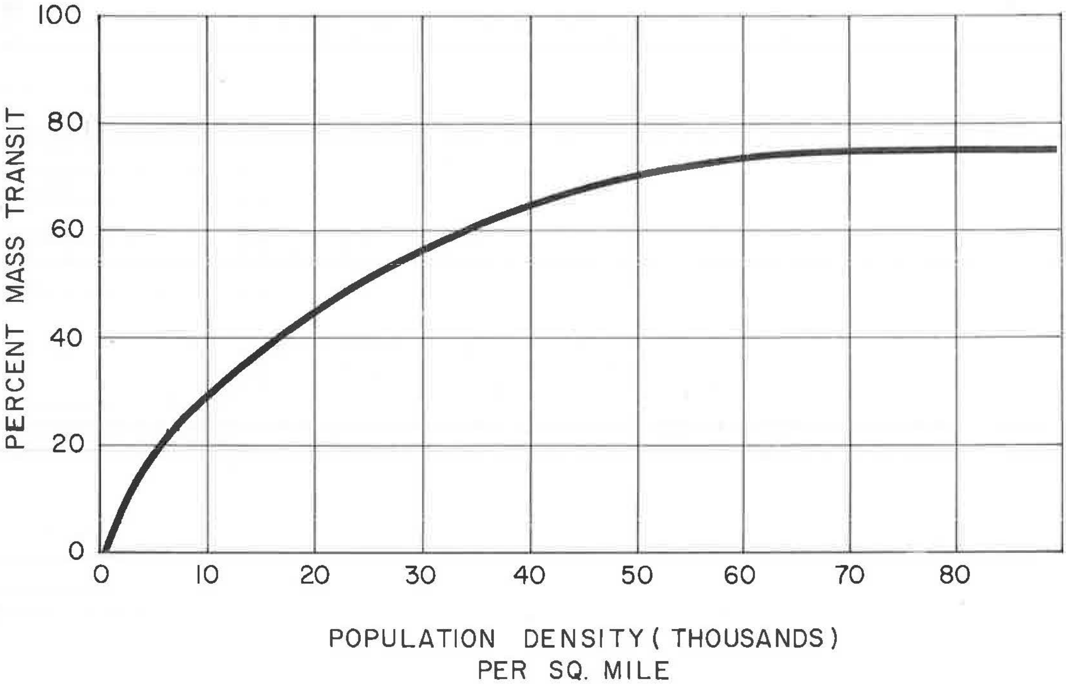


Figure 5. Travel by modes.

area and a specified number of quantitively identical metropolitan communities. The distribution of land use squares within each community, however, differs. It was mapped intuitively. Thus the sketch plans speculate on the quantitative aspect of the region's growth as well as on the geographic dispersion of these quantities.

In order to evaluate travel characteristics for the six development sketches uniformly, it was necessary to define the communities in mathematical terms. Since the quantities varied not only between sketches but also between communities of the same development sketch, this made the application of mathematical formulations problematic.

The exponential density gradient has been found to fit the density distribution in old cities (2). In arranging the sketch plans, the planners were inclined to see small community subcenters surrounding the major urban centers. In addition to commercial, manufacturing and other job-producing land uses, these subcenters also include high-density residential developments.

The net effect of clustering subcenters about a major center upon the density distribution pattern was such that the density gradient for the sketch plan urban units approached a declining straight line. These observations and the awareness that this analysis is to be the first approximation in the process of narrowing down the alternative choices led to choosing the cone-shape density distribution model.

Thus, the analysis was carried out on the assumption that the urban unit's population confined within the residential land area A is distributed in such a manner that

$$P = (1/3)\ A\ H$$

where H is the peak density and equals 3P/A. The density d at a distance r from the center equals

$$d_r = 3P/A\ (1 - r / \sqrt{A/\pi})$$

Trip generation potential and the trip segregation by modes were established for each model utilizing the graphs shown in Figures 4 and 5. These graphs were developed from preliminary Tri-State survey data and from findings in other metropolitan areas.

Figure 6 illustrates the process of applying the trip generation rates to sketch plan models. All models were divided into analysis rings. Uniform boundaries for the corresponding rings of all sketches were defined by selected density ranges on the density scale of the trip generation curve. Projecting the selected densities to the model outlines, the intersection of such horizontal density lines with the model surface delineated the analysis ring.

After determining the ring population, this quantity was multiplied by the corresponding average trip generation rate and by the appropriate coefficients segregating the trips

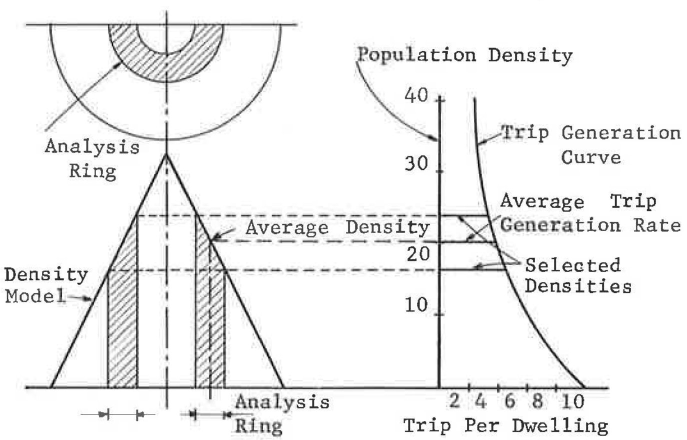
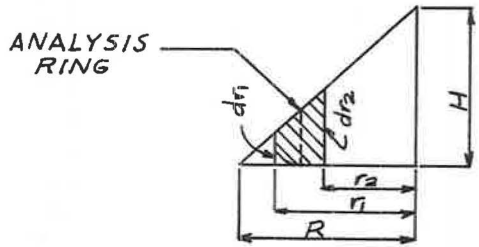


Figure 6. Uniform designations of analysis rings.



SCHEME 2B CORE

POPULATION DISTRIBUTION P = 1/3 AH

Population in (000) P = 14,000
Area A = 1184 Sq. mi.
$H = 3\ P/A = 35.47$; $R = \sqrt{A/\pi} = 19.42$
$S = H/R = 35.47/1942 = 1.826$
Average density $d_{av} = P/A = 11.\ > 4$
(It was taken that urban units with average population density of 4000 and over would require mass transit)

1	2	3	4	5	6	7
Boundary Density d_r	$\Delta H = H - d_r$	$r = \Delta H/S$	πr^2	$\pi r^2 d_r$	$1/3\pi r^2 \Delta H$	(5) + (6)
0	35.47	19.42	1184	0	14000	14000
2	33.47	18.33	1055	2110	11770	13880
5	30.47	16.69	875	4375	8887	13262
10	25.47	13.95	611	6110	5187	11297
16	19.47	10.66	357	5712	2317	8029
25	10.47	5.73	103	2575	359	2934
35	.47	.26	0	0	0	0
¢	.00	.00	0	0	0	0

8	9	10	11	12	13	14	15
Ring Area	Ring Volume	d_{av} (Ring)	Trip Rates	Person Trips	% Mass Trans.	Mass Trans. Trips	Auto Trips
129	120	1.0	10.6/3.4	374	-	-	374
180	618	3.5	9.6/3.3	1823	14	255	1568
264	1965	7.5	8.3/3.0	5345	24	1283	4062
254	3268	13.0	7.0/2.8	8170	34	2778	5392
254	5095	20.5	5.6/2.6	10954	45	4929	6025
103	2926	30.0	4.4/2.5	5150	56	2884	2266
0	8	35.2	3.9/2.5	18	60	8	5
1184	14000			31829		12137	19692

Figure 7. Evaluation of the model.

TABLE 4

TRAVEL CHARACTERISTICS

Pattern	Sketch	Part of Region	Number of Units	Population (000)	Res. Land (sq mi)	Total Trips (000)	Mass Transit Trips (000)	Auto Trips (000)
Decentralized		Core	1	10,000	533	18,815	9,168	9,647
	1A	Met. Area	40	20,000	7,120	58,800	–	58,800
		Total	41	30,000	7,653	77,615	9,168	68,447
		Core	1	11,000	435	18,206	10,031	8,175
	1C	Met. Area	38	19,000	4,902	53,504	–	53,504
		Total	39	30,000	5,337	71,710	10,031	61,679
New Towns		Core	1	14,000	1,184	31,829	12,137	19,692
	2B	Met. Area	16	16,000	3,328	44,074	9,728	34,336
		Total	17	30,000	4,512	75,903	21,865	54,028
		Core	1	10,000	410	16,803	9,211	7,592
	2C	Met. Area	10	20,000	3,190	53,030	13,910	39,120
		Total	11	30,000	3,600	69,833	23,121	46,712
Concentrated		Core	1	26,000	2,026	55,923	23,178	32,745
	3A	Met. Area	1	4,000	1,123	11,442	–	11,442
		Total	2	30,000	3,149	67,365	23,178	44,187
		Core	1	22,000	2,077	51,915	18,613	33,302
	3B	Met. Area	2	8,000	1.190	21,029	5,778	15.251
		Total	3	30,000	3,267	72,944	24.391	48,553

by travel modes. This analysis process was carried out numerically. A sample of the computations is shown in Figure 7.

Table 4 presents the summary of the computed travel characteristics for all sketches. Figure 8 demonstrates the relative increase in trips for auto and mass transit modes above 1960 volumes.

This analysis presents the first approximation of the travel implications. Subse-

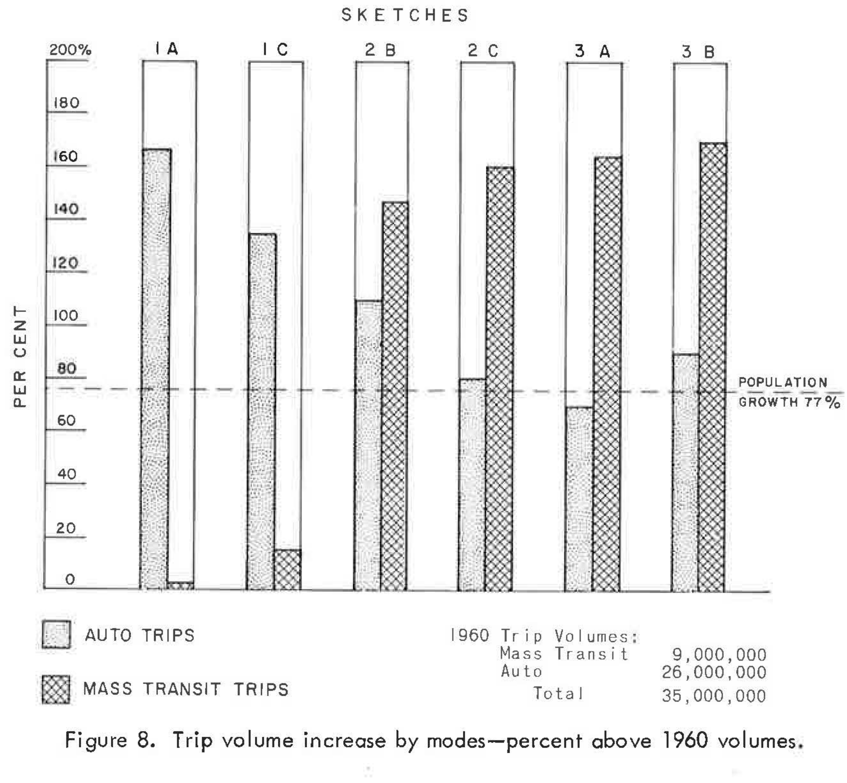


Figure 8. Trip volume increase by modes—percent above 1960 volumes.

quent analysis of selected alternatives would have to work with a more sophisticated density distribution fit for future communities. These could be developed through reasonable deductions.

EVALUATION OF RESOURCE NEEDS

The resource allocation for transportation in a metropolitan area is proportional to the mileage of trips and to the total travel cost per mile for each mode of transportation. The magnitude of resources required for this purpose can increase or decrease, depending on the average number of trips generated per person, the average trip length, and the cost per mile of travel. Resources for this purpose are being raised by means of user payments for facilities or services, individual expenditures, special taxes, general taxes, and borrowing.

Transportation costs which were used in this study include the installation and operation of facilities, improvements, and other incidental expenditures attributable to urban travel. Only two modes of transportation were considered, auto and rail mass transit. Designating the number of auto trips as T_a, mass transit as T_m, and indicating the average trip length for respective modes as l_a and l_m and the cost per mile of travel as C_1 and C_a, the total resources allocation for travel can be shown as

$$R = C_1 l_a T_a + C_2 l_m T_m$$

Trip volumes denoted as T_a and T_m were evaluated in the preceding section. Transportation costs were adopted from a study by Wohl (3). This study utilized three sizes of rapid transit systems: 6-mile, 10-mile, and 15-mile long routes. Travel costs for these systems are shown in Figure 9.

Each sketch plan community that indicated potential to support mass transit was fitted with one of the three mass transit networks. Whether or not a community could support mass transit and the extent of such systems were determined by the following criteria: (a) it was assumed that communities with an average population density of 4,000 or more persons per square mile are capable of sustaining rail or bus mass transit, and communities with less average density than this would resort primarily to auto travel; (b) it was taken that mass transit within a given metropolitan transportation system primarily accommodates the centrally oriented rush-hour travel.

For communities which indicated propensity to support mass transit, such lines were extended from the core outward to areas of about 3,000 persons per square mile density. It was assumed that buses serving lower densities would connect with the rapid transit at these points. Thus, the mass transit route length was determined by the radius extending from the center out to the density ordinate of 3,000 in a community model. This radius was rounded off to one of the three systems—6, 10, or 15 miles (Table 5).

In determining the number of service sectors in the system, the trip load on each line was kept within practical limits for convenient and economical travel. The maximum arc length between the outer ends of two lines was limited to about 6 miles.

The number of one-way passengers at the maximum load point of a line was arrived at by assuming that 50 percent of daily mass transit trips are made during the four rush-hours of the day. Ten percent of this volume was assumed to travel in the opposite direction. Allowing another 10 percent for along-the-line destinations, the volume of trips collected in a sector and accumulated at the maximum load point per one rush-hour equals

$$\frac{0.5 \times 0.9 \times 0.9}{4} - 0.1012 \times 100 = 10.12\% \text{ of 24-hour volume}$$

Thus, multiplying this factor by the 24-hour trip volumes per sector, the one-way hourly volume was obtained. On the basis of these volumes the mass transit trip costs were derived from Figure 9.

The cost variation between bus and rail mass transit is not significant enough to be taken into account at the sketch planning stage. Only rail transit was considered, but

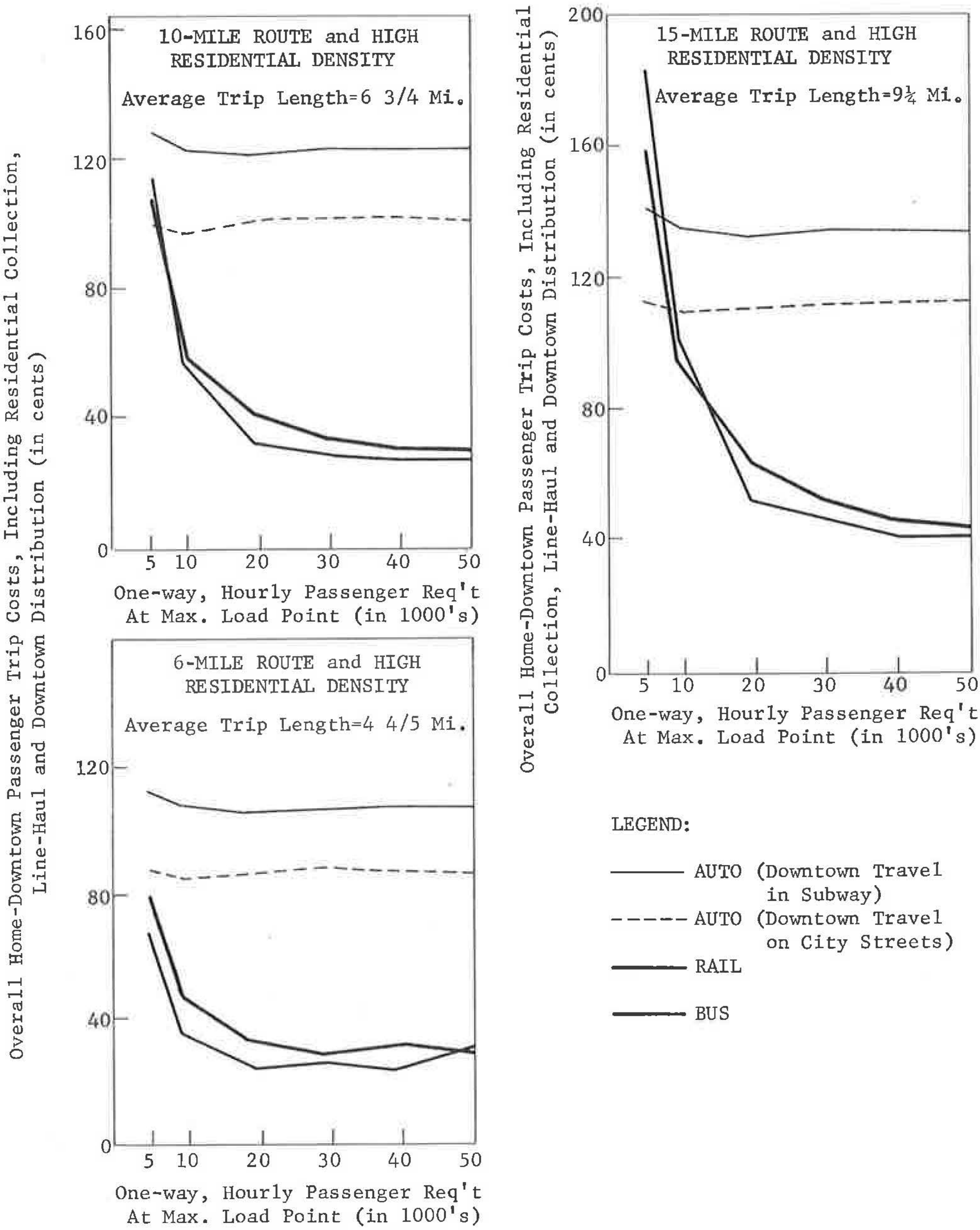


Figure 9. Overall system passenger trip costs between home and downtown (total of residential collection, line-haul and downtown distribution costs, to include all terminal and parking charges) (3).

some of these can be considered as express bus lines with the same cost characteristics as rail facilities.

Rush-hour travel greatly influences the cost of mass transit services; therefore, the average rush-hour trip cost was taken to be reasonably representative for the average daily trip. All of these costs include expenditures for roads, rolling stock, and operation.

The downtown-bound auto travel cost, as shown in Figure 9, remains nearly constant at different loads but responds to the average trip length. These graphs indicate auto travel costs in high-density areas.

TABLE 5

MASS TRANSIT TRIP COSTS

Pattern	Sketch	Part of Region	Number of Units	r_d*	Selected Route Length	Number of Sectors	24 Hour Trips (000)	24 Hour Trips Per Sector (000)	Trips Per Hour at Max. Load Point (000)**	Rush-Hour Trip Cost (Fig. 8)
Decentralized	1A	Core	1	12.3	15	18	9,168	509.3	51.6	.40
		Met. Area	40	—	—	—	—	—	—	—
	1C	Core	1	11.3	10	18	10,031	557.3	56.4	.40
		Met. Area	38	—	—	—	—	—	—	—
New Towns	2B	Core	1	17.8	15	18	12,137	674.3	68.3	.40
		Met. Area	16	6.5	6	6	608	101.3	10.3	.35
	2C	Core	1	11.0	10	18	9,211	511.7	51.8	.40
		Met. Area	10	8.5	10	10	1,391	139.1	14.1	.45
Concentrated	3A	Core	1	23.4	15	30	23,178	772.6	78.2	.40
		Met. Area	1	—	—	—	—	—	—	—
	3B	Core	1	23.3	15	24	18,613	775.5	78.5	.40
		Met. Area	2	12.8	15	15	3,399	226.6	23.0	.50

*Radius extending to 3,000 persons per sq mi density.
**Conversion factor 0.1012.

This study made no distinction between the downtown-bound and the circumferential auto travel. The auto trip cost, as shown in Figure 10, reflects the population density in which the trips originate. In establishing the range of costs shown by this figure reference was made to several sources. The extreme cost values adapted from other studies were superimposed by a straight-line proportion over densities occurring in this study. The auto travel costs represent road construction, maintenance, auto ownership, operation expenditures, and parking. The average trip length for all sketches was assumed to be 6 miles.

Table 6 shows the computation results indicating travel costs for the six sketch plans. Viewing these costs as part of the population's resources, the analysis results indicate the extent of resources to be expended for travel purposes under conditions of the six development schemes. In the last column Table 6 shows these daily expenditures on a per-person basis. Figure 11 demonstrates the increase in resource allocation by modes above the 1960 level.

APPLICATION OF DENSITY MODELS FOR THE EVALUATION OF SELECTED ALTERNATIVES

The cone-shaped sketch planning models for the selected development alternatives could be transcribed into density models of the hyperbolic parabola type on the basis of existing and projected densities (Fig. 12).

The selected sketch alternatives, in all likelihood, would consider the scatter of existing urban units as the basis for the urbanization pattern of the future. These units would be projected for the population increase and, perhaps, a number of new communities would be planned to rise in the course of time. Future urban units in the metropolitan area would not be uniform in size. The regional urbanization system would reflect not only the anticipated population growth, but also the interaction of communities. Urban units could be ranked by the scope and character of planned activities.

Employing density models, such alternatives could be evaluated for the basic travel characteristics and for resource

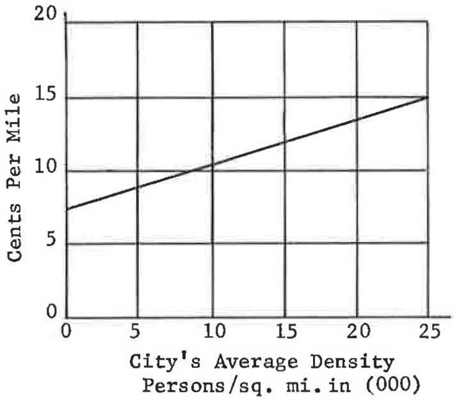


Figure 10. Auto travel cost per person trip.

allocation requirements. On the basis of these findings, alternative development schemes could also be provided with conceptual layouts of facility networks.

Utilizing the inventory data, criteria for travel generation and for the determination of travel costs could be refined to represent these factors more accurately. The analysis output of final alternatives on this basis could give a fairly realistic picture of changes that might take place in the evolution of transportation systems as well as of the resource allocation requirements for such development processes.

Should the selected alternatives be detailed by development stages, such as programs for each decade, this method of analysis could estimate the changes in travel demand, modal use, and the required resources allocation for transportation systems at each development period. Detailing long-range plans by development steps would provide the opportunity for a rational planning of transportation systems. The required land for transportation facilities

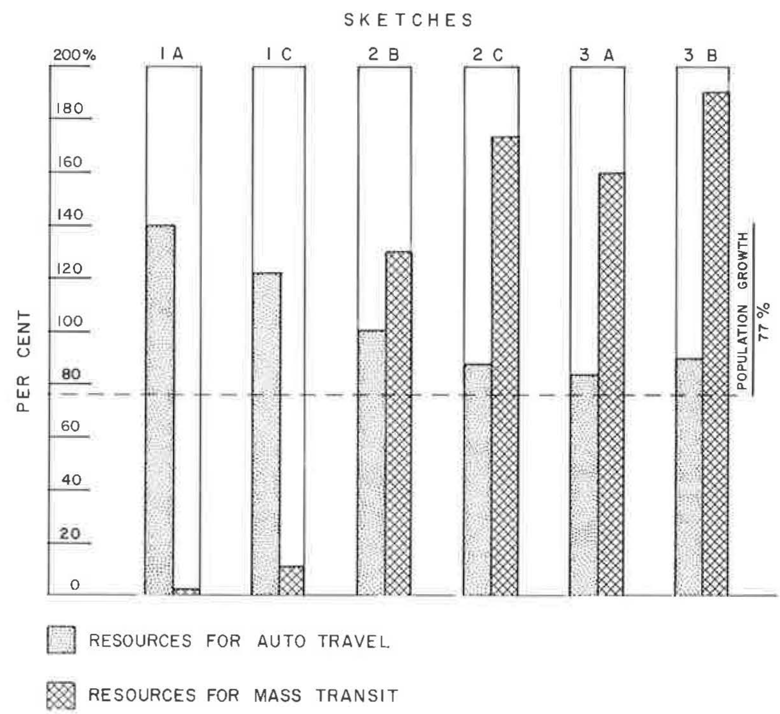


Figure 11. Resource allocation increase by modes—percent above present volume.

TABLE 6

TRAVEL COSTS PER 24 HOUR DAY

Pattern	Sketch	Part of Region	Total Trips (000)	Mass Trans. Trips (000)	Trip Cost ¢	Mass Trans. Travel Cost $(000)	Auto Trips (000)	Trip Cost ¢	Auto Travel Cost $(000)	Total $(000)	Per Person $
Decentralized		Core	18,815	9,168	40	3,667	9,647	91.0	8,779	12,446	1.24
	1A	Met. Area	58,800	—		—	58,800	59.5	34,986	34,986	1.75
		Total	77,615	9,168		3,667	68,447	69.0	43,765	47,432	1.58
		Core	18,206	10,031	40	4,012	8,175	105.0	8,584	12,596	1.15
	1C	Met. Area	53,504	—		—	53,504	59.5	31,835	31,835	1.68
		Total	71,710	10,031		4,012	61,679	65.0	40,419	44,431	1.48
New Towns		Core	31,829	12,137	40	4,855	19,692	77.0	15,163	20,018	1.43
	2B	Met. Area	44,074	9,728	35	3,405	34,336	63.0	21,632	25,037	1.56
		Total	75,903	21,865		8,260	54,028	68.0	36,795	45,055	1.50
		Core	16,803	9,211	40	3,684	7,592	105.0	7,972	11,656	1.17
	2C	Met. Area	53,030	13,910	45	6,260	39,120	66.5	26,015	32,275	1.61
		Total	69,833	23,121		9,944	46,712	69.0	33,987	43,931	1.46
Concentrated		Core	55,923	23,178	40	9,271	32,745	80.5	26,360	35,631	1.37
	3A	Met. Area	11,442	—		—	11,442	59.5	6,808	6,808	1.70
		Total	67,365	23,178		9,271	44,187	75.0	33,168	42,439	1.41
		Core	51,915	18,613	40	7,445	33,302	73.5	24,477	31,922	1.45
	3B	Met. Area	21,029	5,778	50	2,889	15,251	66.5	10,142	13,031	1.63
		Total	72,944	24,391		10,334	48,553	71.0	34,619	44,953	1.50

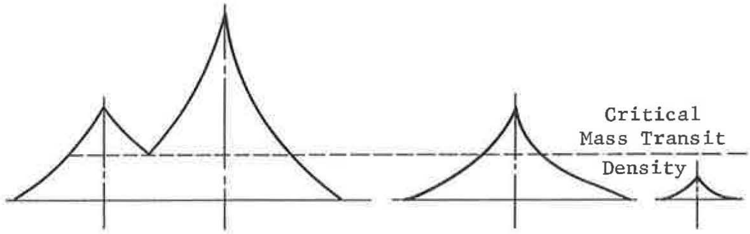


Figure 12. Illustration of density model for final planning alternatives.

could be mapped in advance and the introduction of new facilities could follow the rationale of long-range urban development. Shifts in travel modes could also be accommodated at the proper time.

Study of Mass Transit Levels for Large Cities

If some of the region's cities were to reach high density levels, and if technological advances were to be experienced in mass transportation technology, the different urban development states would have to be provided with appropriate means of mass passenger conveyance. Figure 13 illustrates four possible types of mass transportation systems.

Mass Transit I, in very high density zones, could be slow- to moderate-speed continuous passenger conveyance facilities such as pedestrian conveyors or moving sidewalks. Mass Transit II, in high density areas, would be medium-speed facilities. The network would be extensive and with only little local street transit. Mass Transit III, in medium-density areas, would be a combination of high-speed regional transit system and local bus or equivalent services. Low density areas would depend on auto travel.

The indicated levels of mass transit systems are hypothetical concepts. A separate study would be necessary to better define such services and to correlate them to densities that would demand and have the propensity to sustain such facilities.

Density models could be employed to relate the stages of urban growth with the needs of different level transportation systems. Urban development stages could also be timed to regard the life span of such systems. Major shifts in development policies could be proposed in order to prepare a logical transition from lower to higher rank of mass transit facilities. Resources allocation and methods of financing could be part of such a study.

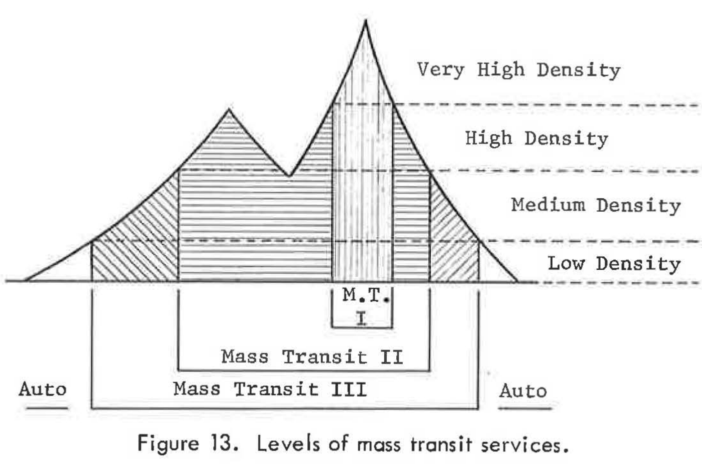


Figure 13. Levels of mass transit services.

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A Rational Decision-Making Technique for Transportation Planning

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Evaluation of transportation improvements by conventional benefit-cost analysis raises the problem of trying to evaluate benefits (or costs) which cannot readily be converted to dollars and cents. Sometimes these benefits are neglected. Sometimes they are converted to dollars no matter how crude the estimate. Most often they are merely qualitatively weighed in the mind to determine whether or not they are sufficient to alter the decision recommended by the economic analysis based on the quantifiable factors.

To help in these situations, a technique or framework is presented which would treat all pertinent factors more rationally and systematically. Examples are presented showing the results of the technique at each intermediate step. An extension of the technique is made to consider a system of possible projects and the optimal allocation of available capital among them. This extension results in a problem which may be solved by integer linear programming techniques. The formulation of this linear program is shown.

•MOST major transportation facility plans today evolve from a procedure wherein various alternatives are generated and evaluated, and the one which appears most favorable is selected. The evaluation process utilized is quite often a benefit-cost ratio technique or something closely related to it. This means that each of the benefits and costs associated with an alternative are itemized and appraised in dollars and cents to avoid the "apples and oranges" comparison dilemma.

Several problems confront the engineer or planner who is trying to evaluate alternatives by this method. He must be sure he has stood far enough away from an alternative to have considered all its effects on the overall system. For many effects which he has delineated there are serious problems of how to convert their impact on the system to dollars and cents. Quite often the solution to the problem of not being able to assess the dollar value of some of the benefits or costs is to ignore this factor on the grounds that its impact cannot be measured accurately enough with the monetary yardstick. There is also the frustration of having singled out a pertinent benefit or cost and converted it to its estimated dollar value, only to realize that the factor is an order of magnitude more important than some more obvious factors which he has painstakingly developed and evaluated. Perhaps he is reluctant to believe this, even though the dollars point it out. Finally, although everyone is in favor of better transportation, there is considerable difference in points of view as to what this means. The transit manager, the city engineer and the local communities may have radically different goals for "better transportation."

It is useful to consider the example of a public transit agency or a highway department evaluating a facility being built in a growing suburban region. Many objectives

Paper sponsored by Committee on Transportation System Evaluation and presented at the 46th Annual Meeting.

or goals, both public and private, must be considered in selecting the optimal length and location of the facility and the level of service to be provided. It should be appreciated that all examples of objectives used here should be viewed liberally since it is the decision technique and not a recommended set of objectives that is the central theme in this paper. The following are some examples of objectives which might be deemed important:

1. The facility should show the best possible revenue-cost picture or tangible return on capital invested. This includes not only the facility being considered, but any other facilities in the system which are also affected, including feeder bus service and private transit companies in the case of transit.
2. The highway or transit facility should serve as many users as possible.
3. The facility should remove as much congestion as possible from neighboring facilities.
4. Priority should be given to an area which has long been without sufficient service, or one which has a critical transportation need.
5. In the case of transit, an improved quality of service should be provided to enhance the public's image of transit and to halt the general trend of diversion from transit facilities to automobiles. The type of improvements in service quality may vary from area to area depending on marketing recommendations.
6. The alternative selected should further the economic development of the communities it is affecting. In addition to the level of economic impact on the community, this objective involves both the timeliness of making this impact now, and the direction of the communities' own plans for development or redevelopment. The generation of potential tax revenue by new residential or industrial development along the new route is included here.
7. The agency must satisfy certain political requirements and constraints.
8. The facility should have the most flexibility to meet anticipated future growth or a variety of assumptions on anticipated growth.

This very general list of objectives would need to be refined before being applied to a particular facility study. Still, all the above factors merit inclusion as legitimate objectives of a transportation agency. Collectively they present an appealing description of what an agency is setting out to accomplish. However, when it comes time to apply these objectives to the evaluation of alternatives, some difficulty is usually encountered.

A good deal of time and effort is spent analyzing the first objective, maximization of direct return on capital. This is especially true in the example of a transit agency planning a new extension, where the return on capital is in the form of increased net operating revenue. The third objective, removal of congestion from highways, is often evaluated by determining the number of minutes the average automobile commuter on the highway saves and multiplying by some dollar value of time saved and the number of automobiles using the highways. However, in transit cases, this estimate can rarely be as accurate as an operating balance forecast because of the crudeness of present-day dollar values for time. Yet, it is probably the same order of magnitude as the estimated operating balance even if logically it might not seem as important. For instance, a typical rapid transit extension may result in an increased operating balance (increased revenue minus increased operating cost) of $200,000 per year. Yet, if the transit extension results in decreased peak-hour highway congestion such that the 6000 rush-hour commuters still in their automobiles save 5 minutes each way on the average, this can be calculated as a saving of (6000 people) (2 directions) (5 minutes) ($1.50[1] per hour value of time) (250 days per year)/(60 minutes per hour) = $375,000 annually—and this is for the rush-hour alone. Most transit agencies would probably feel that the increase in operating balance really is worth far more than the decrease in automobile congestion in spite of these figures.

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[1]$1.50 per hour is typical of a value assigned for this type of estimate, although there is, of course, much discussion about what amount should be used.

The same situation applies to the objective of maximizing the economic welfare of the affected communities. Some crude value estimate is often made for this factor, but usually it only serves to water down the effect on the decision of the more accurately measured costs and benefits. Often the recourse is to abandon any attempt to quantify these factors for benefit-cost analysis purposes and merely use them in an all-or-nothing manner. In effect, this means determining whether or not these factors are sufficient to alter the decision recommended by the economic analysis based on the quantifiable factors.

Other objectives in the above list are almost always considered qualitatively only. Improvement in quality of service, the satisfying of a critical transportation need, and the satisfying of certain political constraints are examples, with the latter managing to demand a large amount of attention historically. Still other objectives are converted dogmatically to dollar units in spite of difficulties or inadequacies.

The problem, therefore, is to find a way to consider explicitly the significant benefits and costs not given to monetary measurement simultaneously with those which can be estimated in dollars and cents.

THE SINGLE PROJECT EXAMPLE

The solution described in this paper to the stated problem is best introduced in the context of planning a single project. Such a project may, as before, be a radial highway or a transit extension to be built in a rapidly growing suburban corridor. The alternatives in the case of the highway vary in terms of the location and lengths of new highways, the design standards to be applied, number of lanes, etc., and, of course, whether or not to build any facility at all. In the case of the transit extension, the alternatives vary in the length and the location of the line, the type of cars, the seating standards, the operating speeds, number of stops, etc., as well as whether to build anything at all.

The technique offered for the evaluation of alternatives is given in five steps. The corridor transit extension is a useful example since it is characterized by both public and private motives.

Itemize the Objectives

Assume that the transit agency feels there are five major objectives which ought to be met by the extension of transit service into a particular corridor. Again, this list of objectives should not be thought of in any way as a recommended set of goals, but rather merely as examples:

1. The immediate direct rate of return on investment, i.e., the increase in operating balance at the end of the first year of operation divided by the annualized capital cost of the extension, should be as large as possible. (Operating balance is passenger revenue less total operating costs.) Reference to changes in net revenues over a longer period of time are left out here to avoid excessive complication.
2. Riding volume on the line after the extension and the system have reached a state of equilibrium should be maximized.
3. The image of the transit agency should be enhanced by offering as much comfort and convenience as possible.
4. The transit agency feels it is desirable for political reasons to extend as far as possible into the corridor to promote development of an area rendered relatively inaccessible by inadequate transportation facilities.
5. As many automobile users as possible should be diverted to transit so as to relieve congestion on the corridor's primary highway.

Next, assume that five feasible and different alternative extensions, varying in location, length, and service characteristics have been proposed. (The no-action alternative is not included for purposes of the illustration.) These will be called alternatives A through E and are to be evaluated according to how well they meet the five objectives.

Define the Best Measure for Each Objective

The transit agency decides that the measureable characteristics of the alternatives which best exemplify the five objectives are as follows:

Objective	Measure of Objective
1.	Increase in annual operating balance divided by annual capital cost of building the extension.
2.	Total daily inbound rider volume.
3.	Average percent seated during the peak hour at the peak load point.
4.	Miles of extension into the corridor.
5.	Auto-users diverted to transit during the peak hour.

Weight the Objectives

The transit agency further decides that the first objective is worth about 40 percent of the total decision. Similarly, weights or fractions of the decision are assigned to the other four objectives so that the objectives are weighted as follows:

Objective	Weight	Alternate Weighting Scheme
1.	0.40	8 points
2.	0.20	4 points
3.	0.15	3 points
4.	0.15	3 points
5.	0.10	2 points
	1.00	20 points

Since the weightings are relative only, fractions which total one do not need to be used; any set of numbers with the appropriate relative values may be used, as indicated by the alternate weighting scheme. For purposes of this presentation, the alternate weights will be used.

One point to note regarding the selection and weighting of objectives is that it is easy to choose objectives which are not mutually independent. For instance, hauling the most people possible and diverting the most automobiles from the highway are very much related to each other as objectives for a transit line. It is not wrong to use non-independent objectives as long as judgment is used in the weighting of them. However, it probably helps to select just one of the two if they are very closely related.

Evaluate the Way Each Alternative Meets Each Objective

Assume, for this example, that values of the pertinent descriptors of each alternative have been estimated by various suitable techniques. Discussion of the actual techniques used are not important to this paper and will not be discussed. The estimates assumed for the five alternatives in the example appear as follows:

Measure		A	B	C	D	E
1.	a. Increase in annual operating balance ($ millions)	0.780	0.812	0.550	0.702	0.675
	b. Annualized capital cost of building the extension and purchasing rolling stock ($ millions)	6.000	5.800	5.000	5.200	4.500
	c. Annual return on investment (= a/b) (%)	13.0	14.0	11.0	13.5	15.0
2.	Daily inbound riding (thousands)	25.0	23.0	20.0	18.0	17.0
3.	Average percent seated, peak hour (%)	25.0	35.0	40.0	50.0	50.0
4.	Miles of extension into corridor	8	7	6	5	5
5.	Peak-hour auto users diverted to transit (thousands)	3.5	3.0	2.0	1.5	1.5

The simplest method of evaluating the alternatives with respect to a particular objective is to arbitrarily say that within each objective, the best alternative in the category receives the full number of points under the weighting scheme, and the worst alternative receives no points. Each other alternative receives a number of points which is linearly proportional to where this alternative lies in this category relative to the best and worst alternatives. For example, in meeting objective 4 (length of extension), alternative A rates highest with 8 miles and receives a full 3 points. Alternatives D and E each get zero points since they are the shortest with 5 miles. Alternative B gets 2.0 points since it is ⅔ of the way from the worst alternative to the best $\left(\frac{7-5}{8-5} \times 3 \text{ pts. max.} = 2 \text{ pts.}\right)$. Similarly, alternative C receives 1.5 points.

Selecting the Best Alternative

When each objective is evaluated for all alternatives, the rated points can be summed for each alternative and the alternative with the highest number of points is said to best meet the combined objectives of the transit agency. Had the fractional weighting scheme been used (sum of all weights equals one), the sum total for any alternative would be a fraction less than or equal to one. The fraction would express how close this alternative was to the "ideal" alternative, that is, one which ranked best in each category. With the point scheme used in this example, dividing each alternative's total by the number of points possible, 20, accomplishes the same thing. Complete results for this example are shown below.

Objective Measure	Results of Evaluation of Alternatives				
	A	B	C	D	E
1.	4.0	6.0	0.0	5.0	8.0
2.	4.0	3.0	1.5	0.5	0.0
3.	0.0	1.2	1.8	3.0	3.0
4.	3.0	2.0	1.0	0.0	0.0
5.	2.0	1.5	0.5	0.0	0.0
Total	13.0	13.7	4.8	8.5	11.0
% Total of Ideal	65.0	68.5	24.0	42.5	55.0

It should be pointed out that some objectives might not be so easily quantifiable. In this case it would be perfectly legitimate to use a quality judgment scale such as high–3 points, medium—2 points, low—1 point.

One shortcoming of the particular "relative" rating scale chosen for each objective in this example is that the best alternative gets a full score even though it may be far from perfect, while the worst alternative gets zero, even though it may be almost as good as the best alternative. However, for other objectives there may be large differences between two alternatives and they can end up with about the same number of points. This shortcoming is illustrated by considering what happens in category 4 (mileage of extension) if a new alternative is added. Before the inclusion of the new alternative, alternative A had 3.0 points in this category, while alternative D had zero. Suppose the new alternative proposes only 2 miles of extension into the corridor. Alternative A still has 3.0 points but now alternative D has 1.5 points since the new alternative becomes the zero point on the scale. Thus it is conceivable that addition of the new alternative, even if it is the worst of the six, has the ability to change the recommended outcome from one alternative to another. This problem may be avoided by the use of utility curves[2] to evaluate alternatives within each objective. However, in defense of the simple-to-use "relative" rating scale, the problem is not as severe as it may appear at first glance. The original weights could be attached to each objective, keeping in mind the magnitude of variation within the alternatives to be evaluated. If, for any objective, a large range of values among the alternatives is anticipated, more or less weight may be assigned to that category to properly express the importance of the objective. Thus, the addition of another somewhat different alternative could very well mean that a new weighting of the objectives is in order, and therefore the problem cited in this example is unlikely to occur.

Use of Utility Curves in Evaluating Alternatives

One way of avoiding the problem altogether is to use a predetermined absolute scale for each objective instead of using the relative scale. For example, the agency may decide before examining any physical alternative that a 10-mile extension is the ultimate and should be worth 3 points, while building no extension at all should be the zero point alternative (see Figs. 1a and 1b for comparison of the two scales). As can be seen, alternative B now rates 2.1 points instead of 2.0 under the relative scheme. The utility curve approach has the advantage of not being affected by the addition of another alternative.

The relationship represented in Figure 1b need not be linear. For example, the first mile extension into the corridor may be more desirable than the second, and so on, until the marginal utility (with respect to achieving the proposed objective) approaches zero beyond a 10-mile extension. Figure 1c expresses this relationship.

Figures 1b and 1c are utility curves in statistical decision theory terms. They represent the agency's feelings about the utility of each mile of extension with respect to the satisfaction of the particular objective.

There are pros and cons to each of the two methods of evaluating objectives—or three methods if the linear utility curve is thought of as different from the nonlinear one because the simplicity of the former requires only two points to be defined. The utility curve approach is more difficult to use, yet it forces the planner to think in terms of the complete range of values of an objective within which any of the possible alternatives may lie. It may be advantageous to carry out this thought process before proceeding to examine the alternatives in detail. The relative technique has the advantage of simplicity of use, and bypasses having to define the utility curve. (However, one of the bigger objections to utility curves is the difficulty in getting a person to define his utility curve.) In reality there is no reason why a mixture of techniques could not be

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[2]Utility curves are described in detail in: Schlaifer, R., Probability and Statistics for Business Decisions, McGraw-Hill, 1959; Shelly, M. W., and Bryan, G. L., Human Judgments and Optimality, John Wiley and Sons, 1964; and others.

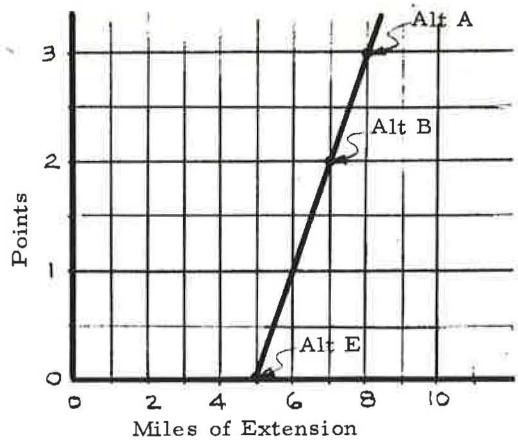

Figure 1a. Relative technique for evaluating objective in example.

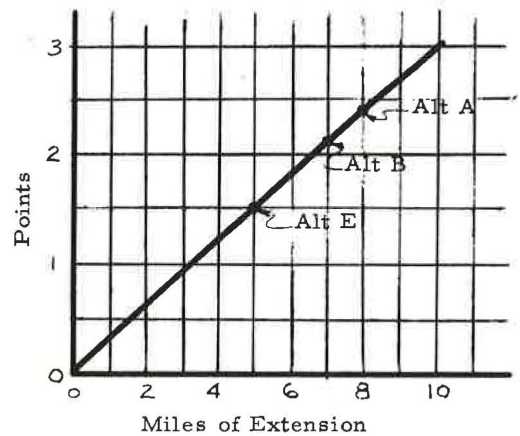

Figure 1b. Linear utility curve technique for evaluating objective in example.

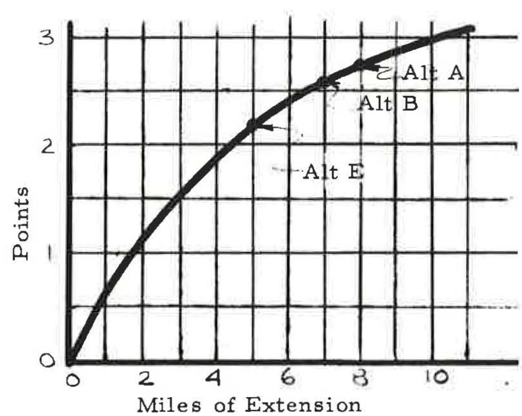

Figure 1c. Nonlinear utility curve technique for evaluating objective in example.

used for different objectives, if so desired. For example, automobiles taken from a highway might well be measured using a nonlinear utility curve, whereas net operating balance increase could be analyzed using the relative technique.

An important exercise which could be very interesting as well as very revealing in the examination of certain controversial highway or transit projects would be to have (or to simulate having) each different faction involved in the controversy—planning staff, city officials, academics, etc. —weight the objectives and evaluate the alternatives according to their own value schemes. The question to be answered is, How do the different value schemes affect the decision reached? Often the decision is the same for the different spheres of interest. However, the decisions sometimes differ, and the knowledge gained as to why they differ may be valuable. Persons familiar with the thought processes of the various interest groups in a community can gain much insight into underlying reasons for controversies surrounding a project. They may thus more easily achieve a suitable compromise for implementing the transportation improvement as well as promote good planning. In addition, a user may find it valuable to vary his own weights where he is unsure about them, to test the sensitivity of the final decision to his weights.

THE COMPLETE SYSTEM SOLUTION

In an earlier section, the five-step technique for aiding in decision-making was presented in the context of alternative proposals for a single transportation project.

One objective which was not explicitly mentioned previously, but which is a legitimate one in some single transportation facility studies, is the goal of minimizing capital cost. In fact, using this decision technique, the capital issue could even be handled by plotting various total values of the objectives against the capital necessary to achieve this degree of satisfaction of objectives. This sensitivity analysis on capital cost could then be analyzed and the most desirable combination of cost and level of satisfaction could be chosen. Another variation involving capital cost might be the introduction of an objective such as maximizing total utility per dollar spent for situations where there is no budget as such.

A more common situation, however, is one in which the transportation agency has a limited but definite budget and a number of projects to be constructed from that budget. Now the emphasis is on optimal allocation of the budget among projects rather than the minimization of capital expended on all projects. The expansion of the decision-making technique from a single project to a system-wide set of projects, each with several alternatives, may thus be considered. The decision technique becomes part of the structure of an integer linear program for complete system analysis.

Assume that several transit extensions into various corridors are being considered and that a limited capital budget exists with which to carry them out. These corridors can be generalized as subsystems, since corridor extensions need not be the only projects which the agency is contemplating. Within each subsystem there is a set of alternatives to be evaluated, including the null or do-nothing alternative. The agency defines four objectives, weighted as indicated:

No.	Weight	Description
1.	Z_1 pts	Maximize daily passengers hauled
2.	Z_2 pts	Divert as many cars as possible from the highways during the peak hour
3.	Z_3 pts	Exhibit the maximum annual net operating balance with the new system
4.	Z_4 pts	Operate the most comfortable and convenient service possible during the peak hour

The agency has decided that for each alternative the parameters which best reflect the above objectives are, respectively, (a) total daily volume carried; (b) total peak hour volume carried; (c) increase in net annual operating balance (increased revenue minus increased operating cost); and (d) average percent seated during peak hour.

The agency has decided to use the linear utility curve for evaluation of objectives (although the formulation is identical if the relative technique or the nonlinear utility curve method is used). The formulation is as follows.

Define:

N = number of subsystems or corridors
n_i = number of alternatives in subsystem i
B = total budget available
Z_k = weight assigned to the k th objective
c_{ij} = total capital cost of subsystem i, alternative j
v_{ij} = total daily volume carried under subsystem i, alternative j
w_{ij} = total peak hour volume carried under subsystem i, alternative j
b_{ij} = net annual operating balance estimated for subsystem i, alternative j
p_{ij} = average percent seated, peak hour, for subsystem i, alternative j
$\overline{v}$, $\underline{v}$ = upper, lower limits of utility curve for daily volume chosen so that no v_{ij} lies outside the range $\underline{v}$ to $\overline{v}$ (or $\overline{v}$, $\underline{v}$ could be the largest and smallest volumes among each subsystem's alternatives if the relative technique is used)
$\overline{w}$, $\underline{w}$ = upper, lower limits of utility curve for peak hour volume
$\overline{b}$, $\underline{b}$; $\overline{p}$, $\underline{p}$; etc. = respective upper, lower limits

(Note: the above terms all are estimated parameters whose value is fixed for this analysis.)

Let x_{ij} be the variable describing subsystem i, alternative j such that x_{ij} = 1 indicates project is selected and x_{ij} = 0 means it is not; x_{ij} can only be 0 or 1.

Normalize each of the parameters v, w, b, and p for ease in notation:

$$v_{ij}' = \frac{v_{ij} - \underline{v}}{\bar{v} - \underline{v}} \text{ for all } i, j$$

(Such normalization applies to the two linear methods only. The nonlinear case is no more difficult, however.)

This calculates the percentage of full points to be awarded to subsystem i, alternative j under the highest daily volume objective. For example, if Z_1 was 4 points, $\underline{v}$ was 1000, $\bar{v}$ was 5000, and v_{ij} was 4000, then v_{ij}' would be 0.75 and the value of that alternative and that objective would be (0.75) · (4 points) = 3 points.

Now the problem can be stated as

Maximize

$$\sum_{i=1}^{N} \sum_{j=1}^{n_i} Z_1 v_{ij}' x_{ij} + \sum_{i=1}^{N} \sum_{j=1}^{n_i} Z_2 w_{ij}' x_{ij} + \sum_{i=1}^{N} \sum_{j=1}^{n_i} Z_3 b_{ij}' x_{ij} + \sum_{i=1}^{N} \sum_{j=1}^{n_i} Z_4 p_{ij}' x_{ij}$$

or equivalently,

Maximize

$$\sum_{i=1}^{N} \sum_{j=1}^{n_i} \left[(Z_1 v_{ij}' + Z_2 w_{ij}' + Z_3 b_{ij}' + Z_4 p_{ij}') \, x_{ij} \right]$$

Subject to

(1) $\sum_{i=1}^{N} \sum_{j=1}^{n_i} c_{ij} x_{ij} \leq B$ (Budget constraint.)

(2) $\sum_{j=1}^{n_i} x_{ij} = 1$ for all i (One and only one alternative will be selected within each subsystem. If it is feasible to build more than one project within a subsystem, let a new alternative be defined to describe each such combination.)

(3) all $x_{ij} = 0$ or 1 (All or none of a project must be built.)

The formulation is now an integer linear program and can be solved as such. However, it is really a special, simpler case, since $x_{ij} = 0$ or 1 only. This special zero-one variable case can be solved by some different, shorter algorithms which are available[3].

It should be noted that this full system example was formulated assuming that the same objectives and objective weights apply to each subsystem. However, it is usually relatively simple to extend the linear programming formulation to a group of subsystems which do not have the same set of objectives or objective weights by reverting to the fractional weighting scheme. The possibility of having different objectives and weights in different project areas is a realistic one and each sector can set its own criteria.

One other direction which may be taken from this point is the use of parametric programming techniques[4] to study the behavior of the system under a wide variety of assumptions for costs, benefits or budgets—for example, the sensitivity of various objective measures to a wide variety of changes in budget assumptions.

CONCLUSION

Although the examples used in this paper generally refer to a transit situation, the technique appears equally applicable to a state highway department situation, or any number of other public works situations. The technique is not offered as a panacea for all transportation alternative evaluation problems. It is presented as one other, perhaps more systematic, way of handling such an analysis, and appears to have several advantages over conventional economic analysis procedures in certain applications. It is characterized by the inclusion of judgment and subjective feeling in an organized framework and provides for the mixing of subjective measures with those derived by rigorous mathematical technique. This would seem to be in tune with recent tendencies to emphasize judgment and subjective probabilities more, possibly a natural backlash to the rapid expansion in development of computer models.

This concept of weighting objectives and evaluating the degree to which each alternative meets the objective is not a new one, although it may be relatively new to the transportation field. It is similar to techniques currently being used in personnel evaluation as well as in other fields of engineering.

It should also be pointed out that, while the examples in this paper deal primarily with the benefit side of the economic picture, the same techniques are equally useful in dealing with the cost side.

This decision-making process was applied to the Massachusetts Bay Transportation Authority's 1966 Master Plan for system modernization and expansion. All actual numbers, formulation of objectives, and statements of policy used in the examples in this report are fictitious and were not intended to reflect the results of any MBTA studies.

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[3]Examples of algorithms: Glover, Fred, A Multiphase Dual Algorithm for the Zero-One Integer Programming Problem, Operations Research, Vol. 13, No. 6, Nov.-Dec. 1965; Balas, Egon, An Additive Algorithm for Solving Linear Programs with Zero-One Variables, Operations Research, Vol. 13, No. 4, July-Aug. 1965.

[4]Dantzig, George B., Linear Programming and Extensions, Rand Research Corp. Study, Princeton Univ. Press, p. 245, 1963.

Modeling and Evaluating the Indirect Impacts Of Alternative Northeast Corridor Transportation Systems

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This paper describes the design-conceptualization and implementation of the model system for forecasting and evaluating the indirect impact of alternative transportation systems in the Northeast Corridor. The set of computer models developed for forecasting and evaluating the indirect impacts of alternative transportation systems contains two sub-models. The first of these is an interregional interindustry input-output model, the formulation of which includes transportation sensitivity between major subregions in the corridor. The second model is an intraregional allocation model which is transportation-sensitive at the more "micro" level of counties. Since the models have not yet been completed the descriptions of them are rather brief, with a good deal of the text being devoted to an exposition of alternative evaluation measures and their appropriate uses within the context of the overall project.

•THE Northeast Corridor Transportation Project of the U. S. Department of Commerce is a comprehensive regional transportation planning activity to determine passenger and freight transportation requirements in the region to 1980 and beyond. This paper describes the work done to date toward modeling and evaluating the indirect impacts of alternative transportation systems within the Northeast Corridor.

The overall project design calls for interrelated studies to forecast the regional change and the demand for transportation, to simulate the operation of transportation networks, to analyze the impact of network modifications on the region and its subareas, to evaluate these alternatives, and to examine ways of managing and financing possible future transportation systems. Other studies will provide information on future transportation technologies and their costs, on state and metropolitan plans likely to affect or be affected by the regional planning activity, and on various patterns of spatial organization in the region and its subareas.

In previous transportation systems planning studies, the predominant approach has been to project employment, population, and land use independently of the expected internal transportation system from which anticipated origin-destination patterns were derived. These in turn form the framework for ultimate transportation system design. In the Northeast Corridor Project, however, an attempt is being made to evolve methods for estimating the impact of the transportation system design and facilities themselves on the projected levels and spatial distributions of employment, population, and land use, and also to develop methods for evaluating network designs for consistency with alternative regional spatial orderings and regional development objectives.

The Northeast Corridor Transportation Project staff specified the following objectives for the economic and demographic impact studies:

Paper sponsored by Committee on Indirect Effects of Highway Improvements and presented at the 46th Annual Meeting.

1. To seek to determine whether transportation effects on the rate of growth of the entire region can be isolated for analysis.
2. To determine the influence of such effects, in isolation or in combination with others, on the rate of growth of the region.
3. To determine the redistributive effects of alternative transportation network mixes on the location of population and employment.
4. To estimate the gross patterns of change in land use to be expected.
5. To ascertain the effects, short- and long-term, of alternative levels of expenditure on transportation facilities on a region such as the Corridor.
6. To develop quantitative measures of benefit and cost resulting from changes in transportation systems performance, through new technology or facilities or both, in the region and its subareas. In effect, an effort to develop community benefit-cost criteria was desired.

THE OVERALL MODEL SYSTEM

The present modeling effort has been designated as the "Phase I" model system. The design and construction of these models placed emphasis on their being completed at the earliest possible time so that they might be used for gross policy determination. As a consequence much attention was given to the derivation of feasible models from the present state of the art rather than any concerted effort to extend it. At the same time that these models are being used, they are also being retested and evaluated, during the latter stages of the Phase I efforts. A proposed Phase II effort will both refine the Phase I models and design new ones, including, when necessary, confrontation with the problems of having to advance the state of the art.

The Phase I model system is designed to produce information necessary to study the following questions:

1. What is the preferred mixture of land uses, economic, and residential activity, from the standpoint of net economic and social benefit?
2. Which multi-county areas correspond to given degrees of social and economic interchange (both personal and interindustry), and the performance of multi-county governmental functions?

The Phase I impact analysis will be based primarily on the concept of "accessibility" and will reflect the consequences of changes in accessibility that result from changes in transportation networks or their characteristics. The Phase I impact modeling system consists of several interrelated sub-models (1). The overall relationships between these sub-models is shown in Figure 1.

The primary inputs to the Phase I impact models are of three types: (a) forecasts of regional totals of income, population, and employment; (b) distributions of the existing levels of all of the impact variables; and (c) data on existing and proposed transportation networks. The forecasts of regional totals of income, population, and employment are produced by an econometric model (2). The network information is provided by the project staff.

INTERREGIONAL INPUT-OUTPUT MODEL

The first of the impact sub-models is IRIO, the interregional input-output model. This model first converts the forecasts of regional totals from the econometric model into vectors of "final demand." The model considers the Northeast Corridor region as divided into from three to five major subregions. The remainder of the United States is treated as being divided into another three to five major subregions. The industrial sectors correspond roughly to the major employment classes of "County Business Patterns" (3).

Realizing that the theory of multiregional input-output analysis is well established, and differences in approach, for the most part, can only be subtle ones, variations in approach are principally in the treatment (both theoretical and operational) of flows between regions. The motives of this study strongly dictate that the analysis be rendered transport-sensitive. In accordance with the criterion that the model must not

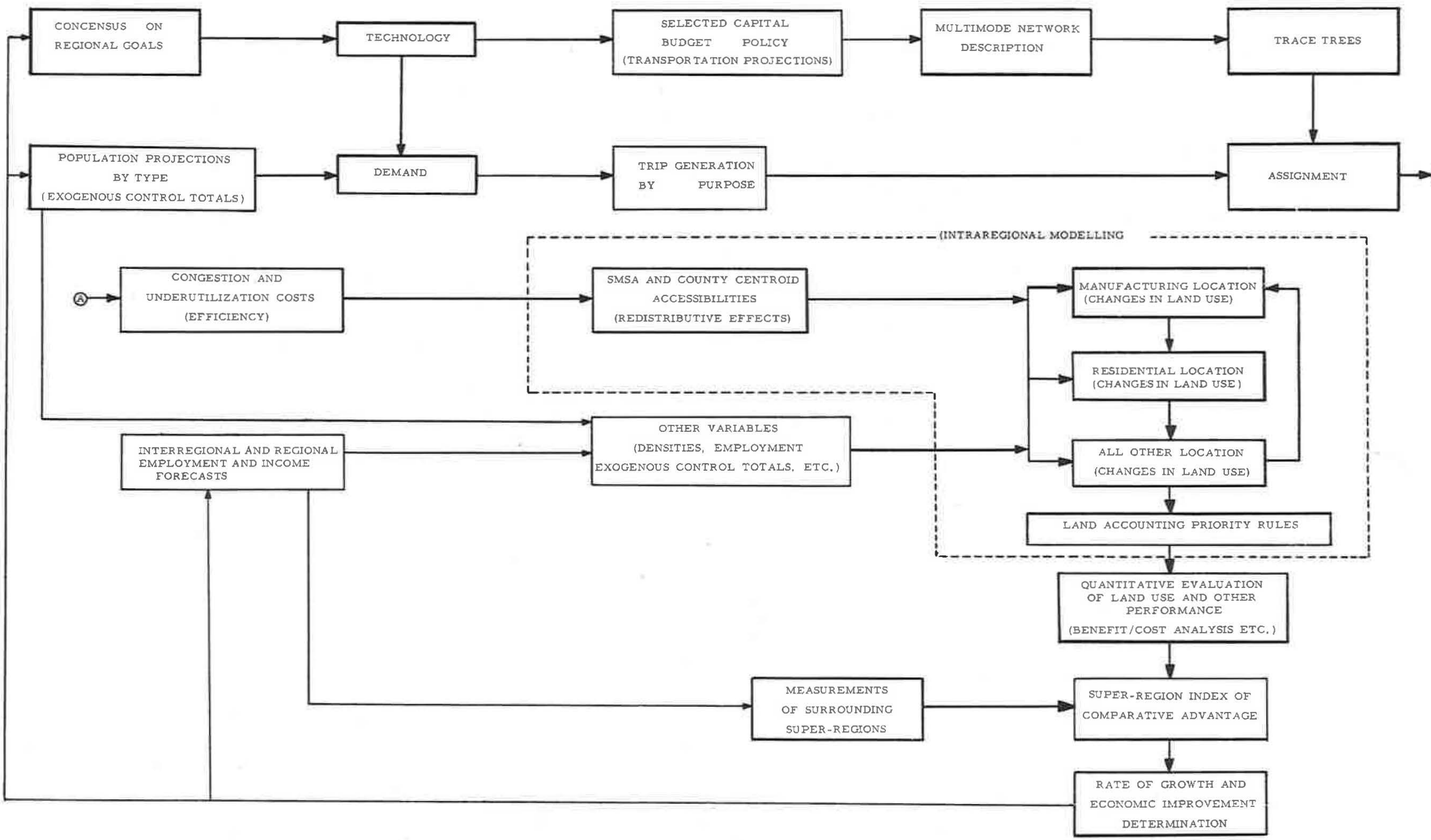

Figure 1. Northeast Corrior analysis on the basis of small-area allocations.

only be transport-sensitive in theory but that sensitivity must be capable of being exploited straightforwardly at an operational level, the respective influences on interindustry, interregional flows of the transportation network and the technology of industry were to be dichotomized, to the extent possible. An approach which referred to merely one coefficient for each combination of originating industrial sector and region and terminating sector and region (frequently used in past efforts) would provide no such dichotomy (and, incidentally, would require more detailed data than are available). The separation of such a coefficient into two additive components (one for the transportation, the other for the interindustry, technology) would not help much in the way of reducing obscurity either.

The basic formulation (5) of IRIO is a modification derived from the Leontief-Strout framework. The Leontief-Strout (4) framework very explicitly separates the intraregional industrial structure from the interregional trade structure, utilizing a concept of regional supply and demand pools for each good to link the two structures in a manner that leads to a simultaneous solution to both. The interregional system is basically a gravity formulation which distributes pool-to-pool flows as a function of pool levels and of the resistance offered by the transportation network.

Three primary modifications to the Leontief-Strout model were necessary to adapt it to the requirements of the IRIO model problem for the Northeast Corridor Project. First, instead of solving the system for a single point in time or a single horizon year, the alternative version of Leontief-Strout is solved for discrete steps in time. Second, while the Leontief-Strout system requires the interregional distribution of shipments for each industrial sector, the extended version of the model has the additional flexibility of allowing for the combination of several sectors into more aggregated shipment sectors to alleviate the problems which we anticipate in data collection. Third, the Leontief-Strout model incorporates only one sector of final demand, whereas the modified version of the model may have a number of such sectors of final demand—that is, households, government, farm, trade, etc.—whichever are deemed necessary upon completion of thorough analysis of the data. In fact, analysis of the data may show it to be desirable to partition some of the final demand sectors, or those sectors which are normally considered final demand, into a final demand and an intermediate demand sector, such as the case where the government might for instance be consuming intermediate goods as well as final goods.

INTRAREGIONAL ALLOCATION MODEL

The outputs of IRIO become the inputs to INTRA, the intraregional allocation model. These outputs consist of projections of employment by major Corridor subregions, by the previously mentioned type classes. INTRA requires two other classes of input data: (a) an inventory of data on the obtaining distributions of population, employment, and land use; and (b) information on the transportation facilities, both present and proposed.

From these inputs, INTRA produces projections of population, income, employment, and land use on two areal system bases (6). The first of these areal systems is the super-district system which defines twenty-nine areas within the Corridor, each of which is an aggregate of several districts. The second of these systems is the basis of the first and is the district areal system consisting of about one-hundred-thirty areas within the Corridor, the majority of these areas being counties (see Fig. 2). The district areal system is the smallest areal unit being considered in the Phase I impact studies.

The basic structure of INTRA is both sequential and iterative. This structure is a logical derivation of the Lowry "Model of Metropolis" (7) and CONSAD's TOMM (8). The structure of the model (1, Chap. IV) is as follows.

1. Inputs are:
    a. Region total projections of income population, and employment by types.
    b. Present and forecast transportation facilities.
    c. Obtaining distributions of income, population and employment by type by area.

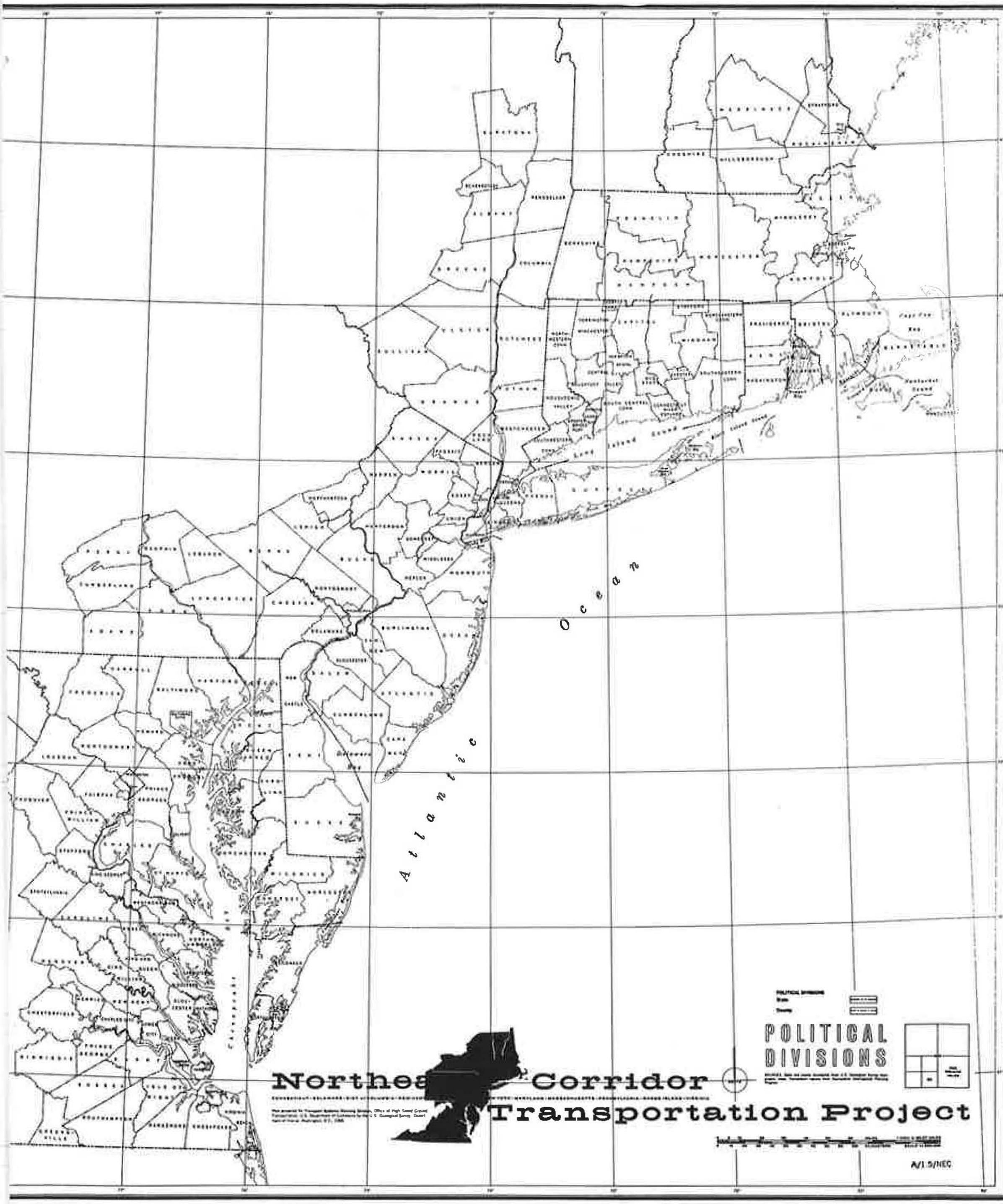

Figure 2. The Northeast Corridor area.

2. Allocation of Class I employment forecasts to areal units.
3. Trial income and population allocations to areal units.
4. Trial allocation of Class II employment to areal units.
5. Trial allocation of Class III employment to areal units.
6. Recycle to steps 3, 4, and 5 until the difference between the n'th and the (n + 1)'th trial allocations is less than a given tolerance (usually 1%).

The classes of employment are derived from "County Business Patterns" data according to the following scheme:

Class I:
Type 1—Agricultural services, forestry, fisheries
Type 2—Mining
Type 3—Contract construction
Type 4—Manufacturing
Type 5—Transportation and other public utilities
Class II:
Type 1—Retail trade
Type 2—Finance, insurance, real estate
Type 3—Services
Class III:
Type 1—Wholesale trade

Further disaggregations of employment are being calibrated, such that certain individual 2-digit S. I. C. classes of employment can be allocated. All of these allocations are made to the Corridor district level of areal detail.

The impact of transportation facilities enters the allocation calculations through an accessibility term. In each of the above allocations (except that of Class II employment) the data on network characteristics are combined to produce a term which is summed over all of the network links and to which the intensity of the activity being allocated is inversely proportional. Alternative networks are therefore tested by observing the results of varying network characteristics which are input to IRIO and INTRA.

Thus this set of models produces as outputs the primary economic-demographic impacts of alternative transportation systems. These outputs are, to summarize: (a) population by district, (b) employment by class-type, by district, and (c) personal income.

There are numerous other variables for which estimating equations have been or are being developed. These variables include such things as labor force, occupation classes, auto ownership, land values, local government revenues and expenditures, and other socioeconomic indicators. Another set of impacts calculated is that of various composite measures. These measures are of such things as dispersion of various activities, measures of global accessibility, measures of average local accessibility, various measures of market and supplier accessibility, and others of the same ilk.

Finally, all of this information is manipulated in order to develop the evaluation outputs to be described in the next section.

EVALUATION

The methods to be used in evaluating the "goodness" or "badness" of alternative Corridor transportation system alternatives, the criteria which guide the evaluation effort, the strategy for implementing the evaluation process, and the attributes of the various techniques which might be utilized for evaluation purposes have been discussed elsewhere (9; also 1, Chap. VI). The discussion here will be restricted to evaluation of the "indirect" effects, since the consideration of the time and cost consequences to those who use the facilities (as well as those who pay for the facilities) are considered elsewhere in the overall Corridor Project.

The following list summarizes the criteria to be applied to evaluation techniques per se.

1. The methods must be capable of evaluating costs and benefits when there are radical changes in the environment.

2. The methods must recognize the diversity of quantities and qualities of existing investments in developing new investment requirements.

3. The methodology should attempt to produce lists of effects, including growth, resource allocation, and distributional consequences. While initially the methods should be "forward-seeking" (in extrapolating the trend and structure of the current systems into the future), they should eventually be capable of "backward-seeking" evaluation. Here, with specifically stated growth, distributional and resource allocation objectives for the regions under consideration, the method would produce the desirable, feasible and preferred transportation systems for each alternative budget and set of system cost functions (10).

4. The method should reflect other policy measures, conceivably more or less expensive in application than a transportation policy. Thus, the results are to be consistent with the program budgeting methods used in ultimate and overall resource allocation decisions (11). The method, therefore, must evaluate alternative uses of resources, not activities, per se.

5. The method should be able to differentiate at areal, travel type, socioeconomic class, and sectoral levels.

6. The analytic level of detail must carry below the regional level to differing activity densities and contextual mixtures.

7. The criteria which govern the evaluation process must permit users to sort program budgets into resources needed for various end-state requirements, including such classifications as (12):

   a. Functional budget allocation criteria (i.e., within or between transportation, housing, public safety, etc.). An example of such a criteria might be "a balanced transportation system" or "integrated housing."
   b. Urban/regional budget allocation criteria (e.g., the proportion of dollars devoted to basic maintenance of city facilities vs dollars devoted to maintenance of "the impoverished," vs dollars to "develop all the peoples").
   c. Subject area budget criteria (e.g., social, physical, fiscal, aesthetic, economic).
   d. Absolute vs relative budget criteria (e.g., "nobody in essence has less than $2,000 to spend per family spending unit").
   e. Effects budget criteria (e.g., users vs nonusers and, within the latter, completely vs partially collective).

8. There is no intent to "optimize" the use of resources in application to the entire system; where constraints for subsystems can be correctly specified, however, optimization techniques can be used.

9. Maximum use of expert (human) intervention at critical nodes in the evaluation process, such as in alternative specifications, and weighting of effect vectors, is encouraged.

The model system discussed previously is part of the creation of a set of "evaluation accounts" for each alternative examined. But it also follows, from the above discussion, that evaluation analysis must begin with a specification of the arguments of one or more objective functions (i.e., the identification of all of those effects which should receive nonzero weights in aggregating effects). It is appropriate to launch this specification with a listing of those effects which most obviously belong in the welfare function, viz., the goals of the Corridor.

It appears reasonable to assert that a primary objective of the Corridor Project is economic efficiency. To be feasible and attractive the program must assert minimally that investment in improved transportation facilities in this region would yield a stream of goods and services which, when properly valued and discounted, would outweigh the costs of constructing, operating and retiring these facilities. Included among the returns to be generated by the new facilities are increased output due to improved spatial organization, lower vehicular operating costs, decreased congestion costs, and greater comfort and safety. The primary costs of the project are the value of material and the opportunity costs of land and labor used to construct and operate the facilities. The objective of economic efficiency dictates that the time stream of goods and services generated by the project be included as arguments in the welfare function, and that their discounted unit values be used as their weights. The assignment of proper unit values is crucial to the evaluation process.

In addition, improved transportation facilities are often desired on grounds other than those of economic efficiency. There are political and social goals which can be satisfied by a more widely traveled citizenry. Improved transportation may also have a beneficial effect on defense capability. All that can be suggested is that such effects be noted. The weighting of these effects should be left to the policy maker.

The task of evaluating the Corridor Project would be vastly simplified if the primary objectives were the only significant consequences of transportation improvements. However, there are many ramifications, the most obvious of which is income redistribution. Income redistribution has long been recognized by economists as an element in a social welfare function. Most persons have a vague notion that extreme income inequality is undesirable but do not know exactly how much weight to attribute to it; political experts must explicitly choose between alternative distributions. To assist this, the models must permit the tracing through and identifying of all major income redistribution effects associated with each alternate program. Again, it will be up to the policy maker to weigh these effects.

In addition to income redistribution, there are other intangible economic, social and political effects which may be attributed to the Corridor Project, such as aesthetic considerations, degree of population density, the urban-suburban mix, Federal vs local control, viability of metropolitan governments, erosion or growth of state and local tax bases. For the most part, each of these effects is extremely difficult to quantify, although first approximations to population distributions and government control could be obtained by measures of land-use patterns suggested above. It may be argued that the very nature of public investment, particularly in transportation, has a disproportionate effect upon these intangibles, and hence they must be taken into account. The most that the evaluation analysis can do is to identify them and include them in the vector of effects so that, as with income redistribution effects, policy makers will have the information to assess their relative importance.

Use of Models in Analysis

In Table 1 are listed seven different levels of evaluation probes, the types of analyses which are to be used to perform the evaluations, and six "dimensions," or evaluation choices. Turning to the latter first, there is the set of choices associated with whether or not:

1. A project or an entire program is being evaluated, i.e., whether the entire Corridor system is seen as an interconnected system of projects constructed at different times;
2. Local or national considerations are dominant, i.e., whether or not only local (in a geographical sense) effects are considered;
3. Only transportation, or associated multi-county public functions, such as the provision of water resources, the control of pollution, or the pursuit of regional economic development, are considered;
4. Quantitative alone, or both quantitative and qualitative factors are considered;
5. The human decision maker is an integral part of the evaluation process, either as an estimator of parameters or chooser of values (at least in an ordinal sense);
6. A partial or general solution is obtained, i.e., whether a general equilibrium approach considering all interactions within a closed system is used.

The following paragraphs elaborate upon each of these methodologies, and their use in the Corridor Project.

<u>Project Appraisal: Benefit-Cost Analysis</u>—This traditional approach to the appraisal problem ordinarily presumes that all economic benefits are represented by the savings in transportation costs incurred by users, as measured (or, more appropriately, estimated) "at the source." It offers a predominantly supply-side view of the problem,

TABLE 1

CLASSIFICATION OF NORTHEAST CORRIDOR EVALUATION PROBLEMS, TYPES OF ANALYSES, AND EVALUATION DIMENSIONS

Classification of Evaluation Problems	Dimensions						
	Types of Analyses	Project or Program	Local or National	Transp. or All Functions	Quant., Qual., or Both	Degree of Man-Machine Interaction	Partial or General Solution
A. Project appraisal	Benefit-cost	Proj.	Local	Transp.	Quant.	Little	Partial
B. Systems of projects appraisal	Search and/or programming optimization models	Prog.	Local	Transp.	Quant.	Little	Partial
C. Measures of effects of projects/ programs: simple, unweighted	Truncated moments (measures of relative accessibility)	Prog.	Local	All	Quant.	Little	Partial
D. Evaluating pricing consequences	Simulation of priced-out transportation networks	Either	Local	Transp.	Quant.	Little	Partial
E. Distributional consequences:		Prog.	Local	Transp.	Quant.	Much	Partial
1. Regional 2. Sectoral (nontransportation) 3. Transportation industry	Comparative and absolute regional advantage, analysis of transport-sensitive industries, financial analysis						
4. Individuals, families, and households	Corridor econometric, INTRA, and IRIO models						
F. Combining different effect sectors	Cost-effectiveness analysis	Prog.	National	All	Both	Much	Partial
G. Developing systemwide indices	General equilibrium analysis	Prog.	National	All	Quant.	Much	General

referring to demand only implicitly through the relation of operating costs to transportation output. The technique itself traditionally ignores explicit attention to the non-quantifiable, thus rendering all pertinent benefits and costs to be commensurable. Costs refer to all "public costs," namely, capital and maintenance expenditures required to implement the project. Of course, with all benefits and costs both quantifiable and commensurable, the concept of project appraisal in the context of this approach implies a once-and-for-all binary decision regarding whether the project is justified. The general criterion which guides this decision is to determine whether the discounted total time stream of net benefits exceeds the discounted time stream of costs. Because benefits are defined strictly in terms of user costs, the problem may also be approached from the point of view of minimizing total transportation costs (either in terms of present worth or annual costs). Both interpretations, used correctly, give identical results. Frequent use of net benefit/cost ratios by the disciplines responsible for this approach has led to the fashioning of the term "benefit-cost analysis." This approach is not intended to invalidate the "consumer surplus" approach, the use of which does look to the differences in utility among various users. The consumer surplus concept is distinguished from the benefit-cost approach primarily in that consumer surplus focuses directly on demand for its measurement of benefits, while benefit-cost analysis takes more of a supply viewpoint.

Systems of Projects Appraisal: Search and/or Programming Models—The problem, here, is to define an appropriate model for selection of programs consisting of groups of projects under conditions where (a) risk and uncertainty are important, (b) compromise must be made between realism and computational feasibility, and (c) the real world is characterized by discreteness, project interdependency, real budget constraints, time interdependency and multiple goals. Under these circumstances, with the number of network links contemplated in the Corridor Project a quadratic programming technique has been tentatively selected as the method best suited to assist in the choosing of both an optimal program set (within numerous constraints) as well as an optimal time-staging of the program. Basically, the model used is an extension of benefit-cost analyses but examines the interactions between the timing of each project relative to the whole system.

Measures of Effects of Projects/Programs: Simple, Unweighted Truncated Measurements—In at least four instances, it is possible to use the population, land use, economic activities and density consequences of INTRA and IRIO to develop moments reflecting access to opportunities, truncated at different "reasonable" time and distance estimates, e.g., one hour for the journey-to-work measures. These movement-measures would reflect: (a) people to jobs, (b) people to recreation opportunities, (c) business to customers (final goods), and (d) governmental bodies serving multi-jurisdictional clients. Complexity can be introduced by using weighting systems (e.g., business products by the value added of each business sector), and by developing separate measures for "people," "job," "business," "recreation," and "customer types." These measures would be intended to reflect the shifts (Fig. 3) showing an indifference surface (or trade-off between space/activity and access) caused by higher incomes, A to A′, and shifting production possibility surface, B to B′, caused by technological shifts (i.e., transportation improvements). The resulting changes in demand and supply functions would determine the new "equilibrium" solution for access and space use functions (vs price and income).

Evaluating Pricing Consequences: Simulation of Priced-Out Transportation Networks—To the extent that market pricing prevails, the evaluation of new systems must take the possible variation of prices into account. Prices may be exogenously determined, such as those paid for tools, gasoline, or automobile depreciation, or may be endogenously determined in a model, such as the amount of congestion cost to be charged to delay of passengers. These "administered" and nonadministered or marketplace figures must be classified and provided as either inputs or made determinable by within-model relationships. There is an interaction between the proportion of total passengers who are available to use each mode, the amount of congestion and underutilization experienced, the manner in which the costs thereof are accounted for, and the way in which prices are set. On the other hand, indirect costs could be quite different—namely, the

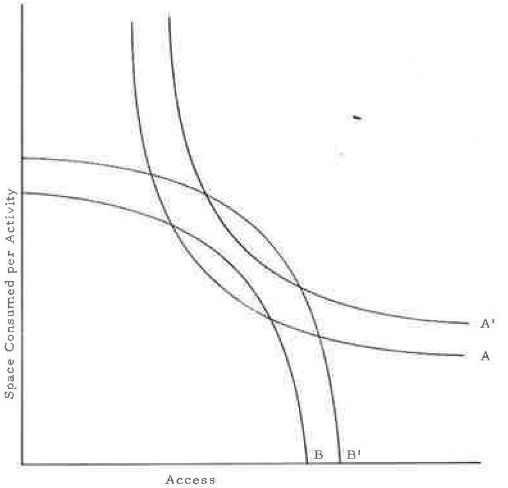

Figure 3. Shifting indifference and production surfaces.

costs of underutilization and overutilization of the transportation facilities. The costs of underutilization are the opportunity costs of owning twice as much or more facility, for example, as would be needed if the trips were distributed evenly, in both directions, each hour of the 24 hours per day. Indirect costs would include discounted capital costs, costs of unused crews, depreciation, and maintenance, and should include loss of tax revenue on wider rights-of-way, and so forth. These indirect costs are almost completely invisible to the passenger, but again, not to the policy maker. A simulation model is being constructed which allows experimentation with pricing methods, demand functions, network characteristics, and variable and fixed cost functions.

Distributional Consequences: Regional, Sectoral, Transportation and Individuals—There are a number of analytic methods to be used to measure and depict the distributional consequences of differential transportation alternatives. As for regional differences, e.g., whereby large portions of the Corridor are measured against large portions of the "remainder of the world" with respect to changes in the ability of each to engage in interregional trade, there is a "dynamic comparative advantage" model under development which draws upon the knowledge and theory underlying the economics of international trade. The substantial differences, however, between "regions" and "nations" has entailed significant modification in the overall theory. Other analytic methodology, including the use of linear programming methods to define the new, normative locational patterns for "transport-sensitive" industries following a substantial change in transportation technology, will be used to explore some likely tendencies for changes in industrial locations. And, finally, the models described in earlier sections of this paper will be used to ascertain the changes in income distribution, by population socioeconomic type, by geographic area. The income distribution will not be of the functional variety (e.g., return to rents, labor, capital, etc.) but will indicate the degree to which overall real income is distributed more or less "equitably" following the technological transportation changes and the other associated changes.

Combining Different Effect Sectors: Cost-Benefit Analysis—Cost-benefit analysis (as distinguished from benefit-cost analysis) is that broad methodology of project appraisal of which economists are the main proponents. Cost-benefit analysis concentrates more on uncovering and presenting all probable consequences of a public project, rather than devoting most attention to the easily quantified effects. It is much more like cost/effectiveness analysis than any of the preceding techniques. Cost-benefit analysis takes on two facets. First and foremost, it represents a methodology. Prest and Turvey emphasize this point (13):

> ...Cost-benefit analysis as generally understood is only a technique for taking decisions within a framework which has to be decided upon in advance and which involves a wide range of considerations, many of them of a political or social character....

In this sense, the approach discussed here is a methodology or a framework, and hardly a cut-and-dried computational procedure for making a decision. It specifically aims toward including effects other than user consequences. For a good description of the methodological facet of cost-benefit analysis, it suffices to recall here that three fundamental pursuits are involved: (a) the identification of all (nonredundant) costs and effects (overtime, of course); (b) the measurements of such costs and effects insofar as possible; and (c) the valuation of these estimates, insofar as possible. The identification problem consists of specifying the length of two vectors (i.e., identifying all relevant effects, one to each vector element). The measurement task consists of entering estimates into the elements of the row of vectors. The valuation task involves entering estimates into the elements of the column vector. While both vectors should be completed insofar as possible, some effort may be saved by passing over the measurement of those effects for which a valuation of zero is anticipated (e.g., based on feedback from policy makers). Where entering into these vectors is impossible, honesty dictates the use of a question mark. While any description of cost-benefit analysis usually warns against double-counting, it is presumed that there are nonredundant effects consequent to a public investment project over and above those incurred "at the source." These effects are treated by filling in the two vectors insofar as possible (the methodological facet). Those effects for which the corresponding elements in both vectors have been filled in are then "partitioned" from other effects, and the two partitioned vectors multiplied together (the comparison of commensurable effects facet).

Developing Systemwide Indices: General Equilibrium Analysis—When investment in transportation is so large that it alters prices other than that of the transportation project itself (therefore feeding back and causing a shift in the demand curve for the project), the partial equilibrium approach is no longer adequate. The simplest form of general equilibrium approach, namely, interregional input-output analysis, is of use only in this evaluation analysis if it is rendered transport-sensitive and if it utilizes demand theory in such a way that prices are not obscured by the analysis. Several general equilibrium models have been designed which, though complicated, offer promise. For example, Friedlaender (14) solves three models for total net (social) benefits, defined by the vector expression $w \Delta p (Q_1 + Q_2)$ where each element in a vector represents a different commodity, and compares these results to the more traditional estimate given by the weighted sum of the cost savings multiplied by the sum of the levels of traffic before and after the improvement. In all three models a difference is demonstrated, although the direction of that difference is indeterminate in general terms, depending as it does on such unknowns as the elasticity of the various factor supplies, the nature of the factor substitutions and the nature of the commodity substitutions. All models attribute all consequences, of course, to the transportation improvement, and therefore their application for purely forecasting purposes is not warranted (15).

The general equilibrium approach offers the maximum opportunity to satisfy the evaluation criteria specified above. First, the size of the proposed transportation investment is such that it probably requires a general equilibrium approach. Second, the total social net benefits estimated by such a formulation can be compared with that generated by the consumer (and producer) surplus approach. Third, the construction of an interregional input-output framework is required, for other purposes, within the family of models already under construction for this study (freight forecasting, for example). Fourth, the areal level of detail of the study would appear to require an interregional approach, and a general equilibrium model is one well suited to this need.

SUMMARY AND CONCLUSIONS

This paper has described the model system and evaluation techniques being used by CONSAD to evaluate the indirect impacts of alternative Northeast Corridor transportation systems. The impact model system consists of two sub-models: IRIO, an interregional input-output model, and INTRA, an intraregional allocation model. The problems of selecting an evaluation measure (or measures) are also described.

As of the date of the writing of this paper (September 1966) the status of each of the sub-models is as follows: IRIO is fully programmed and debugged, the final data are being sought for use in calibration, the remainder of the data are being processed; INTRA is fully programmed and debugged, preliminary calibrations have been completed and work is being done to refine these where necessary.

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Preliminary Engineering Economy Analysis of Puget Sound Regional Transportation Systems

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•THIS paper is a preliminary engineering economy analysis of five alternative urban transportation systems formulated and studied by the Puget Sound Regional Transportation Study (PSRTS). Each transportation system is based on the possible inclusion and use of the following facilities in various degrees: highway facilities (freeways, expressways, and arterials), bus transit facilities, rapid rail transit facilities, automobile parking facilities, ferry vessels, and a floating bridge.

The paper has more merit for development of concept and methods of procedure than it does for quantitative answers. One problem encountered was determining what costs of providing and operating transportation facilities are relevant and significant in conducting an engineering economy analysis of urban transportation systems.

The principles of engineering economy analysis are applied to the evaluation of PSRTS transportation systems using three methods of engineering economy analysis: (a) the total annual transportation cost method; (b) the benefit-cost ratio method; and (c) the rate-of-return method.

The overall land-use plan on which a transportation system is based can be a critical factor which affects the economy of the transportation system relative to other transportation systems. Because of relatively light density population in the land-use plans, the predicted level of use of rapid rail transit facilities, as a component of a transportation system, was not high enough to indicate economy of rapid transit facilities over highway facilities for which it was a substitute.

The paper is a guide for evaluation of transportation systems containing multi-modes of transportation. It does not evaluate the socioeconomic factors which must be considered in transportation planning, but it does present to transportation planning administrators one of the most important tools needed in the decision-making process—the means to establish the relative order of economy of transportation systems based on tangible costs.

DESCRIPTION OF PROPOSED TRANSPORTATION SYSTEMS

This description of proposed Puget Sound regional transportation systems contains figures extracted from a few of the more than 20 major studies and reports made by the Puget Sound Regional Transportation Study (PSRTS). Figure 1 shows the location of the study area in the Puget Sound region of the State of Washington.

The alternative transportation systems analyzed in this report were based on two land-use plans and were developed, tested, and evaluated as to their ability to serve the future needs of the Puget Sound region for the year 1990. Plan A is based on a continuation of present trends and policies with respect to residential development. Plan B is based on a concept of cities, corridors, and open spaces. Plan B has smaller travel demands than Plan A because the close proximity of places of employment to home in Plan B decreases the length of trips. As a result, there is a decrease in numbers of lanes required for many sections of highways in Plan B when compared to Plan A.

Five regional transportation systems loaded with 1990 travel demands were analyzed. Table 1 summarizes the component parts of each transportation system.

Paper sponsored by Committee on Highway Engineering Economy and presented at the 46th Annual Meeting.

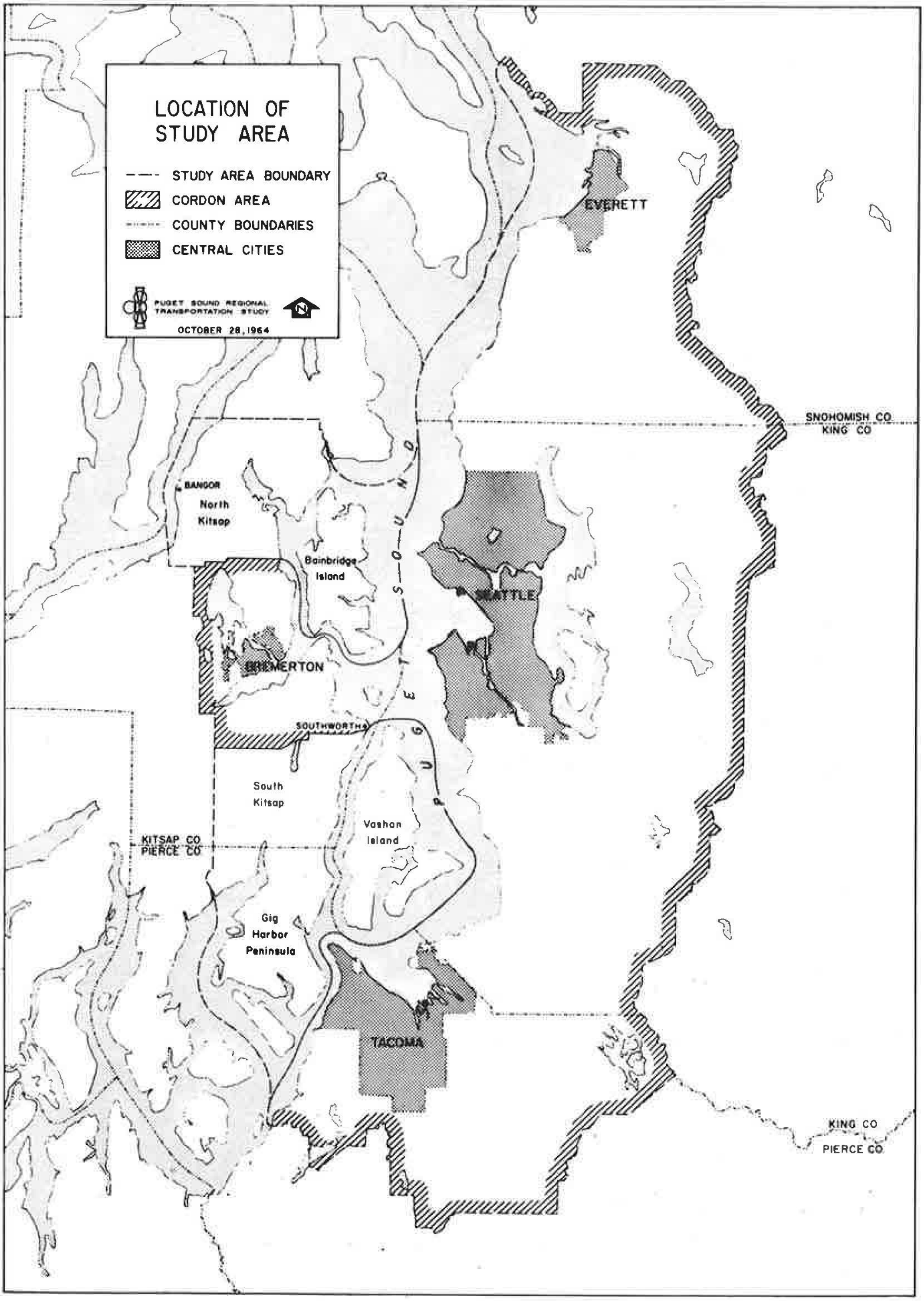

LOCATION OF
STUDY AREA
STUDY AREA BOUNDARY
CORDON AREA
COUNTY BOUNDARIES
CENTRAL CITIES
PUGET SOUND REGIONAL
TRANSPORTATION STUDY
OCTOBER 28, 1964
EVERETT
SNOHOMISH CO
KING CO
BANGOR
North
Kitsap
Bainbridge
Island
SEATTLE
BREMERTON
PUGET SOUND
SOUTHWORTH
South
Kitsap
Vashon
Island
KITSAP CO
PIERCE CO
Gig
Harbor
Peninsula
TACOMA
KING CO
PIERCE CO

Figure 1.

TABLE 1

TRANSPORTATION SYSTEMS AND THEIR COMPONENT PARTS

Transportation System Number and Basic Components of the System	
Land-use Plan A—The continuation of present trends and policies with respect to residential development.	Land-use Plan B—The concept of satelite cities, corriders, and open spaces which generate less total miles and hours of travel demand than Plan A.
System 2A Highway facilities obligated for construction by early 1970's loaded with 1990 travel demands of land-use Plan A. Bus transit facilities. Ferry facilities. Parking facilities.	System 5B Highway facilities obligated for construction by early 1970's loaded with 1990 travel demands of land-use Plan B. Cross-Sound bridge facilities. Bus transit facilities. Ferry facilities. Parking facilities.
System 3A Highway facilities in System 2 with additional miles of highways to accommodate 1990 travel demands of land-use Plan A. Bus transit facilities. Ferry facilities. Parking facilities.	System 6B Highway facilities in System 5 with additional miles of highways to accommodate 1990 travel demands of land-use Plan B. Cross-Sound bridge facilities. Bus transit facilities. Ferry facilities. Parking facilities.
System 4A Highway facilities similar to those in System 3 except that certain highway facilities competitive with rapid rail transit facilities were deleted. Rapid rail transit facilities. Bus transit facilities. Ferry facilities. Parking facilities.	

Transportation System 2A

The highway facilities included in System 2A were the existing plus committed and budgeted facilities which will be completed by the early 1970's. The system includes 110 miles of freeways and expressways which were in use in 1961 plus an additional 215 miles which were then under construction or budgeted (Fig. 2).

The bus transit facilities in System 2A include almost 750 miles of transit route compared to the approximately 575 route miles which were being operated in the region in 1961.

Travel across Puget Sound is accommodated by ferry facilities.

The system includes 35,000 additional parking spaces above those available in 1961.

Transportation System 3A

The highway facilities in System 3A include approximately 140 miles of freeway and expressway in addition to the 325 miles in existence in 1961 or committed and budgeted for construction by the early 1970's (Fig. 3).

The bus transit facilities, ferry facilities, and parking facilities are essentially the same as in System 2A.

Transportation System 4A

The highway facilities in System 4A include approximately 103 miles of freeways and expressways in addition to the 325 miles included in System 2A (Fig. 4). The highway facilities are similar to those in System 3A except that certain routes competitive with rapid rail transit facilities were deleted.

System 4A includes 20 miles of rapid rail transit facilities between the northwest portion of Seattle, downtown, and across Lake Washington to Bellevue (Fig. 5). In conjunction with the rapid rail transit route, an integrated network of local, feeder, and express buses was provided. In rapid rail transit corridors, the bus facilities were oriented to serve the rapid rail transit stations. The freeway eliminated by rapid rail transit facilities in northwest Seattle can be found by comparing Figure 4 with Figure 3.

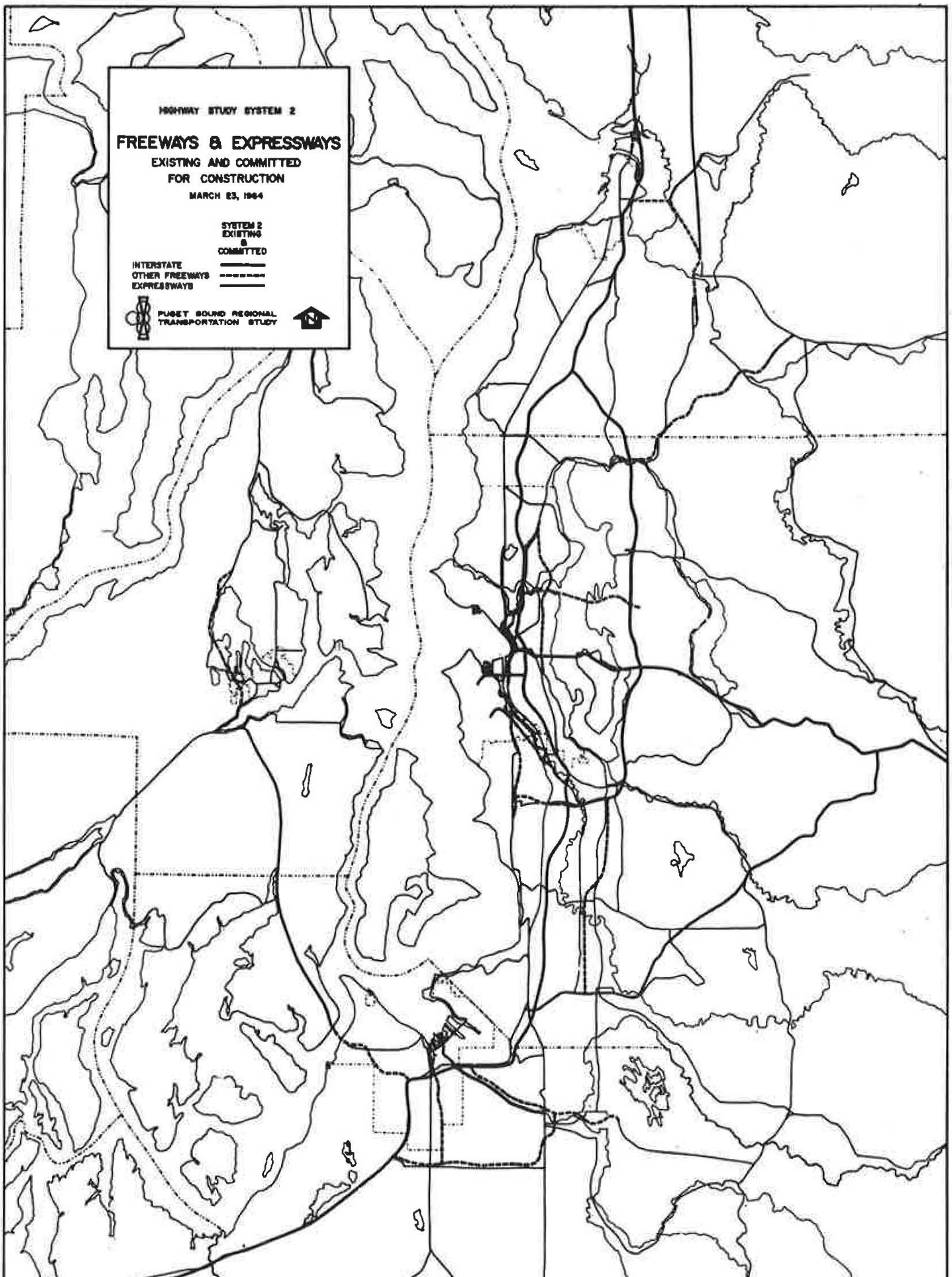

HIGHWAY STUDY SYSTEM 2
FREEWAYS & EXPRESSWAYS
EXISTING AND COMMITTED
FOR CONSTRUCTION
MARCH 23, 1964
SYSTEM 2
EXISTING
&
COMMITTED
INTERSTATE
OTHER FREEWAYS
EXPRESSWAYS
PUGET SOUND REGIONAL
TRANSPORTATION STUDY
N

Figure 2.

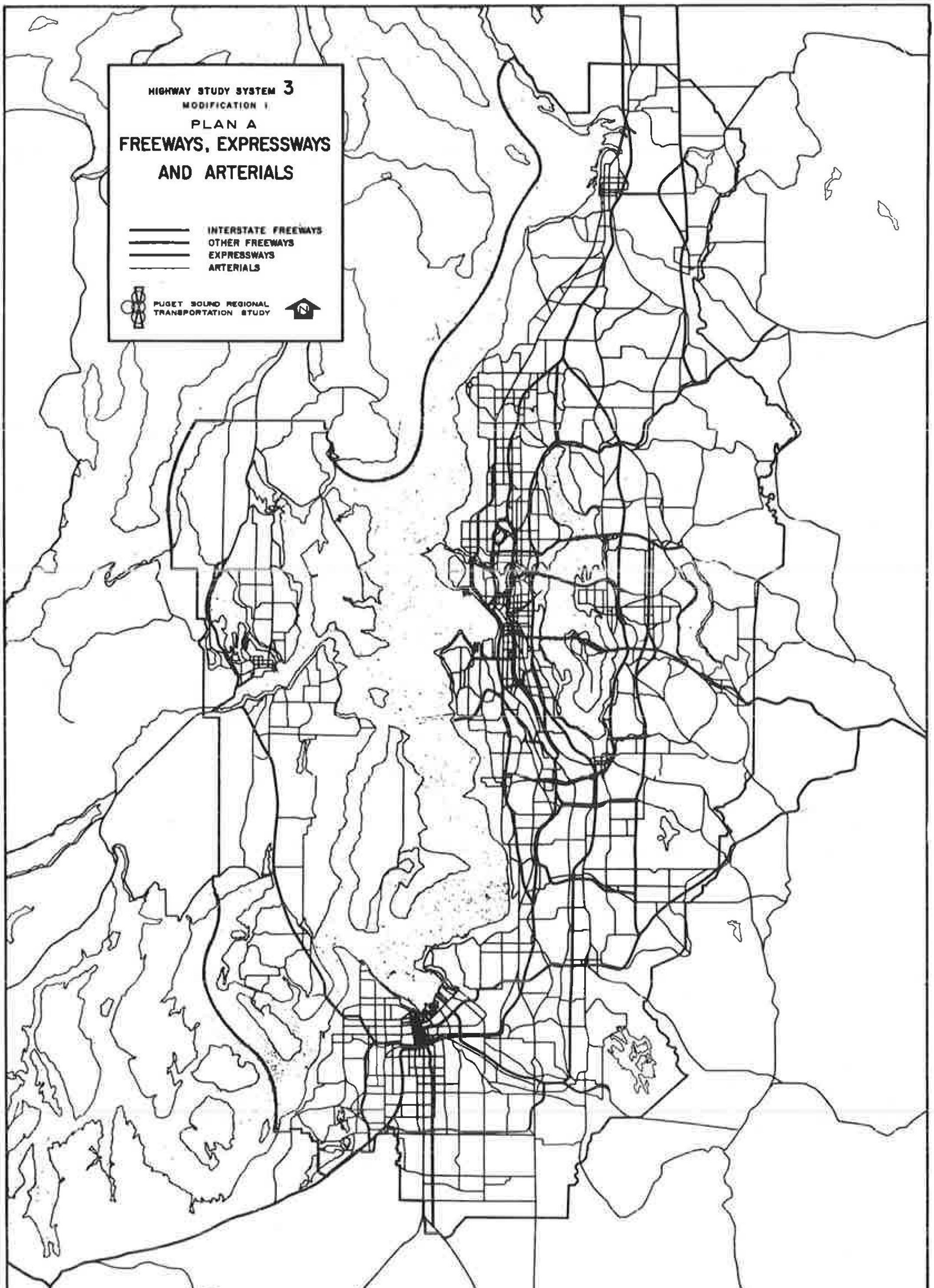

HIGHWAY STUDY SYSTEM 3
MODIFICATION I
PLAN A
FREEWAYS, EXPRESSWAYS AND ARTERIALS
INTERSTATE FREEWAYS
OTHER FREEWAYS
EXPRESSWAYS
ARTERIALS
PUGET SOUND REGIONAL TRANSPORTATION STUDY

Figure 3.

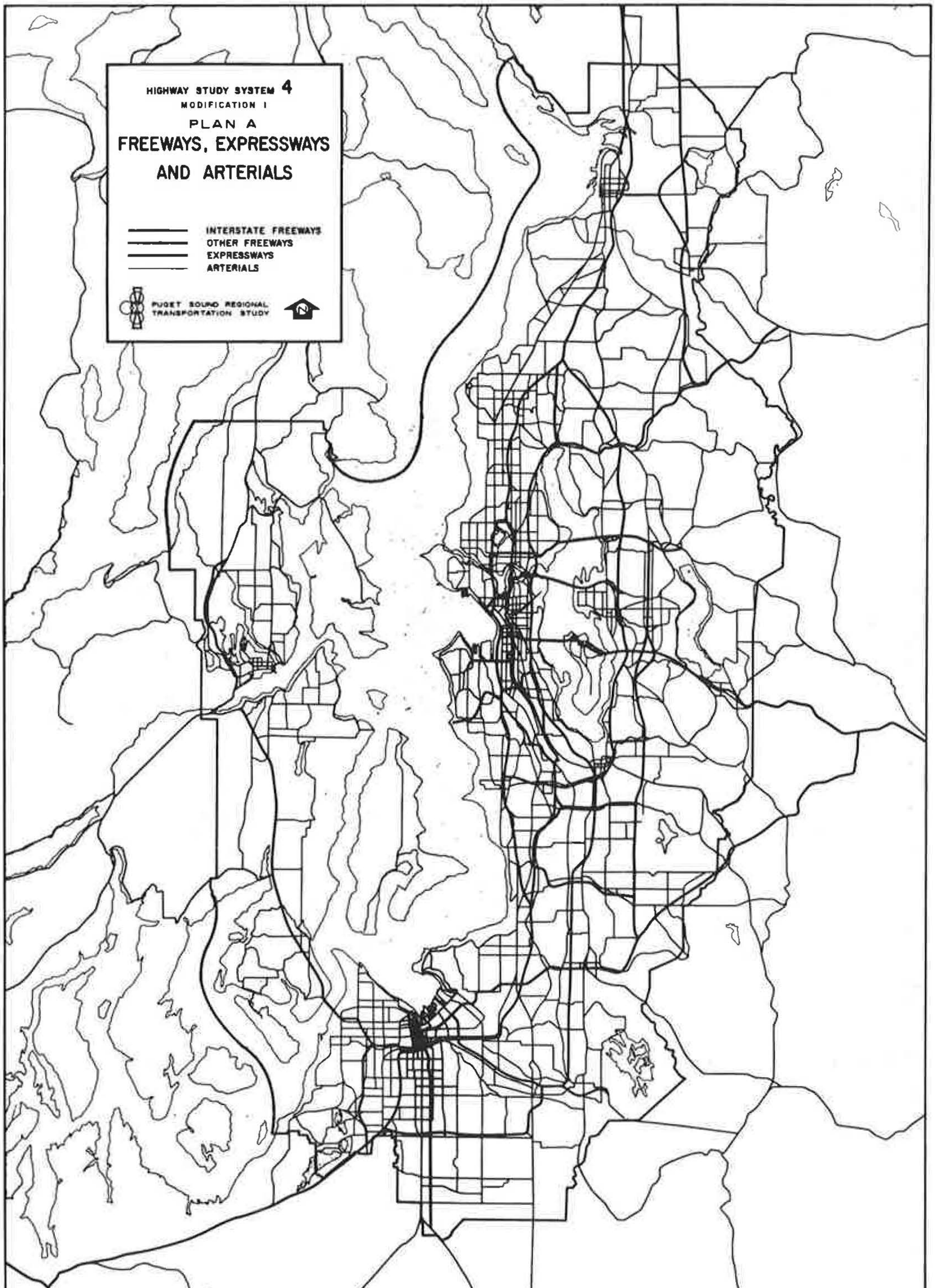
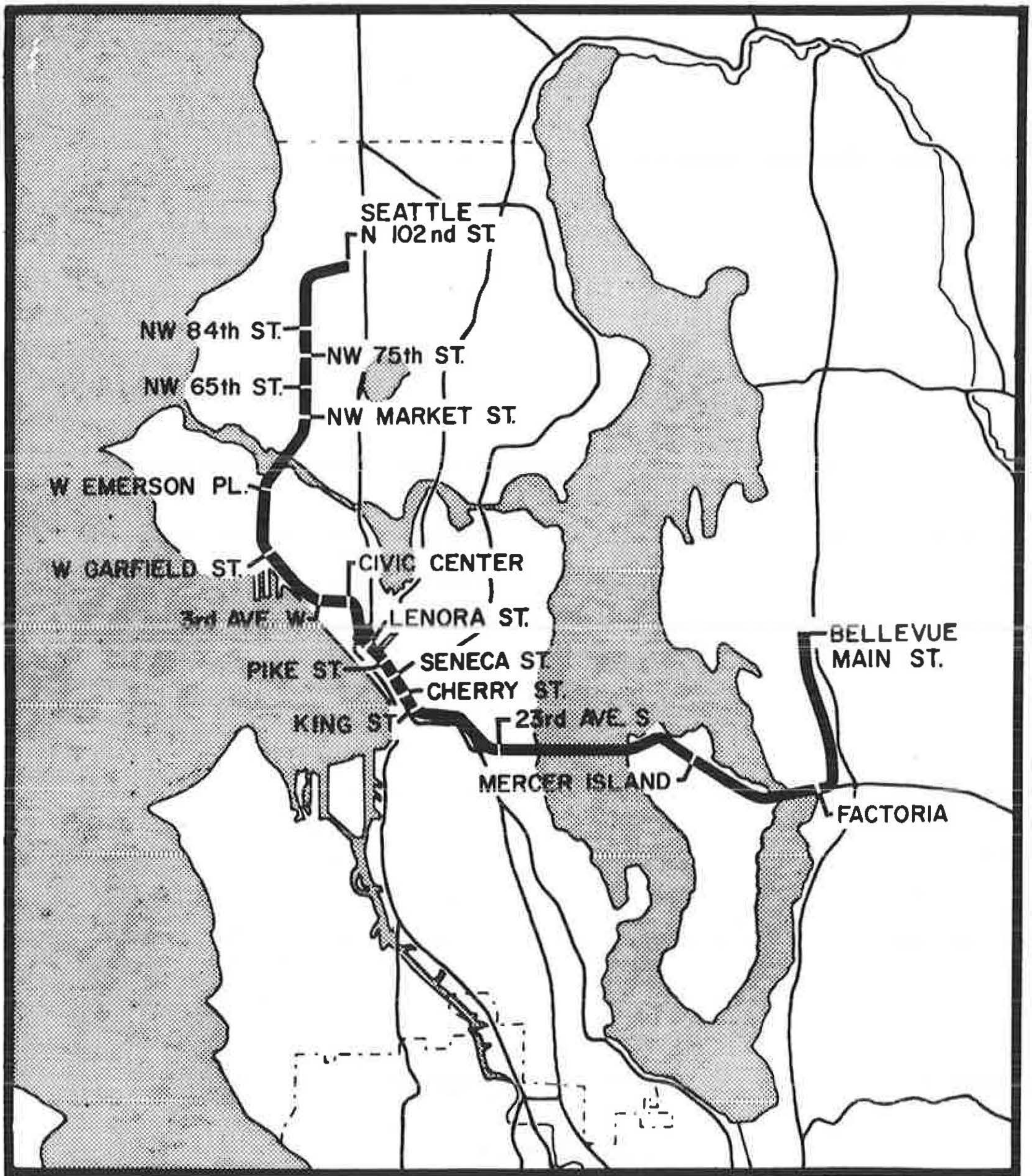

HIGHWAY STUDY SYSTEM 4
MODIFICATION I
PLAN A
FREEWAYS, EXPRESSWAYS
AND ARTERIALS
INTERSTATE FREEWAYS
OTHER FREEWAYS
EXPRESSWAYS
ARTERIALS
PUGET SOUND REGIONAL
TRANSPORTATION STUDY

Figure 4.



TRANSIT STUDY SYSTEM 4

RAIL RAPID TRANSIT ROUTE AND STATIONS

Figure 5.

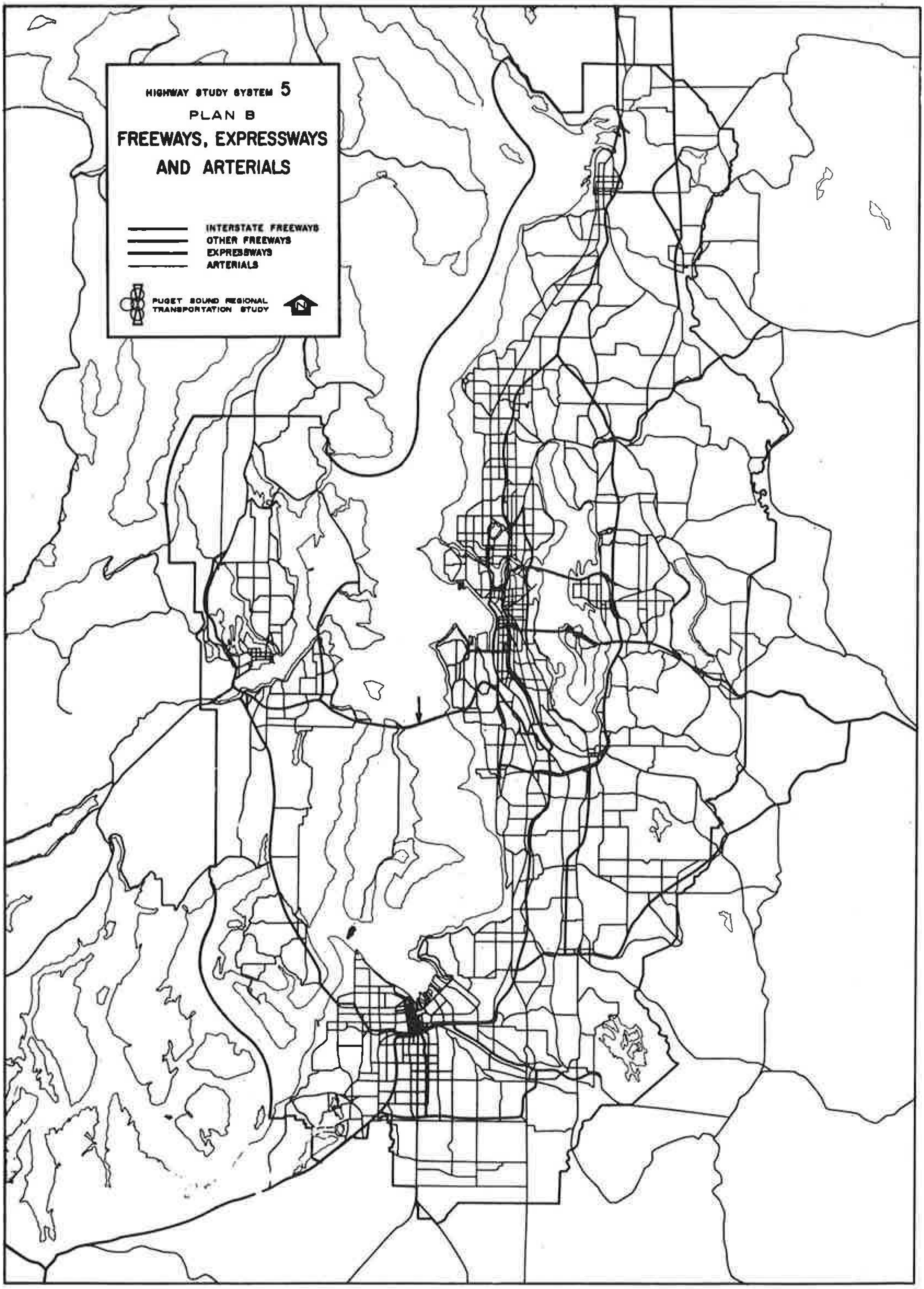

HIGHWAY STUDY SYSTEM 5
PLAN B
FREEWAYS, EXPRESSWAYS
AND ARTERIALS
INTERSTATE FREEWAYS
OTHER FREEWAYS
EXPRESSWAYS
ARTERIALS
PUGET SOUND REGIONAL
TRANSPORTATION STUDY
N

Figure 6.

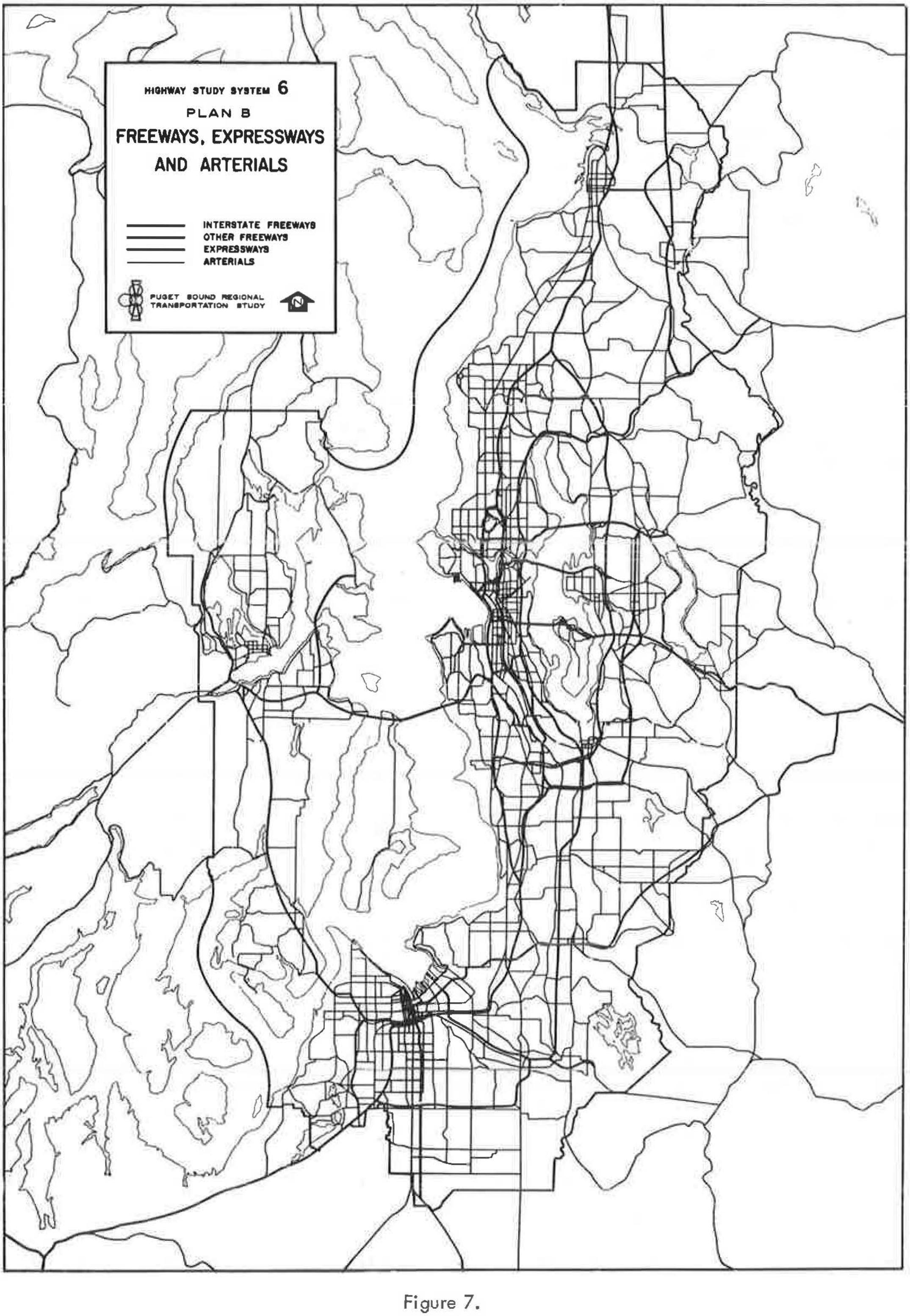

HIGHWAY STUDY SYSTEM 6
PLAN B
FREEWAYS, EXPRESSWAYS AND ARTERIALS
INTERSTATE FREEWAYS
OTHER FREEWAYS
EXPRESSWAYS
ARTERIALS
PUGET SOUND REGIONAL TRANSPORTATION STUDY
N

Figure 7.

The ferry facilities are essentially the same as those in System 2.

The need for additional parking spaces in System 4A with rapid rail transit facilities is reduced to 29,000. It will be recalled that Systems 2A and 3A, which did not include rapid rail transit facilities, required 35,000 parking spaces above those available in 1961.

Transportation System 5B

The highway facilities in System 5B are identical to those in System 2A except that cross-Sound bridge facilities partially substitute for ferries. The cross-Sound bridge is shown by the arrow in Figure 6.

Because land-use Plan B relative to Plan A results in smaller travel demands, the bus facilities and service required are not as great. The requirement for parking facilities relative to System 2A are also smaller.

Transportation System 6B

The highway facilities in System 6B include approximately 110 miles of freeways and expressways in addition to those in System 5B (Fig. 7). The transit facilities, cross-Sound bridge facilities, ferry facilities, and parking facilities are identical to those in System 5B.

TRANSPORTATION SYSTEM COSTS

The primary purpose of this report is to present a procedure for economic evaluation of transportation systems based mainly on tangible costs. It would require a great deal of space to present the development of cost estimates made as a co-effort with PSRTS. The summarized cost estimates will be presented with limited discussion but additional comments will be made as to costs that should be included or excluded from engineering economy analyses. Preliminary PSRTS transportation cost estimates as of May 1, 1965, are used to demonstrate the engineering economy analysis of transportation systems.

A basic concept used in this analysis is that transportation system costs are based on the estimated costs to provide and operate transportation system facilities. The source of funds, whether it be from cash box fares, taxes, bond issues, or the state or federal government, is not relevant to the problem of determining the relative economy of one transportation system to another. Also, the possible profits to be derived from some components of a transportation system, whether those profits be accrued as a result of public or private investment of capital, are irrelevant to the problem. Regardless of whether an investment, such as for parking facilities, is to be made by a public agency or a private firm, the costs that are relevant to an economy analysis are those to provide and operate the facilities.

Two major categories of costs that are included in the engineering economy analysis are (a) the capital costs or outlays for construction of the transportation facilities and purchase of transportation equipment, and (b) annual costs for the items of operation, maintenance, accidents, and travel time costs.

TABLE 2

CAPITAL COST FOR TRANSPORTATION SYSTEM CONSTRUCTION AND EQUIPMENT
(in thousands of dollars)

Component	Transportation System				
	2A	3A	4A	5B	6B
Highways	885,761	1,396,494	1,321,647	861,694	1,279,745
Cross-Sound bridge facilities	—	—	—	134,002	134,002
New buses	22,932	22,932	20,696	15,860	15,860
New ferries	70,300	70,300	70,300	25,250	25,250
Parking facilities	97,330	97,330	85,136	53,462	53,462
Rapid rail transit facilities	—	—	147,000	—	—
Total	1,076,323	1,587,056	1,644,806	1,090,268	1,508,319

TABLE 3

TOTAL NET ANNUAL COSTS FOR EACH TRANSPORTATION SYSTEM
BASED ON VARIOUS UNIT COSTS FOR TRAVEL TIME
(in thousands of dollars)

Travel Time Cost Per Person Per Hour	Transportation System				
	2A	3A	4A	5B	6B
$0.00	649,536	667,549	680,293	573,850	581,288
0.50	896,341	859,658	905,675	762,262	748,786
1.00	1,143,146	1,051,769	1,131,059	950,636	916,285
1.50	1,389,951	1,243,877	1,356,441	1,139,090	1,083,784
2.00	1,636,756	1,435,987	1,581,825	1,327,502	1,251,282

Capital outlays for transportation system construction and purchase of transportation equipment, as estimated for PSRTS systems, are shown in Table 2. The major construction items include highways (freeways, expressways, new arterial streets, and improvement of arterial streets); cross-Sound bridge facilities; parking facilities; and rapid rail transit facilities. Included in all these items are the costs of land and engineering. The major transportation equipment items include new buses and new Puget Sound ferries. Capital outlays for rapid rail transit facilities include the cost of land; construction of track, tunnels, stations, and maintenance facilities; engineering; and purchase of rolling stock. Note that the order of increasing total capital cost of the transportation systems is 2A, 5B, 6B, 3A, and 4A.

The net total annual cost for maintenance, operation, accidents, and travel time costs for each PSRTS transportation system is shown in Table 3. The travel time costs are based on the unit travel time costs per person per hour shown in the first column. The $1.00 per hour per person figure is most commonly used in engineering economy analyses. Various unit travel time costs were used to discern the sensitivity of the final results of the analysis to the values of travel time. Travel time includes walking time to transit stops and waiting time for transit vehicles as well as actual travel time on all modes of transportation.

The estimates of costs are in general based on 1964 price levels. Where cost records for 1964 were limited, data from prior years were updated by the use of cost indexes in order to increase the reliability of unit cost estimates.

Table 3 is comprised of costs for the following items (additional comments are provided as to the costs which should be included or excluded from engineering economy analyses):

1. Motor vehicle operating costs for the cost of fuel, tires, oil, maintenance and repairs, and depreciation. The additional operating and time costs for stopping, idling, and resuming speed at intersections (or as a result of traffic congestion delays) over uniform speed operation should be included. Motor vehicle operating costs in engineering economy analyses should exclude fuel taxes as they are transfer payments used for highway construction.

2. Maintenance costs of all highway facilities. In the case of the cross-Sound bridge this includes maintenance of the bridge, toll-booth operation, and insurance premiums.

3. Motor vehicle accident costs, including fatalities, injuries, and property damage, on highways with various levels of access control.

4. Operating costs of bus transit facilities. In the PSRTS analysis this includes items for payrolls, maintenance, insurance, and overhead.

5. Operating costs of ferries. In the PSRTS analysis this includes items for payrolls, maintenance, insurance, and overhead.

6. Operating costs of parking facilities. In the PSRTS analysis this includes maintenance, insurance, and overhead.

7. Operating costs of rapid rail transit facilities. In the PSRTS analysis this includes payrolls, maintenance, insurance, and overhead.

The discussion of costs as related to PSRTS systems is limited and for further detail, reference can be made to the PSRTS staff report on transportation system costs.

In general, appreciation of costs to account for rising prices in the future is not included in an engineering economy analysis. However, when the result of such an analysis is sensitive to appreciation of costs that factor should be considered for each item of cost. The PSRTS transportation systems cost estimates were not based on appreciation of costs related to rising prices.

The dates when capital outlays would be made in the future for the transportation systems are unknown. Therefore, for the purpose of this preliminary engineering economy analysis, the total capital costs show what it would cost if all capital outlays were made now. Technically speaking, future capital expenditures have not been adjusted or discounted for the time value of money in order to arrive at total capital costs.

ECONOMIC ANALYSIS

The engineering economy analysis is a systematic approach to making a selection of the most economic transportation system from among the several alternative transportation systems studied. The basic proposal is a "do nothing" alternative. In other words, the base transportation system includes no further construction than what has already been scheduled for construction by the early 1970's. All other alternative transportation systems are compared to this base system for justification. All transportation systems are then compared to one another in order to study their relative economy. The latter comparison emphasizes the fact that it is the differences between the transportation systems which are important.

The benefits to be rendered by any transportation facility in the future must at least be equal to the costs over the period the benefits are rendered. In order to compare benefits and costs, both must be determined over the same time period and must be reduced to dollar values as far as reasonably possible. The time period used and the procedure used to express all costs on a comparable basis will be discussed.

Analysis Period

A 25-year economic analysis period was used in this report. There were several reasons for this. Traffic predictions were based on a population and level of development which will occur by 1990, or roughly 25 years in the future. The economic analysis period then was equal to the period covered by traffic predictions. An increase in the length of the period for which traffic predictions were made would decrease the reliability of traffic predictions and the related estimates of transportation system user benefits. Possible changes in transportation technology, public travel trends, and rate of population growth make it risky to predict the need and use of proposed transportation systems beyond a 25-year period. The possibility of new and better means of transportation (which may compete with the proposed systems) increases with the length of the analysis period chosen. Therefore, it is reasonable to require that the value of the benefits to be rendered by the proposed transportation facilities be equal to or greater than the costs over the period that reliable predictions can be made (1).

Benefits

Benefit as used in this analysis is the net reduction in the total of annual maintenance, operating, accident, and travel time costs resulting from any additional expenditure of capital made in order to obtain those benefits. Higher total capital costs for any transportation system compared to another system should result in benefits. Since the dates when capital expenditures would be made were unknown, the time periods over which benefits (reductions in the net annual costs mentioned above) would be rendered were also unknown. Therefore, the analysis was based on the benefits determined by loading each transportation system with 1990 travel demands and using the resulting benefits over a 25-year analysis period. Any attempt to state whether the benefits determined on that basis are high or low would be questionable. For the sake of this preliminary analysis, however, it is the most equitable basis for comparison of the systems.

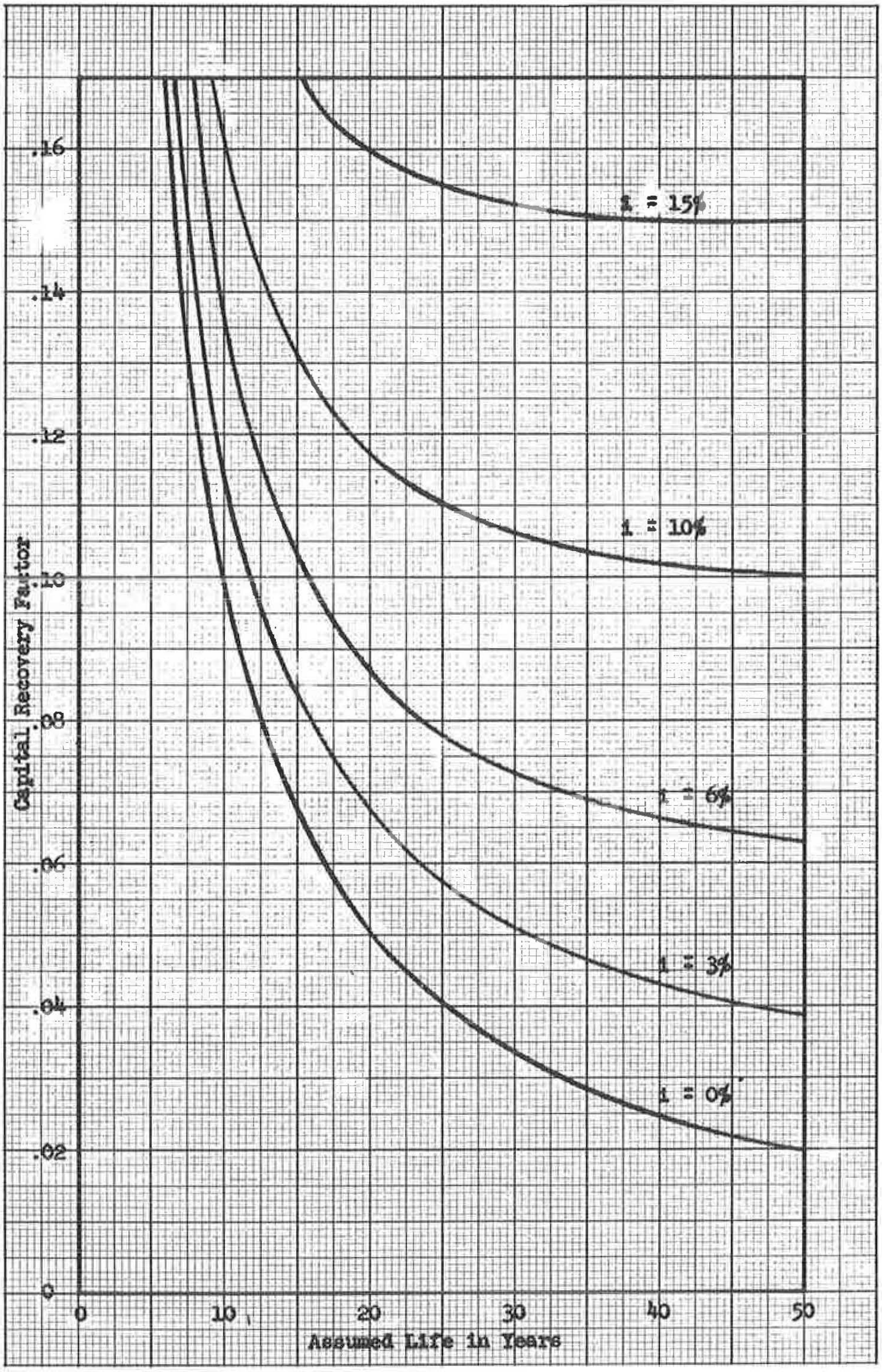


Figure 8. Capital recovery factors for selected interest rates (i) and periods of years.

Interest Rates

Interest is the rent paid on borrowed money. It is a concept of return on productive capital investments in physical assets. In private enterprise the return is in a monetary form. In the case of public transportation systems the return is in the form of general benefits evaluated in dollars.

The selection of the minimum attractive rate of return or the interest rate to use in the analysis of transportation systems was based on consideration of the following factors: the rate of interest commonly paid by the government on borrowed funds, the risks and uncertainties involved, and the "opportunity cost" of captial.

The fact that funds can be obtained by the government by the sale of bonds at relatively low interest rates is misleading when considering the cost of money on the market. Low interest rates are available because of the usual tax reduction provisions allowed by the government and the virtually risk-free guarantee to repay the principle plus interest. Considering the tax reductions granted to the purchasers of such bonds, the low 3 to 4 percent interest rate paid by the government effectively equals a much higher rate.

The minimum attractive rate of return should increase with the degree of risk and uncertainty involved in the investment. Therefore, if the soundness of an investment is in doubt the potential return on the investment should be higher in order to warrant the risk of capital funds.

Another factor considered in the selection of the minimum attractive rate of return was the "opportunity cost" or capital or the investment opportunities forgone by the taxpayers who provide the funds for investment in the transportation systems. It is common knowledge that a large portion of the population in the United States borrow money and make purchases on credit. The taxpayer could use his tax funds to help pay his existing debts and in so doing obtain a risk free return on his capital equal to at least 6 percent and usually higher.

Another example of taxpayer "opportunity cost" is that of persons making investments in one manner or another in the stock market or private enterprise. It is common for private enterprises to stipulate at least a minimum attractive rate of return equal to 10 percent, after taxes, as criteria for investment of capital (2).

In consideration of these factors it is reasonable to require that the justification for construction of transportation systems should be based on the proof that government administrators can invest taxes as productively as could the taxpayer. The measuring stick used for such a comparison is the rate of return on investment or the minimum attractive rate of return.

The minimum attractive rate of return selected for use in this report is 6 percent per annum. This report also includes analyses based on other interest rates (0, 3, 6, 10, and 15 percent in total) in order to study the sensitivity of the economic analysis to changes in interest rates.

Another concept of interest was employed in this report. Interest is also a mathematical concept by which values at one point in time may be converted to equivalent values at another point in time. Or it can be used to convert values at one point in time to a series of equivalent uniform annual values over a period of time. The latter approach was used in this analysis to convert total capital costs to equivalent uniform annual capital costs. When expressed on an annual basis the capital costs can be compared to or combined with annual maintenance, operating, accident, and travel time costs. In order to convert total capital costs to equivalent uniform annual capital costs, the total capital cost for each transportation system component was multiplied by the capital recovery factor related to each interest rate and assumed years of life for the particular component. Figure 8 is a graph from which the capital recovery factor can be obtained for the various interest rates and assumed lives used in this report for transportation system components (3). The particular capital recovery factors used are shown in Table 4.

Annual Capital Costs

The results of multiplying the total capital costs shown in Table 2 by the capital

TABLE 4

CAPITAL RECOVERY FACTORS FOR VARIOUS INTEREST RATES AND PERIODS

Period (years)	Interest Rate (%)				
	0	3	6	10	15
15	0.06667	0.08377	0.10296	0.13147	0.17102
25	0.04000	0.05743	0.07823	0.11017	0.15470

recovery factors shown in Table 4 are shown in Table 5. The results are equivalent uniform annual capital costs.

The amortization period or the period used to select the capital recovery factor for the transportation system components was 25 years for highways, parking facilities, ferries, and rapid rail transit facilities, and 15 years for new buses. For this preliminary engineering economy analysis the life of the present bus fleet was ended at the 10th year of the 25-year economic analysis period. The purchase of the new bus fleet was assumed to occur in the 10th year making the end of the service life coincide with the end of the economic analysis period.

The reader will note that the amortization period of 25 years used for some of the transportation system component costs is shorter than their probable lives. For

TABLE 5

EQUIVALENT UNIFORM ANNUAL CAPITAL COSTS OF TRANSPORTATION SYSTEM COMPONENTS BASED ON VARIOUS INTEREST RATES
(in thousands of dollars)

Transportation System and its Components	Interest Rate (%)				
	0	3	6	10	15
2A					
Highways	35,430	50,869	69,293	97,584	137,027
New buses	1,529	1,921	2,361	3,015	3,922
New ferries	2,812	4,037	5,500	7,745	10,875
Parking facilites	3,893	5,590	7,614	10,723	15,057
Total	43,664	62,417	84,768	119,067	166,881
3A					
Highways	55,859	80,201	109,248	153,852	216,038
New buses	1,529	1,921	2,361	3,015	3,922
New ferries	2,812	4,037	5,500	7,745	10,875
Parking facilities	3,893	5,590	7,614	10,723	15,057
Total	64,094	91,749	124,723	175,335	245,892
4A					
Highways	52,867	75,904	103,395	145,609	204,463
New buses	1,380	1,734	2,131	2,721	3,539
New ferries	2,812	4,037	5,500	7,745	10,875
Parking facilities	3,405	4,889	6,660	9,379	13,171
Rapid rail transit	5,880	8,442	11,500	16,195	22,741
Total	66,344	95,006	129,186	181,649	254,789
5B					
Highways	34,468	49,487	67,410	94,933	133,304
Cross-Sound bridge facilities	5,360	7,696	10,483	14,763	20,730
New buses	1,057	1,329	1,633	2,085	2,712
New ferries	1,010	1,450	1,975	2,782	3,906
Parking facilities	2,138	3,070	4,182	5,890	8,271
Total	44,033	63,032	85,683	120,453	168,923
6B					
Highways	51,190	73,496	100,114	140,990	197,977
Cross-Sound bridge facilities	5,360	7,696	10,483	14,763	20,730
New buses	1,057	1,329	1,633	2,085	2,712
New ferries	1,010	1,450	1,975	2,782	3,906
Parking facilities	2,138	3,070	4,182	5,890	8,271
Total	60,755	87,041	118,387	166,510	233,596

example, two of the major cost items for highway construction are right-of-way and grading. In reality the life of right-of-way is perpetuity. From just general observation of old highway and railway cuts and fills it also appears that grading for roadways, with reasonable maintenance, could have a life in excess of 40 years. The life of parking garages is another good example of possible physical life exceeding 25 years. Last of all, the estimated service life of rapid rail transit rolling equipment was estimated to be 40 years (by transit consultant Deleuw Cather and Company). There were three factors which were considered in the decision to amortize capital costs over a 25-year period for those components and their parts having lives in excess of 25 years.

The first factor considered was that there are three types of probable lives which have to be dealt with and the differences between them are significant (4). They are actual physical life, service life, and economic life. Actual physical life is ended because of physical deterioration. Service life is the length of time the facility is used in its major original function without major rebuilding. Economic life is that life which is ended at the time the services rendered by the facility could be produced at a lower cost by a new facility. It is readily apparent that it is the economic life which is significant and should be used to amortize the costs of transportation system components in this analysis. This economic life was considered to be 25 years.

The second factor considered, related to the preceding one and already discussed under the heading "Analysis Period," was that the increasing rate of change in transportation technology increases the chances that the proposed transportation system components will be competing with new, better and more desirable means of transportation in the future. When one considers the general reluctance of the public today to use transportation facilities and equipment approaching 25 years in age (transit facilities, for example), it would be unwise to amortize costs over a longer period.

The third and final factor considered can be explained with the use of Figure 8. The discussion of interest rates gave the reasons for stipulating that the rate of return on the investment in transportation facilities should be above 6 percent. In Figure 8 it can be seen that the change in the capital recovery factor decreases as the assumed life in years increases. It can also be observed that as the interest rate increases there are smaller percentage decreases in the capital recovery factor between any given range of years. For example, the capital recovery factor for the 6 percent interest rate falls from 0.078 at 25 years to 0.066 at 40 years, a 15 percent decrease. The capital recovery factor for the 10 percent interest rate falls from 0.110 at 25 years to 0.102 at 40 years, a decrease of 7 percent. Though the assumed life was increased by 60 percent in going from 25 years to 40 years, the resulting changes in the capital recovery factor were only 15 percent at the 6 percent interest rate and only 7 percent at the 10 percent interest rate. The point to be made is that as the minimum attractive rate of return increases, any change in the assumed life above 25 years plays a role of decreasing importance in the analysis. Also, since predictions of transportation system use and therefore the benefits to be received cannot be made with a high degree of reliability beyond 25 years, it would be unwise to amortize capital costs over a period exceeding the 25 years.

Salvage Values

For this preliminary analysis salvage values were considered to be negligible or zero at the end of the 25-year economic analysis period. Estimates of salvage values 25 years in the future usually prove to vary from the true figure by wide margins. Also, the use of reasonably high rates of return tends to nullify the importance of salvage values. Figure 9, which shows the relationship between salvage value at the end of the study period and the present worth of that salvage, demonstrates the principle. For example, use of the curve based on the 6 percent rate of return and the analysis period of 25 years, and using salvage values in the range of 10 percent to 20 percent of first cost, shows that the present worth is effectively 2 to 5 percent of first cost. The difference between including and excluding salvage values was considerably less than the possible variations in other estimates. Therefore, salvage values were not included in the analysis.

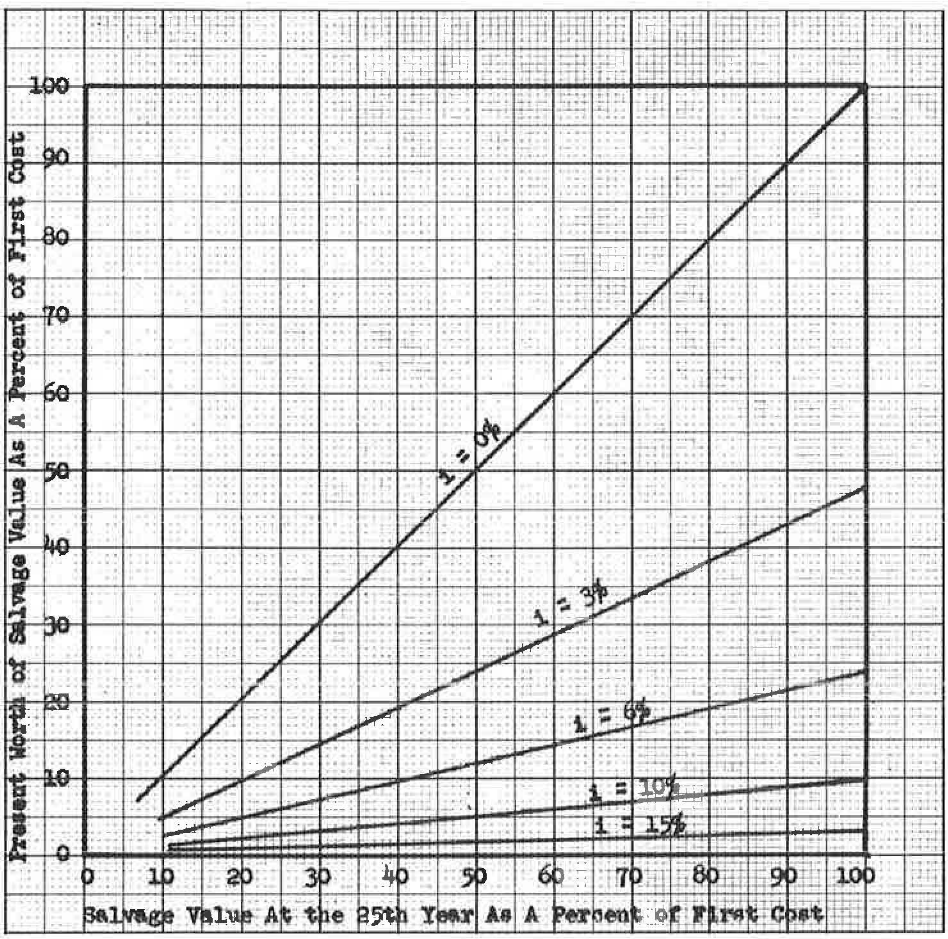


Figure 9. Relationship between salvage value at end of 25-year study period and present worth of salvage value (5, p. 35).

Engineering Economy Analysis Methods

Three methods of engineering economy analysis are used in this report. They are the total annual transportation cost method, the benefit-cost ratio method, and the rate-of-return method. The basic ingredients in all the methods include total capital costs or their equivalent uniform annual value, and annual costs for maintenance, operating, accident, and travel time costs. Though the methods use the ingredients in different ways the result of each method is the selection of the same transportation system as being the most economic when based on similar minimum attractive rates of return and unit travel time costs.

In the total annual transportation cost method the systems are analyzed as a group to find the one most likely to produce the minimum total annual cost. In the benefit-cost ratio method and the rate-of-return method, however, the analysis is accomplished by the use of pairs when one transportation system alternative is compared to another transportation system alternative. Successive comparisons eliminate the poorest systems economy-wise until only the best one is left.

Total Annual Transportation Cost Method

The concept of the total annual transportation cost method is that the transportation user or society in general deserves to obtain transportation at the lowest cost. Therefore,

TABLE 6

TOTAL ANNUAL TRANSPORTATION COSTS BASED ON VARIOUS CONDITIONS
(in thousands of dollars)

Transportation System	Travel Time Cost Per Person Per Hour	Interest Rate (%)				
		0	3	6	10	15
2A	$0.00	693,200	711,953	734,304	768,603	816,417
	0.50	940,005	958,758	981,109	1,015,408	1,063,222
	1.00	1,186,810	1,205,563	1,227,914	1,262,213	1,310,027
	1.50	1,433,615	1,452,368	1,474,719	1,509,018	1,556,832
	2.00	1,680,420	1,699,173	1,721,524	1,755,823	1,803,637
3A	0.00	731,643	759,298	792,272	842,884	913,441
	0.50	923,752	951,407	984,381	1,034,993	1,105,550
	1.00	1,115,863	1,143,518	1,176,492	1,227,104	1,297,661
	1.50	1,307,971	1,336,626	1,368,600	1,419,212	1,489,769
	2.00	1,500,081	1,527,736	1,560,710	1,611,322	1,681,879
4A	0.00	746,637	775,299	809,479	861,942	935,082
	0.50	972,019	1,000,681	1,034,861	1,087,324	1,160,464
	1.00	1,197,403	1,226,065	1,260,245	1,312,708	1,385,848
	1.50	1,422,785	1,451,447	1,485,627	1,538,090	1,611,230
	2.00	1,648,169	1,676,831	1,711,011	1,763,474	1,836,614
5B	0.00	617,883	635,882	659,533	694,303	742,773
	0.50	806,295	825,294	847,945	882,715	931,185
	1.00	994,669	1,013,668	1,036,319	1,071,089	1,119,559
	1.50	1,183,123	1,202,122	1,224,773	1,259,543	1,308,013
	2.00	1,371,535	1,390,534	1,413,185	1,447,955	1,496,425
6B	0.00	642,043	668,329	699,675	747,798	814,884
	0.50	809,541	835,827	867,173	915,296	982,382
	1.00	977,040	1,003,326	1,034,672	1,082,795	1,149,881
	1.50	1,144,539	1,170,825	1,202,171	1,250,294	1,317,380
	2.00	1,312,037	1,338,323	1,369,669	1,417,792	1,484,878

TABLE 7

RELATIVE ORDER OF ECONOMY OF TRANSPORTATION SYSTEMS AS DETERMINED BY TOTAL ANNUAL TRANSPORTATION COST METHOD

Travel Time Cost Per Person Per Hour	Order of Increasing Cost	Interest Rate (%)				
		0	3	6	10	15
$0.00	1	5B	5B	5B	5B	5B
	2	6B	6B	6B	6B	6B
	3	2A	2A	2A	2A	2A
	4	3A	3A	3A	3A	3A
	5	4A	4A	4A	4A	4A
$0.50	1	5B	5B	5B	5B	5B
	2	6B	6B	6B	6B	6B
	3	3A	3A	2A	2A	2A
	4	2A	2A	3A	3A	3A
	5	4A	4A	4A	4A	4A
$1.00	1	6B	6B	6B	5B	5B
	2	5B	5B	5B	6B	6B
	3	3A	3A	3A	3A	3A
	4	2A	2A	2A	2A	2A
	5	4A	4A	4A	4A	4A
$1.50	1	6B	6B	6B	6B	5B
	2	5B	5B	5B	5B	6B
	3	3A	3A	3A	3A	3A
	4	4A	4A	2A	2A	2A
	5	2A	2A	4A	4A	4A
$2.00	1	6B	6B	6B	6B	6B
	2	5B	5B	5B	5B	5B
	3	3A	3A	3A	3A	3A
	4	4A	4A	4A	2A	2A
	5	2A	2A	2A	4A	4A

TABLE 8

INCREMENTAL BENEFITS BASED ON VARIOUS UNIT TRAVEL TIME COSTS
(in thousands of dollars)

Transportation Systems Compared	Travel Time Cost Per Person Per Hour				
	$0	$0.50	$1.00	$1.50	$2.00
2A-5B	75, 686	134, 079	192, 510	250, 861	309, 254
2A-6B	68, 248	147, 555	226, 861	306, 167	385, 474
2A-3A	-18, 013	36, 683	91, 377	146, 074	200, 769
2A-4A	-30, 757	-9, 334	12, 087	33, 510	54, 931
5B-6B	-7, 438	13, 476	34, 351	55, 306	76, 220
5B-3A	-93, 699	-97, 396	-101, 133	-101, 787	-108, 485
5B-4A	-106, 433	-143, 413	-180, 423	-217, 351	-254, 323
6B-3A	-86, 261	-110, 872	-135, 484	-160, 093	-184, 705
6B-4A	-99, 005	-156, 889	-214, 774	-272, 657	-330, 543
3A-4A	-12, 744	-46, 017	-79, 290	-112, 564	-145, 838

all the costs related to each transportation system are totaled on an annual basis to determine the one resulting in the minimum total annual cost. Table 6 shows the result of adding the equivalent uniform annual capital costs from Table 5 and the maintenance, operating, accident, and time costs from Table 3 for each system. Table 7 shows the transportation systems arranged by order of increasing total annual transportation cost for the various interest rates and unit travel time costs. Based on the use of $1.00 per hour per person travel time costs and the 6 percent interest rate, system 6B has the lowest total annual cost.

Benefit-Cost Ratio Method

One measure of economic desirability in comparing two proposed alternate transportation systems is the ratio of net annual benefits to net annual capital costs. In order to satisfy the concept that benefits must at least equal costs, the benefit-cost ratio must be 1.0 or larger.

Benefit-cost ratios were calculated for all possible comparisons of paired alternative transportation systems. Two general uses were made of those ratios. The first use was to determine whether or not the construction and equipment costs of Systems 3A, 4A, 5B and 6B would result in benefits that would justify construction of the systems when compared with the base transportation system, 2A, which will soon be in existence. The second use was to determine whether or not each increment of capital cost in going to successively more costly transportation systems also resulted in benefits. The latter use of the benefit-cost ratio method is a systematic approach

TABLE 9

INCREMENTAL EQUIVALENT UNIFORM ANNUAL CAPITAL COSTS BASED ON VARIOUS INTEREST RATES
(in thousands of dollars)

Transportation Systems Compared	Interest Rate (%)				
	0	3	6	10	15
2A-5B	369	615	915	1, 386	2, 042
2A-6B	17, 071	24, 624	33, 619	47, 443	66, 715
2A-3A	20, 430	29, 332	39, 955	56, 268	79, 011
2A-4A	22, 680	32, 589	44, 418	62, 582	87, 908
5B-6B	16, 722	24, 009	32, 704	46, 057	64, 673
5B-3A	20, 061	28, 717	39, 040	54, 882	76, 969
5B-4A	22, 311	31, 974	43, 503	61, 196	85, 866
6B-3A	3, 339	4, 708	6, 336	8, 825	12, 296
6B-4A	5, 589	7, 965	10, 799	15, 139	21, 193
3A-4A	2, 250	3, 257	4, 463	6, 314	8, 897

that selects the most economic transportation system. It eliminates the need for some of the paired comparisons of transportation systems, but all comparisons are shown for the reader's perusal.

The incremental benefit for each paired comparison of transportation systems is shown in Table 8. The figures are based on the data in Table 3. For example, System 2A compared with the higher total capital cost System 3A at the $1.00 per hour unit travel time cost show respective net annual totals of maintenance, operating, accident, and travel time costs equal to $1,143,146,000 and $1,051,769,000. Therefore, the benefit or net reduction is equal to $91,377,000 as shown in Table 8 for the paired system comparison. Sometimes the comparisons do not result in reductions of net annual totals of maintenance, operating, accident, and travel time costs; instead of a reduction there may be an increase. In that situation the benefits shown in Table 8 are indicated as being negative.

The incremental cost for each paired comparison is shown in Table 9. The figures are based on data in Table 5. For example, System 2A compared with the higher total capital cost System 3A at the 6 percent interest rate shows respective equivalent uniform annual capital costs equal to $84,768,000 and $124,723,000. Therefore, the increment or increase in equivalent uniform annual costs is $39,955,000 as shown in Table 9 for the paired comparison. The increments of equivalent uniform annual capital costs will always be positive since the lower total capital cost transportation system is always the base for the paired comparisons.

The result of dividing incremental benefits by incremental costs for each paired comparison of systems is summarized in Table 10. Using the paired comparison of

TABLE 10

INCREMENTAL BENEFIT-COST RATIOS BASED ON VARIOUS INTEREST RATES AND UNIT COSTS FOR TRAVEL TIME

Transportation Systems Compared	Travel Time Cost Per Person Per Hour	Interest Rate (%)				
		0	3	6	10	15
2A-5B	$0 00	205.1	123.1	827.2	54.6	37.1
	0.50	363.4	218.0	146.5	96.7	65.7
	1.00	521.7	313.0	210.4	138.9	94.3
	1.50	679.8	407.9	274.2	180.9	122.9
	2.00	838.1	502.9	338.0	223.1	151.4
2A-6B	0.00	4.0	2.8	2.0	1.4	1.0
	0.50	8.6	6.0	4.4	3.1	2.2
	1.00	13.3	9.2	6.7	4.8	3.4
	1.50	17.9	12.4	9.1	6.5	4.6
	2.00	22.6	15.7	11.5	8.1	5.8
2A-3A	0.00	*	*	*	*	*
	0.50	1.8	1.2	0.9	0.7	0.5
	1.00	4.5	3.1	2.3	1.6	1.2
	1.50	7.1	5.0	2.3	1.6	1.2
	2.00	9.8	6.8	5.0	3.6	2.5
2A-4A	0.00	*	*	*	*	*
	0.50	*	*	*	*	*
	1.00	0.5	0.4	0.3	0.2	0.1
	1.50	1.5	1.0	0.8	0.5	0.4
	2.00	2.4	1.7	1.2	0.9	0.6
5B-6B	0.00	*	*	*	*	*
	0.50	0.8	0.6	0.4	0.3	0.2
	1.00	2.0	1.4	1.1	0.7	0.5
	1.50	3.3	2.3	1.7	1.2	0.9
	2.00	4.6	3.2	2.3	1.7	1.2
5B-3A	0 - 2.00	*	*	*	*	*
5B-4A	0 - 2.00	*	*	*	*	*
6B-3A	0 - 2.00	*	*	*	*	*
6B-4A	0 - 2.00	*	*	*	*	*
3A-4A	0 - 2.00	*	*	*	*	*

*Negative benefit-cost ratios.

TABLE 11

TRANSPORTATION SYSTEMS ARRANGED BY ORDER OF INCREASING TOTAL CAPITAL COSTS

Transportation Systems	Total Capital Cost	Transportation Systems	Total Capital Cost
2A	$1,076,323,000	3A	$1,587,056,000
5B	1,090,268,000	4A	1,644,806,000
6B	1,508,319,000		

Systems 2A and 3A again, the incremental annual benefits ($91,377,000) based on the $1.00 per hour unit travel time costs when divided by the incremental equivalent uniform annual capital cost ($39,955,000) based on the 6 percent rate, produces the benefit-cost ratio of 2.3 shown in Table 10. Therefore, the benefits to be derived by the reduction of the net annual total of maintenance, operating, accident and travel time costs exceed the additional capital cost required in order to obtain the benefits. On that basis the investment of the increment of capital costs for System 3A compared with 2A would be economical.

Benefit-cost ratios lower than 1.0 or negative in sign indicate that the investment of the increment of capital for the paired comparison of transportation systems would be uneconomical. The asterisks in Table 10 indicate negative benefit-cost ratios.

Transportation System Economy and Justification—The paired comparisons of Systems 2A-5B, 2A-6B, 2A-3A, and 2A-4A by the benefit-cost ratio method of analysis indicate that three of the transportation systems can be economically justified. Using the 6 percent minimum attractive rate of return and the $1.00 per hour unit travel time costs, Systems 5B, 6B and 3A, when compared with the base System 2A, each show benefit-cost ratios larger than 1.0.

The largest benefit-cost ratio does not necessarily indicate the most economical transportation system. It will be noticed that the largest benefit-cost ratios occur for the paired comparison of Systems 2A and 5B. System 5B will have to be compared with the other transportation systems having higher total capital costs in order to determine if the increment of cost in going to the more expensive system would result in incremental benefits that exceed the increment of costs. Thus, the need for a systematic approach in analyzing the economy of the transportation systems is established.

Economy of Transportation System Formulation—The following discussion describes the systematic approach that is used in selecting the most economical transportation system using benefit-cost ratios. It is an approach commonly used in engineering economy analysis to select the most economical alternative from among a list of multiple alternatives (5, p. 24).

TABLE 12

EXAMPLE OF PROCEDURE USED TO DETERMINE MOST ECONOMICAL TRANSPORTATION SYSTEM USING INCREMENTAL BENEFIT-COST RATIO METHOD BASED ON 6 PERCENT INTEREST RATE AND $1.00 PER HOUR TRAVEL TIME COSTS PER PERSON

Transportation Systems Compared		Incremental Annual Benefits Resulting from Net Reductions in Maintenance, Operation, Accident and Travel Time Costs	Incremental Equivalent Uniform Annual Capital Costs	Incremental Benefit-Cost Ratio	Conclusion
Base Alternative Transportation System for Comparison ("Contender")	Next Most Costly Transportation System Based on Total Capital Costs ("Challenger")				
2A	5B	$192,510,000	$ 915,000	210.39	Drop 2A
5B	6B	34,351,000	32,704,000	1.05	Drop 5B
6B	3A	-135,484,000	6,336,000	< 1.00	Drop 3A
6B	4A	-214,774,000	10,799,000	< 1.00	Drop 4A 6B is the winner

TABLE 13

MOST ECONOMICAL TRANSPORTATION SYSTEM AS DETERMINED BY INCREMENTAL BENEFIT-COST RATIO METHOD BASED ON VARIOUS INTEREST RATES AND UNIT TRAVEL TIME COSTS

Travel Time Cost Per Person Per Hour	Interest Rates (%)				
	0	3	6	10	15
$0.00	5B	5B	5B	5B	5B
0.50	5B	5B	5B	5B	5B
1.00	6B	6B	6B	5B	5B
1.50	6B	6B	6B	6B	5B
2.00	6B	6B	6B	6B	6B

Successive paired comparisons of transportation systems are made in the order determined by increasing total capital costs. The alternative systems arranged by order of increasing total capital costs are shown in Table 11.

An example of the procedure used is shown in Table 12 based on the 6 percent minimum attractive rate of return and unit travel time costs of $1.00 per hour per person. The incremental annual benefits shown in column 3 for each paired comparison of transportation systems were taken from Table 8. The incremental equivalent uniform annual capital costs were taken from Table 9. The first comparison is that of Systems 2A and 5B. System 2A, the "contender," must meet the "challenge" by System 5B. The benefit-cost ratio for that comparison is 210 which shows that System 5B is superior to System 2A. Because of the superiority of 5B to 2A a comparison of the three remaining alternative systems with 2A has no relevance in choosing among the five original alternatives. The conclusion as shown in Table 12 is to drop System 2A from any further comparison with the other systems.

The next paired comparison takes System 5B as the "contender" and its "challenger" as the next most costly system, which is 6B. The benefit-cost ratio is slightly greater than 1.0 and the conclusion then is to drop 5B from further comparison with other transportation systems.

System 6B is now challenged by System 3A. But the resulting benefit-cost ratio is less than 1.0, so System 3A is dropped and 6B remains to meet the last remaining challenger, System 4A. The resulting benefit-cost ratio is less than 1.0 and System 6B is the winner or the most economical transportation system.

It is evident that in comparing System 6B with any transportation system having lower total capital costs, the prospective increments of benefits in going to 6B are more than the prospective increments of costs. It is also evident that for all the transportation systems having higher costs than 6B, the prospective increment of benefits as compared to 6B is less than the prospective increment of costs.

A similar approach was used for the selection of the most economical transportation system based on the use of other interest rates and unit travel time costs per person. The results are shown in Table 13. A line has been drawn through the table to delineate the interest rates and unit travel time costs where the selection of the most economical system changes from 5B to 6B and vice versa.

Rate-of-Return Method

The rate-of-return method of analysis is the one to be preferred to both the total annual transportation cost method and the benefit-cost ratio method. The rate-of-return method measures the benefits shown by comparisons of transportation systems in a term easily understood and used in business decisions. Another advantage of the rate-of-return method is that it makes it unnecessary to select an interest rate for the amortization of total capital costs over the analysis period.

The rate-of-return method is similar to the benefit-cost ratio method of analysis in two respects. Transportation systems are paired for the purpose of making comparisons, and the systematic approach described earlier can be used for the selection of the

TABLE 14

INCREMENTAL TOTAL CAPITAL COSTS RESULTING FROM COMPARISONS OF TRANSPORTATION SYSTEMS

Transportation Systems Compared	Increment of Total Capital Cost (000)
2A-5B	$ 13,945
2A-6B	431,996
2A-3A	510,733
2A-4A	658,483
5B-6B	418,051
5B-3A	496,788
5B-4A	554,538
6B-3A	78,737
6B-4A	136,487
3A-4A	57,750

most economical system. The minimum attractive rate of return is used instead of the benefit-cost ratio of 1.0 to serve as an indicator of the economy for each paired comparison of systems. The incremental benefit shown by any paired comparison of transportation systems for the rate-of-return method is the same as those used in the benefit-cost ratio method (Table 8).

In the rate-of-return method the benefit shown by any paired comparison of transportation systems is divided by the increment of total capital cost between the two systems. The increment of total capital cost between paired comparisons is shown in Table 14. The quotient from the division is the capital recovery factor for the 25-year analysis period. The capital recovery factors for all the paired comparisons are shown in Table 15.

These capital recovery factors were used to enter interest tables and select the appropriate rate of return (3). An example can be made by the use of Table 4. For

TABLE 15

CAPITAL RECOVERY FACTORS FOR TRANSPORTATION SYSTEM COMPARISONS
(Incremental Annual Benefits Divided by Incremental Total Capital Costs)

Transportation Systems Compared	Travel Time Cost Per Person ($)				
	0	0.50	1.00	1.50	2.00
2A-5B	5.4275	9.6148	13.8049	17.9893	22.1766
2A-6B	0.1580	0.3416	0.5251	0.7087	0.8923
2A-3A	*	0.0718	0.1789	0.2860	0.3931
2A-4A	*	*	0.0104	0.0509	0.0834
5B-6B	*	0.0322	0.0822	0.1323	0.1823
5B-3A	*	*	*	*	*
5B-4A	*	*	*	*	*
6B-3A	*	*	*	*	*
6B-4A	*	*	*	*	*
3A-4A	*	*	*	*	*

*Negative benefits (capital recovery factor not applicable).

TABLE 16

PERCENTAGE RATES OF RETURN ON INCREMENTS OF INVESTMENT BASED ON VARIOUS UNIT TRAVEL TIME COSTS

Transportation Systems Compared	Travel Time Cost Per Person Per Hour ($)				
	0	0.50	1.00	1.50	2.00
2A-5B	543	961	1380	1799	2218
2A-6B	15	34	53	71	89
2A-3A	*	5	18	29	39
2A-4A	*	*	0	2	7
5B-6B	*	0	7	13	18
5B-3A	*	*	*	*	*
5B-4A	*	*	*	*	*
6B-3A	*	*	*	*	*
6B-4A	*	*	*	*	*
3A-4A	*	*	*	*	*

*Negative benefits (loss on the incremental investment of capital).

TABLE 17

EXAMPLE OF PROCEDURE USED TO DETERMINE MOST ECONOMICAL TRANSPORTATION SYSTEM USING INCREMENTAL RATE-OF-RETURN METHOD BASED ON MINIMUM ATTRACTIVE RATE OF RETURN AND $1.00 PER HOUR TRAVEL TIME COSTS PER PERSON

Transportation Systems Compared		Incremental Annual Benefits Resulting from Net Reductions in Maintenance, Operation, Accident and Travel Time Costs	Incremental Total Capital Costs for Transportation System Construction and Equipment	Incremental Capital Recovery Factor	Rate of Return (%)	Decision
Base Alternative Transportation System for Comparison ("Contender")	Next Most Costly Transportation System Based on Total Capital Costs ("Challenger")					
2A	5B	$192,510,000	$ 13,945,000	13.8049	1380	Drop 2A
5B	6B	34,351,000	418,051,000	0.0822	7	Drop 5B
6B	3A	-134,484,000	79,737,000	*	*	Drop 3A
6B	4A	-214,774,000	136,487,000	*	*	Drop 4A 6B is the winner

*Negative benefits do not produce a return on increments of investment.

the paired comparison of Systems 5B and 6B at unit travel time costs of $1.00 per hour per person, Table 15 shows a capital recovery factor of 0.0822. Entering Table 4, for a period of 25 years the interest rate for a capital recovery factor of 0.0822 can be interpolated to be near 7 percent. Thus the rate of return shown in Table 16 for the example is 7 percent.

Economy of Transportation System Justification—The comparison of Systems 5B, 6B, 3A, and 4A with the base System 2A by the rate-of-return method shows that three of the systems can be economically justified when using a 6 percent minimum attractive rate of return and $1.00 per hour travel time costs per person (Table 16). Systems 5B, 6B, and 3A each show rates of return in excess of 6 percent when compared with System 2A. System 4A compared with 2A did not result in benefits large enough to meet the 6 percent minimum attractive rate of return and, therefore, 4A cannot be economically justified.

An asterisk has been used in Table 16 to indicate those paired comparisons of transportation systems that would result in negative rates of return on investment of the increment of total capital costs. Such incremental investments of total capital, therefore, would not be economical.

The highest rate of return shown in Table 16, which results from the comparison of Systems 5B and 2A, does not necessarily indicate the most economical transportation system. Again, as for the benefit-cost ratio method, the procedure for selecting the most economical alternate from a list of multiple alternatives is used to select the most economical transportation system.

Economy of Transportation System Formulation—An example is shown in Table 17 of the procedure used to select the most economical transportation using the incremental

TABLE 18

MOST ECONOMICAL TRANSPORTATION SYSTEM AS DETERMINED BY INCREMENTAL RATE-OF-RETURN METHOD BASED ON VARIOUS UNIT TRAVEL TIME COSTS AND MINIMUM ATTRACTIVE RATES OF RETURN

Travel Time Cost Per Person Per Hour	Minimum Attractive Rates of Return (%) 0	3	6	10	15
$0.00	5B	5B	5B	5B	5B
0.50	5B	5B	5B	5B	5B
1.00	6B	6B	6B	5B	5B
1.50	6B	6B	6B	6B	5B
2.00	6B	6B	6B	6B	6B

rate-of-return method based on a 6 percent minimum attractive rate of return and $1.00 per hour travel time costs per person. The transportation systems are compared by pairs in the order of increasing total capital costs. The incremental benefits shown in column 3 are taken from Table 8 for the respective transportation system comparisons at the $1.00 per hour unit travel time costs per person. The increments of total capital costs shown in column 4 are taken from Table 14 for the respective comparisons of transportation systems. The capital recovery factor shown in column 5 is obtained by dividing the incremental annual benefits in column 3 by the incremental total capital costs in column 4. For capital recovery factors above 0.28 based on the 25-year analysis period the percentage rate of return can be determined by moving the decimal point two places to the right. For capital recovery factors smaller than 0.28 interpolation must be made in interest tables showing capital recovery factors for the 25-year period in order to determine the interest rate.

The first comparison is System 2A, the "contender," meeting the next higher total capital cost "challenger," System 5B. The incremental rate of return exceeds the 6 percent minimum attractive rate of return so System 2A is dropped as a contender for further comparisons. System 5B becomes the new contender and it is successfully challenged by 6B, so 5B is dropped from further comparisons. System 6B is now challenged by the next higher total capital cost transportation system, which is 3A. System 3A does not prove to be a successful challenger as it does not show a return on the increment of investment. The contender, System 6B, remains to be challenged by System 4A, but it too does not show a return on the increment of investment of total capital costs. Therefore, System 6B is the winner or the most economical transportation system based on a 6 percent minimum attractive rate of return and $1.00 per hour travel time costs per person.

A similar approach was used for the selection of the most economical transportation system based on the use of various rates of return and unit travel time costs per person. The results are shown in Table 18. The line through the table is a visual aid. It delineates the change in the most economical transportation system based on various interest rates and unit travel time costs.

SELECTION OF THE MOST ECONOMICAL SYSTEM

The selection of the most economical transportation system by the three methods of engineering economy analysis is shown in Tables 7, 13, and 18. The tables show that the methods confirm one another in the selection of the most economical transportation system when using the same interest rate and unit travel time costs. For reasons given earlier an interest rate or minimum attractive rate of return equal to 6 percent and unit travel time costs of $1.00 per person per hour were considered preferable for use in this analysis. Based on these conditions, System 6B is the most economical transportation system.

Tables 7, 13, and 18 indicate the sensitivity of the analysis to interest rates and travel time costs. At low unit travel time costs ($0.00-$0.50) and relatively high interest rates (10-15%), System 5B is the most economical. However, low unit travel time costs in effect do not give credit for the decrease in traffic congestion and travel time that would result from providing additional transportation facilities over those included in System 5B. Also, the use of high interest rates favors any transportation system with relatively low total capital costs, as is the case for System 5B. System 2A and 5B in reality are unacceptable as systems to accommodate 1990 travel demands. But they must be used as base comparisons in order to determine the economy of other transportation systems. Realizing these conditions, it is significant that System 6B is indicated as being the next most economical system for the conditions of low unit travel time costs.

It should be noted that the presentation of all possible comparisons of the transportation systems enables a selection to be made of the most economical transportation system based on individual land-use plans. The selection from land-use Plan A would be System 3A and from land-use Plan B it would be System 6B. Where resulting total costs for transportation systems based on different land-use plans vary on a wider scale than in this analysis, such an approach may be preferred by analysts. Of course that approach is dependent on a sufficient number of study systems, based on each land-use plan, being available for analysis. Since there is an admitted limitation in comparing incremental benefits and incremental costs for systems based on different land-use plans, it is safe to predict that there will be increased emphasis on, and use of, the method of total annual transportation system costs. Though it has been proven many times that the results by the three methods of analysis are the same, the method of total annual costs is more convincing when transportation systems are based on different land-use plans.

LIMITATIONS OF THE ANALYSIS

Engineering economy analysis is used as a means to compare the tangible costs of competing alternative uses of funds. Socioeconomic or intangible factors, although they are important considerations, are difficult to evaluate in monetary terms. These intangible factors are not included in an engineering economy analysis. Because of their importance, however, they must be included as part of the decision-making process. Realizing these limitations, it should be understood that this particular economic analysis is a tool delineating, on an overall region-wide basis, the best choice (based only on tangible costs) among a series of alternative transportation systems.

There were a large number of transportation systems that could have been analyzed. Because of the limitations of manpower and time only five general transportation systems were selected for study in detail by PSRTS. Rapid rail transit facilities were not included in any Plan B transportation system. Since the Plan B land-use concept of cities and corridors would decrease transit usage as compared to Plan A transportation systems, that limitation was not significant.

Within the five transportation systems analyzed, Plan A systems did not include cross-Sound bridge facilities and the significance of that fact was not clear-cut. The presence of cross-Sound bridge facilities in the most economical transportation system (a Plan B system) does not necessarily mean that it would be best to replace ferry service by a bridge from a cost standpoint. The cross-Sound bridge would have to be studied by the use of engineering economy analysis methods to determine the advisability of including the bridge in either land-use plan.

CONCLUSIONS

The engineering economy analysis of alternative transportation systems established that the worst course of action from a cost standpoint that could be followed in the future would be to construct no new freeway, expressway, or other major street and highway facilities after completion of those currently being constructed and those budgeted for near-future construction.

The Plan B land-use pattern, which was the goal-oriented development pattern, from a cost standpoint was obviously preferable to Plan A, which represents a continuation of present trends in development following the current planning and land-use zoning of separate governmental jurisdictions in the region.

The most costly alternative transportation system from the standpoint of meeting regional objectives was found to be the one which includes a rapid transit system in the Seattle area.

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Economic Evaluation of Investments in Agricultural Penetration Roads in Developing Countries

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This paper briefly describes the nature of agricultural penetration roads and the highway engineer's part in their evaluation. Two reasons are then given for abandoning the traditional methods of evaluation; these stem from the characteristics of both developing countries and penetration roads. Next an alternative set of procedures is described that begins with the concepts of engineering economy and becomes modified by principles of economic development. Concepts of the former include estimation of direct costs and receipts over time, discounting, and the like, while those of the latter include consideration of a country's goals and development strategy, "shadow prices," indirect consequences, and the loci of the decision-making process. The paper closes with a summary and some comments on the applicability of the recommended procedures.

•THE PURPOSE of this paper is to offer a set of procedures for analyzing investments in agricultural penetration roads in developing countries. These procedures depart from those traditionally used by highway engineers. Some of the results of a case study of the Tingo María-Tocache colonization project in Peru (1) are incorporated in the description of the suggested procedures. They are only illustrative, however, and are not necessarily representative of agricultural penetration roads in general.

AGRICULTURAL PENETRATION ROADS

In a number of developing countries, roads are being extended into regions where little or no automotive traffic previously existed. Such roads are sometimes built for political or social reasons, but many are built to tap the agricultural potential of an area. In most cases, these agricultural penetration roads will handle relatively low volumes of traffic (ADT under 400) and will probably not be built to standards of any higher quality than those typical of farm-to-market roads in the United States. They would be important in providing an all-weather means of travel for heavily laden trucks. Noncommercial auto traffic would be light because of the rural nature of the area and the low income of the inhabitants.

A new road might make it possible to convert the existing output of an area from a subsistence character to one in which cash crops are marketed. Not only would transportation be cheaper, but the new road might permit perishable crops to be delivered to market, and it would give much easier access to those who wish to colonize the area.

In Peru, considerable interest and activity has surrounded the building of penetration roads designed to facilitate the colonization of the eastern slopes of the Andes. The projects under study (including the Tingo María-Tocache project) and those in which investments have already been made offer the possibility of relieving the overcrowded

Paper sponsored by Committee on Highway Engineering Economy and presented at the 46th Annual Meeting.

conditions in the rural highlands and also offer the potential colonists more fertile land to cultivate. If these projects develop as planned, agricultural production could increase significantly.

EVALUATION OF INVESTMENTS IN PENETRATION ROADS

Not infrequently, transportation specialists will be asked to play either a principal or a supporting role in the analysis of investments in penetration roads. Of course, agricultural investment is important, and if the government promotes or controls the project, agricultural specialists may have prime responsibility. But regardless of who is the primary authority, transportation specialists are likely to take an active part in the economic analyses.

Analyses that have been made to date are often based on standards, principles, and evaluation procedures used in the United States. This approach has resulted from the active participation of U. S. consultants in other countries, as well as from the exposure of persons in the developing countries to our consultants, universities, and literature.

But how useful are these procedures? Can they be transferred directly or easily adapted to the evaluation of agricultural penetration roads in the developing countries? Or should new concepts and procedures be employed? We believe that new concepts are involved that require abandoning many of the existing procedures, and only a portion of the underlying principles and techniques should remain intact. The reasons are twofold: (a) there are basic differences in the characteristics of the advanced and the developing economies; and (b) most procedures for analyzing road investments in the advanced economies relate to conditions where traffic is already served by a road network and frequently where traffic congestion is a problem.

Differences Between the Developing and the Advanced Economies

A number of key assumptions underlying project evaluation in the United States cannot be carried over to the developing countries because of the important differences in their economies. These assumptions include the propositions that the economy is relatively competitive and that the impact of a project, or set of projects, on other sectors of the economy and on income distribution can usually be ignored. Such a basis for project evaluation in the developing countries does not apply for the reasons discussed below.

Lack of Competitive Conditions—Even though monopolistic conditions exist in many countries, they are often accentuated in the developing countries where industries may be dominated by a few enterprises. This situation results from several factors, such as the smallness of the domestic market, the concentration of political, economic, and social power in the hands of a few, and the difficulty of market entry. Sometimes pivotal industries are operated directly by the government.

In addition, communications, transportation, and marketing facilities are generally inadequate, and investors, sellers, and workers are often unaware, misinformed, or cannot easily take advantage of opportunities elsewhere in the economy. Consequently, the economy may be spotted with shortages in one area and surpluses in another. The government may further distort the market from the ideal concept of a competitive economy by passing social legislation or by its intensive regulation of the country's foreign exchange transactions. Thus, market prices may be substantially out of line with the real value of goods and services.

The Impact on Other Activities—Because of these shortages and surpluses and because of the often expressed desire for rapid economic development, the evaluation of a project in the developing countries should not be confined to its immediate consequences. Opportunities may exist for the use of underemployed or unemployed facilities and resources, and magnified difficulties may arise when demands are placed on those facilities and resources that are already scarce or crowded. Then, too, opportunities often are present for the coordination of investments. Indeed, due to the limited availability of capital in such countries, projects should ideally be screened in the hopes of finding those that will have a catalytic effect on the economy.

Poor Distribution of Income—Clearly, social unrest, the absence of a large middle class, and low per capita income combine to impress on many governments the urgency of improving the lot of its low income groups. In some developing countries, the impact of a program of investments—sometimes of a single investment—may loom so large that special attention should be paid to its income-distributing effects and to other factors which influence general welfare.

This brief comment on the differences between the developing and the advanced economies could be extended and further elaborated, but it should be sufficient to reveal the necessity for reconsidering the assumptions that underlie the techniques currently employed in the analysis of projects in the developing countries.

Differences Between Penetration Roads and Other Types of Roads

The procedure commonly recommended for evaluating the merits of most road investments is to estimate the volume of traffic with and without the improvement, and then to assign a set of benefits and costs that are related to these two estimates. Benefits are usually divided according to users and nonusers of the road. If benefits exceed construction and other costs, after the values have been properly discounted, the project is considered desirable. Most of the emphasis in estimating benefits has been given to the subject of user benefits. One common subdivision of them cited by Lang and Wohl (2) is "(a) vehicle operating cost savings; (b) time savings; (c) a reduction in accident costs; and/or (d) an increase in 'comfort and convenience'." The same authors have even argued that "there is no logical basis for assuming highway improvements can produce any net economic benefits over and above user benefits."

Note the weakness of this approach when applied to an agricultural penetration road in a developing economy. If a region is largely undeveloped and without adequate road facilities, estimates of future traffic are tenuous at best. As for imputed benefits, it is possible that those attributed to noncommercial traffic and to certain commercial traffic may be very limited. As Adler (3) puts it, "In many developing countries there is extensive underemployment, so that time savings may merely make the situation worse." Moreover, increases in comfort and reduction in annoyances may have very low priority if the collective will of the society, or the government, favors a higher rate of economic development.

If a road is built to stimulate economic growth, a much more satisfactory basis for estimating the benefits would be one that measures the resulting increase in goods and services. This measurement can be made directly without reference to traffic volume. But once this approach is undertaken, accompanying investments must also be considered because the road by itself is not sufficient to increase agricultural production. Farmers must settle, invest, and incur operating costs. Additional services are required: marketing, technical assistance, and so on. Road investment becomes only one of several categories of costs. In addition, the value of output that may be allocated to the road investment alone becomes of much less interest; emphasis is on the increase in total output, together with the accomplishment of other goals, that can be attributed to the integrated set of investments. Estimating traffic volume becomes only a poor surrogate for measuring the value of the project to the economy. Under these circumstances, the reason for estimating traffic volume is to learn what type of road facility should be provided.

AN ALTERNATIVE APPROACH

If the general approach to project analysis in the United States, particularly that related to road investments, is rejected, what is to take its place? The remainder of this paper outlines an alternative approach, together with some of the reasons for its selection. First, the goals and development strategy of the particular country under study should be known. Second, the integrated set of costs and benefits resulting from the project should be considered. Third, market prices should be adjusted in the light of their corresponding "shadow prices." Fourth, the indirect consequences of the project should be examined. Finally, the decision-making process should be expanded to include those whose scope of interest is broader than that of the project analyst.

A Country's Goals and Strategies

It seems obvious that a public project should be evaluated in terms of a country's goals. Yet often this is not done, nor is it easy to do, because the goals may be diverse and even inconsistent. But because of the nature of many of the problems in the developing countries, a clear understanding of what the government is attempting to accomplish should receive high priority.

If the government is to act effectively, it must be able to resolve conflicting goals, decide on an appropriate strategy of development, and translate this strategy into programs of action—some of which will involve investments in public facilities. An enlightened approach to project evaluation can help accomplish these objectives.

An example of conflicting goals is a government's wish to maximize its rate of economic development, while also wanting to redistribute income, preserve its cultural heritage, develop a particular region, or possibly build certain prestige facilities, such as a steel mill. While the project analyst is hardly in a position to resolve these conflicts in goals, he should learn which ones take priority. Not only is it possible for him to show how the project helps to accomplish major objectives, but he might also show the costs of obtaining some of the objectives in terms of the loss in economic efficiency.

With a country's goals in mind, the strategy (explicit or otherwise) of economic development should be easier to understand. A sampling of some of the strategies suggested for developing countries includes emphasis on balanced growth and the "big push," emphasis on unbalanced growth, monetary measures vs structural measures to correct a country's problems, industrialization as the best way, improvement of agriculture as fundamental, and dispersal of industry as the key. Some even say that the economists are off the track on all these counts because they have unduly ignored the human factor.

Part of this diversity of opinion is due to the widely varying conditions found among the developing countries; indeed, it would be surprising if a single remedy could be prescribed for all. Thus, the strategies selected would depend on the characteristics of each country: its goals, resources, stage of development, economic advisors, and related factors. Regardless of what strategy is selected, however, it would be expected to help identify important sectors of the economy, such as agriculture, agricultural-based industries, or foreign trade, that may be strategic during a given point in a country's growth process. It should also stress the importance of certain components of economic activity, such as capital, foreign exchange, and entrepreneurship.

Government influence should be exerted and investment encouraged where sectors and activities accommodate the strategy being employed. Thus, the strategy facilitates the selection of candidate projects for evaluation. Efficiency criteria related to benefit-cost analysis remain, but the decision-makers will also want to know about other aspects of a project, namely, (a) the extent to which it affects key sectors of the economy, (b) its use or generation of components important for economic activity, such as capital and foreign exchange, and (c) its impact on noneconomic factors.

Direct Consequences of a Project

If an area is to be opened for colonization, as was the case in the Tingo María-Tocache project, then a primary economic objective would be to increase agricultural production. A social or political objective might be the provision of self-employment for the colonists.

Proper appraisal of the project would include a detailed study of the investment, operating costs, output, and other anticipated benefits. In accordance with the principles of engineering economy outlined by Grant and Ireson (4), an estimate would be made of the amount and timing of investments, i.e., in the penetration road, access roads to individual farms, land clearing and preparation, houses and farm structures, tools, equipment, and whatever community and marketing facilities might be required to make the project viable. Annual operating costs would include road maintenance, farm operation, and technical assistance for the farmers; miscellaneous expenses should also be estimated.

TABLE 1

ECONOMIC EVALUATION OF THE TINGO MARIA-TOCACHE PROJECT ACCORDING TO THE PRINCIPLES OF ENGINEERING ECONOMY[a]
(Thousands of Soles)[b]

Year	Road Costs			Farm Costs			Ancillary Costs	Total Costs	Receipts	Net of Costs and Receipts[c]		
	Investment	Maintenance	Total	Investment	Operating	Total				Undiscounted	Discounted at: 6%	7%
1963	54,500	0	54,500	2,865	1,831	4,696	114,181	173,377	1,075	(172,302)	(172,300)	(172,300)
1964	66,000	450	66,450	5,407	6,547	11,954	73,143	151,547	3,503	(148,044)	(139,600)	(138,400)
1965	62,462	2,050	64,512	6,811	13,201	20,012	57,299	141,823	11,692	(130,131)	(115,800)	(113,700)
1966	14,500	14,750	29,250	16,024	24,483	40,507	52,881	122,638	26,881	(95,757)	(80,400)	(78,200)
1967	14,500	16,275	30,775	28,682	47,460	76,142	57,286	164,203	54,679	(109,524)	(86,800)	(83,600)
1968	10,000	17,400	27,400	29,701	72,037	101,738	39,411	168,549	91,745	(76,804)	(57,400)	(54,800)
1969	0	18,400	18,400	31,127	97,776	128,903	34,852	182,155	133,193	(48,962)	(34,500)	(32,600)
1970	0	18,400	18,400	31,651	126,867	158,518	36,722	213,640	179,701	(33,939)	(22,600)	(21,100)
1971	0	18,400	18,400	20,181	147,099	167,280	29,522	215,202	221,528	6,326	4,000	3,700
1972	0	18,400	18,400	14,593	162,625	177,218	34,153	229,771	264,252	34,481	20,400	18,800
1973	0	18,400	18,400	11,605	176,637	188,242	22,108	228,750	307,279	78,529	43,800	39,900
1974	0	18,400	18,400	10,759	189,163	199,922	22,108	240,430	348,425	107,995	56,900	51,300
1975	0	18,400	18,400	10,629	200,932	211,561	22,108	252,069	387,643	135,574	67,400	60,200
1976	0	18,400	18,400	11,843	212,426	224,269	22,108	264,777	422,955	158,178	74,200	65,600
1977	0	18,400	18,400	12,297	221,619	233,916	22,108	274,424	453,808	179,384	79,300	70,000
1978	0	18,400	18,400	12,349	230,048	242,397	19,927	280,724	480,998	200,274	83,600	72,600
1979	0	18,400	18,400	12,512	238,141	250,653	18,656	287,709	505,623	217,914	85,800	73,800
1980	0	18,400	18,400	12,033	246,000	258,033	18,656	295,089	526,503	231,414	85,900	73,300
1981	0	18,400	18,400	12,624	254,595	267,219	18,656	304,275	546,474	242,199	84,800	71,700
1982	0	18,400	18,400	12,930	263,615	276,545	18,656	313,601	566,406	252,805	83,600	69,900
								Net Present Worth			60,300	(23,900)

[a]Based on an assumed project life of 20 years.
[b]27.50 soles are equal to one dollar.
[c]Parentheses indicate costs exceed receipts.

The main source of economic benefits would be the increase in agricultural output, whose value can be taken as that which the crops would receive if sold in the local marketplace. In this way, the value of output is related to the costs incurred in its production. Clearly, the value of output could be taken as that paid by the ultimate consumers, but this would require the consideration of additional expenditures needed to put the product in its proper form and location for consumption. These additional expenditures and receipts will be considered later under the heading of "Indirect Consequences."

Other types of economic benefits commonly associated with road investments—e.g., savings in noncommercial travel time—may be involved, but they are considered to be of less importance and will not be considered further. On the other hand, certain noneconomic benefits may be quite important and will be discussed in a subsequent section.

Finally, the stream of annual benefits and costs may be discounted by an appropriate interest rate to yield the net present worth of the project's direct consequences. Or alternative interest rates may be used for discounting so as to obtain the project's internal rate of return. (Details of these two procedures may be found in Part II of Ref. 4.)

The results of such an analysis for the Tingo María-Tocache project are given in Table 1. The table shows (at the bottom of the last two columns) that the internal rate of return lies between 6 and 7 percent, since it is between these two discount rates that the net present worth is zero. Considering the capital needs of a country in Peru's stage of development, this rate of return is no doubt too low, and the project might be rejected largely on these grounds. However, in one of the final chapters of the Tingo María-Tocache study (1), the length of project life and other variables were altered to test the sensitivity of the outcome. It was found that lengthening the project's life beyond 20 years considerably improved its economic attractiveness.

Consideration of "Shadow Prices"

The estimates of costs and values of output described above were based on market prices. Although these prices may be appropriate for financial analyses and for economic analyses in the advanced economies, they should be replaced by "shadow prices" when the governments of the developing countries consider alternative investments and policies.

The concept of shadow prices is fundamental to economics. According to Tinbergen (5), "They are the prices at which supply is just sufficient to satisfy demand." Under conditions frequently encountered in the advanced, competitive economies, shadow prices are generally similar to market prices and adjustments are seldom made. But, as indicated earlier, "in a number of underdeveloped countries, the market price structure is not a correct guide for taking decisions" (5).

The use of shadow prices can be justified on three counts: (a) the fundamental disequilibrium of the economic system of a country, (b) the influence that large investments may have on future prices (5), and (c) the failure of the market to reflect the social values of goods, where these differ from the sum of individual private values (6).

Chenery (7) has this to say about disequilibrium:

> Important cases involve structural unemployment of labor, balance of payments deficits, excess demand for capital, and similar phenomena. These types of disequilibrium are particularly important in the underdeveloped countries, where it is one of the main purposes of governmental develop-

> ment programs to offset them.... In fact, the use of such [shadow prices] may be one of the most effective ways of improving resource allocation without execessive centralization of investment planning and production control.

The possibility of a project influencing future prices requires careful analysis of the markets that are affected—those where inputs are obtained and outputs are sold.

Finally, social values may differ from private market values when the market fails to reveal the full impact of economic activity on the individuals involved. For instance, the political process may be the only substantive way for a society to show its preference for economic development, i.e., a willingness to sacrifice and save during the present time period in order to invest, increase the country's productive capacity, and enjoy greater consumption in some future period.

Despite the logical appeal for considering shadow prices, their practical application in project analysis has scarcely begun. Undoubtedly, a major cause has been the difficulty of measuring them. To measure shadow prices precisely requires more information about an economy, and the alternatives that are open to it, than is currently available. Nevertheless, the need to consider shadow prices is clear-cut. For instance, few persons in the United States would argue that our government's "pegged" farm prices represent their true economic value to the economy. For a developing country that controls the price and supply of foreign exchange, the official rate would hardly seem appropriate when it is known that many are willing to pay a higher price for it. Also where substantial amounts of labor are either unemployed or are not engaged in productive activities, the "going" wage may be significantly above the shadow wage. Such a condition could arise as a result of minimum wage laws or from other conditions that interfere with a competitive market.

The dilemma caused by the need to consider shadow prices and the current lack of techniques and data to provide refined solutions is not as serious as it might appear. The answer lies in understanding the causes of the deviation of market prices from their true economic values. This understanding not only indicates the direction of the deviation but often the relative magnitude of it. Therefore, some estimate of shadow values should be attempted, even though it is approximate.

Writers on this subject usually suggest that the shadow prices of foreign exchange, capital, and labor—the three primary factors of production—be considered in analyses. If certain skills, materials, or products are in short supply, their shadow prices could also be included. However, the reason for treating just the primary factors is that the costs of goods and services can ultimately be broken down into these three. Foreign exchange is distinguished from (domestic) capital in that the two are not fully interchangeable. Concerning labor, Boon (8) argues that "from an economic point of view, only unskilled labour can be considered as labour, and skilled labour as a combination of unskilled labour and capital."

Estimating shadow prices is a complex task that should be carried out at the central planning level, but the application of these prices is conceptually straightforward and can be readily undertaken by the project analyst. For this the analyst should have a clear and detailed understanding of the components that make up the project's direct costs and benefits.

In the Tingo María-Tocache study, this author estimated the costs of roads, farming, and ancillary activities on the basis of anticipated expenditures for unskilled labor, skilled labor and domestic materials, and purchases from abroad. According to these classifications, the breakdown of road costs during the first 20 years was estimated to range from 30 to 55 percent for foregin purchases (mostly road-building equipment), from 30 to 40 percent for skilled labor and domestic materials, and from 15 to 30 percent for unskilled labor. The percentage of farm costs attributed to unskilled labor averaged about 70 percent, while skilled labor and domestic materials were expected to dominate the ancillary costs.

Benefits were categorized according to whether or not the farm commodities produced by the project would earn foreign exchange. Such currency would be earned if the commodities were exported or if they were to displace imports. In the Tingo María-Tocache study approximately 40 percent of the output was assumed to earn foreign exchange. Now it should be clear that the delivery of farm commodities to the local marketplace (the point for measuring the value of the direct ouput) cannot be used in estimating the full amount of foreign exchange earnings. For example, coffee destined for export must be shipped to the coast, prepared for delivery, and so on. Eventually, this shortcoming should be corrected. The discussion of indirect consequences, in the next section, will provide a basis for doing so.

TABLE 2

ECONOMIC EVALUATION OF THE TINGO MARIA-TOCACHE PROJECT USING SHADOW PRICES[a]
(Thousands of Soles)

Year	Adjusted Costs				Adjusted Receipts	Net of Adjusted Costs and Receipts	
	Road	Farm	Ancillary	Total		Undiscounted	Discounted at 10%
1963	56, 306	3, 476	109, 939	169, 721	1, 089	(168, 632)	(168, 600)
1964	68, 375	8, 193	69, 443	146, 011	3, 574	(142, 437)	(129, 500)
1965	66, 189	12, 290	54, 778	133, 257	12, 628	(120, 629)	(99, 700)
1966	28, 479	27, 581	50, 365	106, 425	28, 954	(77, 471)	(58, 200)
1967	29, 851	51, 706	54, 701	136, 258	58, 577	(77, 681)	(53, 100)
1968	26, 288	67, 620	38, 225	132, 133	98, 120	(34, 013)	(21, 100)
1969	17, 038	84, 778	33, 338	135, 154	142, 163	7, 009	4, 000
1970	17, 038	102, 842	35, 198	155, 078	191, 600	36, 522	18, 700
1971	17, 038	106, 452	28, 554	152, 044	236, 493	84, 449	39, 400
1972	17, 038	111, 999	33, 340	162, 377	282, 273	119, 896	50, 800
1973	17, 038	118, 724	21, 683	157, 445	328, 810	171, 365	66, 100
1974	17, 038	126, 100	21, 683	164, 821	373, 595	208, 774	73, 200
1975	17, 038	133, 599	21, 683	172, 320	416, 586	244, 266	77, 800
1976	17, 038	141, 821	21, 683	180, 542	455, 738	275, 196	79, 700
1977	17, 038	148, 039	21, 683	186, 760	490, 008	303, 248	79, 800
1978	17, 038	153, 501	19, 541	190, 080	520, 199	330, 119	79, 000
1979	17, 038	158, 840	18, 294	194, 172	547, 418	353, 246	76, 900
1980	17, 038	163, 439	18, 294	198, 771	570, 319	371, 548	73, 500
1981	17, 038	169, 401	18, 294	204, 733	591, 040	386, 307	69, 500
1982	17, 038	175, 387	18, 294	210, 719	614, 713	403, 994	66, 100
				Net Present Worth			324, 300

[a]Based on an assumed life of 20 years.

To complete the analysis, estimates of the shadow prices—as a percent of their market values—were made as follows: 50 percent for unskilled labor, 100 percent for skilled labor and domestic materials, and 120 percent for foreign exchange. Unskilled labor was known to be abundant in Peru, and there were reasons to suspect that the current wage was too high. Therefore, a shadow wage of 50 percent of the market wage was used to reflect this condition. Domestic materials and skilled labor were assumed to be properly priced when consideration was given to certain offsetting tendencies, and foreign exchange was assumed to be worth 20 percent more than the official rate of exchange. Together with these assumptions, an interest rate of 10 percent for the price of capital was applied for discounting the adjusted costs and benefits of the project.

The substitution of these shadow prices for market prices significantly influenced the economic evaluation of the direct consequences of the Tingo María-Tocache project because much of the overall cost was for unskilled labor engaged in farming and because of the sizable portion of the agricultural output that was anticipated to earn foreign exchange. Results of the revised analysis based on shadow prices are shown in Table 2. The discounted values yield a positive net present worth, which indicates that the project is economically efficient in terms of its direct consequences.

Indirect Consequences of a Project

In addition to the direct consequences, just described, indirect and secondary consequences are also important in project evaluation. Indirect consequences relate to the inputs required by the project and to the manner in which the output is distributed. Secondary consequences are those that stem from the increased income created by the project. The increased income of the farmers, for instance, should lead to greater consumer sales of both domestic and imported products. These secondary consequences are more related to broad economic factors than to the specifics of the project itself. Consequently, they are believed to be better handled at the central planning level and will not be considered further in this paper.

Evaluating the nature and extent of the indirect consequences calls for an estimate of the indirect production requirements of the project. Therefore, attention will first be given to the measurement of such indirect production followed by the way in which this information might be utilized at the planning level.

Measuring the Indirect Production—An approximation of the indirect production can be made by noting the amount of inputs according to the type of supplying industries and by following the flow of the project's output to its point of final consumption. The value of these estimates will be a first approximation to the value of indirect production. This can be illustrated by considering the inputs and outputs of the farming activity once farm investment has been made. In this section, which is based on anticipated market transactions, it is necessary to rely on market prices. Shadow prices may once again be applied by those at the planning level after the indirect production has been estimated.

Depending on the type of farming activity foreseen, certain types and amounts of agricultural inputs would be needed from other industries—both domestic and foreign. These intermediate inputs would be such things as seed and seedlings, insecticides and

TABLE 3

INPUTS FOR THE FARMING ACTIVITY OF THE TINGO MARIA-TOCACHE PROJECT IN 1982

Inputs	Value (Thousands of Soles)	Coefficients
Intermediate		
Seed and seedlings	2,800	0.005
Insecticides and fertilizers	22,200	0.039
Transport	24,400	0.043
Miscellaneous	10,600	0.019
Total	60,000	0.106
Primary[a]	506,400	0.894
Value of Output[b]	566,400	1.000

[a]Primary inputs include wages, profits, rent, interest, and whatever else remains after the cost of intermediate inputs has been deducted from the value of the output.

[b]As measured in the local market.

TABLE 4

ADDITIONAL ACTIVITIES REQUIRED IN THE SALE OF THE TINGO MARIA-TOCACHE PROJECT'S OUTPUT IN 1982[a]
(Thousands of Soles)

Product	Trade	Net Transport[b]	Manufacturing or Processing[c]	Total
Rice	10, 205	1, 288	0	11, 493
Beans	5, 327	541	0	5, 868
Peanuts	2, 122	388	10, 200	12, 710
Corn	3, 049	98	0	3, 147
Tobacco	3, 910	523	24, 615	29, 048
Bananas	43, 920	5, 594	0	49, 514
Other food	4, 690	(1, 377)	3, 614	6, 927
Fruit	117, 375	15, 744	43, 353	176, 472
Fibers	22, 134	2, 180	145, 873	170, 187
Rubber	18, 081	2, 855	70, 514	91, 450
Cacao	8, 204	861	36, 876	45, 941
Coffee	1, 169	214	1, 880	3, 263
Other industrial	6, 511	837	31, 973	39, 321
Beef	5, 058	272	17, 770	23, 100
Milk	2, 136	197	2, 912	5, 245
Hides	601	72	1, 612	2, 285
Total	254, 492	30, 287	391, 192	675, 971

[a]Includes only additional activities implied by the project; thus, that portion of sales of raw rubber which displaces imported raw rubber does not imply additional manufacturing activity.

[b]Net transport is the amount of additional cost involved in moving the farm commodities from the local market to more distant points of use, less savings when they are consumed on the farm.

[c]This is the estimated f.o.b. value of the manufactured or processed product at a Lima plant. Actually, some manufacturing or processing would occur elsewhere, but such possibilities were not considered.

Parentheses indicate a net reduction in transport activity when the source of demand is taken into account.

fertilizers, supplies, and various services. The amounts of such inputs for the last year of the analysis period for the Tingo María-Tocache project are given in Table 3. The amount of intermediate inputs is small compared with the value of output because the method of farming is to be small-scale and relatively unmechanized.

The section on direct consequences mentioned that the value of farm output was based on the prices received in the local market, but it is unlikely that all of the output will be sold there for consumption in its unprocessed form. Instead, some of the commodities will be consumed on the farm, while others will be consumed in more distant markets, will be exported, or will be transformed into higher priced commodities.

As noted earlier, approximately 40 percent of the value of the farm output was assumed either to be exported or to displace imported products. This percentage includes exports of coffee, cacao, and hides, and the substitution of imported vegetable oils, fiber sacks, and meat products. In following the flow of farm commodities from the local market to their point of final domestic consumption, or export, a variety of activities is involved, including those of export agents, wholesalers, retailers, transporters, manufacturers, and processors. The estimates of the 1982 value of these activities for the Tingo María-Tocache project are shown in Table 4.

It is important to realize that the activities associated with supplying the inputs and marketing the output are implied in the design of the project. In order to estimate the costs of the farming activity, farming practices and the inputs required for agricultural production must be known; otherwise, there would be little basis for estimating farm costs. Similarly, some estimate of the demand for the farmers' crops is necessary if the estimates of the value of output are to be reliable. Therefore, estimating the indirect production should involve little more than the careful recording of costs, activity by activity. The first approximation of the value of indirect production would then be the value of the sum of the production by all of these activities. Clearly, unless these activities are capable of accommodating the farming activity, the project will not develop as planned.

Considering the limitations in the amount of data available to the project analyst, the estimate of indirect production probably cannot be carried much further than this

TABLE 5

INDIRECT PRODUCTION FOR THE TINGO MARIA-TOCACHE PROJECT IN 1982 BASED ON PERU'S TWENTY SECTOR INPUT-OUTPUT TABLE (Thousands of Soles)

Industry	Indirect Production
Agriculture	91, 200
Extractive	19, 500
Foodstuffs	139, 700
Beverages	100
Tobacco	103, 600
Textiles	337, 500
Footwear	1, 900
Wood manufactures	2, 300
Furniture	6, 400
Paper	6, 200
Printing	4, 600
Leather	1, 900
Rubber	47, 100
Chemicals	25, 300
Petroleum and coal	18, 200
Cement, etc.	1, 400
Basic metals	500
Metal transforming	2, 700
Miscellaneous	14, 000
Services	237, 100
Total	1, 061, 200
Percent of direct output[a]	187%

[a]Direct output is 566,400,000 soles.

first approximation. However, industries that contribute to the indirect production will require inputs from still other industries. For instance, a manufacturer of peanut oil who might purchase peanuts from the project could require inputs of certain additives, containers, shipping cartons, power, and so on. Each of these industries will, in turn, have its own requirements from still other industries. Some of the requirements may be imported, while others must be supplied by domestic industries.

Tracing these additional activities is not easily accomplished in a straightforward manner. However, if the country should have an appropriate input-output table for its economy, the sum of these activities can be estimated with relative ease. Fortunately, Peru has such a table, so that a more detailed and extensive estimate of the indirect production could be made than that shown in Table 4. The results are given in Table 5, which shows that the level of indirect production is considerably larger (187 percent) than the value of direct output.

Using the Estimate of Indirect Production—It has been shown that if a project is to function as planned, certain inputs must be supplied to the project and the project's output must flow to its ultimate source of demand. The overall result of these transactions may be thought of as a "pressure" on the economy. Where the economy is slack, the pressure should be a positive factor in stimulating production; where it is not slack, the pressure could create problems by placing demands on factors that are already in short supply.

What is important about this pressure is that it is seldom neutral and therefore deserves careful consideration. In this regard, an analysis of the characteristics of the indirect production would be helpful in three ways: (a) it would provide data for general planning purposes, (b) it would indicate the use and generation of resources of special importance to economic growth, e.g., foreign exchange, and (c) it would point out the extent to which the project might affect those industries that occupy a pivotal role in the economy.

However, consideration of these matters should not be the responsibility of the project analyst; instead, their analysis should be undertaken at the planning level, where the view of the overall economy is clearer. But the project analyst is in a preferred position to estimate the nature and amount of the indirect production. After making his estimate, the project analyst should pass it along to the planners for their evaluation of the project's implications for the rest of the economy.

Levels of Analysis and Decision-Making

The levels at which analysis and decision-making take place depend on the nature of the data being considered and on the qualifications and authority of those doing the analysis—the politicians, the economic planners, and the project analysts.

Because developing countries have goals besides those that are purely economic and because strategies of development must ultimately be reflected in some form of investment program, the highest level of project evaluation should rest with the politicians. Their authority or responsibility spans the breadth of society's interest, and only at this level can weights, or values, be assigned to the mix of economic and noneconomic factors.

The importance of the noneconomic goals of a project can hardly be overemphasized. In the developing countries, progress toward the attainment of better income distribution, land reform, improved diets, political unity, and so on, cannot be left to chance without ultimately endangering the political, social, or economic stability of the country. Accordingly, noneconomic goals tend to take on more significance in project evaluation in the developing countries than in the advanced ones. And the project analyst should be alert to the contribution (or obstruction) that the project makes toward the attainment of these noneconomic goals, doing what he can to quantify them for review at the political level. Examples of what might be included are the number of jobs created, the number of families resettled on their own land, and the possibilities for improved diets.

The next level of analysis and decision-making involves questions of economic growth and nationwide efficiency. This requires study by economists at the central planning level along the lines already described.

Finally, the project analyst is concerned with the economic evaluation of matters related to the direct consequences of the project. The fact that his decisions are made at the bottom level should not diminish the importance of his activities. The degree of detail involved in estimating the direct consequences should make the results of his analysis more reliable than those related to the indirect consequences.

CONCLUSION

Highway engineers will have noted that this paper has cautioned against the use of the tools of analysis commonly employed in the evaluation of road investments. Instead, more general methods have been suggested, such as estimation of direct costs and agricultural benefits and their subsequent discounting. Additional procedures have also been recommended that take into account conditions typically found in the developing countries; that is, attention should be given to a country's goals and strategies, shadow prices should be applied, indirect consequences should be estimated, and the decision-making process should be split. The reasons for this emphasis may be summarized as follows: (a) costs of the penetration road are only a portion of total costs, with farming expenditures expected to dominate the rest; (b) benefits from the investment can be measured more comprehensively by considering the increases in agricultural production than by relying on estimates of future traffic and assigning benefits to such traffic flows; and (c) the need to relate the project to the country's goals and strategies and to other sectors of the economy calls for additional information and new procedures.

However, the preceding argument applies to the type of road where little or no prior vehicular traffic existed in the region under study. Should this not be the case, i.e., if prior traffic were substantial, then the road could hardly be classified as a penetration road and the foregoing procedures would have to be reexamined. It is the author's suspicion that the more traditional methods of road analysis would have to be incorporated with some of those suggested for penetration roads.

The author has been questioned about the difficulties of applying these revised procedures because a country may lack the personnel, time, or funds to conduct such extensive and intensive studies. It can be claimed that a "poor" decision made in time is better than a "good" one that is too late. Also, the inadequacy of data may preclude all but very crude methods. Furthermore, an approach that returns the analysis to the central planners for additional study can hardly be applied to all of the many road investment decisions.

On the other hand, large investments, or those affecting a great number of people, should be weighed carefully. Also, some analysis, such as the one presented in this paper, is necessary if substance is to be given to the theories of economic development. Furthermore, recent strides in computational procedures should help the analyst. For instance, high-speed computers ease the work load, and their use is certain to increase. Finally, the amount of additional computational time needed for such analyses may often be small compared with the effort involved in gathering the original data and presenting it in its final form.

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