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Foreword

The papers contained in this Record are concerned with various administrative concepts, mathematical models, and other planning concepts directly related to the urban transportation planning process.

Norman Beckman emphasizes the need to identify ways of increasing the effectiveness of implementing comprehensive planning recommendations. Beckman cites many factors that must be considered in the planning process if it is to be effective in the decision-making process.

Alan Voorhees discusses the need for greater emphasis on community values as an important element of the transportation planning process. Voorhees emphasizes current methods being used to establish overall community values and new emerging techniques being developed in the location and design phase of the planning process to measure values in neighborhoods through which a facility might pass.

A series of four papers focuses on mathematical models and their applicability and usefulness in the planning process. In the paper by T. R. Lakshmanan and W. G. Hansen, the authors emphasize the formulation, testing, and application of a market potential model to guide the scale, location, and scheduling of major retail concentrations in a growing metropolitan area.

Charles Graves reports on the development and testing of two population distribution models, one for population growth and the other for population decline. Multiple regression analysis was used to develop the models which were tested with data from the Puget Sound Region.

J. R. Hamburg, G. T. Lathrop, and G. F. Young, describe a model which attempts to bring into an objective framework methods and concepts which have been commonplace in planning for several years, such as holding capacity, access, and density, but whose application has often been subjective and defied replication.

The final paper on various mathematical techniques by J. R. Hamburg, C. R. Guinn, G. T. Lathrop, and G. C. Hemmens discusses a method by which the sensitivity to travel time can be measured. The method is called an index of indifference and attempts to measure the extent to which linkages among urban space activities are indifferent to time.

Gordon Edwards emphasizes the needed procedures for planning the metropolitan airport and the necessity to integrate airport system planning with highway and mass transit planning within the context of a long-range comprehensive planning program.

George Hoffman, presents a provocative discussion on the possibilities of reducing the land used for urban transportation in the central core by providing automotive access with underground tunnels and parking areas. Hoffman's thesis is that it might be cheaper before the end of this century to travel by car and bus underground rather than above ground in the center of American cities.

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Politics and Administration of Plan Implementation

NORMAN BECKMAN, Assistant Director, Advisory Commission on Intergovernmental Relations

•AS A NATION, we have made at least one contribution to the world's philosophy--namely, pragmatism. This philosophy has direct relevance to anyone concerned with implementing the results of urban transportation studies. It is a philosphy of expedience which holds that plans, theories, abstractions, and dogma in and of themselves are of limited value and rejects them in favor of practicality, common sense, flexibility, and action. Its first American exponent, William James, wrote:

> Grant an idea or belief to be true, what concrete differences will its being true make in anyone's actual life? True ideas are those that we can assimilate, evaluate, corroborate, and verify. False ideas are those that we cannot.

In short, the best transportation or land-use plan is the one that works, the one that is implemented. The bad plan is one that gathers dust on the shelf—no matter what its content. The professional, just as much as the politician, must put his skills to the test of community acceptance.

Planning and the planning profession are on the upswing. Major comprehensive metropolitan transportation studies with budgets of $2 million or more are currently under way or recently completed in Chicago, Philadelphia, Boston, Minneapolis-St. Paul, and Milwaukee. There is increasing reliance on planning requirements in Federal grant-in-aid legislation. The National Association of Counties has just published a report, Federal Assistance Programs Available to Comprehensive County Planning, listing some 20 different Federal agencies' programs of assistance for comprehensive planning, basic data collection, and transportation and public facilities planning. Metropolitan or regional planning agencies are operating in three-fourths of the metropolitan areas in the country. These actions indicate acceptance of planning in the administration of the public business.

Yet there is a pervasive attitude held by many planners and others of the urban scene that little progress has been or is likely to be made toward implementation of sound transportation and comprehensive urban developmental plans--a feeling that something is rotten in the state of the art. In a national survey, almost half the metropolitan planning agencies cite as major weaknesses that: (a) their powers are inadequate, (b) they have too limited funds and staff, and (c) they have insufficient public and government support. Although more than half were satisfied that they had a good technical program, only 20 percent thought that metropolitan planning was being accepted (1). Victor Fischer of the Housing and Home Finance Agency, in a recent speech before the American Institute of Planners evaluating the results of the recent transportation studies, found it "inconceivable...that any single one of them could give birth to, say, a brand new subway system for a community that does not have it today" (2). He concludes that the transit proposals and action in Toronto, San Francisco, Atlanta, Boston, and Los Angeles are a result of community will and political decisions made, in large part, outside the framework of transportation planning. Even Zettel and Carll's useful review of major metropolitan transportation studies reluctantly concludes, "It must be said, that the results of the major transportation studies remain highly speculative (3, p. 65).

Paper sponsored by Committee on Organization and Administration.

Given this background of great expectations and modest results, I would like to discuss some five factors affecting the chances of technically sound plans being accepted, adopted, and implemented. These factors are:

1. The importance of recognizing the political nature of planning recommendations;
2. The need to identify the direct and indirect costs and benefits to various groups and jurisdictions;
3. The need to improve the pattern of organization, representation, and financing for regional transportation planning;
4. The relationship of transportation planning to other development plans and activities; and
5. The range of alternatives for organizing and financing a transportation development agency.

POLITICAL NATURE OF PLANNING RECOMMENDATIONS

Planners and planning agencies are inevitably involved in the political process. In the field of government, every administrative action, from the behavior of a licensing clerk to a health department decision to prohibit individual wells and septic tanks in an urban area, is weighed on a political scale. Those actions which benefit or hurt individuals produce a reading on that scale. Planning agencies help to determine "who gets what, when, and how," and to do that means to function politically.

Numerous examples of the political implications of transportation proposals can be cited. The location of expressways and mass transit routes has a relatively permanent impact on the form in which a metropolitan area will grow, the tax base of individual communities, the demand for governmental services, and the nature of the population in each community. The future of the central city is almost always at stake in transportation plans. Bernard Spring has cited the effects of Rt. 128, the circumferential highway around Boston, as an example. He notes that Rt. 128 was built before highways needed in built-up areas because of the minimum displacement involved and the ease of assembling the land. And, he concludes, the result has been misfortune for the city of Boston. The circumferential, becoming the prime location for research and electronics firms, helped bring about a motor-oriented pattern of transportation to the Boston region and contributed to low-density development on the fringe of the metropolitan area and the economic decline of the central city (4).

No plan is politically neutral. This is especially true for any transportation plan in our governmentally fragmented metropolitan areas when the makeup of the population, tax resources, and demand for public services may vary significantly from one jurisdiction to another. Any plan which concerns itself solely with technical and engineering questions and ignores the question—Who is going to be mad? How mad? Who is going to be glad? How glad? is headed for the political shoals. Henry Fagin, in reflecting on the experience of the Penn-Jersey Transportation Study, has written:

> The important question of political acceptability cannot safely be handled solely by theoretical studies, nor can it be deferred to the end, but it must be faced as an integral part of the [planning] program itself. Opportunities must be built into the work program for potential acceptability to be tested periodically during the very course of the planning process. (5)

More research needs to be done on such practical day-to-day working problems as how to keep the interest of elected officials, advisory groups, and functional administrators over a period of years, how to translate technical data into public policy issues and keep testing them politically, and how to make community relations a really meaningful activity.

It is an occupational hazard of the professional public employee (and both comprehensive and transportation planners perhaps are especially susceptible on this score) to become absolutely convinced of the rightness of his plan. He finds it hard to understand why responsible officials, and the public generally, do not do what he is satisfied is the best thing to do. Yet, the planner, by himself, can accomplish little.

It must be constantly kept in mind that planning agencies have almost no levers, no gifts, no grants, no weapons, no operating programs, and no strong base of independent political support. It is, therefore, imperative to stick close to (and serve to the extent possible as key staff) responsible officials who do have decision-making powers—the mayor, the county council, and even the city manager.

Decisions on metropolitan transportation come about only after bargaining and negotiating among the various associations and interest groups that have a stake in development decision—a cumbersome but reasonably democratic process. The transportation planner's effectiveness is most enhanced if he is willing to leave this kind of bargaining to the politician and play the vital but more limited role that our system assigns to the public employee. His role is to understand the political forces involved while providing a factual basis for the consideration of transportation policy considerations. The transportation planner should be working with other functional and comprehensive planners to present feasible alternative balanced transportation development choices and their economic, social, and political implications and present them in such a way that it is understandable to other people. The plan should contain a reasonable degree of flexibility and adaptability and, at the same time, be sufficiently technical in detail so that it can be understood and evaluated and acted on by the many forces involved in political action and implementation. Finally, the planner should direct attention to two aspects of development in which the politician is weakest—orientation to the whole metropolitan area and focus on future conditions as well as on the immediate and intermediate stages of planning, development, and operation.

IDENTIFY COSTS AND BENEFITS

Transportation services, by their very nature, require large and integrated physical facilities with service boundaries economically dictated by population density and topography. Often these service areas have little or no relationship to the boundaries of local governments within the area. The benefits derived from these services cannot be confined to the jurisdiction which might provide them. Implementing even the most technically correct transportation plan revolves around determining an equitable distribution of costs among the local governments involved, over and above those borne by user charges or Federal and state contributions.

The late Carl Chatters once observed, "The metropolitan area problem is primarily a public finance problem." Such financial planning involves a proposed commitment of resources, energy, and time. As such, it cannot safely be separated from physical development and organizational planning. Any methodology and information identifying the direct and secondary benefits and costs of a transportation proposal would contribute materially to negotiations by local political officials in a metropolitan area for determining what is a "fair and equitable" basis of distributing transportation development and operating costs. In this connection, increasing attention is being given to use of cost-benefit analysis techniques.

Highway cost-benefit analysis to date has been largely limited to identification of savings in money and time to the present highway users in the area, including vehicle operating costs reductions, fewer accidents and reduced travel time, and increased economic activity due to improved access to particular locations.

These efforts can perhaps be criticized as primarily limiting their attention to the direct benefits to road users. Transportation development in metropolitan areas inevitably involves costs and benefits not only for road users in the area, but also by the individual jurisdictions and other interest groups in the area. Alternative transportation mixes such as highway, highway-bus, or highway-bus-rail transit will produce different sets of costs and benefits which should be considered by the governments involved. Litchfield and Margolis (6), in their study of Cambridge, England, identify the implications of two alternative town plans. Although a town plan may be somewhat simpler than the problem facing transportation developers in a large metropolitan area, the alternative plans approach does merit attention.

Cost-benefit studies, identifying as many as possible of the direct and indirect costs and benefits, such as increased valuation of real estate around a rapid rail transit line and relocation of low-income minority families in a tight housing market situation, should be made a part of transportation studies and should serve as the basis for negotiation among the governments involved.

Recent advances in transportation planning techniques have made it possible to identify user costs for entire transportation systems. When total system user and investment costs are combined, a transportation price tag can be hung on alternative transportation systems. Significantly, when this approach has been tried, the difference in cost among realistically conceived alternatives has been slight—often within a range of 5 percent. Although recognizing the relative crudeness of the techniques currently available to estimate costs, we may, in many instances, be legitimately indifferent to the price tag, make more of an effort to measure community values, and select the alternative that best enables us to achieve these other community benefits and objectives.

There has been sufficient experience in a number of communities of the benefits accruing to the owners of land and buildings and of governments through tax revenues, etc., to begin to grasp the range of costs and benefits. The states and the Federal Government could make a significant contribution by developing standards of measurement of costs and benefits for transportation programs that they support through grant and loan programs. These standards would provide objective measures and ground rules for areawide negotiation and assignment of costs to the separate jurisdictions.

STRENGTHEN ORGANIZATION FOR TRANSPORTATION PLANNING

Any examination of implementation must look not only to the nature of proposals made but also to means of strengthening the organization of the transportation planning study itself. The evolution of transportation planning organization has been traced through three specific stages (7). Until 1953, transportation planning, including such regional efforts as the Detroit and Chicago area studies, was based on the assumption that the existing land-use trends and the status of transit and travel behavior patterns will continue and that transportation systems should be designed to accommodate the demands of these projected uses. The second generation studies were premised on the assumption that transportation systems should not be passive, but should help mold the kind of system desired by the people in the area, for example, and would include the Penn-Jersey, Milwaukee, and Boston regional studies.

The third, and presumably still anticipated, stage of development will be achieved when balanced transportation plans come together with other metropolitan functional systems such as water, air, housing, and industry, and are part of a comprehensive areawide development effort.

Zettel and Carll have observed that the more recent transportation studies have generally been more formally organized, employed specialists in disciplines other than engineering, and created a committee structure to provide policy as well as technical guidance of study staff. Time and cost have increased, and a greater concern is being shown on how study results are to be implemented (3, p. 8).

Paraphrasing Clemenceau on war and the generals, the chairman of the Penn-Jersey transportation study has been quoted as saying: "Long range transportation decisions are too important to be left solely to transportation officials." Transportation planners along with other professional specialists are increasingly being placed "on tap," not on top. The American Association of State Highway Officials, in a useful guide for organizing a continuing urban transportation planning process, has recommended membership of the organizing committee as follows: representatives from governing bodies and official agencies having responsibility for implementing transportation plan, including the state highway department, county and municipal governments.

The rationale in favor of political leaders of the governments within the metropolitan area playing a dominant role in transportation planning is strong. The members are familiar with local problems and the obstacles to implementing a transportation plan. They can serve as a useful communication link between planners and other local decision-makers and help break down the isolation or political limbo that any metropolitanwide study must overcome. These politicians are responsible to their local electorate, and are often in a position to initiate necessary local planned implementation.

Zettel and Carll have developed a useful tabulation of the composition of the policy committees of the 13 major transportation studies currently under way or recently completed (3, p. 10). State highway officials are represented on almost all the policy committees, and the U. S. Bureau of Public Roads representatives sit in as nonvoting members. On the other hand, local government officials and representatives make up more than half of the members of the policy committee in only four of the 13 current studies (Los Angeles, Philadelphia, Detroit, and Milwaukee). The Housing and Home Finance Agency (HHFA) is represented in only three studies, and state planning officials in only two. Local financial participation has been extremely limited, financing somewhat less than 10 percent of the study effort. The present pattern of representation and the local contribution raises serious questions about the extent of local interest, participation, and commitment to implementation.

Federal agencies, under their authority to establish performance requirements as a condition for awarding grants, are increasingly establishing guides for the organization and content of transportation studies. HHFA, in awarding "701" grants, must be satisfied that all parts of the metropolitan region are adequately represented on the planning body. Transportation planning is specifically identified as an element of comprehensive urban planning. The planning agency must establish a checkpoint procedure for review of recommendations on preliminary drafts of planning proposals by the chief executive and legislative body of the locality and by other affected local, state, and Federal agencies. Working with councils made up of elected officials in the metropolitan area is recommended as desirable practice. The new mass transit grants must carry out a program "for a unified or officially coordinated urban transportation system as part of the comprehensively planned development of the urban area, and are necessary for the sound, economic, and desirable development of such area."

Since 1961, HHFA and the U. S. Department of Commerce have encouraged the joint use of "701" planning funds with Federal highway 1 ½ percent survey planning funds in the conduct of metropolitan studies. These jointly financed projects must be conducted under the policy guidance of a metropolitan coordinating committee broadly representative of the governing officials of the local jurisdictions within the area and including representatives of the major state planning and development agencies.

Just issued guidelines for transportation planning under HHFA's urban planning assistance program now require that five critical elements be included in the planning process. These elements, designed to meet both U. S. Bureau of Public Roads and HHFA planning requirements are: (a) development of objectives, (b) determination of future transportation demand based on forecast of future activity, (c) proposing alternative transportation systems, (d) determination of future travel demand by mode, and (e) testing transportation alternatives (8).

The Highway Act of 1962, as is well known by now, requires that after July 1, 1965, highway funds in urban areas will not be provided unless projects "are based on a continuing comprehensive transportation planning process carried on cooperatively by state and local communities...."

To sum up current practice, transportation studies have become more formally organized, more comprehensive in outlook and staff, and more expensive. Although local governments of the area are participating in policy formation activities, the Zettel report indicates that study organizations are still not sufficiently representative of these governments, nor do they involve these local governments sufficiently in financing and implementation efforts. The new Federal guides and requirements have properly emphasized the importance of a continuing planning process, more adequate representation and consultation with local officials, and the desirability of having transportation planning a vital part of a more comprehensive area development effort. A genuine acceptance of these objectives by state and local officials, however, is needed before such Federal regulations can have any meaning. To understand what is happening today, there is a need to update the 1962 Zettel and Carll review of transportation studies. We need to know which states are doing a good job with local governments, how they are accomplishing this, and why they are successful. The same questions must be asked of local governments and comprehensive planning agencies.

In organizing future transportation studies, consideration might also be given to a modified version of legislation enacted by Oregon in 1963, "an Act to provide for creation of a metropolitan study commission to study and propose means of improving essential governmental services in urban areas." This general state legislation provides that metropolitan study commissions may be set up by local governmental action or by petition of the voters. Commission members are appointed by the governing bodies of the local jurisdictions. Under such legislation, the commission can be charged with developing programs and recommendations for a balanced areawide transportation system compatible with other development objectives. The real strength of the legislation lies in the requirement that to overcome problems of inertia or obstruction, after a reasonable period these recommendations for implementation must be voted on by the residents of the area affected by the recommendations. No further legislation is needed to initiate studies or implement recommendations after enactment of such general state legislation.

The issue of relating transportation to more comprehensive area development planning has, as a result of the July 1965 highway planning requirement, become of such importance that it is discussed in further detail in this report.

RELATE TRANSPORTATION PLANNING TO COMPREHENSIVE PLANNING

The Federal legislation and regulations previously cited recognize the primacy of general and comprehensive goals for a region as the necessary basis for transportation development decisions. Every metropolitan area would benefit from an increased sense of purposes and objectives to guide it in future growth and development. Each local government and the states and Federal agencies with transportation responsibilities should participate in the development of these goals. Local zoning decisions can cause overcrowding or underutilization of the best-planned highway. Likewise, state or Federal transportation decisions can help preserve or destroy open space, relocation and slum clearance, and other social and community values.

There is always a danger, however, that highway planning will dominate the comprehensive transportation planning process. National and state legislation recognizes the need for more highways, the administering agency is ready and willing to build them, and alternatives are not readily available. In this perhaps too common situation, comprehensive planning becomes merely a support function providing information on economic factors, population, land use, and zoning ordinances to improve the quality of highway planning.

The transportation planning organization patterns that have emerged since the 1962 Highway Act requirement include: (a) the ad hoc project, supported in large part by the state highway department with varying degrees of participation by local elected officials, planners, and others; (b) highway departments taking upon themselves the job of planning for metropolitan areas; and (c) in only a few areas, assignment of the entire transportation planning task to an existing official comprehensive planning agency.

Observing these developments and the undesirability of maintaining permanently duplicate planning organization—one for comprehensive planning and another for continuing comprehensive transportation planning—the Assistant Administrator for Metropolitan Development of HHFA has recently proposed a promising solution; i.e., to divide responsibilities as follows: place comprehensive planning, including general location of public and private transportation facilities, in the hands of an adequately financed and staffed metropolitan agency directed by the local government officials which has tangible review powers over transportation and other development activities in the area; continue to place responsibility for highway programming, design and technical engineering contributions in the hands of the highway department; and let the transit system be programmed by the public and private transit agencies—with both highways and transit developed within the broader comprehensive and transportation planning framework. Primary responsibility for necessary coordination and planning of development would be lodged in the areawide planning agency with formal participation by the state highway department and other development agencies. Such an arrangement would assure that transportation planning is integrated into a strengthened comprehensive planning process and make transportation planning sensitive to local values and objectives. It would assure attention to the proper balance between use of highways and other public transportation systems and to the appropriate relation of these transportation media to other programs of significance to urban development—water and sewerage, parks and open space, pollution control, housing, etc.

The approach taken in the San Francisco Bay metropolitan area could well be given consideration in other parts of the country. The San Francisco Bay Area Transportation Study Commission has been established by the state legislature with responsibility for (a) making a comprehensive study and preparing a regional transportation plan for the Bay Area, (b) recommending means of implementation, and (c) preparing for a transition to a continuing transportation planning process.

As a first step in establishing working relations for conduct of the study, the BATS Commission, the Association of Bay Area Governments (the official organization of elected officials in the San Franciso Bay Area), and the State Department of Public Works (State Highway Department) have just executed a written agreement on working relationships and division of responsibility for the transportation study and planning. In addition to providing for cooperation among the three participating parties, the agreement declares it to be the intent of the parties to cooperate and coordinate their work with the State Department of Finance (its State Office of Planning has responsibility for the preparation and maintenance of a state development plan), and with other public and private agencies performing transportation functions in the area.

Three technical committees will be established:

1. A committee on regional growth will deal with economic factors affecting development, population, and financial resources (elements 1, 2, and 9 of the U. S. Bureau of Public Roads' ten basic elements for a continuing comprehensive transportation planning process required after July 1, 1965).
2. A regional council of engineering will be appointed to advise the commission's study director on transportation facilities, travel patterns, terminal facilities, and traffic control features (elements 4, 5, 6, and 7).
3. The Association of Bay Area Governments will assume primary responsibility for land use, zoning, and other regulations, and social and community value factors (elements 3, 8, and 10). The planning directors' committee of ABAG will also serve in an advisory capacity to the Commission's study director (9).

The Bay Area study is set up on a temporary basis, designed to meet immediate transportation planning needs. It is generally contemplated that ABAG will assume the continuing planning functions.

LEGISLATION ESTABLISHING TRANSPORTATION DEVELOPMENT AGENCY

In addition to studies of travel patterns, traffic engineering, and location of transportation facilities, a stated objective of transportation efforts today includes (a) an examination of existing institutional arrangements in the area affecting land-use planning and transportation development, and (b) development of feasible recommendations for organization, financing, and legislation needed to establish an agency to develop and operate a proposed transportation system.

For highway development, the problems of organization and financing have largely been solved. Other transportation forms are not so blessed. Inertia, current trends, and the path of least resistance place other forms of transportation at a disadvantage. Transportation study proposals to expand public transportation facilities through regulation, subsidy, construction, or even through continued planning must, therefore, be especially well founded and have the support of the highway agency to overcome this handicap.

In almost all cases where public transportation facilities, in addition to highways, are desired, whatever the implementing method chosen, state legislation will have to be enacted. In addition to establishing the agency (some of the organizational alternatives are discussed in this section), and granting it the necessary power to operate, the legislation will have to provide adequate revenue authority to the agency or to the participating local governments. Outmoded constitutional and statutory restrictions on the power of local governments to borrow and to levy property or other taxes may have to be removed.

Excessive state consitutional guarantees of home rule to municipalities can also create problems in attempting to organize or finance an areawide transportation system. Thus, the Colorado supreme court in 1962 held unconstitutional the enabling act for an already functioning metropolitan capital improvement district created in the five-county Denver metropolitan area. The act authorized an areawide local sales tax to permit capital improvements and acquisition of capital equipment needed by the area's governments. The court held that home-rule cities have the "exclusive right to govern themselves and the general assembly cannot reinvest itself with any [local government powers]."

What are some criteria for evaluating the organizational alternatives for a new transit development agency? The agency should have a geographic area of jurisdiction adequate for effective performance, be large enough to permit realization of the economies of scale, and assure that those benefiting from the service pay an equitable share of the costs. Thus, the central city should not be expected to pay all the very high capital costs of constructing a subway system which primarily benefits the suburban commuter. The agency should have the legal and administrative authority to perform its development and operating functions, including some voice in other public and private decisions affecting transportation. Though difficult in a governmentally fragmented metropolitan area, the agency should be controllable by, and accessible to, the public at large. Finally, the recommended approach should have a good chance of receiving approval both in the jurisdictions affected and in the state legislature.

What is the realistic range of organizational choices from which to choose? Aside from a limited number of situations where extraterritorial authority by a central city or direct state action can do the job, there are probably only three feasible choices—county operation, intergovernmental agreement, and limited or multipurpose special districts. Each has certain strengths and weaknesses.

Urban County Approach

More than half of the standard metropolitan statistical areas of the United States are still located within a single county. In addition to having the advantage of geographic coverage, the urban county with authority to carry on transit development functions is directly accessible to the electorate, has a broad tax base, and has administrative working relationships with the state and Federal governments. At the same time, it should be recognized that counties are currently the most hobbled local governments today in terms of constitutional and statutory restrictions on authority to organize, perform, and finance new governmental functions.

Current examples can be cited. Dade County, Fla., has a countywide traffic and transportation department, and four of the seven bus systems in the county are operated by the county government. A unified mass transportation system is expected to begin operating in Allegheny County, Pa.

Interjurisdictional Agreements

Intergovernmental agreement, whereby one local government creates an agency to provide a service for neighboring jurisdictions or the activity is conducted jointly, is the most commonly used organizational approach in the country for handling areawide functions. The county may be the contracting agent, as in the Los Angeles metropolitan area where a number of governmental services are provided by Los Angeles County on a cost basis for cities within its boundaries. Even more commonly, the city may be the contracting agency, as in Washington, D. C., which provides sewage treatment services for neighboring Maryland and Virginia communities. City-county joint operation is also common. This approach has high political feasibility and should be employed to a greater extent than it currently is in the field of transportation development. Sixteen states now authorize across-the-board agreements for all urban services, and 30 others for certain functions.

Related to the interlocal agreement in concept, the interstate compact or agreement will likely be increasingly utilized for transit development in the future. Some 32 standard metropolitan statistical areas today include territory in two or more states. All together, these interstate metropolitan areas had a 1960 population of 41 million persons, or 23 percent of the Nation's total. The Port of New York Authority has gradually been expanding its transportation responsibilities to include mass transit. The Bi-State Development Agency (Illinois-Missouri) in the St. Louis metropolitan area in 1963 established a Bi-State Transit System, consolidated 15 separate systems and extended service on an areawide basis. The agency also performs wharf, airport, air pollution and regional planning functions.

Special Districts

The most common recourse in the past to meet mass transit development needs has been to create a single-purpose development district. The special district approach has a high degree of political feasibility. It provides an areawide geographic base and can often relate costs and benefits. On the other hand, special districts have a "single-mindedness" that often works to the detriment of coordinated transportation and other urban development programs. The Chicago Transit Authority, the new Massachusetts Bay Transportation Authority (Boston) which, incidentally, will be partially financed by statewide taxes, and the San Francisco Bay Area Rapid Transit District which will operate in three counties are examples of state-initiated special transit districts.

To achieve the advantages of the special district while minimizing its disadvantages, the Advisory Commission on Intergovernmental Relations has recommended (based on State of Washington legislation) that when metropolitan special districts are established they be empowered by statute, subject to local voter approval, to carry on additional metropolitanwide functions, in addition to transportation. Governing bodies of such special districts should be primarily made up of local elected officials of the jurisdictions affected who are also likely to be involved in metropolitan comprehensive planning activities. The agency should have taxing as well as borrowing authority, and proposed land acquisitions should be submitted to the local jurisdictions affected for assurance that the proposed actions contribute to the execution of local comprehensive plans.

CONCLUSION

The basic theme of this paper has been to identify ways of increasing the "batting average" for implementation of comprehensive planning recommendations. But it must not be forgotten that planning, and even development and implementation, are not ends in themselves. Planners, administrators, and elected officials must always keep in mind the words of that incisive observer of the American scene, deTocqueville, that "the end of good government is to ensure the welfare of the people, not merely to establish order in the midst of their misery."

The suggestions made in this paper—for constant sensitivity to the political and value-laden nature of planning recommendations, for the development of objective measures of costs and benefits as a basis for negotiation, for greater representation and financial participation by local governments in transportation study decisions, for having transportation planning efforts strengthen the comprehensive planning process, for assuring a proper balance of attention between highways and other public transportation systems, and for establishing effective and responsible transportation development agencies--are designed to help "ensure the welfare of the people."

Planners are uniquely endowed by training, professional tools, and experience to help achieve this objective. The planner's idealism and his orientation in the whole community have placed him, in the eyes of many, in a position of intellectual leadership for achieving the good life for the individual. This help is needed as never before.

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Techniques for Determining Community Values

ALAN M. VOORHEES, Alan M. Voorhees and Associates,
Washington, D. C.

Recent studies have made it evident that transportation planning must take into consideration the values of the community, which are important both to the overall transportation plan and to the location and design of specific facilities and must, therefore, be considered on a community-wide basis, as well as at a more detailed, local level. A weakness in most transportation studies is that the study design does not adequately account for community values.

At the present time, three methods are being used to establish overall community values: focus groups, rating panels, and attitude surveys. Two techniques, community review and political review, are being used to resolve their differences with the planning function. Studies reported in this paper indicate that all these techniques have merit, but that success varies considerably with the situation and with the particular end sought. Additional studies and a more coordinated use of the techniques will, however, be necessary before they can become really effective.

At the location and design level, techniques for determining community values are just beginning to emerge. Teams of engineers, architects, and planners have helped bring together different points of view, but cannot assure adequate recognition of community values. Special techniques now being developed will assist the team in measuring the values of neighborhoods through which a facility may pass. These techniques deal with social values, living patterns, and community attitudes, as well as with aesthetic considerations.

•EVERYONE in the transportation planning field has asked himself, "Just which plan is best?" We have all sought some technique that would give us a dependable answer, some way in which to consider properly all of the many factors involved. We can list many or a few of them, as in the case of Enid, Okla., where the following factors will be used to test alternative plans:

1. Cost to develop the transportation system,
2. User costs and benefits,
3. Losses or gains in taxable revenues,
4. Relocation problems,
5. Consistency with community development goals, and
6. Aesthetic considerations (1).

But the difficulty is in measuring and weighting these factors. The more we think about the latter process, the more we are aware that almost every individual will weight these factors differently. A woman would weight alternative costs differently than would a man. An elected official would weight them differently than would an

Paper sponsored by Committee on Community Values.

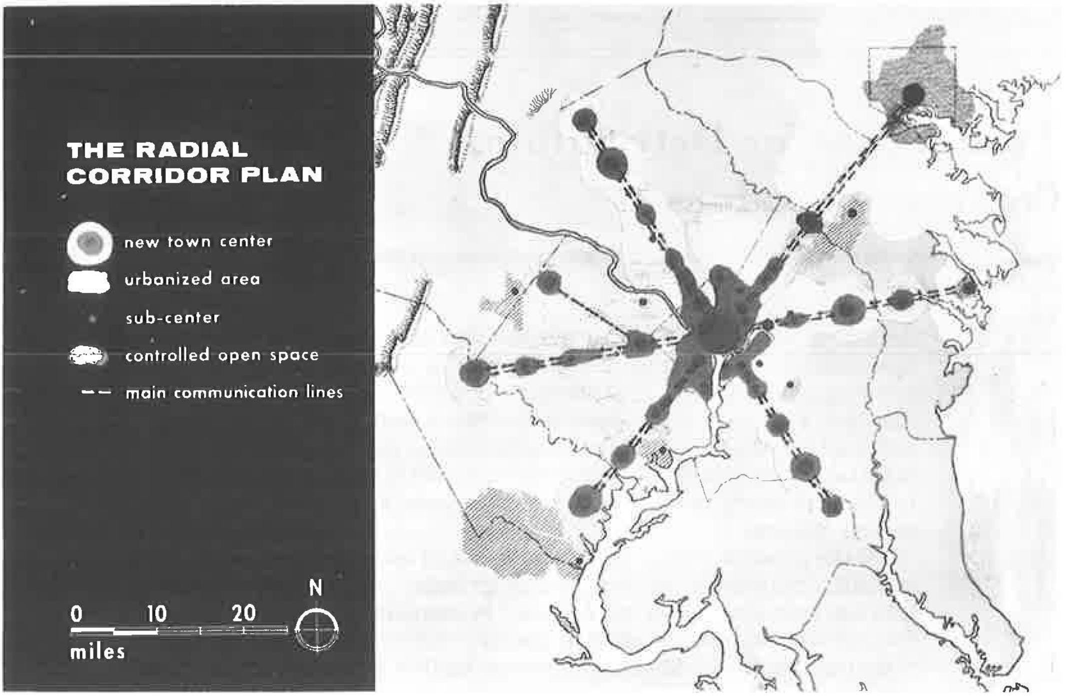

Figure 1. Year 2000 plan (source: National Capitol Regional Planning Council).

engineer. Relocation problems might appear more important to an elected official than could a cost and benefit analysis. An architect would certainly emphasize the aesthetic considerations, a city planner would give more significance to community development goals, and an economist would attach more importance to economic factors.

The difference in emphasis on criteria can readily be seen in the evaluation of existing plans. For example, the choice between the Year 2000 Plan in Washington (Fig. 1) and the Metrotown Plan in Baltimore (Fig. 2) rests largely on how highly one values broad expanses of open space and on the degree of importance one gives to the central business district. If one emphasizes a strong downtown and broad open spaces in the outlying areas, one would probably choose the Year 2000 Plan. However, if one puts less emphasis on downtown and feels that it might be better to distribute open space throughout the metropolitan area, one would then probably prefer the Metrotown Plan. So, in effect, the selection of the "best plan" depends on how much weight is placed on various community goals.

On a smaller scale, the choice between overhead or subway in the construction of a downtown transit system may hinge on one's evaluation of the impact that an elevated structure might have on downtown development. If one does not think it is likely to have much impact, then one might favor the overhead; or, if one feels that an elevated structure would depress real estate values or would be aesthetically undesirable, one would probably insist on developing a subway system. So, in reality, the best plan hinges on the values of individuals, and there is no one best plan from all points of view.

In a democratic society, people's values about public expenditure are largely reflected through the political process. The technician has the responsibility for developing alternative plans that take these values into consideration and then helping to evaluate each alternative. The determination of community values is, thus, a critical step in the planning process (2).

In the past, most urban transportation studies have avoided this issue. Some have tried to develop goals and objectives presumed to reflect community values. Other

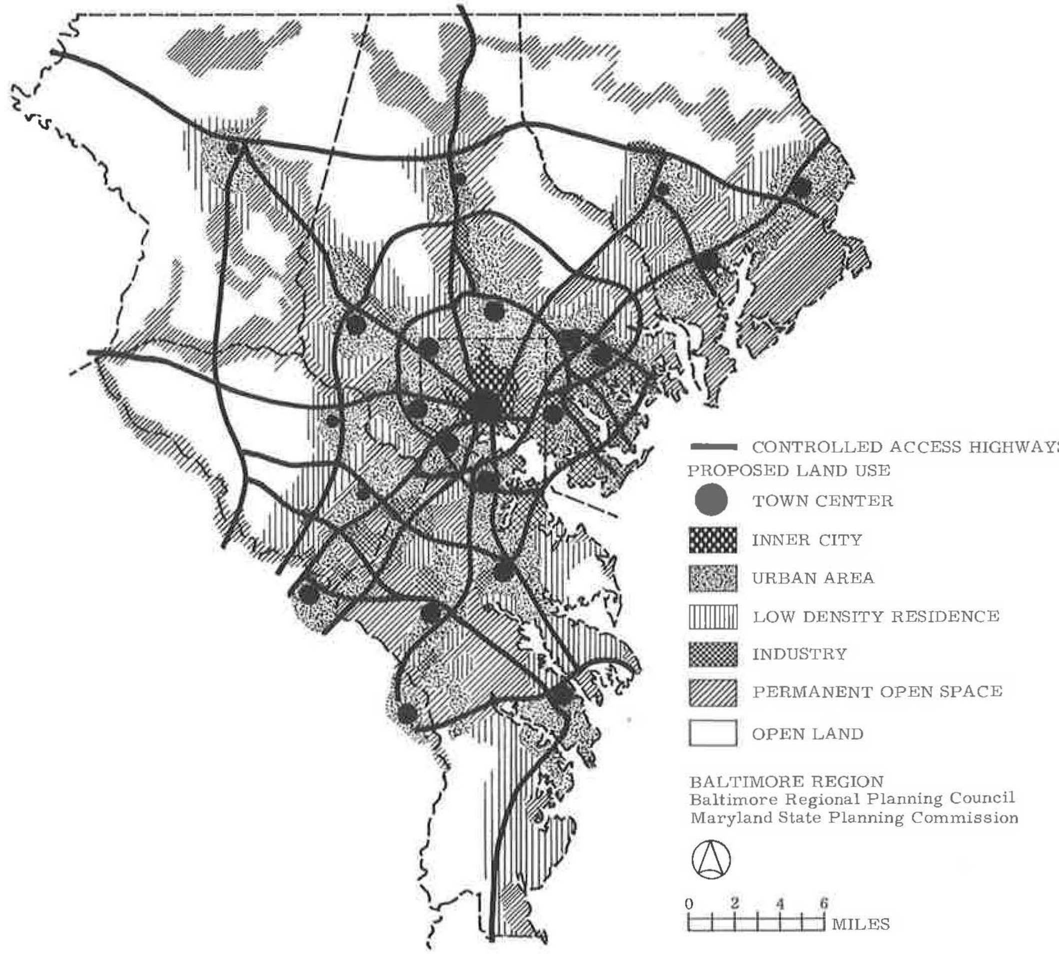

Figure 2. General plan, towns and cities.

studies have developed principles and standards for transportation service which were presumed to rest on such values. But the consensus reached on relative value was never articulated. Now, however, there are a few studies which have made systematic attempts to analyze community values and to incorporate such analyses into their overall programs.

Davidoff and Reiner (3) have indicated many techniques that can be used to determine community values—market analyses, public opinion polls, anthropological surveys, public hearings, interviews with informed leadership, press content analyses, studies of current and past laws, administrative behavior, and budgets. As planners, we are familiar with some of these techniques, but we have often overlooked the fact that we were dealing with individual and community values. For example, we tend to look upon a public hearing only as a necessary legal requirement, but, in fact, it usually brings out people's values quite clearly. It is true that those attending such a hearing often do not represent the community at large (and planners need to be familiar with a wider range of values), but the public hearing still reflects a considerable segment of community sentiment.

THE CINCINNATI EXPERIENCE

One interesting program to determine and resolve differences in community values was recently developed in Cincinnati in conjunction with the preparation of the down-

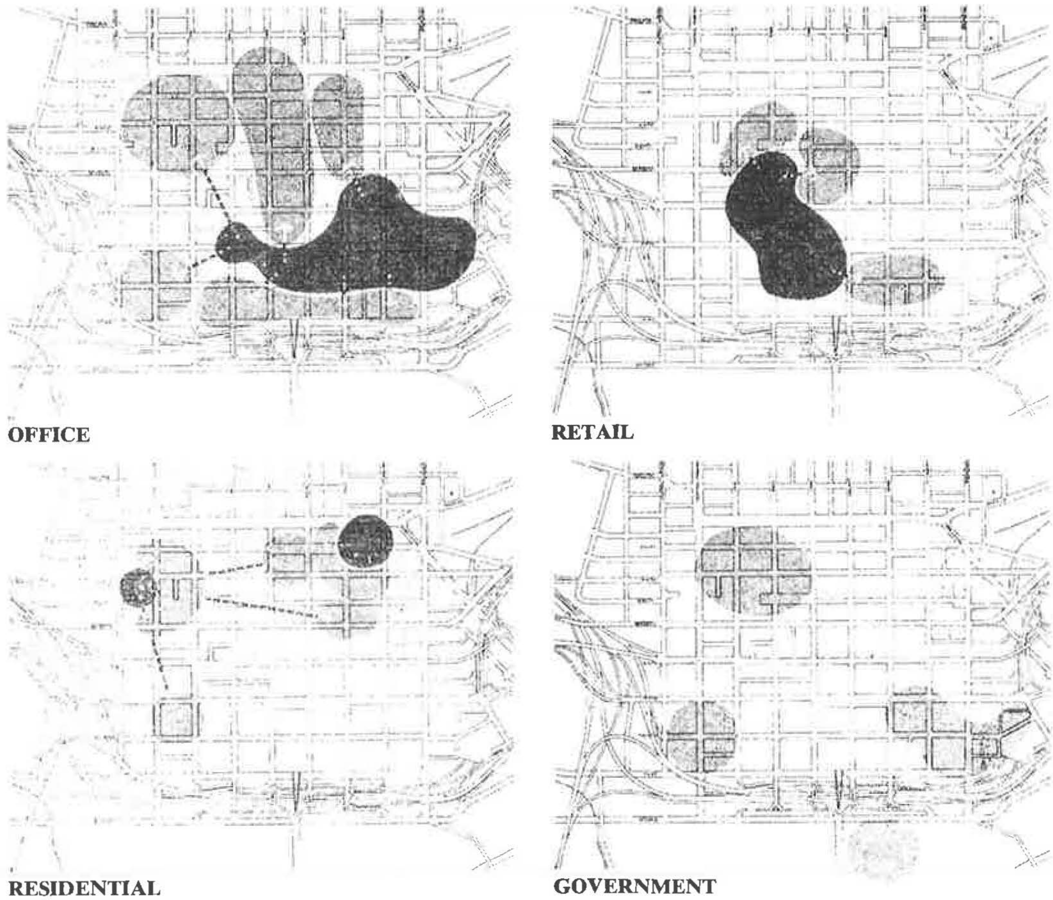

Figure 3. Growth alternatives (source: plan for downtown Cincinnati).

town plan. There, a Working Review Committee, similar to the "task force" outlined in an article by Nash and Durden (4), was set up. This committee consisted of the key Council members and the leaders in the downtown area. A plan was not developed and then presented to them "cold"; instead, it was conceived in a series of meetings between the planners and the Working Review Committee. The technicians working on the study presented the various alternatives to the committee and then let the committee make the final decision as to which alternative was "best."

They started out with the broadest issues, such as where the governmental complex should be located, where office expansion should occur, and whether retailing should be more dispersed (Fig. 3). But before these decisions were made, a thorough study of people's attitudes toward the downtown area—what they liked and disliked—was made. This was, in effect, an attempt to measure community values (5). These studies indicated the strong feeling people had about parking, so parking naturally played an important part in the alternatives conceived. These alternatives were prepared in depth by the technicians and then presented to the Working Review Committee. The committee discussed the alternatives from the points of view of its members, which were, in effect, weighted according to community attitudes.

A good illustration of how values affect the decision-making process was demonstrated by the discussions on the expansion of governmental facilities. It was generally agreed that expansion was necessary and that the new facilities should be located in the downtown area. But the point at issue was whether the expansion should take place around the existing City Hall, because of tradition, or whether the new office buildings should be located in a blighted section of the downtown area where they might stimulate new development. The Working Review Committee's values seemed to favor tradition and, accordingly, they chose to expand the city activities near the present City Hall.

After the broader issues were settled, the committee turned to more detailed ones, such as how wide certain streets should be and what type of traffic control should be used. In these situations, the technicians presented a "preferred" technical solution, and the Working Review Committee either accepted or rejected it. By this process, community values were taken into consideration, and a plan for downtown Cincinnati on which there is agreement was created.

There were various occasions in this latter phase of the process when individual values played an important part. For example, in considering street improvements around Fountain Square, the question was raised as to whether they should be located north or south of the square. The technicians had suggested that they go north, primarily because they would have about the same aesthetic impact on all of the surrounding area. However, the Working Review Committee felt that the improvements should go south of Fountain Square, so that the fountain could be tied in with the redevelopment project to the north. The agreement that was reached strengthened the relative position of this particular project.

OTHER PROCEDURES

Values are important in considering areawide, as well as detailed, plans. Although Davidoff and Reiner suggest various types of studies to determine values, it appears that there are three types of procedure that are used to measure community values for land-use and transportation studies: focus groups, rating panels, and attitude surveys. The means used most often in resolving values are committee review and political review. A look at the work that has been done in these fields should be helpful in formulating more effective planning programs in the future.

Focus Groups

This technique uses a group of people who have common backgrounds and interests, and explores with them a particular subject with which they are familiar. There is usually a discussion leader who guides the group and an observer who does not participate. If the leadership is effective, ideas and concepts will grow, and a better understanding of the motivating factors behind individual values can often be obtained.

In addition to obtaining a better insight into values, the focus group can be used to develop a hierarchy of values, the order of importance of various factors. However, one cannot measure values from a focus group with any statistical precision like that provided by attitude surveys.

In connection with the Washington transportation study, focus groups were used not only to select values but also to determine the kind of language that best described the issues (6). In other words, this process made it possible to phrase more adequately the questions that were to be used in the follow-up attitude surveys.

The focus group technique is an effective way to get at major issues. For example, if one were concerned about freeway location in a certain section of town, it would be good to bring together a group of people who live in that section and who understand the area. By this process one could try to determine a freeway location that would be in harmony with the values of the people living nearby.

It would appear that the focus group technique might also be used effectively in formulating alternatives. Proper application could bring forth ideas and attitudes that would indicate alternatives that might not otherwise have been conceived and might be more in line with community values. In such a case, it would be a positive tool for improving transportation planning efforts.

Puget Sound Regional Transportation Study

RATING FORM FOR EVALUATION OF ALTERNATIVE DEVELOPMENT PATTERNS (*)

CRITERIA FOR EVALUATION	WEIGHTS FOR CRITERIA		ALTERNATIVE DEVELOPMENT PATTERNS											
			CONTINUATION OF PRESENT TRENDS AND POLICIES		METROTOWNS		RADIAL CORRIDORS		LINEAR CORRIDORS		CENTRALIZATION		SATELLITE TOWNS	
(1)	Major Criteria (2)	Sub-Criteria (3)	Score (4)	Weighted Score (5)	Score (6)	Weighted Score (7)	Score (8)	Weighted Score (9)	Score (10)	Weighted Score (11)	Score (12)	Weighted Score (13)	Score (14)	Weighted Score (15)
I DESIRABILITY CRITERIA														
A. OPEN SPACE GOALS														
1. Generous open space should be interspersed between development so that it is accessible to the largest number of people.														
2. Open space should be utilized to give legibility to urban development patterns.														
3. Areas for agriculture should be preserved in close proximity to urban development.														
B. EFFICIENCY AND ACCESSIBILITY GOALS														
1. National and state parks and forests and other major recreation facilities should be conveniently accessible to the region's residents.														
2. Future travel between major destinations should be minimized.														
3. Congestion of circulation facilities serving major employment areas should be reduced.														
4. Circulation facilities should be utilized to guide development.														
5. Development patterns which would make rapid transit feasible should be created.														
II FEASIBILITY CRITERIA														
A. LEGISLATION AND GOVERNMENT STRUCTURE														
1. The extent to which new legislation, policies or programs of land use controls would be needed to implement the development pattern.														
2. Implications for change in government structure or the way in which governmental services are provided or paid for.														
B. COSTS OF GOVERNMENTAL SERVICES														
1. Public utilities costs														
2. Transportation facilities costs														
3. School costs														
4. Police and fire protection costs														
5. Costs of preserving open spaces														
TOTAL SCORE	100	100												
RANK														

Form II-11 1/10/64 (*) See instructions in Alternative Patterns of Development, A Staff Report by PSRTS, January, 1964.

Figure 4.

Rating Panels

Rating panels have been used effectively to evaluate individual values, particularly in terms of general land-use plans. The rating panel used in the Puget Sound Area (7) consisted of planners from various parts of the region who were required to rate alternative plans developed by the Puget Sound Regional Transportation Study. The rating form used is shown in Figure 4. After going through the rating procedure, this panel discussed the alternatives at some length and came up with a plan that was a compromise among several of the alternatives developed by the technical staff. This indicates again that the determination of values can be a positive tool in the planning process.

Of course, rating panel measurements represent only the members' values, not those of the community at large. However, there are times when it is very useful to know the values of a particular group, and in such cases the rating panel has considerable merit. The rating panel has an advantage over the focus group, in that a statistical evaluation of the results can be made.

Attitude Surveys

A well-conceived survey is probably the best way we have to determine values. If the questions are well developed and if there is an adequate sample, a great deal can be determined about community values, whether the surveys deal with attitudes about the home, the neighborhood, or the community at large.

In many cases, attitude surveys have been taken in transportation studies at the same time that the home-interview survey is conducted, either by extending the questionnaire time or by dropping off a self-enumerating questionnaire (8). Generally, these surveys have emphasized the overall aspects of urban living, particularly living patterns. Such facts, of course, increase understanding of people's values, but they do not measure them. For example, the fact that 80 percent of our leisure time is spent around the home suggests why most people are so concerned with their neighborhood environment, but it does not tell just how important it is to them.

But the attitude survey can be used to establish the weights of various criteria. For example, it can quantify the relative weights of such things as the cost of the transportation system, user benefits, impact on taxable revenues, relocational problems, consistency with development goals, and aesthetic considerations. We can obtain the weighting on a community-wide basis, or we can determine the weights for a particular group. This, then, should allow us to present to the policy-makers the values of the people at large or the feelings of a particular segment of the population about a particular alternative.

Unfortunately, this type of procedure has not been used in the past. Attitude surveys have been limited primarily to obtaining information on existing attitudes and have not attempted to measure the reaction of the public to proposed alternatives. This kind of test should certainly be employed in the future; the business world has found the technique very productive.

It has been reported that President Kennedy, in commenting on attitude surveys, felt that they should not be used to predict people's reactions but, rather, to measure what people were thinking. If the political leader fully understood the thoughts of each constituent, he would then be in a position to weigh properly the feasibility of a particular plan or program, even though it might appear in some ways adverse to the thinking of his constituents.

Committee Review

Committee review has been used in numerous cities throughout the country. In fact, most planning commissions serve this function. They attempt to evaluate broad, as well as detailed, proposals and to measure them in light of their values. Although this is not often explicit in their recommendations, it is always implied.

The general-purpose committee has proved rather ineffective because it usually does not have sufficient experience or knowledge of the special issues involved. A lay group, such as a planning commission, often is not in a good position to evaluate alternative plans because, in many cases, its members do not have enough experience to have formulated any opinions or values related to certain types of problems.

In San Francisco, another method of community review, more like the legislative hearing process, is being developed. The Bay Area Transportation Study Commission, created by the State Legislature to develop a transportation plan for the San Francisco Bay Area, is now meeting with many county leaders to learn more about the plans that have been made and the county development concepts of various people. By this hearing process, the Commission will become familiar with the goals and values of the individuals who live in various sections of the region and, therefore, will be in a better position to know the kind of plan that would reflect the aspirations of the people of the region. This technique is certainly sound and will undoubtedly be used in other studies throughout the country.

The Political Process

The final review, of course, is the political process, always the acid test of any plan. The political review can be accomplished through the normal legislative process, or it can be undertaken by an attempt to interpret the values of the power structure of the area through special interviews. A general weakness of most transportation studies in the past is that this has been overlooked. Not much consideration has been given to the political process, and information related to various alternatives has not been prepared in a manner that can be readily understood by the political leaders.

In the Hartford region, the alternatives were presented to the political leaders in a straightforward and simple manner, and over a period of a year. As a result, a plan for the future development of 27 towns was selected without a dissenting vote.

The proposed land-use and transportation study in Detroit is attempting to emphasize the need for cooperation with the power structure in the community and is setting up a special staff to work solely with the political policy-makers (9). The staff will try to assess the values of the policy-makers and to develop alternatives that reflect them. This will be done through interviews with the power structure, as well as an evaluation of existing laws and ordinances related to urban development.

Each of the methods described has its advantages and limitations. In Cincinnati, however, it was discovered that if these various techniques are properly coordinated into an overall approach and if every effort is made to measure subjectively and objectively the value systems of the community, the chances of plan adoption are much greater.

There are, of course, various other techniques that can be used in determining community values, but none of them has been applied successfully in land-use and transportation studies. However, experiments are being made with sophisticated models that can be used to predict the reaction of various groups within a region. Development of such models would be a major step forward. Undoubtedly, this will take some time because the field is so new, so complex, and so involved.

CONCLUSION

The existing tools that thus far have only been partially applied must be improved. We must watch for changes in values, because it is clear that people's values do change, not only for economic reasons but also because of social and technological factors. Therefore, the process of determining community values is a continuing one which must be pursued diligently if we are to cope effectively with the changing requirements of our communities.

The development of a technique similar to the VPA (Vote Profile Analysis) probably is in order—a technique that will establish the factors involved in community values and will show how different groups of people evaluate them. A constant search for changes in these factors and values will help us understand the changing nature of our society and, therefore, enable us to plan more adequately for its future.

SUMMARY

The evaluation of community values is a very complicated issue. It is quite clear that it is fundamental to the whole planning process. It is the one factor that makes planning quite different from many other professional tasks. Until better techniques are developed to measure these values and to resolve them, it will be difficult to develop plans which will have public acceptance and understanding. Although this task is a difficult one, it is nevertheless essential if we are to prepare plans which may be successfully implemented in a democratic society.

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Market Potential Model and Its Application to a Regional Planning Problem

T. R. LAKSHMANAN and WALTER G. HANSEN, Alan M. Voorhees and Associates, Inc., Washington, D. C.

This study considered the following aspects of a regional planning problem in Baltimore: is there a potential in the region under existing policies for the large retail cores envisaged in the metrotown center concept, and if so, how many, where and when? Answers to these questions were sought through the development of an estimating tool (market potential model) that permits a flexible evaluative procedure to consider alternative patterns of future retail growth in the Baltimore region. The scale, location and timing of a large number of retail cores were identified, indicating a key component of the metrotown center concept to be consistent with the urban growth processes.

•A GROWING CONCERN over appropriate concepts and policies of urban spatial organization is noticeable today in many Western countries. The traditional image of an urban community with its tightly knit, articulated form and structure has been seriously eroded by the effect of ever-increasing mobility and communications and by the widely distributed benefits of rising productivity. The consequent desire for a new desirable image of a metropolitan community and the mounting problems of metropolitanization have stimulated a wave of interest in recent years in the development of appropriate concepts and criteria for urban spatial organization. This movement has led in turn to the formulation of metropolitan plans that envisage various goal-forms that will presumably enrich the economic, social, and aesthetic life of the urbanite.

The resultant plans evidence varying traces of utopian ideas as well as pragmatic requirements of effective metropolitan planning and public communication. Generally, they lean towards ideal forms for the future metropolis. Thus, Washington's Year 2000 Plan proposes a starlike configuration with corridors of dense development around a dominant center (1). The Greater London Plan calls for free-standing towns at the outer edge of a permanent greenbelt.

In the Baltimore region, systematic analyses of the present growth patterns and the forces behind them have been made to diagnose the potential for change and the leverage for goal-directed spatial organization. These extensive exploratory studies by the Regional Planning Council indicate that the activity and interaction patterns noticed today in large metropolitan areas suggest a scale for urban organization larger than the traditional concepts of neighborhood and community. As a result of these analyses (2, 3), the Regional Planning Council developed the concept of metrotowns. (One of the interesting points about the results of the analyses is that the development of these towns can reduce travel as much as 20 percent.) The metrotown concept envisages a regional system of suburban towns deployed radially and in a series of rings around the City of Baltimore (Fig. 1). Each metrotown is viewed as a relatively self-sufficient, physically cohesive community, with a population of 100,000 to 200,000, broad and varied choices of housing densities, considerable employment opportunities, a full-scale retail and service hub, and attractive recreational and cultural facilities

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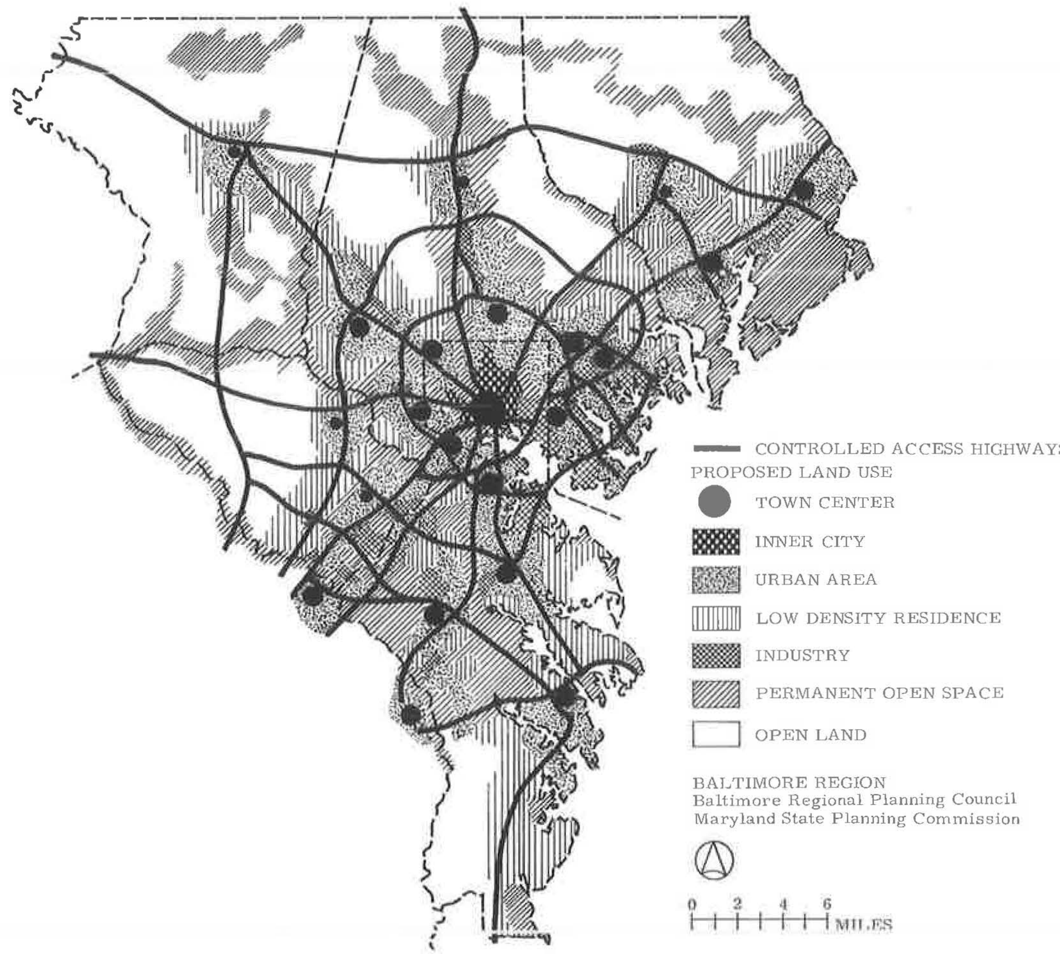

Figure 1. Metrotown concept, Baltimore area.

(Fig. 2). Major open spaces or "greenbelts" will separate the metrotowns and a regional transportation network will link all metrotowns and the "metrocenter" of Baltimore City.

It will be noticed that the metrotown concept is, to some extent, a reformulation of the ideals and spatial structure expressed in the British New Towns Hypothesis, in accordance with the realities of contemporary patterns of living, work, and circulation in the United States. The bias against sprawl, the notion of a desirable size, the emphasis on compact town centers to heighten the sense of urbanity (4), the belief that orderliness depends on boundedness—the greenbelt—and the provision of convenient accessibility from residential areas to high levels of diverse service and employment are commonalities. But there are significant differences. The metrotown concept is intended not to curb but to channel the growth of Baltimore into a desirable urban form. In addition, differences in scale of the towns, and above all in the machinery of plan implementation, must be obvious. Further, the metrotown centers are not viewed as free-standing service or employment centers but as nodes in an interrelated metropolitan spatial system.

Any formalized spatial concept such as the "metrotown" concept is not only a statement of a desired future urban form but also an hypothesis of a viable spatial structure. The validity of the hypothesis rests largely on the consistency of the spatial structure it implies with the nature and operation of urban growth processes and the realities of

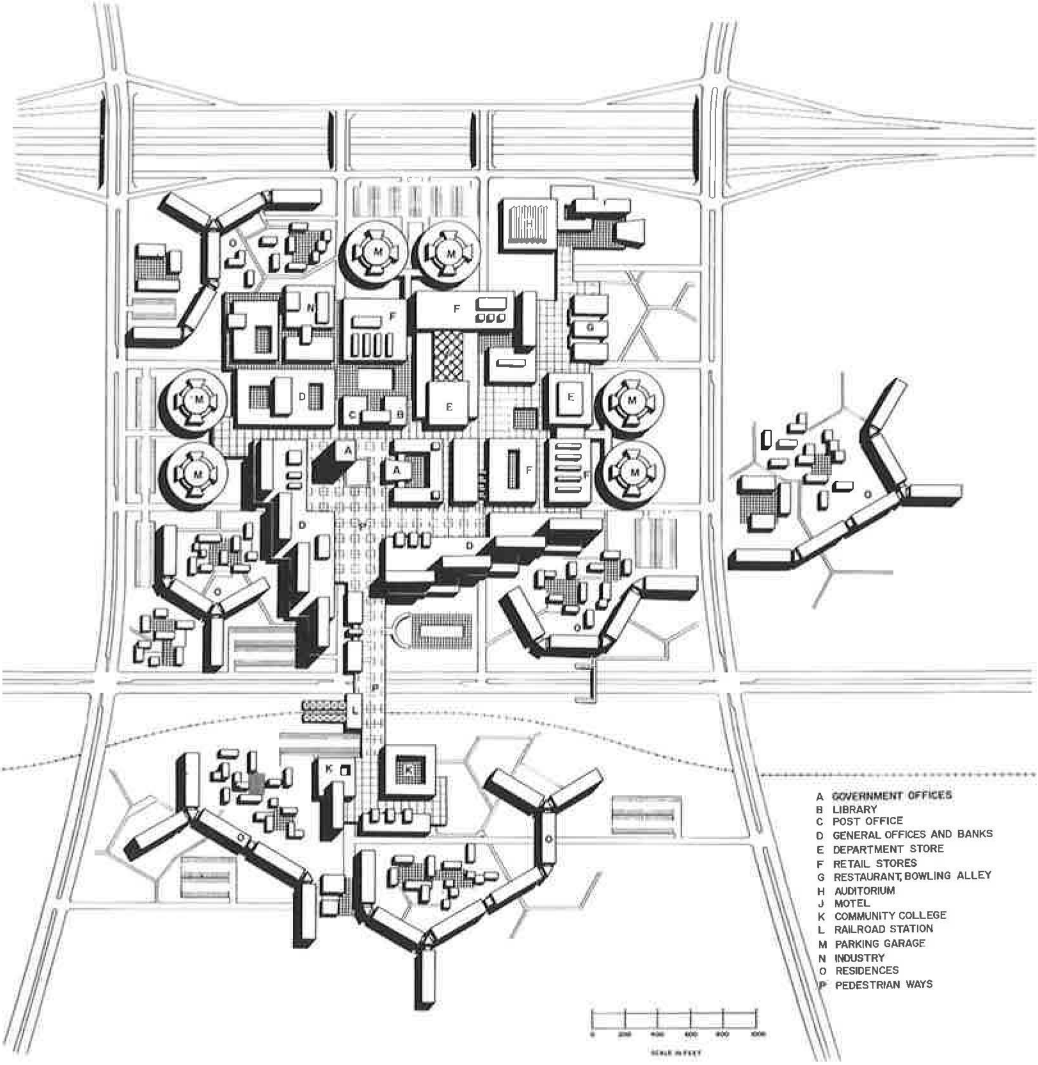

Figure 2. Site plan of a metrotown center.

institutional arrangements in the region. Therefore, the metrotown concept is viewed as an hypothesis of metropolitan spatial organization whose relationship with the factors and forces of development in Baltimore must be evaluated. Such an approach, though by no means easy in the current state of the art, will lead to a more precise and realistic formulation of the scale, composition and scheduling of metrotowns and their centers.

STUDY OBJECTIVES

The objective of the current research effort of the Regional Planning Council is to forge a set of decision-making tools to guide the scale, location, and composition of viable metrotown centers. The necessary research effort, in a concept that envisages a score of metrotowns in the region, dictates the analysis of these new towns as an integrated spatial system. Perhaps it is this explicit analysis of metrotown centers as nodes in an interrelated metropolitan spatial system that may distinguish the metrotown study from the analyses associated with individual new towns—Columbia,

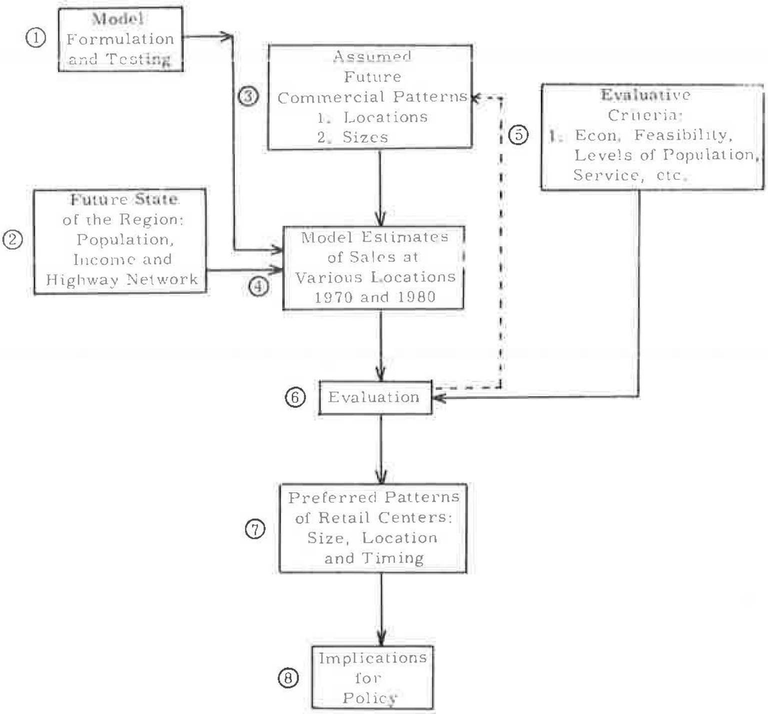

Figure 3. Metrotown centers: market potential analysis flow chart.

Reston, or Irvine Ranch—proposed in the United States today. Analyses try to go beyond the common focus on balance within towns to balance between towns. Consequently, a beginning has been made towards systems analysis techniques that relate function, location and interactions in an urban landscape.

The study reported in this paper is one of a series of related studies (5, 6) that investigate the scale, composition, and location of metrotown centers. The initial formulation of the metrotown concept postulates a gradient of dwelling densities outward from each center, with greenbelt separators for demarcation of towns. The validity of this classical planning premise is also currently examined in view of the increasing diversity of people's residential locational preferences (5). Webber (6) prophesies that recreation may well replace in the future the work place as a major determinant of residential location. Then the greenbelt may be a better location for high-rise apartments than the town center, or even for the town center itself. Again, how realistic is a greenbelt as a "container" in the current context of interaction in an automobile era?

The present study addresses itself to one facet—the retail core—of the complex functional organization envisaged in the town centers. It investigates the possibility that the large commercial hubs implied in the metrotown center concept may be realized. In operational terms, assuming the continuation of current policies and growth trends in the Baltimore region, what is the potential for large regional commercial centers? How many centers? What sizes? Where? When?

STUDY DESIGN

A prerequisite for tackling the foregoing questions is a realistic description of the functioning of the commercial centers today. If such a description—a model—is developed, it could be used to estimate the potential of commercial centers at a future point in time. Such estimates of performance can then be evaluated against stated criteria of planning relevance to guide decision-making on the scale, location and scheduling of large future commercial centers in the region.

The overall study process is shown in Figure 3. First, a market potential model that views each retail center as an integral part of an interrelated spatial system of commercial nodes in the region was developed and tested. Second, data were assembled about the future state of the region. Such data included future population distribution and highway networks assuming existing trends and policies, as well as assumed alternate commercial patterns. Next, the model was used as an estimator of sales at various centers under the different alternate assumptions. Finally, the results of the model application were reviewed in the light of evaluative criteria such as the economic feasibility of centers—existing and future—and levels of retail service. The results of this evaluation yielded a preferred pattern of large retail centers, each described by location, size and timing, and some implications for regional commercial policy-making.

A MARKET POTENTIAL MODEL

Model Formulation

Retail activities are consumer oriented. A reasonable premise of the model would be that the size and the number of retail establishments in an area is a function of the number of consumers, or more appropriately their aggregate purchasing power. Stated differently, within a metropolitan region, which can be considered for the present purpose as an economic and spatial entity, the total sales generated at all the shopping centers must equal the total available consumer expenditures for retail goods. (The following formulation assumes that purchases by residents in establishments outside the region are balanced by the sales made to visitors in the region.) However, the sales at any given retail center will be a function of the consumer expenditures in the surrounding area.

It is in the definition of the surrounding area that the present formulation differs from most approaches to this problem. Since customers bear the burden of costs of movement--economic, temporal, or psychic—to the retail center, the actual locations of the retail centers are influenced by the intricate patterns of the consumer movements for retail goods. Generally, there is a desire to minimize these costs of movement on the part of the consumer (7), hence, the desire of the retailer to choose sites of high accessibility so as to reduce these costs of friction. This overall tendency has persuaded market analysts to assume that a consumer, confronted with a choice among several alternative shopping centers, will inexorably choose the nearest center. This heuristic assumption permits the delineation of trade area—primary and secondary—boundaries, with the inclosed consumer expenditures allocated through other sub-assumptions to the individual shopping centers. Such a procedure is no more accurate than the highly questionable assumption of closed market areas around retail centers. Empirical studies have demonstrated that there is, instead, a continuum of market orientation of consumers to shopping centers (8). From a behavioral point of view it has also been asserted that shoppers engage in an information-seeking process, which, over a period of time, tends to attract them to different centers in some constant proportion (9). Further, the traditional definition of the surrounding region as a closed market area is operationally inflexible for the evaluation of alternate spatial patterns of retail activity attempted in this study.

The present formulation, consequently, asserts that the location or sales potential of a retail center is not to be viewed as a function of the purchasing power of an arbitrary spatial slice of the region. More realistically, it describes a situation of overlapping competition between shopping centers and develops a mathematical framework for measuring it.

Essentially, the model states that the sales potential of a retail center is directly related to its size. This follows from the observation that a large center offers a wider range and depth of goods and attracts consumers from a wider area than a smaller center would in the same location. Further, the sales potential of a center is directly related to its proximity to the number and prosperity of the consumers.

The larger and closer the consumer shopping dollars available, the greater the sales potential. Finally, the model states that the sales potential of a center is related to how disposed it is to competing shopping facilities. The farther away other shopping facilities are spatially, the greater the sales potential of a center.

These relationships are expressed in a mathematical form, using the familiar gravity model framework shown in Eq. 1:

$$S_{ij} = C_i \frac{\frac{F_j}{d_{ij}^{\alpha}}}{\frac{F_1}{d_{i1}^{\alpha}} + \frac{F_2}{d_{i2}^{\alpha}} \cdots \frac{F_n}{d_{in}^{\alpha}}} = C_i \frac{\frac{F_j}{d_{ij}^{\alpha}}}{\sum_{k=1}^{n} \frac{F_k}{d_{ik}^{\alpha}}} \tag{1}$$

where

S_{ij} = consumer retail expenditures of population in zone i, spent at zone j,

C_i = total consumer retail expenditures of population in zone i,

F_j = size of retail activity in zone j,

d_{ij} = distance (in driving time) between zones i and j, and

x = exponent applied to distance variable .

The gravity model was first applied by Reilley to separate the market areas of two cities competing for customers in a hinterland.

Eq. 1 which can be meaningfully applied if the region is divided into a large number of zones, states the retail center in zone j (F_j) attracts consumer dollars (S_{ij}):

1. In direct proportion to the consumer expenditures,
2. In direct proportion to its size F_j,
3. In inverse proportion to distance to the consumers (d_{ij}^{x}), and
4. In inverse proportion to competition $\left(\sum_{k=1}^{n} \frac{F_k}{d_{ik}^{\alpha}} \right)$.

Eq. 1 can be modified to state the consumer expenditures available in all zones of the region that would probably be spent in zone j (retail centers F_j):

$$S_j = \sum_{i=1}^{n} C_i \frac{\frac{F_j}{d_{ij}^{\alpha}}}{\sum_{k=1}^{n} \frac{F_k}{d_{ik}^{\alpha}}} \tag{2}$$

where S_j is total sales in retail center F_j.

Eq. 2 sums up the sales from every zone at zone j. It implies that there is no trade area boundary but a shopping interaction between all zones, though this may fall off sharply with distance.

This model, though new to market potential studies, has been extensively used in traffic studies in many urban areas in the United States. These studies have used operational definitions for the variables meaningful for traffic analysis and found it a good predictor of shopping travel patterns.

Model Verification

The relevance of the model to the real world was verified by applying it to the current shopping patterns in terms of dollar sales and shopping trips in the Baltimore

TABLE 1

VARIABLES WITH OPERATIONAL DEFINITIONS USED IN THE STUDY

Variable	Definition
S_j	Annual sales of shopping goods made in zone j (in dollars).
C_i	Total consumer annual expenditures on shopping goods available from zone i. Operational: The product in dollars of the population in zone i and the per capita shopping expenditures.
F_j	Size of shopping goods activity in a zone. Operational: Square feet of floor space devoted to shopping goods in zone j.
d_{ij}	Distance between the shopping center j and the consumers in a zone i. Operational: Driving time in minutes between the centroids of the zones.
α	Exponent applied to distance factor, d. Operational: In practice, a friction factor, F, is used so that $F = \frac{1}{d_{ij}^{\alpha}}$; exponent α is variable with d_{ij}. The set of F factors used were obtained from the BMATS shopping goods trip gravity model.

region. The model concerned itself with only the shopping goods centers that offer the higher order retail goods, since they constitute the type of retail activity of importance to the metrotown concept. Table 1 summarizes the operational definition of the variables used in the model.

Estimation and Evaluation.—With all the variables measured, standard computer programs developed for traffic studies were used to generate sales in dollars that were attracted to all zones that had shopping goods floor space. Figure 4 compares the annual sales generated by the model and the actual annual sales confidentially obtained for six large shopping centers. The fit appears good except for observation 5, which was not fully open during the comparison period, hence the apparent overestimate.

The sales comparisons, though encouraging, were possible for only six centers. To provide a more pervasive check on the model, an estimation of shopping goods trips was made. This was felt to be a valid check of the model, as previous studies have clearly shown a direct relationship between retail sales and trip generation (11, Figs. 4, 7). The number of shopping goods trips that actually left every residential zone was obtained from origin-destination (O-D) survey data. These trips correspond to the consumer expenditures that went from every zone to different shopping goods centers in the previous estimation. Using the shopping goods floor space as an attractor, these trips were allocated to the various shopping centers.

From the O-D survey it was also possible to obtain the number of shopping goods trips actually attracted to each center. Figure 5 provides a comparison between actual (O-D) shopping person trips and model person trips. The model appears to conform well ($r^2 = 0.91$), particularly when it is remembered that the survey data are based on a 10 percent sample and subject to considerable sampling error in the lower ranges.

The sales comparison at the central business district (CBD) was inconclusive, owing to the unaccountability of purchases made by workers and visitors. However, the shopping trip comparison was extremely gratifying (only about 5 percent difference); (actual) O-D shopping trips to CBD = 17,466, model shopping trips to CBD = 16,425.

Summing up, the comparison of the actual and estimated patterns of current shopping sales and trips in the Baltimore region demonstrates that the model performs reasonably well. The noticeable variations appear to be a measure of the inevitable abstraction in any model formulation as well as data problems. The market potential model was, consequently, accepted for application.

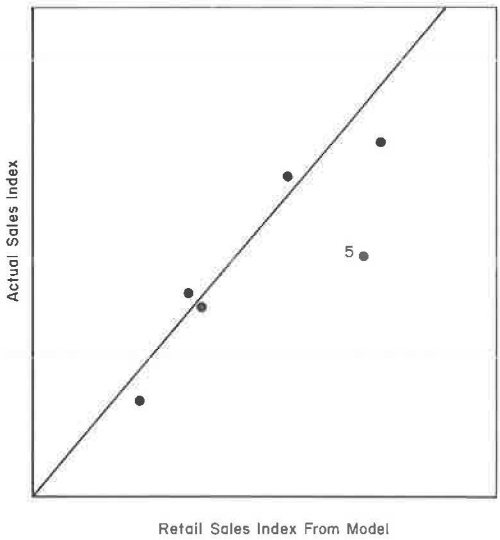

Figure 4. Retail sales at selected shopping centers.

Model Application—Data Requirements

The market potential model formulated and tested in this study is essentially a tool for estimating the market potential of each retail center in a metropolitan region. To be used as an estimating tool, the model requires a description of the urban area in terms of (a) the shopping goods demand described spatially, (b) the supply of competing shopping goods facilities, and (c) the spatial links between the retailers and the consumers. All these components of the retail spatial structure have to be specified before the model can be used for estimating sales of each center in the urban area for a required point in time, e.g., 1970 or 1980.

Demand for Shopping Goods. —The demand for shopping goods is represented by the consumer purchasing power in the region. To compute the demand for shopping goods for a future year, projec-

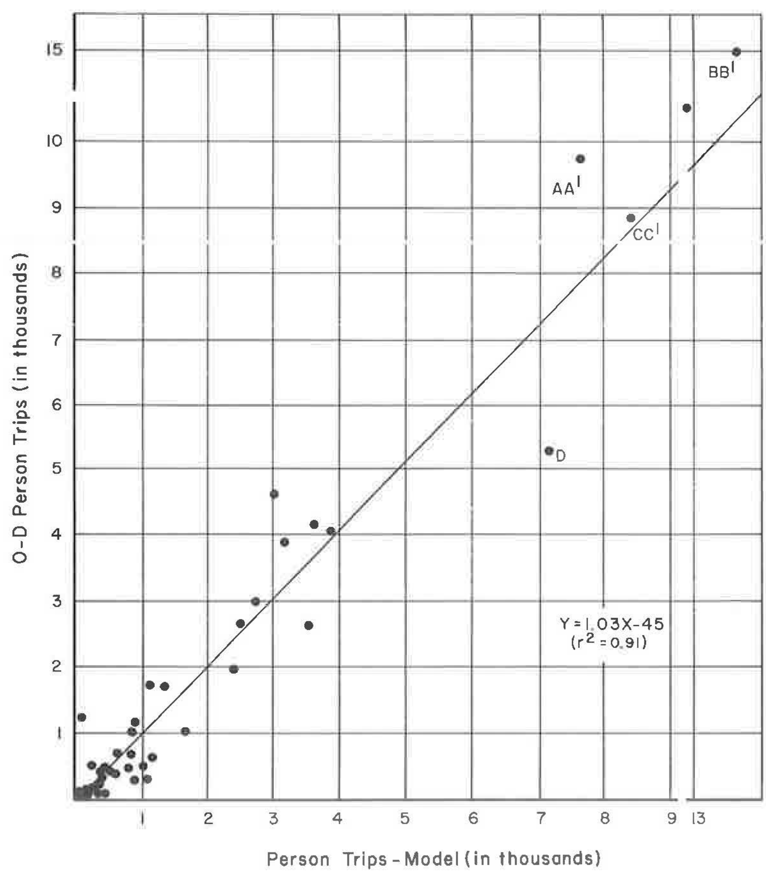

Figure 5. Trips generated by retail center.

tions of population and per capita expenditures are prerequisites. This study used the zonal population projections developed in a recent study by the Baltimore Regional Planning Council (12). These projections resulted from the application of mathematical models that made two basic assumptions: (a) existing trends in the residential site selection process would continue, and (b) existing policies—zoning, public works, etc.—in the region would continue. No policies relating to the metrotown program entered into these projections. Thus, the distribution of consumers in 1970 and 1980 assumed as inputs to the market potential model would reflect the probable effect of existing policies.

The per capita shopping goods expenditures for 1970 and 1980 were developed through the application of an econometric model (13): For 1960, $C_{ij} = 2.3\,Y_i^{0.573}$; for 1970, $C_{ij} = 2.30\,(Y_i + 109)^{0.573}$ and for 1980, $\overline{C_{ij}} = 2.30\,(Y_i + 238)^{0.573}$, where C_{ij} = capita shopping goods expenditures and Y_i = estimated mean income.

The projections of per capita expenditures by zone used the income projections developed in the previously cited study by the Baltimore Regional Planning Council. Thus, both the population and income projections used in the study imply the continuation of existing policies.

Existing Facilities. —The supply of existing facilities refers to the shopping goods retailing units described by size and location in the region in any year for which the model is to be applied. To apply the model for a future point in time, e.g., 1970 or 1980, the size and location of the shopping goods facilities had first to be assumed for that year. The model could then allocate the total consumer expenditures for shopping goods to the various assumed and existing shopping centers. Therefore, use of the model is a trial and error process, and the model framework is not a locational but an evaluative scheme. Generally, models of intraurban location determine locations of shopping facilities, given the distribution of retail demand and the distributive effects of the transportation system (14). The market potential model used in this study, however, accepts locations of shopping facilities as inputs and then estimates their sales levels. Since alternative location-size patterns can be assumed, this model offers a technique for estimating the consequences of alternative patterns of growth of shopping goods facilities.

In practice, alternate assumptions of the sizes and locations of shopping facilities, in addition to the existing facilities, were made. The market potential or sales level of each of the centers in the region in each of the alternatives was then obtained from the model.

Spatial Description of System. —A key variable of the model is the consumer-retailer interaction space. The operational definition used for the variable was the driving time between the consumer's and the retailer's zones. An application of the model to 1970 or 1980 requires, consequently, the zone-to-zone travel times on the 1970 and 1980 highway networks. This data input leads to assumptions concerning the highway networks in 1970 and 1980.

Here again, the assumption built into the model is that current policies will continue. The Baltimore Regional Planning Council prepared a map showing the future highway networks that represented a composite of existing policies. Inside the BMATS area, the recommendations of the recent Wilbur Smith study were incorporated. In the rest of the region outside the BMATS area, the highway proposals of the Maryland Needs Study were assumed.

Model Output

Given a description of the three components of the retail spatial structure—demand, supply, and buyer-seller interaction space--the model output provides the following measures for each alternative: (a) the probable sales levels at each center—existing and future; (b) the average trip length for shopping goods for the system as a whole; and (c) the consumer dollars from each residential zone that are spent at each shopping center.

CRITERIA FOR EVALUATION OF RETAIL POTENTIAL

The major output of the market potential model then is a series of estimates of probable sales at shopping centers, assuming existing trends and policies and under various alternative schemes of growth. They are projections of consequences—in terms of market potential at shopping centers—of stated assumptions and policies and do not by themselves suggest any optimal or preferred patterns. To guide decision-making on preferred (location-size-time) patterns of growth of shopping goods facilities, criteria against which these estimates can be evaluated had to be formulated. These criteria would reflect the regional planning objectives in terms of the metrotown program.

To use the various alternatives and the corresponding sales estimates to identify the locational opportunities for large shopping centers, two broad sets of criteria were formulated. The first would assess any alternative at the individual location level. These would be the broad criteria guiding the investment decisions of individual developers. How does a developer gage his locational opportunities? What is the minimum return considered necessary before investment decisions are made?

The evaluation problem in this study is broader in scope, however, than that of an individual developer interested in a specific location. It involves the consideration of the rigidities in the existing commercial pattern. For instance, what would be the impact of location of a new large shopping center on the performance (or sales level) of a nearby existing shopping center? Therefore, the second set of criteria enlarged the scope of evaluation from an assessment of individual centers to an evaluation of an interrelated system of centers in the whole region. In other words, how do the new (assumed) shopping centers evaluated by the first set of criteria and the existing set of regional centers "add up" as a regional pattern? Do the regional patterns assumed provide comparable levels of service in different part of the region to the consumers? Further, are the regional patterns of centers evaluated in relation to all these questions a reasonable simulation of the market processes? These are ticklish questions and the judgment criteria related to them are by no means easy to establish. But they are very relevant questions and the criteria developed in the study appear, in our opinion, to be the most reasonable in this regard.

All criteria used in this study are explicitly set down in the following, and the rationale for their use is developed in some detail.

Size of Centers

It was stated earlier that this study investigates the potential for large shopping centers to form the cores of metrotown centers. This raises the question of an operational definition of a large center. The definition adopted in this study was in terms of a minimum size for a shopping center to be considered as a metrotown core.

The specification of a minimum size must, of course, be related to the observable trends in retailing. There seems to be a number of factors contributing to the increase in the scale of a shopping center. For one thing, as the population and income per capita increase in a region, the distribution plant in the retailing sector gets more fully utilized and possible economies of scale increase. As the retail establishments increase in size, they also tend to cluster together and offer a wider range of goods and associated services to induce the consumers away from other clusters. Further, as these clusters of establishments develop and increase the size of their market, the probability of new specialty goods stores coming in with special bundles of goods increases (15). As a result, though there are limits for the increase in size of the individual establishments, the clusters of establishments—shopping centers—have been growing in size. However, the increasing searching costs of the consumers in large centers as well as the competition of other clusters may pose restrictions on the indefinite increase in scale of a shopping center. The time costs imposed on a consumer looking for a shopping good increases rapidly with increase in the size of the shopping center. Conceivably, these costs could increase in a very large center to a point where consumers may prefer actually smaller centers.

The shopping goods floor space in a center would, of course, vary in relation to the number of consumers in the part of the region where it would be dominant. Consequently, two minimum sizes related to location in the region were postulated for consideration of shopping centers as metrotown center potential. In other words, in the inner beltway area, which is likely to be more densely settled by 1970 or 1980, the minimum size of centers to be considered was assumed to be 450,000 to 500,000 sq ft of shopping floor space. In the outer beltway with a probably thinner development, a lower minimum of 250,000 to 300,000 sq ft of shopping goods floor space was postulated. Exceptions to these rules would be the older recognized communities such as Aberdeen or Westminster.

Economic Feasibility

A locational decision is made by a shopping center developer when a minimum expected return is assessed at a particular location relative to returns available at alternate locations. So the centers tried in this study must be evaluated as to their relative economic potential at the level of an individual center (termed here as locational level). The evaluation of the individual centers in an alternative at a location level by the minimum sales criterion, as described in the following, points up viable locations.

A further level of evaluation arises; i.e., do the sales levels, size ranges, etc., of a subregional set of centers in an alternative simulate the market conditions? If so, that alternative will be judged as one realistic pattern of probable regional commercial growth. Thus, the alternative has to be evaluated in relation to viability of centers both at the locational and at the subregional level. The criteria for economic evaluation at both these levels used in this study are briefly outlined.

Locational Level.—There appears to be a minimum expected return on a shopping center considered necessary by developers before locational decisions are made. This minimum return is defined here in terms of annual sales per square foot. The use of this measure assumes returns for investment to be the same for different production functions of different retail establishments. Thus, the payoffs between sales levels and costs, such as rent levels, are ignored (though they may be uncovered in the subsequent site analysis). Further, the assumption is made that merchandising and advertising differentials will not be significant and location vis-a-vis consumers is most relevant.

The sales per square foot varies by the type of store in a regional shopping center. Thus, the department stores sell on an average $59/sq ft, the variety stores $27, jewelry shops $55, and shoe stores $40 to $45 (16). So the sales per square foot for a shopping center as a whole are a function of the tenant mix. In the Baltimore region the sales per square foot for all shopping goods stores in a regional center in 1963 ranged from $45 to $53/sq ft. (This information is drawn from confidential information obtained from the Sales Tax Department for a set of six regional shopping centers for 1963.) The shopping goods establishments aggregated over the entire Baltimore region averaged $44/sq ft.

This study assumed that new shopping goods aggregations are viable when the sales per square foot obtained from the model run were at least $50 to $55. This minimum value is in line with the foregoing data and the best thinking among some leading practitioners in the field of marketing.

The sales per square foot obtained at any location at one point in time is related to the size of center tried. Thus, when an assumed shopping center was selling less than $50/sq ft, a reduction of its size in the next trial indicated the same location as workable at a lower size. Thus, this criterion helps in determining the scale at which a shopping center is viable. This criterion also aids in assessing the impact of a large new center on an existing center. Since the sales level at an existing center can be obtained, it is easy to measure the drop in its performance when competition is offered in the form of an assumed center nearby. Judgments can then be made about the size and location of a new shopping center that can be added close by without the existing center dropping its sales below minimum levels.

Subregional Level.—The use of the criterion at the locational level will only indicate which centers are viable in 1970 and 1980 at sizes chosen. It will not show whether the set of future centers tried in any subregion are a reasonable approximation of the probable commercial development as a result of market processes. Such an evaluation is not easy to make, but some indications may be obtained by considering the set of centers tried in a subregion in any alternative simultaneously. The procedure is difficult to outline without the illustrations that will be introduced later in the paper. Only the rationale for such a technique is set forth briefly here.

If the sales per square foot for the major existing centers and the future centers tried in a subregion are plotted for all alternatives, some interesting observations can be made. In some earlier alternatives, the centers varied very sharply among themselves in sales per square foot. In some later alternatives, the centers varied considerably in size but had a narrower range of difference in sales per square foot. It is easy to see that the earlier alternatives are poorer descriptions of the probable future pattern of centers. If some centers did poorly (e.g., \$30), they will not appear. In the same alternative, if some centers did very well (e.g., over \$75/sq ft), they would either increase in size or generate their own competition. In other words, alternatives which assumed such a size-location distribution of centers are not describing the market processes. The later alternatives more truly indicate the typical market situation when centers will vary in size (depending on location vis-a-vis consumers) but will have no such sharp differences in relative performance.

Level of Retail Service

It was indicated earlier that evaluation was necessary at levels higher than individual centers—existing or assumed. Individual centers may be evaluated at the locational level as workable at specific sizes. But do a group of such centers at a subregional level serve the consumers efficiently? This criterion of efficiency of a set of assumed centers that form an alternative was measured in two ways:

1. The sales per square foot of shopping centers aggregated by transportation districts—The underlying assumption is that, if a group of shopping centers in a transportation district (T.D.) has high sales per square foot (e.g., more than \$75), the consumers in such districts are poorly served. The potential for shopping goods floor space exists, and the few shopping goods stores in those transportation districts generate high sales per square foot. The consumers have to go to larger shopping centers in other sections of the region for their shopping. In reality, however, high sales per square foot in such areas would result in either the centers increasing in size or in the development of new stores nearby to serve the consumers. So the implication for our analysis is that if some alternative patterns indicate high sales per square foot for a number of transportation districts in a subregion, those alternatives are poor descriptions of the probable future pattern in that subregion. So in those subregions in subsequent alternatives, more shopping goods floor space will have to be assumed and the evaluation procedures repeated. So this criterion is useful as a corrective in the iterative strategy of setting up alternatives to approximate the probable future patterns of shopping goods growth. The details of application of this criterion are discussed with specific examples later in the paper.

2. Average shopping trip lengths—this is a gross measure of the system efficiency of an alternative. In an alternative, where the assumed centers are tried at locations eccentric to population distribution, the average length of the shopping goods trip will increase. As indicated later, the average trip length increased 15 percent (1.5 min) over present-day levels in one alternative. If the total number of shopping trips is considered, this would involve a very considerable increase in time spent on shopping trips in the region. So an alternative pattern assumed was evaluated as efficient in terms of how close its average trip length was to present-day level. Generally, a 5 to 7 percent variation from the current average trip length for the region was allowed.

It must be obvious that the shopping service level to population is measured on a gross system level by the average trip length measure and on a subregional level by the sales per square foot by transportation district.

APPLICATION OF CRITERIA AND EVALUATION OF RETAIL POTENTIAL

The first step in the estimation of retail potential is the development of alternative patterns of possible future retail development.

Development of Alternatives and Estimation

The development of alternative patterns was basically a trial and error process. Initially, it involved allocating the estimated total regional demand for additional shopping goods by 1970 and 1980 to specific locations in a few exploratory alternatives. The probable sales levels at all centers estimated by the model for such alternatives were then evaluated against the stated criteria to provide guidelines for the formulation of more realistic alternatives.

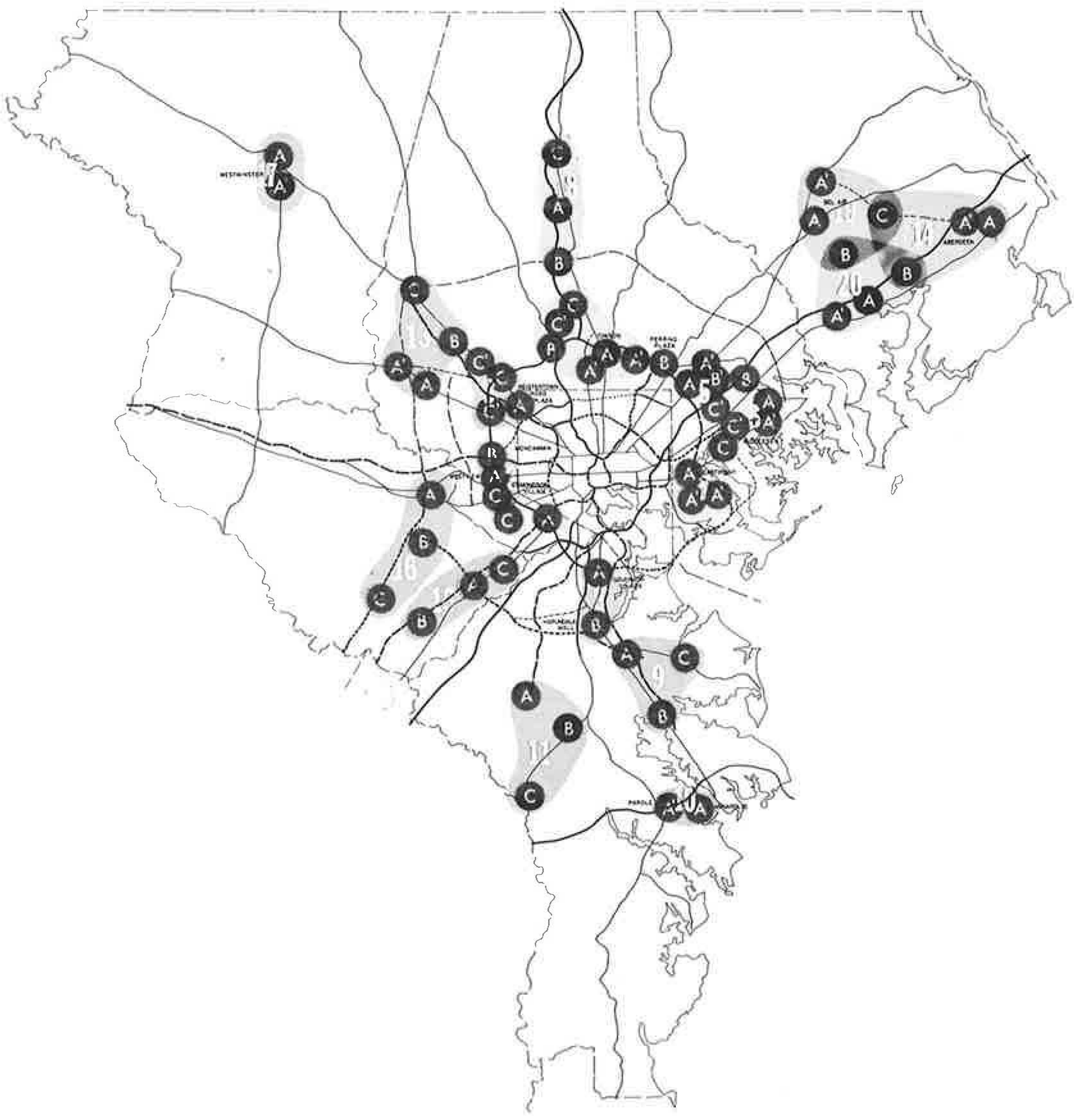

Figure 6. Universe of potential location for metrotown centers.

A prerequisite to the formulation of alternatives is an estimation of future regional demand for shopping goods in the region. The projected growth of consumer expenditures on shopping goods in the region for 1962-70 and 1970-80 was treated as potential demand and expressed in floor space for the respective time periods (on the assumption of an average return of $55/sq ft). Based on an analysis of current trends, 78 percent of the regional floor space demand was assumed as nucleated center potential.

To allocate this estimated regional demand in the form of alternatives, a universe of potential locations was specified by the Regional Planning Council (Fig. 6). (Available land, existing commercial nucleation, general location fixes of previous metrotown studies, and disposition to areas of population growth were some of the factors guiding the choice of these locations.) Each of these locations was treated as a potential candidate for metrotown centers and tested in this study for retail potential.

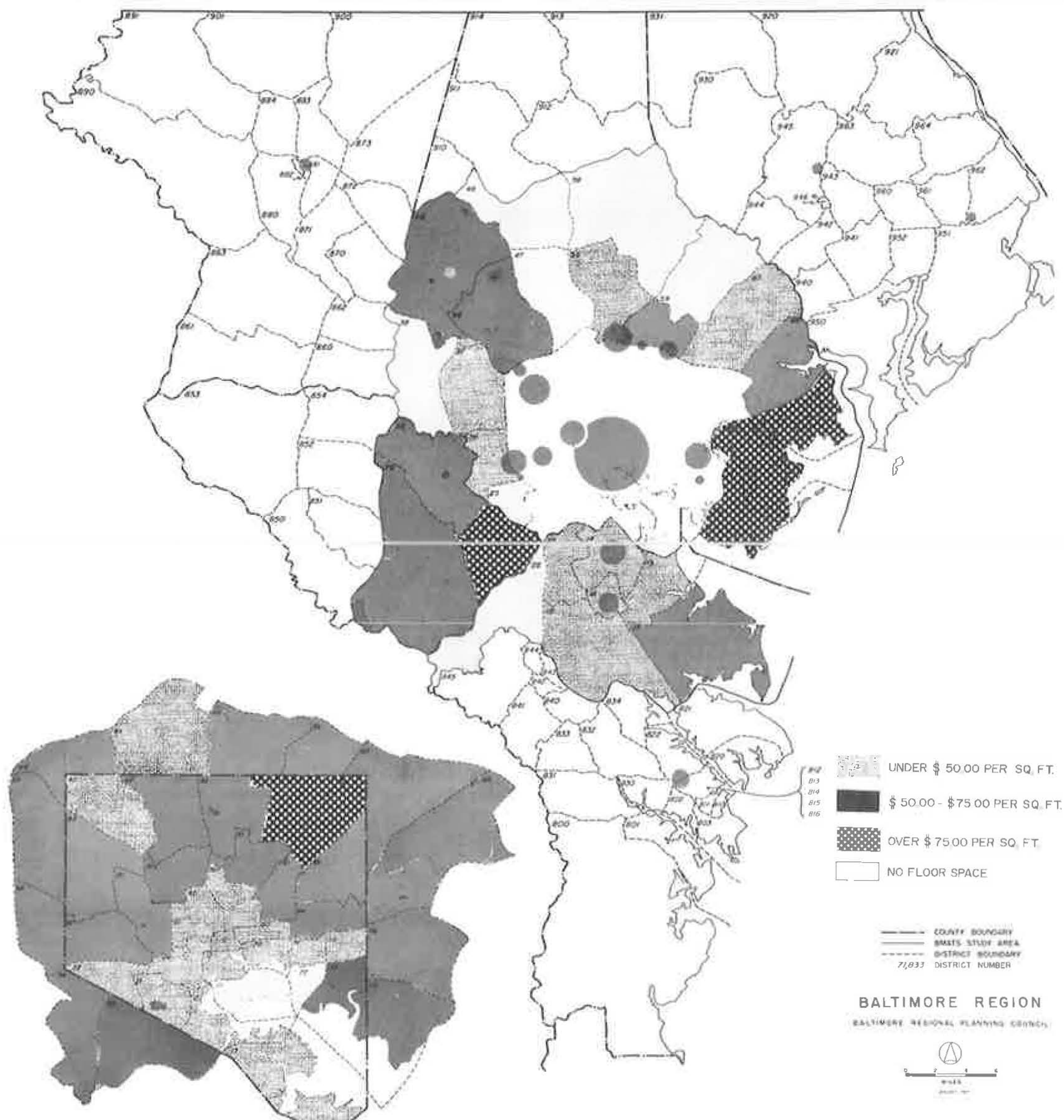

Figure 7. Performance of existing shopping districts, 1963.

Initially, two hypotheses—concentration and dispersion—of retail development were assumed. In the first alternative, all the growth by 1970 was assumed to take place in the inner beltway (identified as 1970 Alt. 1). The second assumption was that most of the growth is likely to skip the more densely settled inner beltway and locate in the less-developed outer beltway area (1970 Alt. 4).

The 1970 consumer shopping expenditures were distributed with the model to all shopping centers—existing and future—in each of these two alternatives. The sales per square foot of shopping centers by transportation districts were computed and mapped for both alternatives. Figures 7, 8, and 9 indicate this measure of retail service for 1963, 1970 Alt. 1, and 1970 Alt. 4, respectively.

In 1963, the areas with sales levels of more than $75/sq ft—areas of poor retail service—are minimal. The few such pockets are mainly peripheral low-density areas.

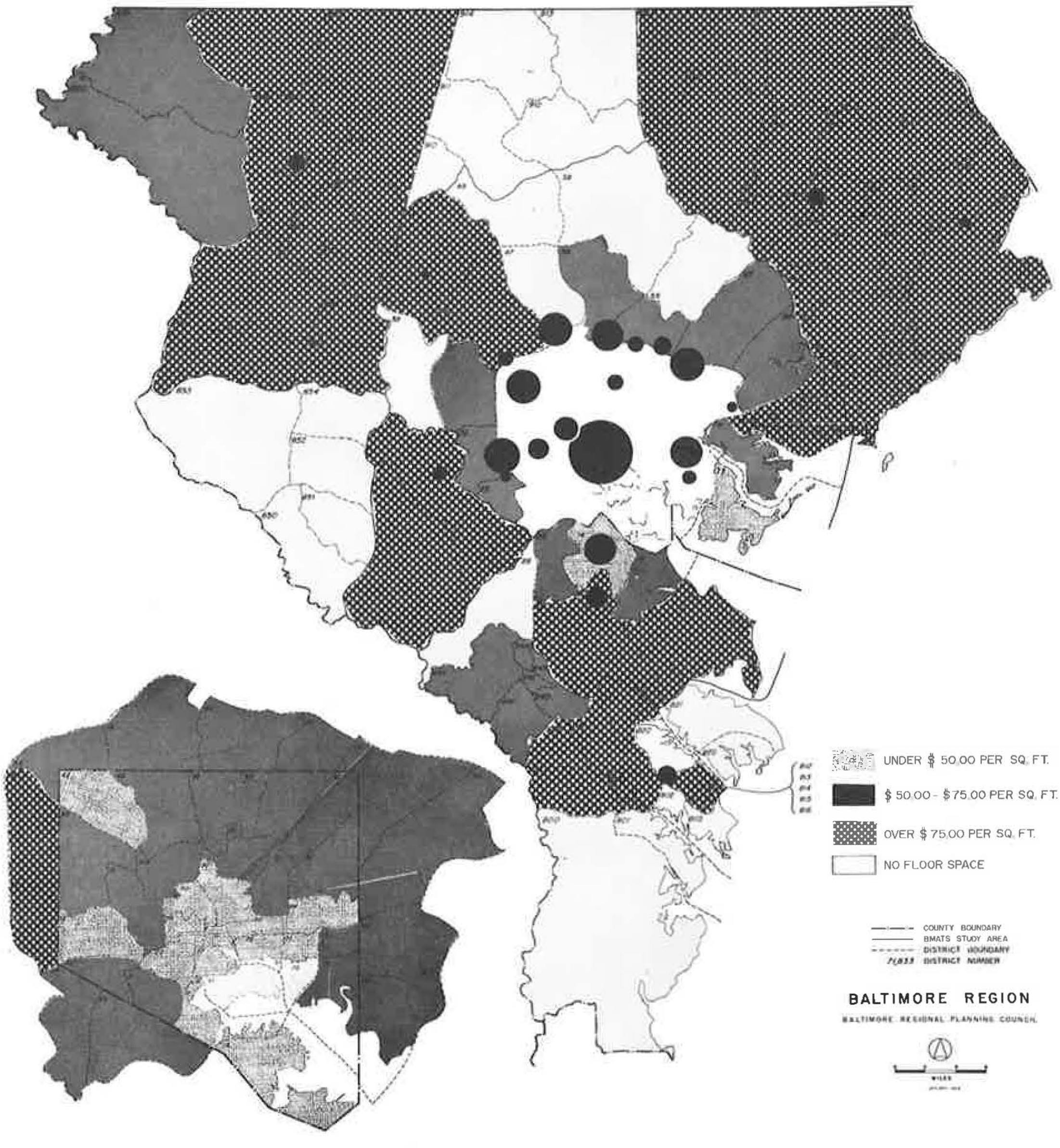

Figure 8. Potential of shopping districts, 1970 Alt. 1.

The main thing to realize is that, except for these few pockets, the system of shopping goods centers today provides a good retail service throughout the region. In contrast, Figure 8 indicates that the concentration alternative provides a low level of retail service for large sections at peripheral regions. It is also indicated in the next section that the sales performance of the various centers varied from \$30 to \$150—an unlikely occurrence in the market process. Conversely, in Figure 9 the level of retail service in the outer areas of the region is good, but large areas of the densely populated inner parts of the region are poorly served. In addition, the average trip lengths for these alternates were 11.8 and 11.4 min—a 10 percent increase over current levels.

The major conclusion from this preliminary evaluation was that both these pure alternatives are poor descriptions of likely future development. Composite alternatives that combine features of both these alternatives were consequently set up for further

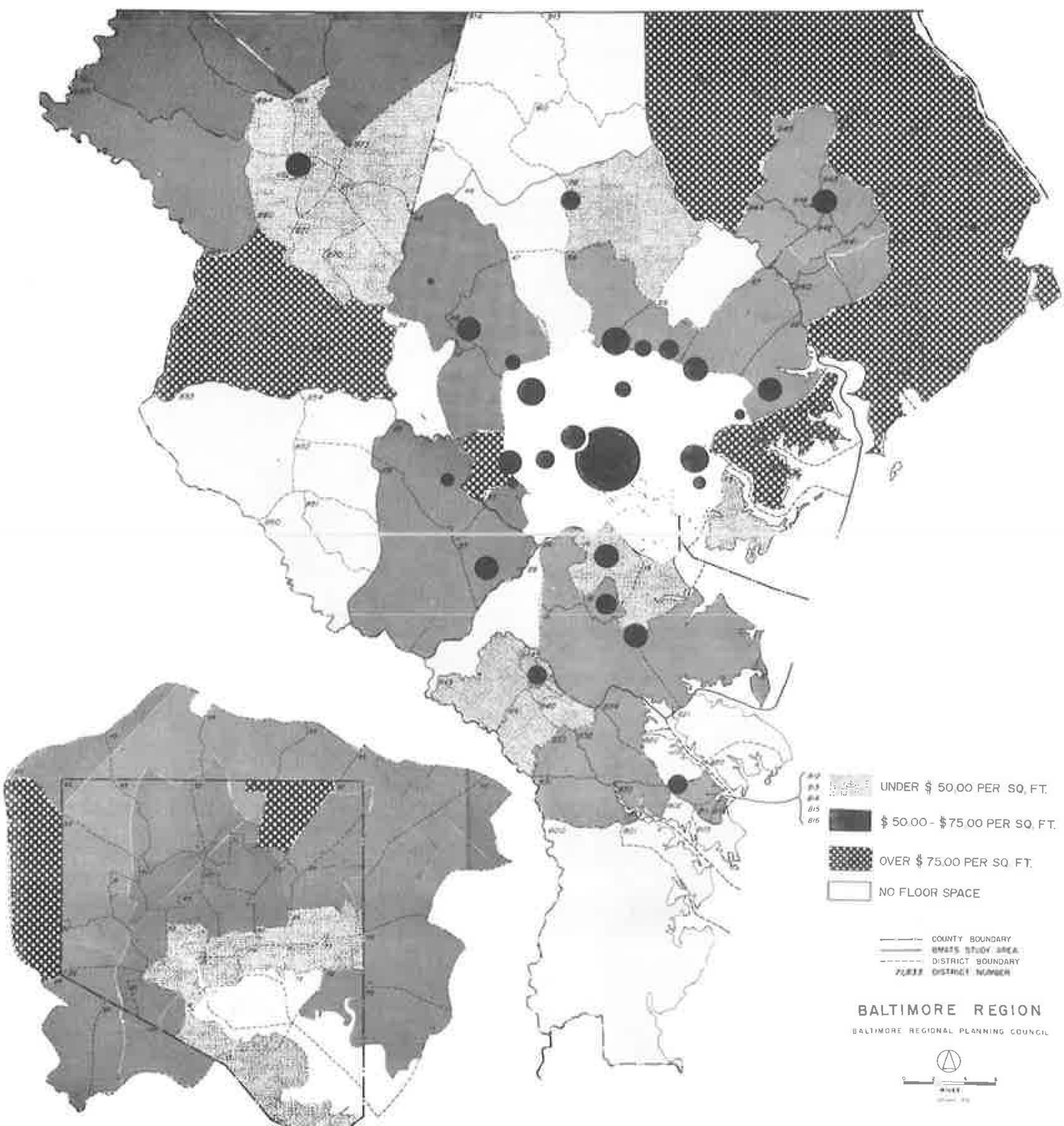

Figure 9. Potential of shopping districts, 1970 Alt. 4.

evaluation. Figure 10 indicates the level of retail service for one such composite alternative. As indicated in this figure, the resulting retail service level is a considerable improvement over the results obtained with the two exploratory runs. The average trip length also dropped to 11.0 min.

Evaluation of Alternatives

Throughout this study, 25 alternatives (14 for 1970 and 11 for 1980) were set up and evaluated. This evaluation is a complex process involving several dimensions of interpretation: the relation of size to performance in several alternatives for the same center, the sensitivity of a center to competition nearby, the interrelation of all

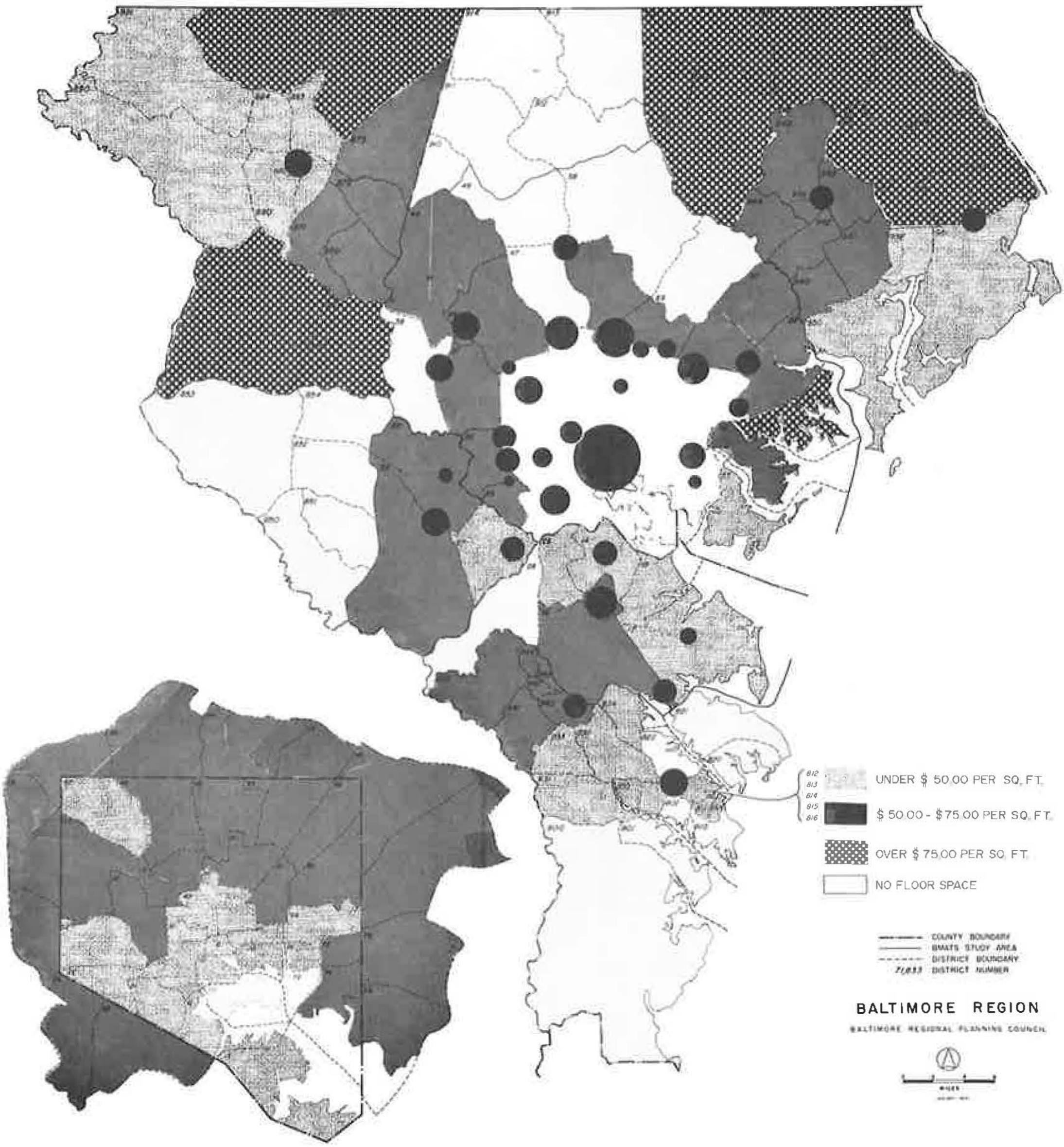

Figure 10. Potential of shopping districts, 1980 Alt. 8.

centers in a subregion, and the assessment of subregional levels of retail service by alternative. Space limitations do not permit a detailed description (17) of all the evaluations performed; however, the following selected examples will indicate the procedures used and the typical findings.

The basic framework of the evaluation was the subregion. It involves the recognition of six overlapping subregional markets. This framework permits the retail centers in each subregion to be viewed as serving one market, which is overlapped by service of some centers in the adjoining subregion. It must be pointed out that the recognition of the subregions is a device of evaluation only and does not affect the sales estimation procedures which still assume a market continuum implicit in the use of the model.

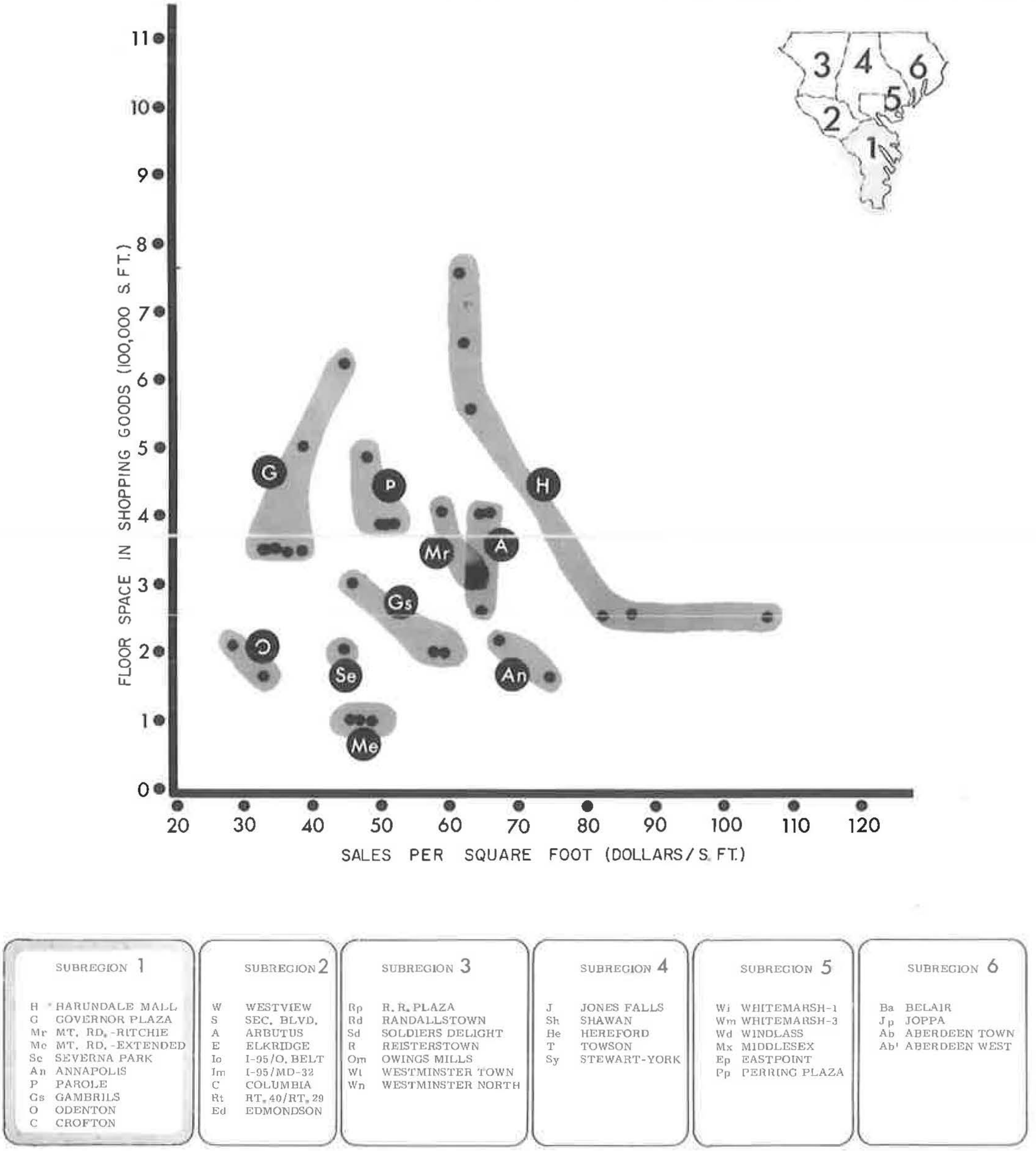

Figure 11. Comparative success of centers, subregion 1, 1970.

For each of the six subregions, four graphs—two each for 1970 and 1980--were prepared. For each point of time, the two graphs were (a) comparative success of centers in the subregion (Fig. 11), and (b) comparative system performance in the subregion (Fig. 12). Both these graphs are plots of sales per square foot vs size of centers for selected alternatives. Figure 11 involves connecting the points in all alternatives for each center. This shows clearly the relation between size and corresponding performance—a measure of depth of market and effect of nearby competition. Figure 12 involves connecting the plots of all the centers for each alternative and gives a visual measure of the performance range of different centers within the subregion. The very wide range of sales per square foot among centers in subregion 1 for alternatives 1 and

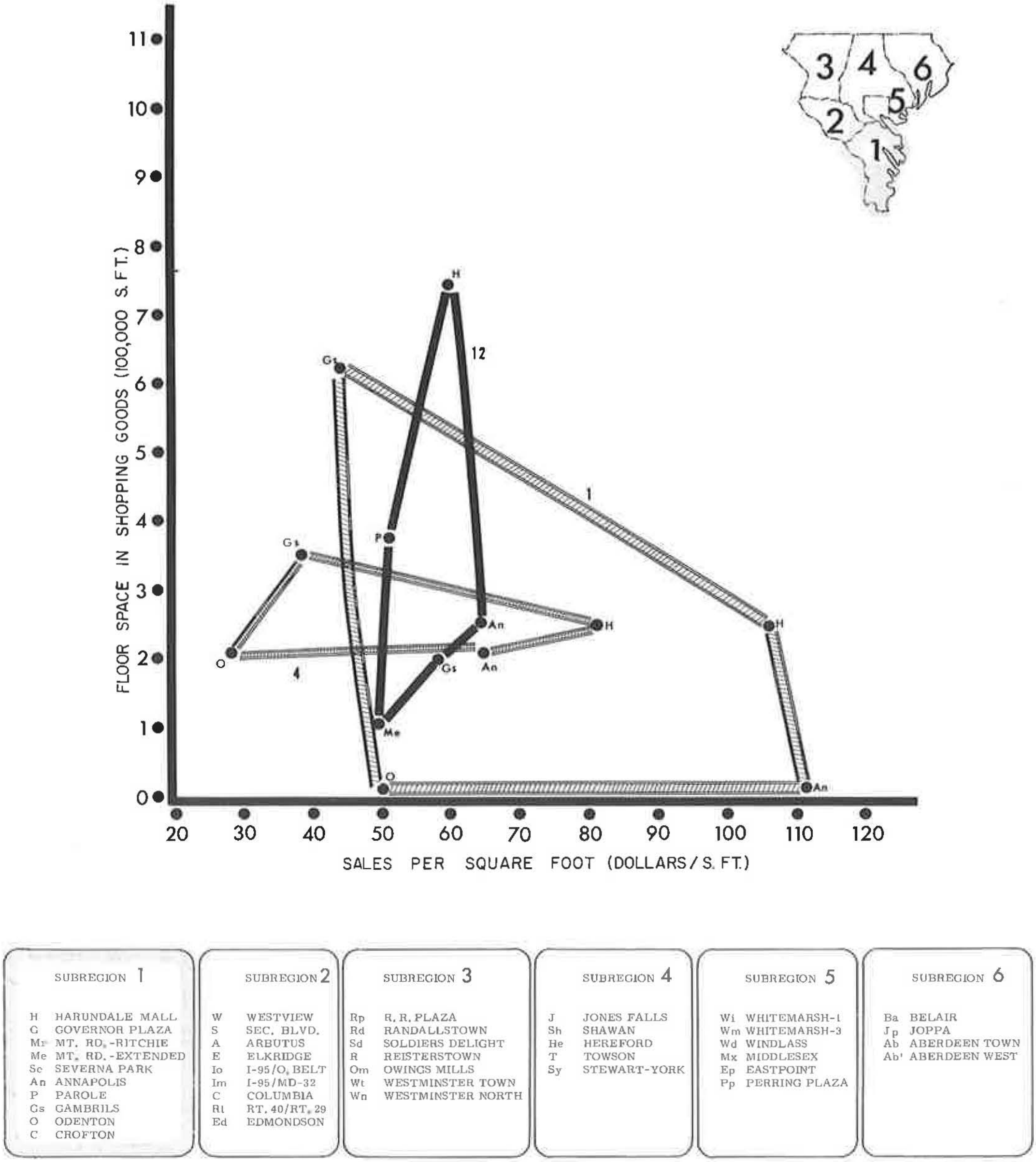

Figure 12. Comparative system performance, subregion 1, 1970.

4 is striking. If a center such as Odenton could generate only very low sales, it would either not be built or it would go out of business. If a center such as Harundale generated more than \$80/sq ft, either its size would be increased or competition close by would be generated. The market process is more truly indicated by alternative 12, where all the centers have sales ranging from \$43 to \$65/sq ft.

It is of interest to recall that alternatives 1 and 4 were the exploratory alternatives providing poor levels of retail service and high values of average trip length. Alternate 12, on the other hand, provided better retail service and lower trip length.

Evaluation of a similar nature involving the system efficiencies and the probable potential of individual locations was carried out for all locations in all subregions. Out of this evaluation emerged two preferred systems of centers. In terms of the

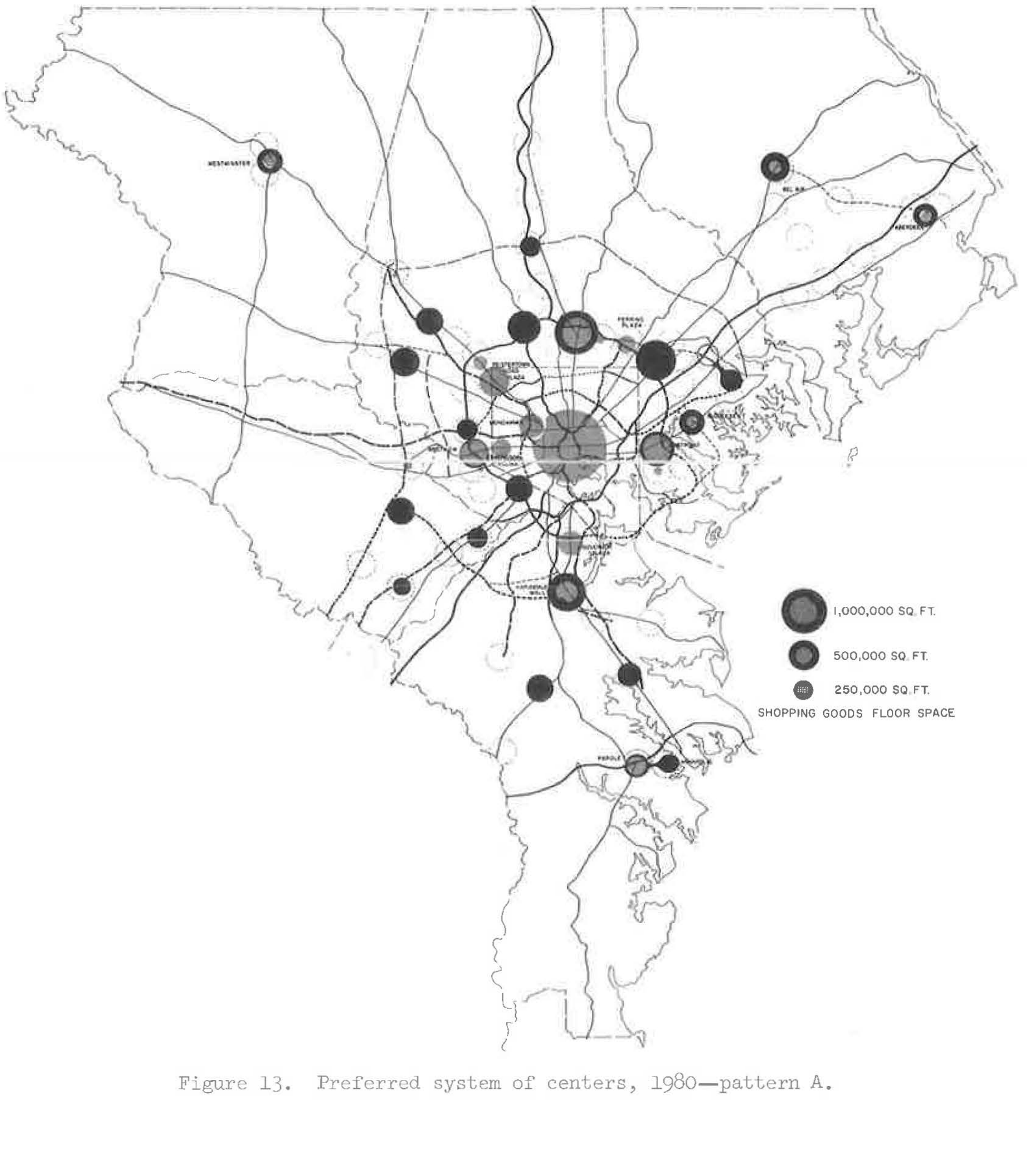

Figure 13. Preferred system of centers, 1980—pattern A.

TABLE 2

PROJECTED GROWTH OF SHOPPING GOODS FLOOR SPACE

Location	1962-1970		1970-1980		Total Growth (%)	
	Million Sq Ft	%	Million Sq Ft	%	1962-70	1970-80
Inner belt	1.90	50	1.04	26	66	34
Outer belt	1.36	36	2.44	60	38	62
Satellite comm.	0.54	14	0.56	14	50	50

criteria used, clear preference of one pattern over the other could not be established. Figure 13 represents one of these systems.

Retail Growth Patterns and Implications

The nature of regional commercial growth pattern indicated by the preferred system of centers can be described in two forms.

1. Table 2 provides a statistical summary of commercial growth. The inner belt area is the ring around the inner beltway where most of the present suburban nucleated

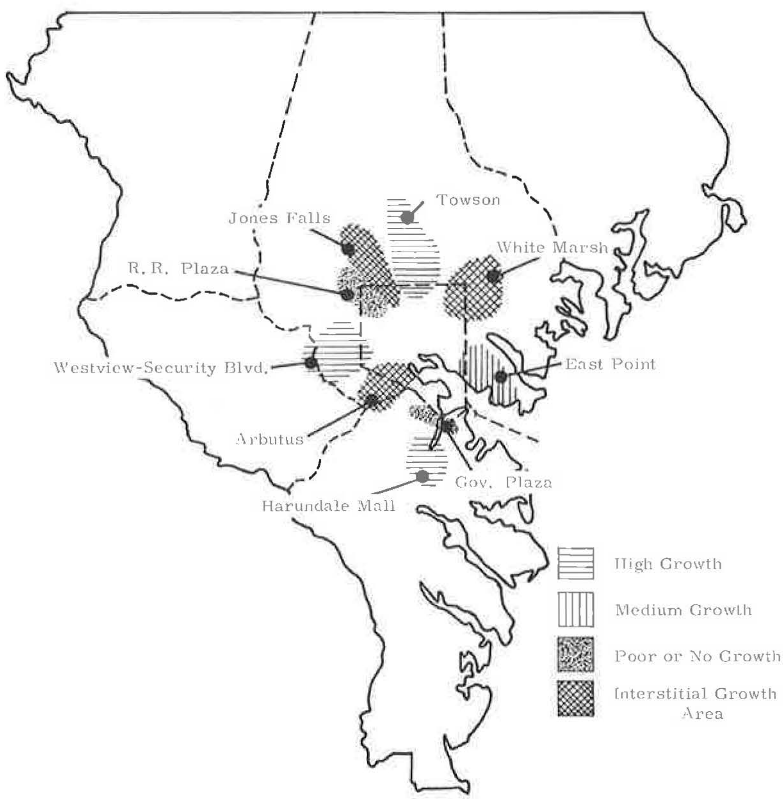

Figure 14. Broad scheme of commercial development, Inner Belt, 1962-80.

shopping centers are located. The outer belt corresponds to the area around the proposed outer beltway and beyond. The satellite communities refer to old established peripheral communities such as Westminster, Belair and Annapolis. It is interesting to note the shifting of the axis of major growth from the inner belt to the outer belt between 1970 and 1980. Up to 1970, the inner belt accounts for half of the total growth, whereas the outer belt is expected to get 60 percent of the next decade's growth. The satellite communities tend to have a constant rate of growth throughout the time period studied, indicating their relative isolation from the wave of metropolitan expansion during this period. Put another way, the inner belt is expected to experience two-thirds of its growth before 1970, whereas the outer belt area will get two-thirds of its growth during the following decade.

2. The patterns of probable retail growth in the belt area have very important sub-regional variations. Figure 14 sketches the growth variations in different segments of the inner beltway area by 1970.

Three of the existing large commercial nucleations—Towson, Harundale Mall, and Westview—have considerable potential growth. One other existing center—East Point—has more moderate growth potential. In addition, three interstitial centers—Whitemarsh I, Arbutus, and Jones Falls area—hold out great possibilities of growth. Two existing centers—Governor Plaza and Reisterstown Road Plaza—in this area appear to suffer from poor location or slow growth in their markets.

CONCLUSION

It may be recalled that this study was prompted by the desire to test out a key component—large commercial cores—of the multi-use centers envisaged in the metrotown concept. Accordingly, all the locations identified by the Regional Planning Council as potential candidates for metrotown centers were evaluated as to their retail potential. This evaluation, assuming the continuation of existing trends and policies, identified the potential for large-scale retail activity at a number of these locations. In other words, under existing policies, market forces seem to point to retail centers of the scale envisaged in the metrotown concept. (By 1970, nine commercial centers could be cores of metrotown centers, and six more could approach this potential by 1980.) This implies that a key component of the metrotown center appears to be consistent with the operation of urban growth processes.

The market potential model, though developed in response to a specific planning problem, has a more general application. In this study, the continuation of existing land and highway policies was assumed and the evaluation criteria were relevant to the needs of a "new town" retail core. The model can be equally well applied with different assumptions of metropolitan policies and various evaluative criteria related to other forms of commercial organization. The estimating procedures are fully computerized and compatible with data being produced by the metropolitan studies under way in many American cities.

ACKNOWLEDGMENTS

The study reported in this paper was undertaken by Alan M. Voorhees and associates, Inc., for the Regional Planning Council, Baltimore, Md., as one of a series of related studies carried out by the Council over the last few years on the investigation of regional development forms. This study was made possible by the generous help and constant encouragement of the staff of the Regional Planning Council. The authors take this opportunity to acknowledge gratefully this debt, particularly to W. Wilson Horst, S. Thyagarajan and John Backer.

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Two Multiple Regression Models of Small-Area Population Change

CHARLES H. GRAVES
Planning Consultant, Puget Sound Regional Transportation Study, Seattle

•IN THE last few years increased attention has been given to the development of models which explain the spatial distribution of population within an urban region. Models have been constructed utilizing multiple regression, linear and nonlinear programming, dynamic programming, calculus, and probability theory (1, 2). The impetus for this research activity has come largely from improvements in computer technology, from regional transportation studies requiring small-area population forecasts to carry out travel forecasting procedures, and from community renewal programs concerned with plans for small areas. A challenge in building models of population distribution designed to be applied to travel forecasting comes from the very small size of the forecast areas, which typically range from several square blocks to a few square miles. A very sensitive model is required to allocate population change accurately to such small areas.

DEVELOPMENT AND TESTING OF MODELS

This paper describes the development and testing of two linear multiple regression models used to explain and to predict the distribution of population change in small areas inside the Puget Sound region. One model was developed to explain population growth and another to explain population decline. The specific objective of the construction of the population models was to discover the relative influence of certain factors hypothesized to have influenced the distribution of population change in the Puget Sound region during the decade of 1950 to 1960.

The linear multiple regression model took the form:

$$Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 \ldots\ldots$$

where

Y = index of population change,
a = constant (intercept),
$b_1, b_2, b_3 \ldots$ = the regression coefficients, and
$X_1, X_2, X_3 \ldots$ = independent variables hypothesized to have influenced the distribution of population change.

Eleven independent variables were hypothesized as determinants of population change: (a) accessibility to employment, (b) logarithm of accessibility to employment, (c) land availability, (d) size of land parcels under single ownership, (e) income level of resident population, (f) occupation index of resident population, (g) combination of income and occupation, (h) age of housing, (i) condition of housing, (j) combination of age and condition of housing, and (k) lot size permitted by zoning.

Area Studied in Model Development

Population change from 1950 to 1960 was used as the basis for developing the regression models. Census tracts were selected as the basic areal unit, since they represent a unit for which considerable data are available from which to measure many

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of the independent variables, and because they provided the only reliable source of information for the basic dependent variable, population change between 1950 and 1960.

Tracts which showed population growth, located primarily outside central cities, were studied separately from declining tracts located within the central area of Tacoma because it was believed that a separate set of residential location factors operate on declining areas compared to growing areas, and because of computational advantages. Data were not available for tracts which did not have comparable boundaries in 1950 and 1960. Therefore, these tracts were excluded from the study. A set of 74 tracts exhibiting population growth and 17 tracts of population decline were selected for regression analysis. Figure 1 shows their location. The population change in these tracts represented about one-half of the total population change between 1950 and 1960 in the Puget Sound study area.

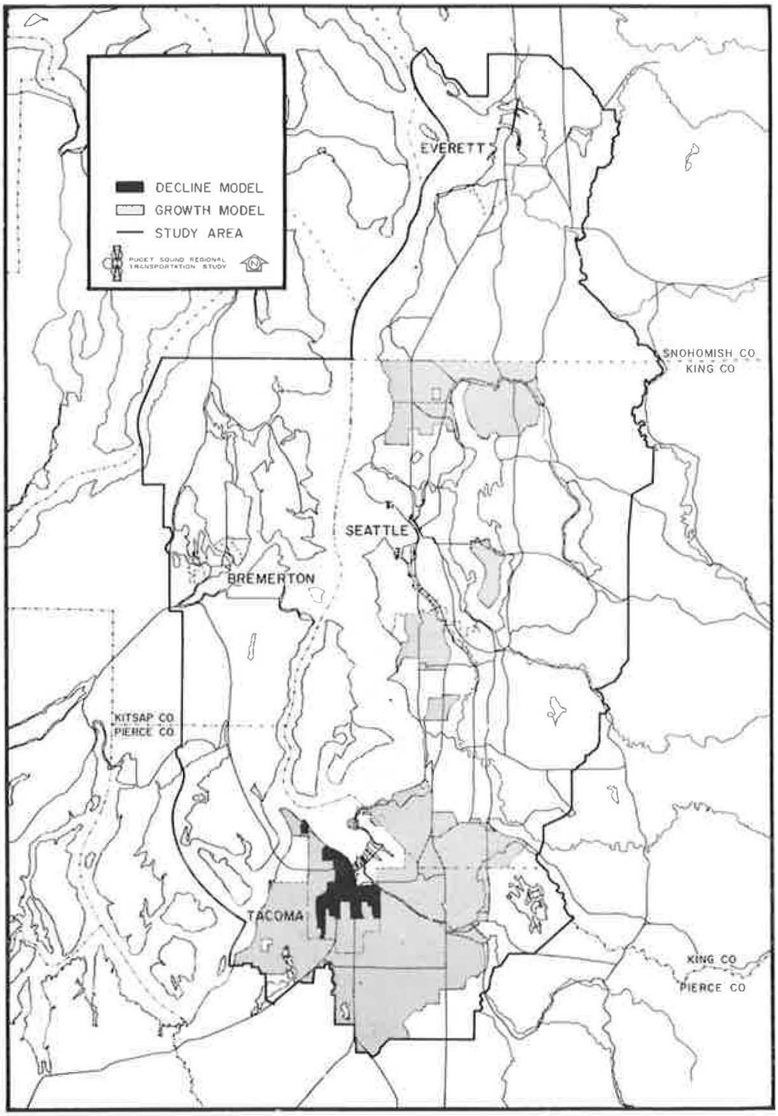

Figure 1. Location of census tract test areas, population model.

Definition of Variables and Their Logic

Six variations of the dependent variable, population change between 1950 and 1960, were chosen for study:

1. Total population change;
2. Ratio of actual to hypothetical total population change;
3. Ratio of actual to hypothetical change in number of single-family dwelling units;
4. Logarithmic transformation of 1;
5. Logarithmic transformation of 2; and
6. Logarithmic transformation of 3.

Variable 1 is a straightforward statement of the dependent variable. Variable 2 is the ratio of the actual to hypothetical population change, where the hypothetical change is that which would have resulted if residential land availability were the only determinant. For example, if a study tract had 10 percent of the additional land available in the area studied, then the hypothetical change was assumed to be 10 percent of the total population change in the area. An attempt was then made to explain the difference between the actual and the hypothetical change by regression against independent variables other than land availability. Dependent variable 3, the ratio of the actual to a hypothetical change in the number of single-family dwelling units, was tested to see if a better model could be built for low-density population than for population as a whole. The hypothetical change was analogous to that developed for variable 2. Dependent variables 4, 5, and 6 are common logarithmic transformations of variables 1, 2, and 3.

The independent variables selected for study were intuitively believed to determine the spatial distribution of population. The independent variables were limited to those which had an intuitive basis to safeguard against the risk of finding specious correlations.

The following eleven independent variables were tested:

1. Accessibility to Employment—Accessibility to employment measures the collective desire on the part of people to locate their residences in relation to employment so as to minimize their work trips, and also their desire to minimize transportation costs to the whole range of urban activities such as shopping centers and office complexes which are also represented by employment. Accessibility to employment was computed over the 1961 highway network to 1961 employment using a gravity-type formula:

$$A = \frac{S_1}{T_{1-1}{}^X} + \frac{S_2}{T_{1-2}{}^X} \cdots \frac{S_n}{T_{1-n}{}^X}$$

where

A_1 = index of accessibility of zone 1 to employment in all other zones,

S_1 = number of employees in zone 1,

T_{1-2} = travel time (including terminal time) between zones 1 and 2, and

X = exponent representing tripmakers' resistance to distance.

A travel time exponent of 2 was used. Employment data used in the equation were derived from 1961 first work trip information collected as a part of the study's origin-and-destination survey. Travel time was computed over the 1961 highway network. The equation produced values representing 1961 accessibility. Independent variables, however, must be considered to be operating at the beginning of the study period, in this case 1950. Travel time and employment data for 1950 were not available and, therefore, it was necessary to assume that 1961 and 1950 values were relatively the same. This probably is a reasonable assumption since the pattern of employment in the Puget Sound area did not change much between 1950 and 1960, and transportation improvements tended to be minor and scattered.

2. Logarithm of Accessibility to Employment—Accessibility to employment was transformed to its common logarithm to replicate Hansen's regression analysis (3).

3. Vacant Residential Land Available—Land availability was defined as the additional holding capacity of land in 1950. Holding capacity was derived from the measurement of the amount of vacant, developable land in 1960. This was defined as vacant land zoned for residences or unzoned, less deductions for the areas of excessive slopes, poor soils, floodplains, and public ownership. Land area was converted to 1960 holding capacity using a density factor derived from the density permitted by zoning and data on average lot sizes. Holding capacity in 1960 was converted to 1950 capacity by adding population change between 1950 and 1960. The logic behind the test of this variable is simply that the chance for residential development increases as the amount of available land increases.

4. Size of Land Parcels in Single Ownership or Control—This variable was defined using land availability as a proxy since it was not feasible to collect actual data about ownership sizes from assessors' or other records.

5, 6, and 7. Income, Occupation, and Their Combinations—An index of income and occupation in 1950 was developed from U. S. Census data. The index of median income of families and related individuals for each of the census tracts being studied was defined as the ratio of the median income of that tract to the median income of the Standard Metropolitan Statistical Area. The occupation index was defined as the ratio of white-collar workers to all workers. White-collar was defined as professional, technical, and kindred workers; managers, officers, and proprietors; salesworkers; and craftsmen, foremen, and kindred workers. It was intended to let income or occupation, or both combined, stand for the relative prestige of the tract. The logic behind the test of prestige as a determinant of population distribution is that many people desire to move upward on the prestige scale through the choice of their residential location. High-income, white-collar families are particularly mobile and their movement may in turn attract other lower income and occupation groups. Thus, prestige areas tend to "trigger" new development. Income and occupation indexes were tested separately and in combination on the theory that both are components of prestige.

8, 9, and 10. Age and Condition of Housing and Their Combination—The age of housing was defined as the ratio of housing built before 1929 to total units in 1950, using 1950 census data. Housing condition was defined as the ratio of unsound to total housing units in 1950. It was expected that these variables would be negatively correlated with population growth because the existence of old or unsound housing should have a depressing effect on the area's attractiveness for growth, particularly in a period of rising incomes.

11. Average Net Lot Size—This variable was defined as the average net lot size for single-family units permitted by zoning. It tests the theory that the market demands smaller lot sizes than generally permitted by zoning.

Equations Tested and Analysis

Simple correlation and linear multiple regression analysis were used to select combinations of variables which statistically best explained population growth and decline. The best combination was defined as the set of independent variables whose simple correlations were in the direction hypothesized when regressed against the dependent variables, and which maximized the proportion of explained variance, R^2, subject to satisfactory confidence levels (1 percent or better). An attempt was made to avoid testing interlinked independent variables in the same equation. Two series of equations were tested, one to explain population growth and another to explain population decline.

1. Population Growth Model—The number of observations in the population growth model was 74. Table 1 gives the simple correlations between all of the variables tested. The direction of correlation hypothesized for the independent variables was

TABLE 1

POPULATION GROWTH MODEL: SIMPLE CORRELATIONS

INDEPENDENT VARIABLES	DEPENDENT VARIABLES								INDEPENDENT VARIABLES										
	Direction Hypothesized	Population Change	Actual/Hypothetical Total Population Change	Actual/Hypothetical Single Family Dwelling Unit Change	Logarithm of Population Change	Logarithm of Actual/Hypothetical Total Population Change	Logarithm Actual/Hypothetical Single Family Dwelling Unit Change	Accessibility to Employment	Logarithm of Accessibility	Land Availability	Land Ownership	Income	Occupation	Income & Occupation	Age of Housing	Condition of Housing	Age and Condition
Accessibility to Employment	+	*-.02	.41	.16	.11	.50	.45										
Logarithm of Accessibility	+	*-.01	.48	.19	.11	.56	.52	.98									
Land Availability	-	*.28	-.49	-.31	*.23	-.64	-.56	-.42	-.49								
Land Ownership	-	*.28	-.49	-.31	*.23	-.64	-.56	-.42	-.49	1.00							
Income	+	.27	.52	.17	.25	.55	.47	.43	.48	-.24	-.24						
Occupation	+	.32	.34	.02	.41	.36	.26	.28	.32	-.08	-.08	.38					
Income and Occupation	+	.33	.54	.14	.36	.57	.47	.45	.50	-.22	-.22	.93	.69				
Age of Housing	-	-.34	-.18	*.22	-.54	-.25	-.05	-.48	-.45	-.01	-.01	-.32	-.49	-.44			
Condition of Housing	-	-.15	-.45	-.27	-.15	-.48	-.47	-.36	-.42	.33	.33	-.33	-.28	-.37	.06		
Age & Condition	-	-.36	-.30	*.13	-.55	-.36	-.17	-.53	-.55	.06	.06	-.45	-.51	-.55	.97	.29	
Lot Size	-	*.16	-.35	-.35	*.25	-.27	-.39	-.25	-.26	.25	.25	-.22	.15	-.11	-.25	.40	-.11

* Not in direction hypothesized

confirmed for the regression of three of the six dependent variables tested. These three variables were (a) the actual to the hypothetical total population change, (b) its logarithmic transformation, and (c) the logarithmic transformation of the actual to the hypothetical change in the number of single-family dwelling units. Table 1 indicates that the regression of the remaining three dependent variables produced some simple correlations in conflict with the hypothesis, casting doubt on their validity.

TABLE 2

POPULATION GROWTH MODEL: REPRESENTATIVE COMBINATIONS OF VARIABLES ANALYZED BY MULTIPLE REGRESSION

	Equation No.	#1		#2		#3		#4		#5		#6		#7		#8		#9	
	Variables	S	P	S	P	S	P*	S	P	S	P	S	P	S	P	S	P	S	P
Independent Variables	Accessibility	.21	25			**NS	17			.33	03			NS	00				
	Logarithm of Accessibility			.19	00			.01	06			.01	07			NS	01	.12	01
	Land Available													.01	07	.04	07		
	Land Ownership	NS	17	NS	22	NS	08			NS	02							NS	21
	Income					.01	14			.23	01	.01	22	.01	10	.06	06	.01	30
	Occupation					.05	04			.21	00	.09	03	.25	04	.18	07		
	Income and Occupation	.01	10	.01	18			.01	18										
	Age of Housing					NS	00			.04	07	.05	01	NS	06	NS	10		
	Condition of Housing	NS	09	NS	23	NS	02	NS	17	NS	01	NS	04	NS	03	NS	02	NS	10
	Age & Cond. of Housing																		
	Lot Size	NS	02			NS	04	NS	07	NS	10	NS	09	.23	04	.09	10		
Dependent Variables	Population Change 1950-1960													X					
	Actual/Hypoth. Total Pop. Change					X													
	Actual/Hypoth. Sing. Fam. D. U. Change									X									
	Logarithm of Population Change															X			
	Log. Actual/Hypoth. Total Population Change	X		X				X										X	
	Log. Actual/Hypoth. Single Family D. U. Change											X							
	Coefficient of Determination (R^2)	.6296		.6289		.4989		.4742		.2334		.4673		.3407		.4436		.6141	
	Significance Level (F test)	.01		.01		.01		.01		.05		.01		.01		.01		.01	

*S = Significance Level (t test) and P = Proportion of explained variance

**NS = Not Significant X = Indicates Dependent Variable

The correlations between independent variables are not high enough to indicate substantial interdependence, except where one variable is a combination of two, as one would expect. Factor analysis could be used to test for interdependence.

Table 2 sets out a few of the combinations of variables analyzed by multiple regression using a BIMD 06 program (4). Table 2 also shows for these equations the coefficient of determination, R^2, and significance level, and for each independent variable the proportion of variance explained and significance level. The regression of population change and the change in the number of single-family dwelling units, and their logarithmic transformations, did not meet the R^2 and significance level criteria as well as the dependent variable actual to the hypothetical population change and its logarithmic transformation.

Equation 01 was selected as best because it exhibited a high R^2 and satisfactory significance level; it contained a larger number of independent variables than its close competitors.

Of the 11 independent variables tested, six were discarded and five retained. The five variables retained were (a) access to employment, (b) income and occupation combined, (c) housing condition, (d) lot size, and (e) size of land parcels under single control.

Figures 2 and 3 show the distribution of actual population growth in the selected study tracts between 1950 and 1960 vs the growth estimated by the model. The model explains approximately 63 percent of the variance in population growth.

2. Population Decline Model—Seventeen observations were used to construct the population decline model. The percent of decline in population between 1950 and 1960 was the dependent variable. Seven independent variables were tested. These are the following (with the + and - signs indicating the expected direction of simple correlation): (a) access to employment (-), (b) income level of resident population (-), (c) occupation index of resident population (-), (d) age of housing (+), (e) condition of housing (+), (f) combination of income and occupation (-), and (g) combination of age and condition of housing (+). These variables were defined the same as for the population growth model.

Table 3 gives the simple correlations between all of the variables tested. In the population decline model the hypothesized direction of correlation was confirmed except for age of housing. This variable was, therefore, eliminated from further analysis. No substantial interdependence of variables was indicated, although a factor analysis was not performed to test for interdependence.

Table 4 gives the combinations of variables analyzed; their coefficients of determination, R^2; significance level; and for each independent variable, the proportion of variance explained and the significance level. Eq. 4 appears to be best because of its high R^2 and satisfactory significance level.

Figure 3 indicates the distribution of the actual percent of population decline between 1950 and 1960 vs the decline estimated by the model. About 81 percent of the population decline is explained by the model.

Use of Models to Make Population Distribution Forecasts

The population growth and the population decline models were used to distribute the forecasted 1961 to 1985 study area population change to nearly 600 analysis zones in the region. For analysis zones in areas which grew between 1950 and 1960 the following steps were taken:

1. Values for the independent variables were determined for each analysis zone.
2. These values were substituted into the best equation to give, for each of the population growth zones, the logarithm of the ratio of actual to hypothetical growth. (Hypothetical growth was defined as that which would take place if the capacity of available residential land were the only determinant.)
3. These logarithms were then transformed to numbers and multiplied by the capacity of the available residential land. This produced a growth index for each zone.

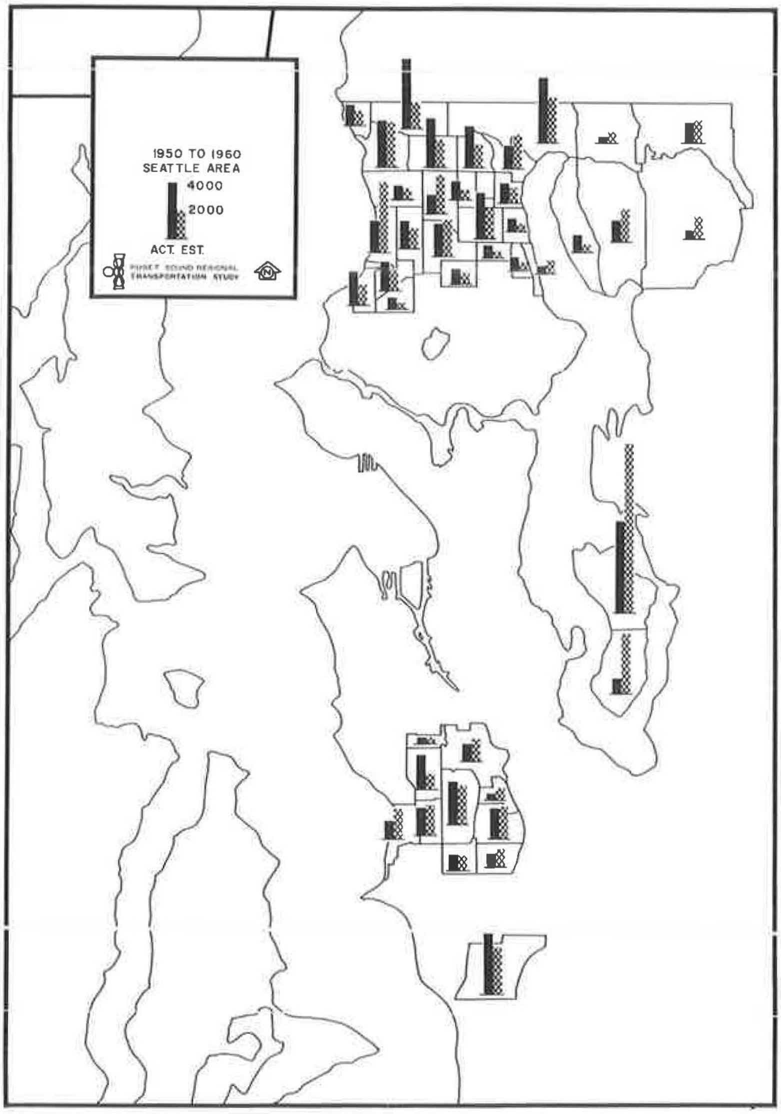

Figure 2. Actual vs estimated change, population models, Seattle area.

4. The 1961 to 1985 population change control totals by county in the study area were distributed to analysis zones by prorating according to the size of the computed growth index.

5. The population distributions to each analysis zone were then checked to assure that they did not exceed the holding capacity of the zones. If the distribution had, in fact, exceeded the holding capacity, the population excess was removed, the zones which were filled to capacity were removed from the group of zones eligible to receive population, and the sum of the excesses was redistributed by repeating Step 4.

The distribution procedure can be stated mathematically as:

$$\frac{P_1}{P_t} = \frac{R_1 AC_1}{R_1 AC_1 + R_2 AC_2 \ldots R_n AC_n}$$

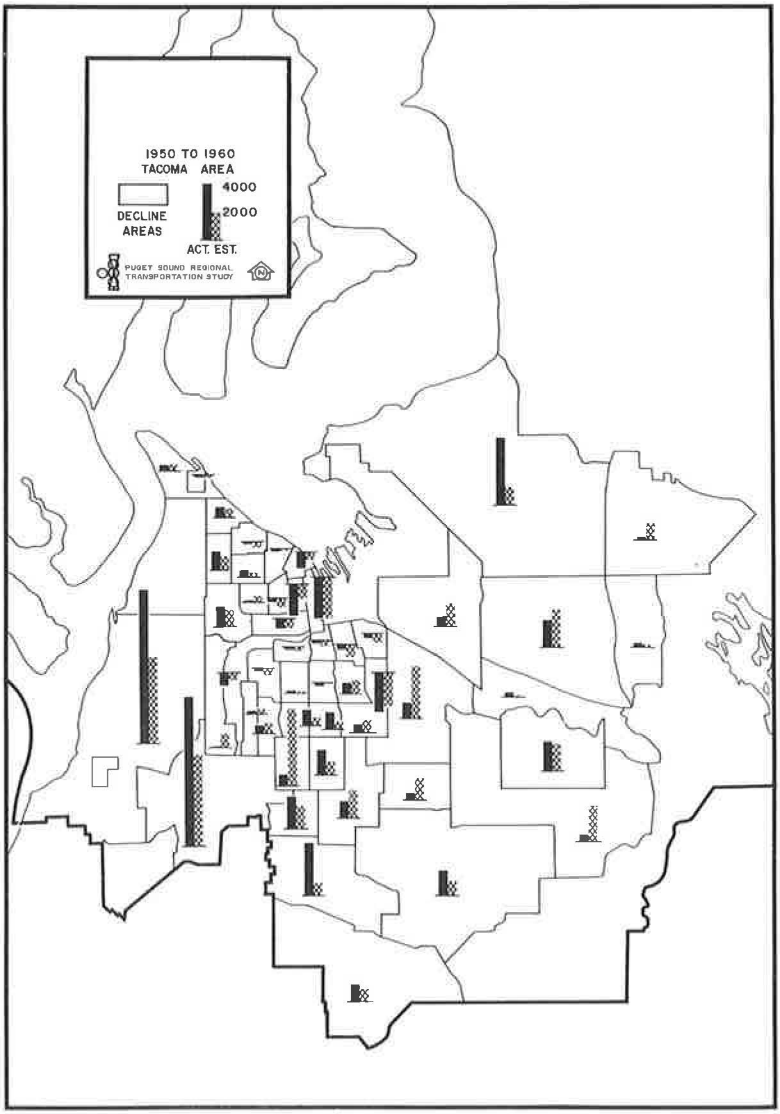

Figure 3. Actual vs estimated change, population models, Tacoma area.

where

P_1 = population change forecast for zone 1 (subject to a holding capacity restraint),
P_t = total population change forecast for the county,
R = ratio of actual to hypothetical change, and
AC = additional holding capacity of developable residential land.

For analysis zones in areas of population decline between 1950 and 1960 the following steps were taken:

1. Values of independent variables were determined for each analysis zone.
2. These values were substituted in the best equation to give for each declining zone the percent decline for a 10-yr period.

TABLE 3

POPULATION DECLINE MODEL: SIMPLE CORRELATIONS

		Direction Hypothesized	% Population Decline 1950-1960	Independent Variables: Access	Income	Lot Size	Occupation	Age of Housing	Condition of Housing	Income-Occupation Combined
	% Population Decrease 1950-1960									
Independent Variables	Access	-	-.05							
	Income		.83	.31						
	Lot Size	+	*-.21	-.38	.30					
	Occupation	-	-.58	-.22	.76	-.02				
	Age of Housing	+	*-.13	.40	-.07	-.65	.22			
	Condition of Housing	+	.63	.02	-.59	-.21	-.46	.34		
	Income-Occupation Combined	-	-.78	-.29	.97	.19	.90	.04	-.57	
	Age-Condition Combined	+	.03	.36	-.21	-.64	.09	.97	.54	-.10

* Not in direction hypothesized

3. The percentages were applied to the 1961 base population to produce a set of estimates of population decline. The total population decline was not set in advance but was aggregated from the results of determining the decline for individual zones.

EVALUATION OF MULTIPLE REGRESSION MODELS AND THEIR APPLICATION TO FORECASTING

This section sets forth some of the advantages and problems associated with the development and use of multiple regression models, and suggests certain avenues of further research. Also, a question is raised concerning the application of the models to forecasting procedures.

TABLE 4

POPULATION DECLINE MODEL: REPRESENTATIVE COMBINATIONS OF VARIABLES ANALYZED BY MULTIPLE REGRESSION

Equation No. / Variables	#1 S	#1 P	#2 S	#2 P	#3 S	#3 P	#4 S	#4 P	#5 S	#5 P
Access							NS	.00	NS	.00
Income	NS	.68	NS	.68			NS	.78		
Occupation			.29	.01			.25	.01		
Condition of Housing	.11	.03	.12	.03	.09	.39	.20	.01	.15	.39
Income-Occupation Combined					NS	.26			NS	.32
% Population Decline	X		X		X		X		X	
R^2	.71		.72		.65		.81		.72	
Significance Level (F)	.01		.01		.01		.01		.01	

S = Significance Level (t Test)
P = Proportion of Explained Variance
NS = Not Significant
X = Dependent Variable

Advantages of Use of Multiple Regression Models

One advantage can be associated with the use of multiple regression to construct population models, as follows:

The multiple regression models in the simple form described in this paper are an operational technique. This quality is important to operating agencies which usually must produce work against severe time and budget limitations. The models described in this paper utilize, for the most part, efficient package programs available from the U. S. Bureau of Public Roads and from the SHARE and BIMD libraries. These package programs keep programming costs low.

The models described in this report share several advantages with some other types of land-use models:

1. Replication or easy updating is possible because all parameters are made explicit.
2. Staff personnel from several agencies can work simultaneously on data collection and model building. Such a joint staff effort encourages effective interagency cooperation.
3. The use of a model and associated computer technology lends an aura of sophistication and correctness to the work, thus facilitating public acceptance of the results.
4. Perhaps the most important advantage of the model is its capacity for projecting population distributions according to novel policy constraints such as those imposed by a regional plan. When an assumption is made of a continuation of past trends and present policies, forecasts produced by handicraft methods based on intuition and experience perhaps may be as accurate as those produced by models. However, when radical or novel assumptions are made about land use, open space and land-use control policies, intuition gained from past experience may not be applicable. When factors, such as the holding capacity permitted by zoning and accessibility to employment over an assumed transportation network, are made explicit parts of a model, these factors can be defined and measured to reflect novel public policies with respect to zoning, employment distributions, and transportation networks. For example, the impact of a proposed bridge or rapid transit system could be translated into accessibility changes which, in turn, could be used to determine the impact of these planned improvements on the population and employment distributions. Similarly, a substantial open space program affects the additional holding capacity of developable residential land, which is one of the independent variables influencing population distributions in the models described in this paper.

Problems with Development of Multiple Regression Models

Certain problems attended the development of the models:

1. One problem is the lack of data or difficulty in developing data. For example, comparable census data were not available for a substantial portion of the study area since it was not tracted by the U. S. Census in 1950. This is likely to be a problem in other urban areas. The accessibility computations require the collection of large amounts of data about employment distributions and operating characteristics of the transportation network which are costly to collect. Regional transportation studies are the only organizations which routinely collect this information.
2. Variables, such as prestige and size of land parcels under single ownership, are difficult to define in a way which accurately reflects the variable to be tested and at the same time permits ease of measurement.
3. Certain problems are presented by the use of multiple regression analysis to develop models. For example, a linear relationship between dependent and independent variables is assumed, there is a danger of interdependence of variables, and the possibility of specious correlations is always present.

Areas for Further Research

Further research may result in improvements in the models described in this paper.

1. Additional variables should be considered for further tests, such as levels of school, sewer, water and gas service; relative tax rates; building code stringency; land value; view amenity; distance from nearest built-up area; and percent built up at the beginning of the study period.

Carroll has tested a promising set of variables with data for the central cities of Minneapolis and St. Paul (5). The dependent variable is percent population change by tract. Independent variables include relative income, percent of dwelling units owner occupied, condition of residential structure, percent of male employed persons in the professional and managerial groups, percent of persons 0 to 19 yr of age, median age of males, average age of structure, relative monthly contract rent, number of persons per room, percent of total dwelling units built in the previous decade, acres of vacant residential land and percent of total dwelling units which are single family. The results of this analysis have not been published. Other variables have been tested by Chapin and Weiss (6). These include marginal land not in urban use, travel distance to the nearest major street, proximity to nonwhite areas, proximity to blighted areas, total travel distance to the high-value corner, proximity to mixed uses, distance to the nearest playground or recreation area, distance to the nearest convenience shopping area, and residential amenity. All of the foregoing variables warrant investigation.

2. The selection of variables would be facilitated by behavioral studies of what motivates the location of homes and employment centers.
3. The systematic mapping of the unexplained variances from regression analysis might uncover additional variables which merit testing (7).
4. Factor analysis should be applied to test for interdependence of variables.
5. Cross-validation should be performed by randomly selecting one-half of the study tracts, constructing a regression equation and predicting the other half, and vice versa.
6. The models should be tested with data from a larger portion of the study area for which a forecast is desired.
7. It might be desirable to build separate models for various parts of the region, such as the central city, suburbia, and exurbia.
8. The equations developed for the Puget Sound region should be tested against data from other regions to determine their universality.
9. Population should be disaggregated by structure type, in a different way than was attempted here, or disaggregated by race, income and other factors.
10. It might be fruitful to experiment with a series of models which explain the migration of population between small zones inside an urban region rather than dealing only with net incremental values.

Problems in the Application of the Model to Forecasting Procedures

Two problems arise in the application of models to long forecast periods in a single step:

1. Values at the beginning of the forecast period should be used for the independent variables but these values can be expected to change over time. The use of a series of short forecast periods rather than one long period permits the values of the independent variables to be updated.
2. The relative weights of the independent variables may be changing over time. The direction and rate of change might be estimated by regressing a set of independent variables against population change for a series of time periods in the past. For example, equations could be constructed to explain population change for 1930 to 1940, 1940 to 1950, and 1950 to 1960. Such an analysis would require historical data which would be costly, difficult, or even impossible to collect.

SUMMARY

This paper has reported the results of research to build two multiple regression models of small-area population change using data from the Puget Sound area. Although the statistical measures of the sensitivity of the models are not very impressive, they produced 1985 forecasts which appeared very good when reviewed by professional planners and engineers familiar with the area's population growth.

A significant advantage in the use of multiple regression as a technique is that it is operational. Another significant advantage of the Puget Sound model, shared by some other models, is its ability to estimate the effect on population distribution of radical or novel land-use and transportation policies.

Finally, there are good prospects for improving the model by carrying out further research along the lines suggested in this paper.

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Opportunity-Accessibility Model for Allocating Regional Growth

GEORGE T. LATHROP, JOHN R. HAMBURG, and G. FREDERICK YOUNG
New York State Department of Public Works

•SYSTEMATIC and comprehensive transportation planning has come to depend more and more on objective techniques involving the use of high-speed computers to deal with problems of data processing, data analysis, traffic simulation, and network evaluation. The selection and design of multimillion dollar transportation plans depend on the simultaneous evaluation of many diverse factors including traffic volumes, operating costs, construction costs, land costs, accident characteristics, and travel costs of thousands of transportation links and population numbering up to and beyond the millions. Subjective evaluations and intuitive speculations have come to play a much smaller role in planning transportation systems.

This trend is also apparent in city and regional planning. Although it is clear that design and aesthetic characteristics have a tremendously important role to play in planning cities of the future, it is also equally clear that the analysis and manipulation of the massive details that make up a functioning city of a million inhabitants require computer technology. Nowhere is this more apparent than in the estimation of the land and transportation requirements for a metropolitan region at a point in time of 20 to 25 years in the future.

The development of the model described in this paper is based on an attempt to bring into an objective framework methods and concepts which have been commonplace in planning for several years, but whose applications have most often been subjective and have defied replication by other professionals. The notions of holding capacity, access, density, etc., are not new. The manual application of these concepts by small geographic areas has been too often a subjective and, at times, an irrational process.

The reader is cautioned that there are both empirical and theoretical shortcomings in the model as it now exists. The model, however, does incorporate some of the more significant factors thought to be associated with the growth and functioning of urban regions into a flexible program which produces spatial arrangements corresponding quite closely to observed patterns. To the extent that it simulates urban growth, the model is extremely useful in providing the measured statements necessary to the planning of transportation facilities.

The model has been developed and is being tested by the Subdivision of Transportation Planning and Programming group. Its purpose is to allocate future estimates of activities (expressed in this instance in the form of trip destinations) to small geographic areas (travel analysis zones). This geographic allocation, in turn, is the input to the traffic assignment model which is used in the testing, evaluation, and design of alternative systems of transportation facilities.

The model leans heavily on the work of Schneider in trip distribution. Previous work in land-use models has also been of immeasurable value in design and development. The number of sources and references is too great to allow individual acknowledgment; however, some should be mentioned. Excellent reviews of literature and current thought in land-use modeling are contained in a special issue of the Journal of the American Institute of Planners, edited by Voorhees (1) (and particularly in his introductory report) and also in an article by Chapin (2). The recent report on current land-use models prepared by the Traffic Research Corp. for the Boston Regional

Paper sponsored by Committee on Land Use Evaluation.

Planning Project also provides coverage of work in progress at the time of its issue. More recently, the following significant seminars pertinent to the subject have been conducted: Seminar on Models of Land Use Development at the Institute for Urban Studies, University of Pennsylvania, Oct. 22-24, 1964; the Second Annual Conference on Urban Planning Information Systems and Programs, the Institute of Local Government and the Knowledge Availability Systems Center, the University of Pittsburgh, Sept. 24-26, 1964; and the meeting of the Committee on Land Use Evaluation of HRB, Nov. 23, 1964.

Although the authors are grateful for the contributions others have made, they accept full responsibility for any of the model's theoretical and practical shortcomings.

CONCEPT OF THE MODEL

The model is an opportunity model. In essence, the spatial distribution of an activity is viewed as the successive evaluation of alternative opportunities for sites which are rank ordered in time from an urban center. Opportunities are defined as the product of available land and density of activity (units of activity per unit area of land):

$$A_j = A\left[e^{-\ell O} - e^{-\ell(O + O_j)}\right]$$

where

- A_j = amount of activity to be allocated to zone j,
- A = aggregate amount of activity to be allocated,
- ℓ = probability of a unit of activity being sited at a given opportunity,
- O = opportunities for siting a unit of activity rank ordered by access value and preceding zone j, and
- O_j = opportunities in zone j.

Clearly, the use of the negative exponential formulation following an access search across an opportunity surface presumes that the settlement rate per unit of opportunity is highest at the point of maximum access or, most usually, the center of a region. This presumption is elementary and agrees well with both empirical observations and the bulk of the theory dealing with the economics of land use.

An example of the empirical relationship was observed in the Niagara Frontier. Figures 1 and 2 illustrate the regularity of the relationship between activity and opportunities for siting that activity when arranged in access (minimum time path value) order. These curves translated to the probability statement form the basis for the model.

Notion of Opportunities

The concept of an opportunity for siting a unit of activity involves both land and a measure of the intensity of use of that land. Land-use intensity or density has been treated as an equilibrium of the price of land and transport costs.

An historical analysis of density must consider changing transportation costs, changing building costs with particular emphasis on the costs of first floor area vs multistoried floor area, and changing requirements or preferences for location among competing activities. In addition to the difficulties that these considerations impose, there is the problem of structural rigidity of the physical region in terms of buildings and transportation facilities. These represent substantial investments which change only slowly.

Largely because of the difficulties involved in simulating the intensity of land use, we have chosen to utilize the present density as an appropriate measure which is independently introduced into the model. This independence allows the use of alternative densities whether analytically derived, guessed, or planned. We would naturally prefer to have these values generated with the model utilizing an algorithm which

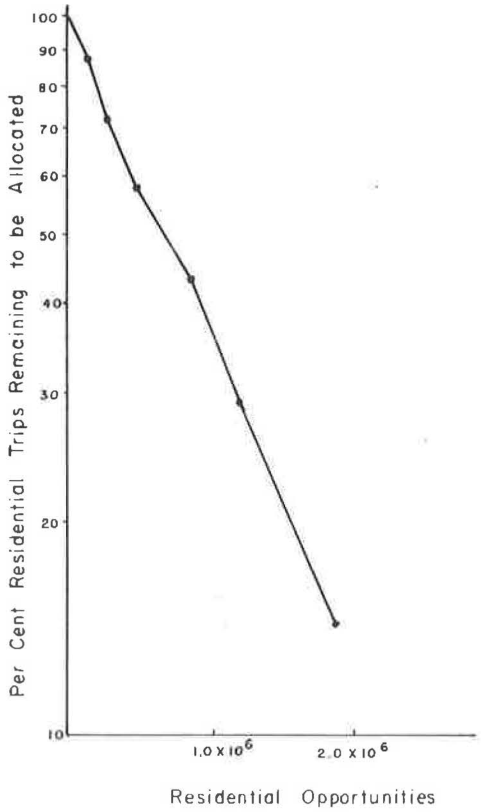

Figure 1.

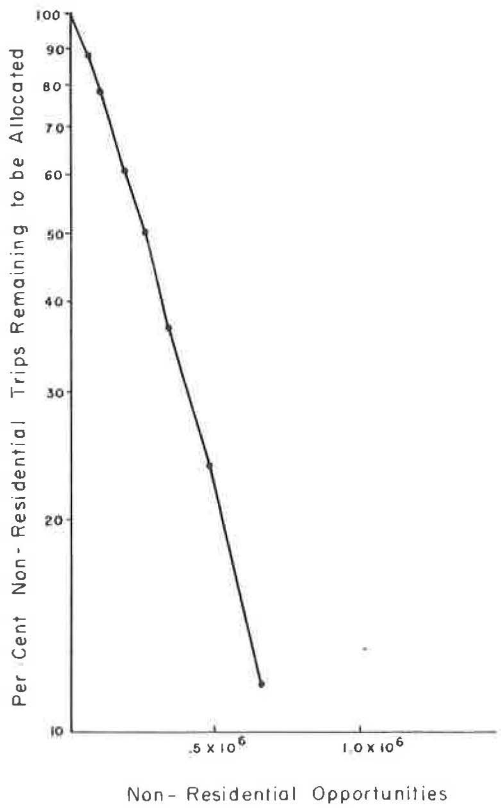

Figure 2.

would simulate the competitive processes that establish land-use intensity. This remains as an area to be resolved in future work on the model.

Notion of Probability of Siting

The parameter ℓ is the probability that a unit of activity will settle or be sited at a unit opportunity. For a given surface of opportunities, the larger this value, the more tightly packed the region will be. The smaller the value of ℓ, the more scattered or sprawling the settlement pattern will be. Thus, it is a measure which describes, within the constraint of the density-land opportunity surface, the relative importance of central positioning within the region.

The model distributes growth increments across an opportunity surface which has been rank ordered by time path value to the center. After each increment of growth is allocated, the available land is reduced by the land required to site the increment of activity, the opportunity surface is decreased, and the activity inventory by zone is updated. Ignoring for the moment competing activities, the use of an ℓ with large values would tend to settle each unit of activity at the first opportunity encountered. Thus, growth would simply be a process of completely using land in ever-increasing bands of access from the center. Very small values of ℓ, on the other hand, would tend to scatter activity across the region. Although the center would still dominate and act as a center, the pattern of settlement would be very sparse. As ℓ approaches zero, the notion of a region simply disappears.

There appears to be some general historical correspondence to a decreasing ℓ, presumably as a result of changes in the transportation technology (especially the

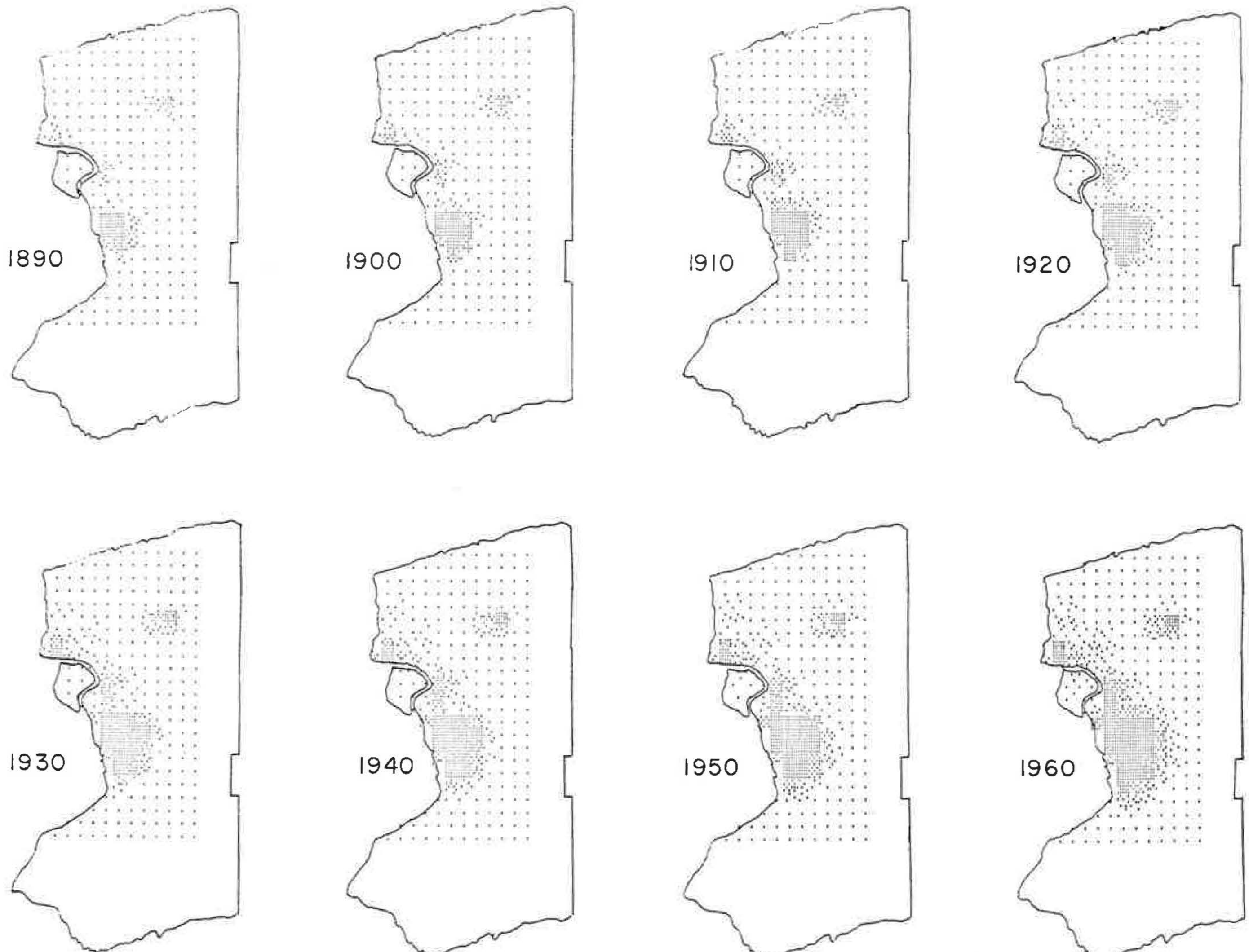

Figure 3. Niagara Frontier population growth simulation with prototype of land-use model.

widespread use of the automobile. Thus, the transition from rural to urban was more abrupt in earlier cities. Land in a given time ring tended to be substantially used up before successive time rings would be settled. Currently, the demarcation is typically in a broad band which may be several miles in width.

An analysis of the Chicago population settlement pattern reveals a lessening of the slope of land saturation at increasing distances from the Loop through time.

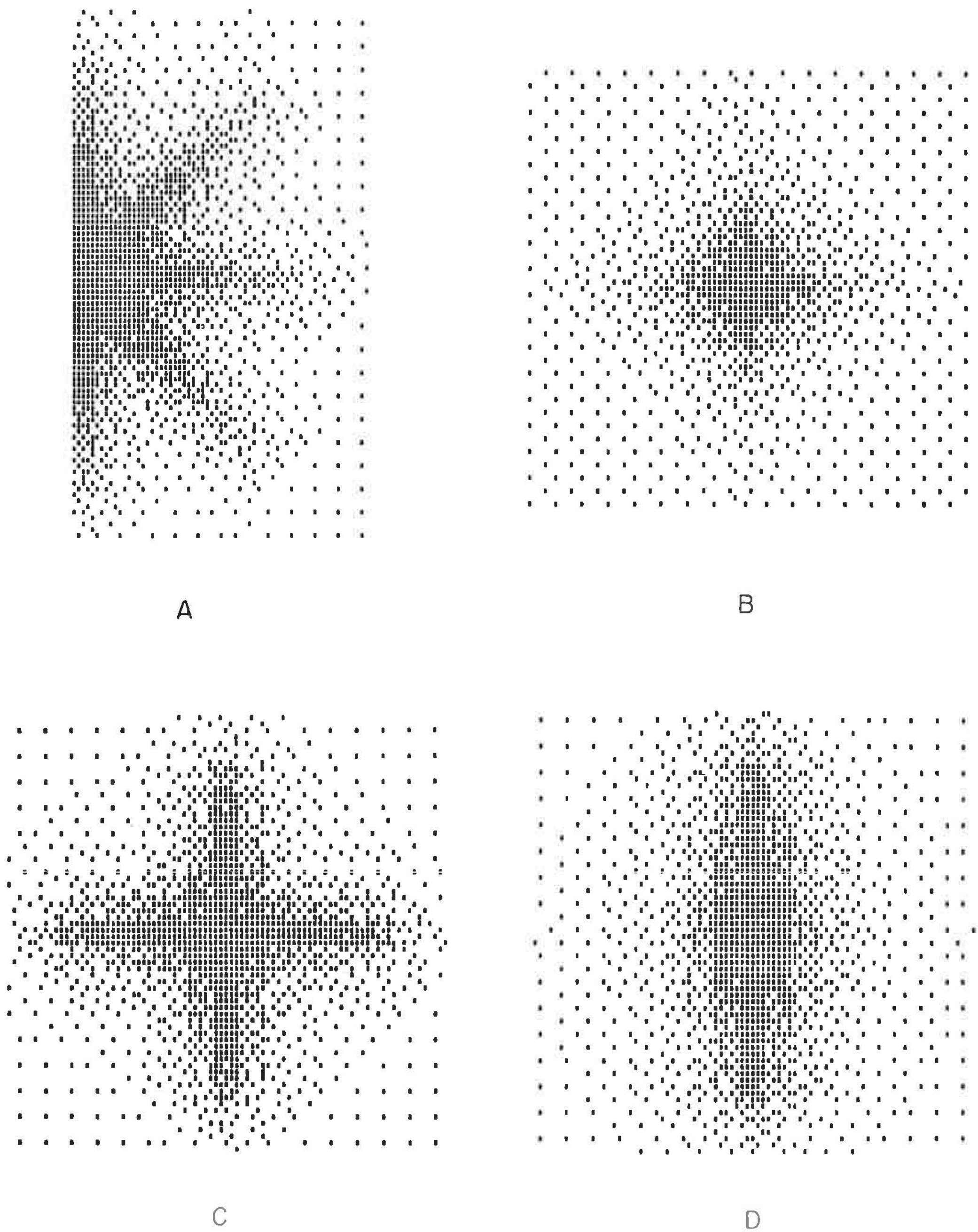

Figure 4. Allocations resulting from use of abstract networks.

Figure 3 shows a simulation of the growth of the Niagara Frontier region produced with a prototype of the present model. The decreasing concentration of activity is apparent in these allocations which are quite similar to the growth which actually occurred in the region.

Notion of Access

The obvious impact of transport costs on the development of a region has long been recognized. The inclusion of some measure of accessibility into any model proposed to simulate present growth or estimate future growth is imperative. However, the form and weight that access should have in the model are not so obvious; in fact, this is the major area which requires clarification.

We have started from a simplified notion that growth begins at a center and proceeds outward. The supply or surface of opportunities for growth will be examined in order of the travel time required to reach any location on that surface. This concept is neither new nor especially unique.

In experimenting with our model prototype, we found that the settlement pattern was very sensitive to the transportation facilities. Figure 4A shows a settlement pattern which might hypothetically have resulted with a transportation system composed of five high-speed facilities radiating out from the center. This pattern has been noted in real cities and is especially conspicuous in the stellate pattern of Chicago which is superimposed on the radial commuter lines.

We have tried other hypothetical networks and found reassuring patterns. For example, a simple grid of facilities with equal speeds gives a square settlement pattern rotated 45° with respect to the grid (Fig. 4B). If the central X and Y dimension facilities have a speed advantage over the other facilities, the sides of the square are pulled in, and the settlement pattern approaches the shape of a four-pronged starfish (Fig. 4C). Some of our midwestern plains cites do, in fact, correspond to just this pattern or are first cousins thereof.

If only a single facility has the high-speed characteristic, the linear form of the city emerges. This is common to cities which fall in a valley with the main street running parallel to the ridges. Here, of course, the topography itself (in the form of the opportunity surface) tends to reinforce the linear form of this settlement pattern (Fig. 4D).

The notion of access, developed here, should not be confused with the accessibility notion wherein a given location is related to all other locations by the sum of the quotients formed by each location's activity divided by its time or distance to the given zone raised to some power. This gravity or propensity for interaction notion of access is a distinctly different measure. We have included an option for calculating this measure within our model. To date, we have not compared the results of using this alternative measure of access.

The major point we wish to make here is that by borrowing the minimum path capabilities of the existing assignment packages, we can order the opportunity surface by a much more refined measure than air line distance to the CBD. Thus, within the limitations of our allocation algorithm, we can incorporate the effects which specific transportation improvements would have on the settlement pattern. We are then in a much better position to handle the knotty question of feedback between land use and the transportation system.

MODEL AS AN AID IN EVALUATING LAND-USE POLICY

The foregoing description of the model illustrates its utility as a basis for forecasting the future distribution of people and trip-making. It is not necessary, however, to so limit its use. The model can be used to examine the regional growth that might occur given certain policies with respect to land development. Two examples will be given, although many more are possible.

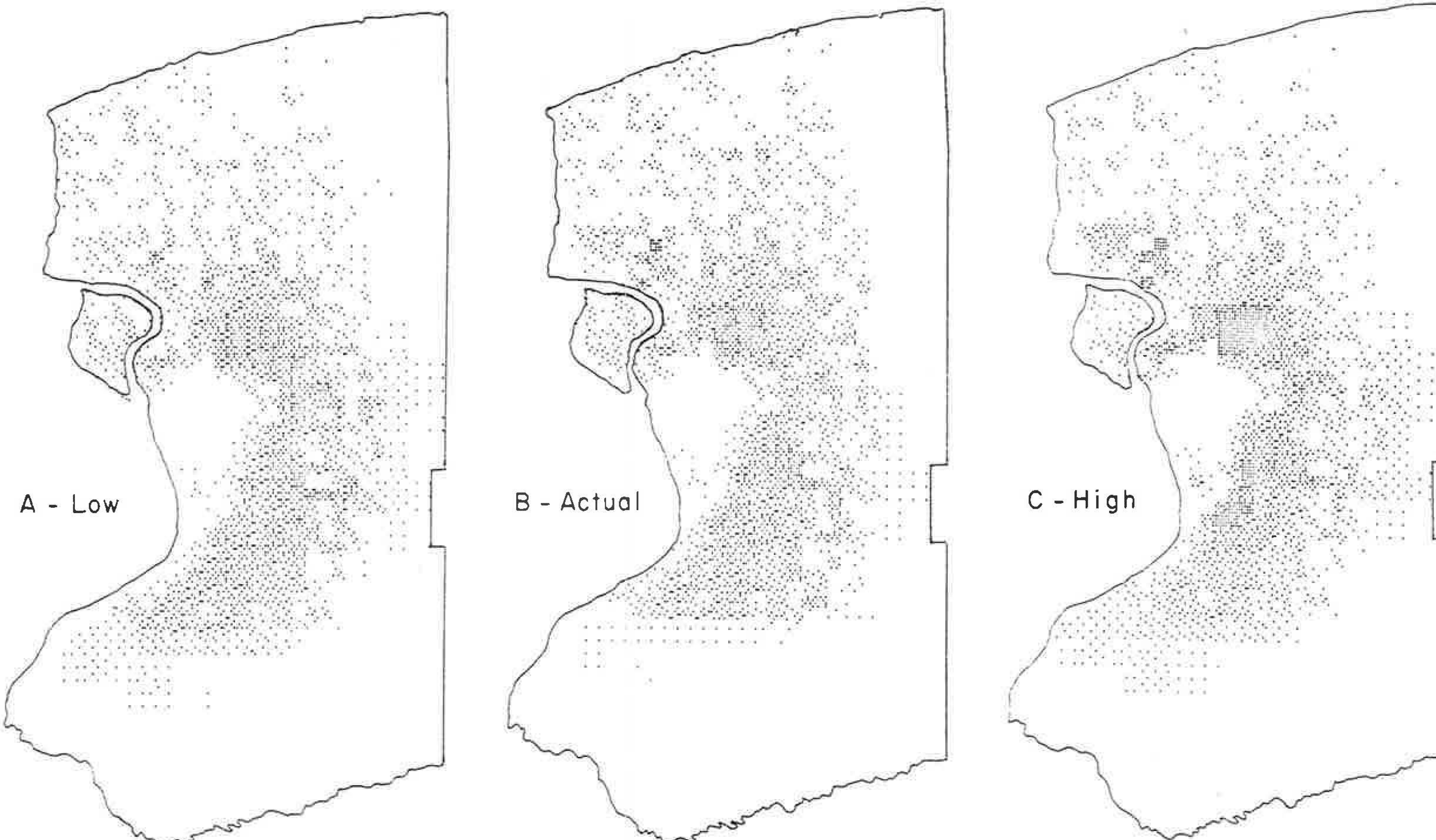

Figure 5. Effect of vehicle trip densities-residential.

Density Controls

The density or intensity of the use of land is fundamental to the structure of urban regions. The contrast between New York City and Los Angeles is the usual example of density extremes that have arisen historically in different regions. This range of densities, though not as extreme, can be found even without leaving a given urban region. The density of population in the center of Buffalo is 93, 250 persons/sq mi of net residential land in contrast to the 10, 000 persons/sq mi of net residential land found in the suburbs.

Sidestepping the issue of whether high densities are good or bad (and we find city planners on both sides of this question) and also avoiding the question of the extent to which planners can effectively control densities, we can use the model to examine the development which might occur with a prescribed density surface as opposed to an extrapolation of present densities.

The two most significant effects that the imposition of these controls might have would be in the shape or pattern of urban settlement and the amount of land which would be required to accommodate new growth. Figure 5A shows the settlement pattern resulting from a hypothetical density surface which is significantly lower than the present pattern of densities in the central cities of Buffalo and Niagara Falls. This spread pattern should be contrasted with Figure 5C which represents a model run with all parameters equal to those used to obtain Figure 5A, except that the density surface imposed is one of relatively high densities (about double present densities) in the central cities of Buffalo and Niagara Falls. Figure 5B shows the resultant pattern obtained by extrapolating present densities. Obviously, a much more compact development occurs with the higher than with the lower densities. Whether such density modifications are good or even possible will depend on many factors peculiar to a given region. The model, however, does give a visual representation of the potential settlement representative of these alternatives. Also, densities might be varied in other systematic ways to test or represent specific policies.

In addition, and perhaps of equal importance, we can obtain a measure of the impact of densities on land use from these alternatives. The total land going into urban use as a result of growth at the lower density scale is 186 sq mi, or 28. 6 sq mi of developed land per 100, 000 people.

The higher density surface required 163 sq mi of land to accommodate the same population growth. This means that 25. 1 sq mi of urban land are required for each additional 100, 000 population added to the area. This compares with land requirements of about 21 sq mi per 100, 000 population that have been required or expected in regions such as Chicago and Pittsburgh.

Open Space Controls

Another policy often considered in the shaping of the urban settlement pattern is the use of controlled open space. Without entering the discussion of feasibility, we can enter an open space plan into the model as a separate input, zone by zone. We can then see our resultant hypothetical settlement pattern. This may be used in conjunction with density controls or completely independent of them. Again, however, we are able to obtain a rapid, visual picture of the region just as though we had done a broad stroke sketch plan. The difference, however, is that we also provide a measured statement of how many people and trips will be located in each zone of the region. Thus quantified, the settlement can be converted into loads on the transportation network which is proposed, and the resulting transportation costs, including transportation facility construction as well as travel, can be used to evaluate the transportation plan. Eventually, of course, one would wish to cost out land development as well as transportation to evaluate alternative plans.

Incorporation of Plans Into Model

It should be clear that the use of the model is not restricted to forecasts alone. Specific plans for redevelopment, shopping centers, the central business district,

TABLE 1

PERCENT OF TOTAL REGIONAL POPULATION ALLOCATED OVER ALTERNATIVE NETWORKS

District	Network A Minimal	Network B Extensive	District	Network A Minimal	Network B Extensive
00	0.61	0.61	50	0.87	1.44
10	8.84	8.84	51	4.41	4.77
20	2.05	2.05	52	2.72	2.23
21	2.24	2.24	53	3.15	3.21
22	4.13	4.13	54	1.63	1.01
23	2.11	2.12	55	1.94	1.71
24	2.58	2.57	60	6.65	7.01
25	0.57	0.57	61	3.03	3.60
30	1.88	1.88	62	2.25	1.30
31	4.46	4.45	63	1.85	1.92
32	4.34	4.34	64	1.68	2.36
33	1.57	1.55	65	2.17	1.85
34	2.57	2.58	66	0.95	0.78
35	1.69	1.65	70	1.81	1.71
40	1.20	1.38	71	5.85	5.72
41	3.59	3.87	72	1.44	1.18
42	2.89	2.80	73	1.37	1.50
43	1.09	1.07	74	0.42	0.77
44	1.83	1.79	75	1.81	1.71
45	1.38	1.30	76	2.18	1.53

open space, density controls, and highways can be entered into the model. Such plans are considered as givens, and the model then estimates the population and travel distributions which would accompany these plans. As an example of the variation in allocations which result from different network plans, Table 1 gives percentage of population by analysis district following allocation over two alternative networks. The access levels of the two networks are shown by the travel time contours in Figure 4. Network A represents a minimal network with about 120 mi of expressways, whereas Network B has more than 400 mi.

CRITERIA FOR MODEL DESIGN

During the actual design and development of the model, an explicit list of criteria evolved from considerations implicit in the day-to-day work of assembling the model:

1. The model should be based on some theoretical statement of the mechanisms of land development. Although it need not simulate individual decisions within the land market, it should give results which correspond to the real world.
2. The model should be incremental and recursive. Ideally, data on past land use and transportation systems should be used to simulate the present development pattern. Lacking this ability, increments of growth should be layered on the present structure.
3. The model should be relatively simple. A finite number of land uses and a minimum number of subsets of households should be required to minimize data acquisition and handling difficulties.
4. Ideally, the calculation of activity density should be endogenous to the model. Failing this, the model should readily accept exogenous densities.

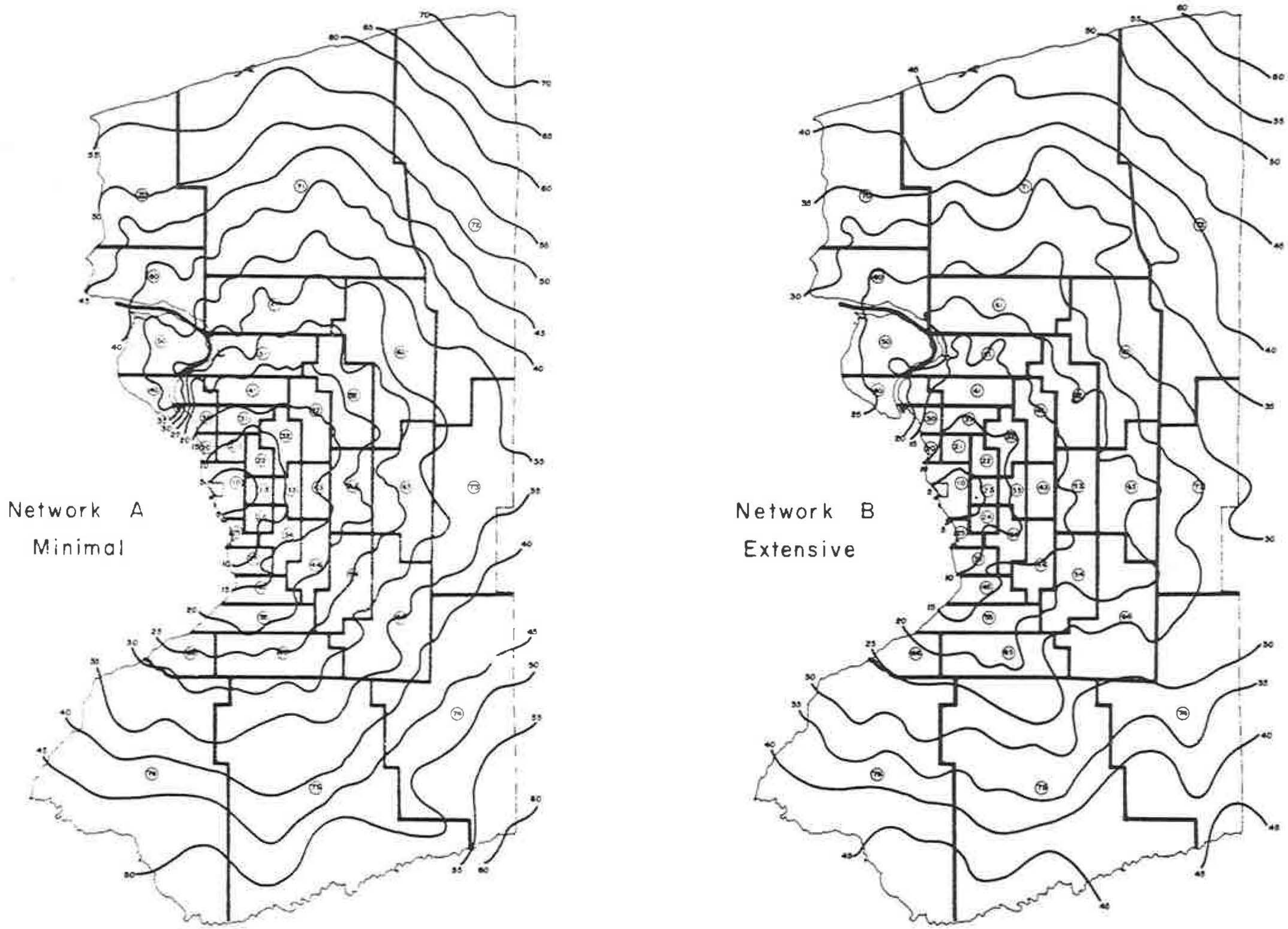

Figure 6. Travel time contours generated from two networks.

5. The model should accept alternative measures or indices of access. This provides the required flexibility should one measure be particularly appropriate to a given activity type and a different measure of access be best suited to other activity types.

6. The model should be able to accept data from redevelopment, urban renewal, or new-town plans. This might be done as a preliminary updating (internal to the model) of the land use and activity base or within the main frame of the model.

7. The model should be capable of being calibrated. For example, it should be possible to simulate past growth, or at least calibrate the model parameters using the present structure.

8. Provision for sensitivity analysis should be considered in the design of the model. It is vital to be able to evaluate the effect of unit changes in a given parameter on all facets of the allocation produced by the model.

9. The output of the model should permit easy and rapid comprehension of allocation results with particular emphasis on a simple graphic description of settlement patterns. This graphic output is particularly important to the comprehension and evaluation of alternative model inputs. Tabular outputs which can be used in calibration, sensitivity analysis, and allocation evaluation are also an obvious requirement.

10. Output from the model should be directly usable in existing traffic assignment procedures to minimize the difficulty and time involved in applying the results of the operation of the model.

Operation Description

A simplified flow diagram illustrating the inputs and operation sequence is shown in Figure 7. Actual operation of the model is initiated by providing seven sets of data describing the conditions in each zone at the beginning point in time. These are vacant land, nonresidential land, residential land, nontrip-generating land, nonresidential trips, residential trips, and population.

Vacant land is partitioned into two categories: available for development, and permanently withheld (the latter considered to be an irreducible minimum on the order of 10 percent). The opportunities for an increase in activity in each zone are then calculated by applying internally calculated (or previously supplied) activity densities to the vacant available land. The estimate of growth in the activity is then allocated across the opportunity surface from one or more regional centers. Opportunities are considered in the order established by the particular accessibility measure being used. The opportunity surface is updated, summary tables are revised, and the decreased opportunity surface is reconverted to vacant available land. Allocation of a second activity follows in a similar manner.

After all activities for a given time increment have been allocated, the model repeats the entire procedure beginning with the first activity for the next increment. A simultaneous allocation of population is made, independent of the allocation of other activities, to help to maintain perspective and to provide a population growth allocation for subareas of the region.

The population allocation is made in a similar manner with an opportunity surface described as a function of (a) the proportion of used and vacant land, (b) the population density, and (c) externally provided limiting values for these proportions and densities. Accounts of the change in the number of opportunities available are again maintained along with estimates of the used land and vacant available land.

Currently the output of the model consists of a series of tables reporting the input values, the opportunity surfaces and the allocation for each activity and each center, the final totals for each activity, and the remaining opportunities. In the present application, an estimate of future trip ends directly useful in the current version of the Chicago or Schneider assignment and trip distribution model is produced, as well as an input to a mapping program used to produce graphic output for analysis and display.

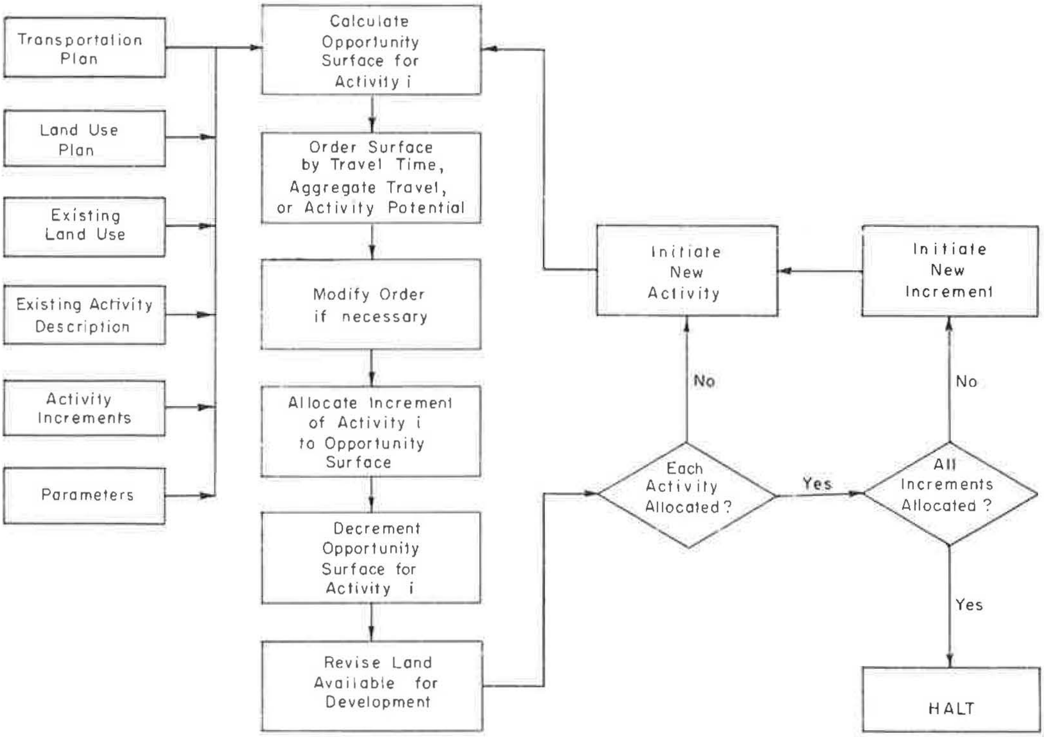

Figure 7. Sequence of operations within model.

Preliminary allocations for the Niagara Frontier region have been made in about 6 min using a minimum time path value tree to measure accessibility, three regional subcenters, and two increments of growth.

Alternatives Available in Model

The model has several intentional points of flexibility within the basic operation sequence. Input data may be varied to simulate almost any situation of land use and activity density. Plans for both land use and transportation networks may be incorporated by stating amounts of different classes of land at the outset, by establishing trip density values to meet some predetermined level, and by providing minimum travel time trees from various networks. Alternative base data may also be substituted at the start of any increment.

The order of consideration of the zones may be altered by factoring any accessibility measure by an exogenously provided multiplier. The model also will consider the region as completely undeveloped, permitting allocation from a zero condition rather than incrementing the existing trips or population.

SUMMARY

In this brief paper we have given a general description of an allocation model which is largely based on access to a regional center or set of regional subcenters. Currently, variables other than access can be introduced by modifying the rank order of opportunities.

Qualitative examination of hypothetical results provides persuasive evidence that the settlement pattern has historically responded to access as we have measured it. Quantitative verification and calibration is difficult because of the lack of historical data on land use and transportation networks. We are attempting, however, to measure the extent to which population growth since 1940 can be explained by use of the model. This requires the assumption that net activity densities have remained fairly constant in this period.

We are not satisfied with the use of external independent estimates of activity density. Eventually, these densities must be made endogenous to the model.

The operating speed and output flexibility of the model are a great advantage in research. We are quite interested in evaluating the extent of variation in growth attributable to other variables or to different statements of access. In this sense, we consider the model an experimental technique which will allow us to measure further and, hopefully, come to a better understanding of the urban growth process.

Linear Programming Test of Journey-to-Work Minimization

JOHN R. HAMBURG, CHARLES R. GUINN, and GEORGE T. LATHROP, New York State Department of Public Works; and,
GEORGE C. HEMMENS, Joint Center for Urban Studies of Massachusetts Institute of Technology and Harvard University

•THE TRANSPORTATION planner, as well as the city planner, is concerned with the spatial arrangement of activities within an urban region. The transportation planner looks for an understanding of the different arrays of human activity in order to plan a transportation system which will serve the region most efficiently. The city planner seeks to achieve a better arrangement of these activities in order to maximize the benefits accruing to urban living.

Since residential land comprises the bulk of urban development and is the base on which the bulk of urban travel is organized, residential location is a major concern of analysis of urban spatial patterns. Residential location in turn is thought to be influenced most heavily by the location of workplaces and by the length of the journey-to-work. It has generally been assumed—implicitly and frequently explicitly—that workers are not indifferent to the length of the work trip. The usual hypothesis is that persons attempt to minimize their journey-to-work in selecting among potential residences subject to a variety of other influences such as income, residential amenity, auto ownership, family characteristics, and personal preferences. There can be little doubt that the journey-to-work influences residential location. The principal question, which has not been adequately answered, is the degree of influence. To what extent does the journey-to-work influence residential location, and to what extent is journey-to-work travel traded off against other factors? One approach to understanding the magnitude of the influence of the work trip on the residential location decision is to compare the actual travel time involved in the journey-to-work with some expression of what the travel time might be under some ideal condition. This paper discusses a method by which the sensitivity to travel time can be measured. Called an index of indifference, it attempts to measure the extent to which the linkages among urban space activities (in this case, places of residences and places of work) are indifferent to time. Specific application is made to the journey-to-work in the Buffalo, N. Y. area.

THE MEASURES

Several measures are already available by which to study spatial distributions. These vary from simple average travel times and distances to sophisticated measures of accessibility and of minima or maxima. Many of these measures are absolute, which, while useful, do not permit comparisons between different activities; that is, they do not standardize for basic differences in geographic distribution. The access measures of time (involving an exponential treatment) are difficult to interpret and to relate to alternative measures such as minima or maxima. Minimum measures tend to be hypothetical unless related in some way to actual or other hypothetical measures. What is needed is a measure that relates actual linkages to the linkages which would result if time within the region meant nothing and if time meant everything, e. g., as if a travel czar decreed that overall travel be minimized.

Paper sponsored by Committee on Land Use Evaluation.

Notion of Probable Interchanges

The most probable set of interchanges which would occur if travel were irrelevant to location would be a simple proportional distribution as shown by the following formula:

$$L_{ij} = \frac{A_i B_j}{\Sigma B_j} \qquad (1)$$

where L_{ij} is the linkage between activity A located in zone i and activity B located in zone j. This particular measure has been used as a base against which to compare actual linkagcs, particularly in the gravity approach to linkages. For example, the gravity model can be expressed as:

$$L_{ij} = \frac{K A_i B_j T_{ij}^{-x}}{\Sigma B_j} \qquad (2)$$

where

K = constant of proportionality,
T_{ij} = travel time between zones i and j, and
x = empirically derived constant reflecting friction of space.

This formula is identical with Eq. 1 if x = 0 and k = 1. This is the distribution which we would obtain if the friction of space measured in time units were zero. The exponent in a gravity model can be measured by the rate of change of the ratio of the actual linkage to the probable linkage per rate of change of travel time. This exponent, though useful as a measure of propensity for interaction, says nothing about the minimization of time for a set of linkages. Presumably, there is some exponent which would give the same average time as the average time for the minimum case. It probably would not satisfy the criterion that all linkages be made between the two activity types. As the exponent is further decreased (moving toward negative infinity), serious system inbalances occur and absurdity is the result.

Notion of Minimum Time Linkage

This notion states that linkages between two activity types can be rearranged in such a way that the travel time represented by the linkages is the minimum possible. This is a system minimum rather than a series of individual minima.

The notion also assumes that there is equal substitutability within the activities involved. For example, if work places and worker residences are the two activities, it is assumed that one job is as attractive as another and that all residences are equally attractive. The defects in this assumption are mitigated by the use of strata or classes within the activity types. It is presumed that the classes are homogeneous and that within classes equal substitutability exists.

Notion of Actual Travel Time

The actual travel time is the travel time required by the linkages as they actually occur in the real world. Origin and destination studies are specifically designed to inventory linkages. When these linkage sets are assigned to a transportation network and the travel times are recorded, we obtain the aggregate actual travel time. This time does not include terminal time, that is, the time spent walking to and from the vehicle or waiting for a transit vehicle. Since the travel time for all three cases—minimum, probable, and actual—are calculated across the same network, the exclusion of this time seems justified.

Calculating Measure

Given the three sets of linkages and the travel time required for each set, the index follows:

$$I_i = \frac{T_A - T_M}{T_P - T_M} \qquad (3)$$

where

I_i = index of indifference,
T_M = minimum travel time for linkages,
T_A = actual travel time for linkages, and
T_P = probable travel time for linkages.

Thus, we have a measure which relates actual travel linkages to the range of travel time defined by a set of linkages in which travel time is irrelevant and a set of linkages resulting when aggregate travel time is minimized.

An index of indifference equal to zero is achieved when the linkages between the two activities are so formed that the travel time represented by this set of linkages would be exceeded by the travel time formed by all other possible sets of linkages. When the index of indifference is equal to one, the linkages are those which would result if time within a region was irrelevant to the location of activities. The index is thus based on the relation of actual linkages to two hypothetical sets of linkages: (a) a probable distribution where time has no bearing and (b) a minimum distribution where the time represented by the linkages is minimized.

JOURNEY-TO-WORK APPLICATION

In this residential location study, the journey-to-work, or more specifically the work-home linkage, is defined as the factored total of the first reported work trip by each resident of each dwelling unit sampled in the Niagara Frontier home-interview survey. The data set was then stratified into white and nonwhite workers to isolate the probable irrational influence of the segregated real estate market on residential location.

The white data set was further stratified into three sets according to reported income class. This partitioning was done to determine whether indifference to the journey-to-work time varied by income class. The three income classes are: (a) those whose annual salary is less that \$5, 000; (b) those whose salary is greater than \$4, 999 but less than \$8, 000; and (c) those whose salary is \$8, 000 or greater.

A second stratification of the basic data was made to study the effect of auto availability on the journey-to-work time indifference. Both the white and nonwhite sets were partitioned based on whether or not the journey-to-work traveler was an auto driver. Thus, four sets were created (white drivers, white nondrivers, nonwhite drivers, and nonwhite nondrivers) for which time indifference was measured using the indifference index.

The reported work and home locations of each linkage in each set were coded to 435 geographic zones used for analysis and reference. The travel time between each zone and all other zones was obtained from a file of minimum path trees created by an assignment of present trips to the present network. The times were adjusted systematically to reflect volume.

To illustrate the variation in the distribution of income classes across the region, Figures 1 through 6 show the home locations and workplaces of the classes into which the population was divided. The relative concentrations among the higher and lower income groups are noticeable and support the common assumption of great selective ability among the former group and restricted opportunities for the latter.

Determining Indifference Index

The actual calculation of the indifference index is dependent on knowledge of

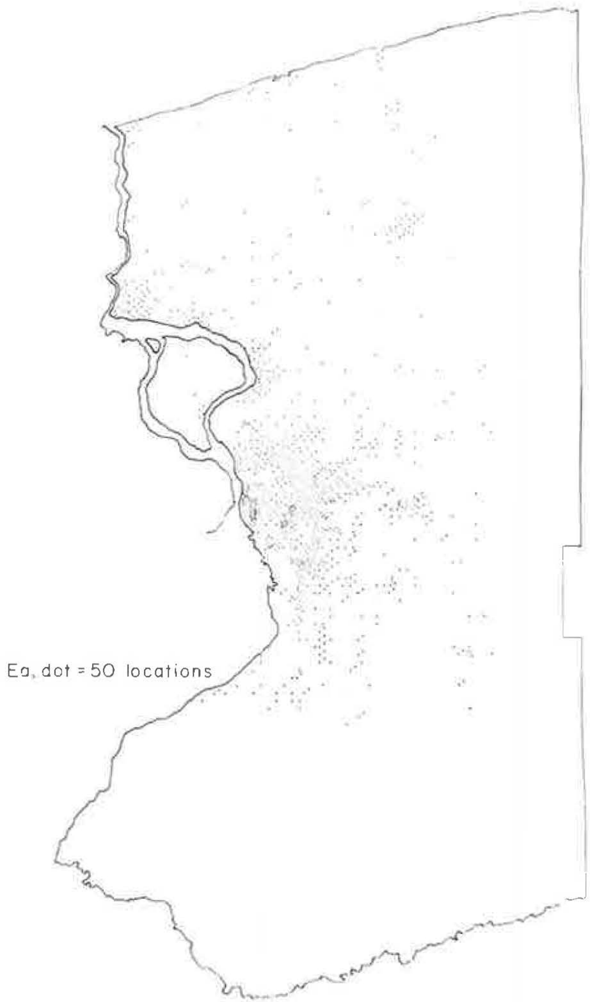

Figure 1. Residences of workers with income less than $5,000.

Figure 2. Workplaces of workers with income less than $5,000.

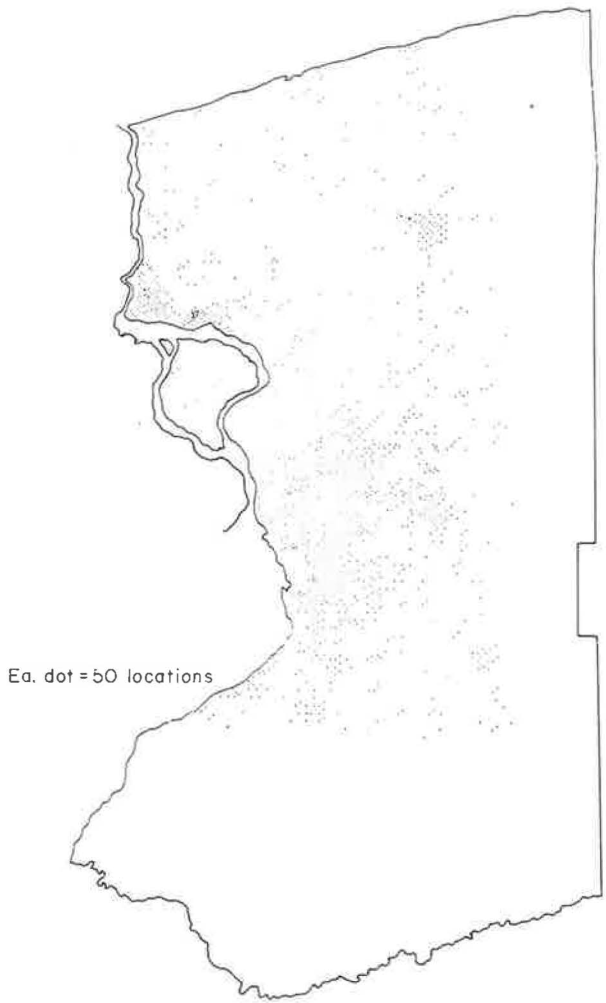

Figure 3. Residences of workers with income of $5,000 to $7,999.

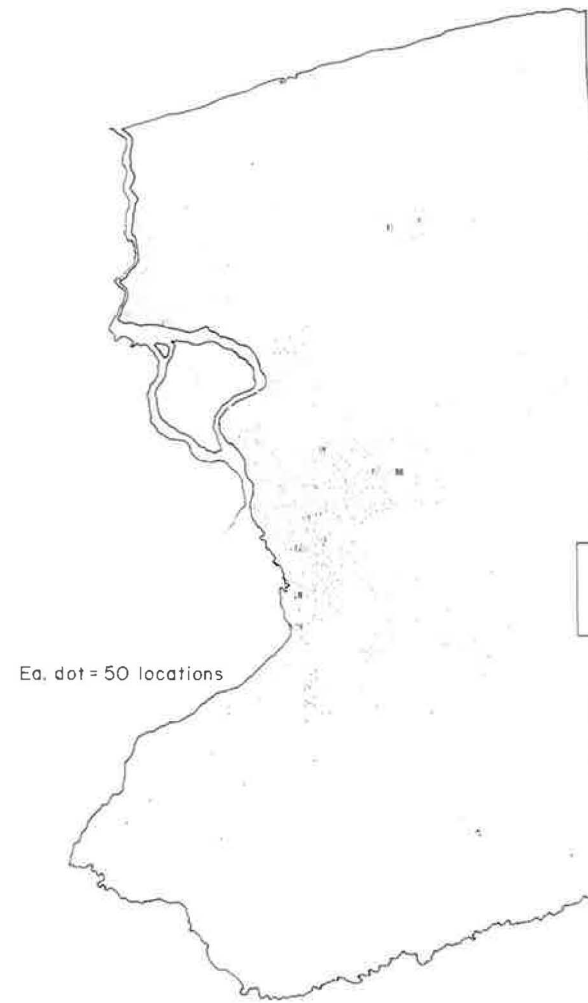

Figure 4. Workplaces of workers with income of $5,000 to $7,999.

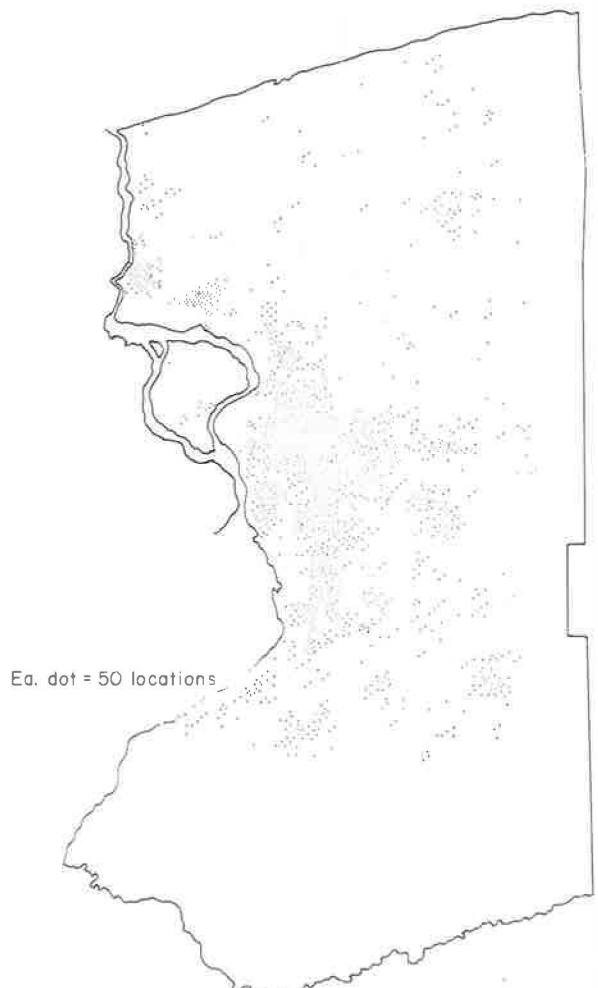

Figure 5. Residences of workers with income of $8,000 and over.

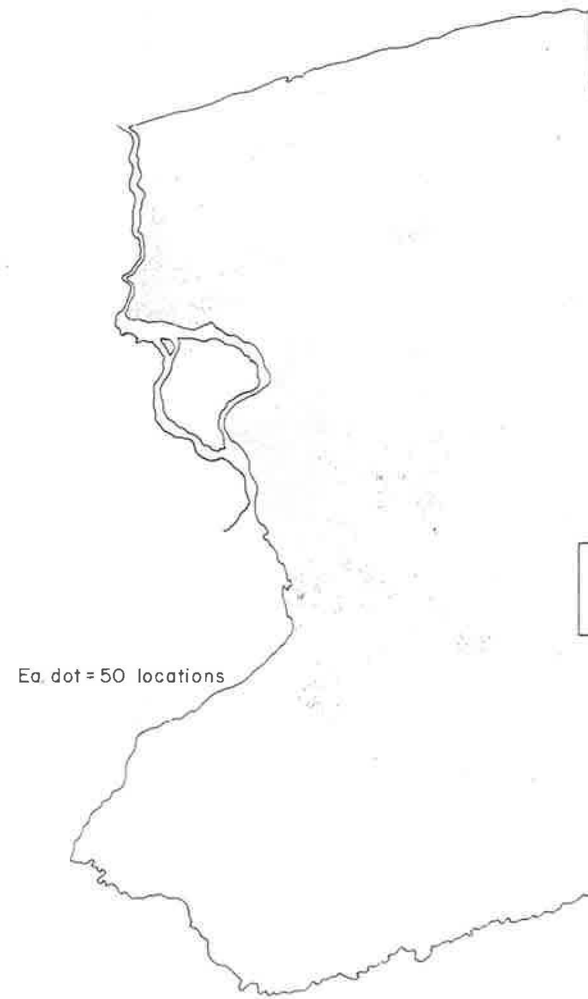

Figure 6. Workplaces of workers with income of $8,000 and over.

three points on the continuum representing the extent of indifference: complete indifference, absolute system minimization, and the world as it exists.

Complete substitutability of homes was assumed within each set. That is, when calculations were made for a specific set, all homes were considered to be equally acceptable to all workers.

The real-world value was obtainable quite simply by summarizing the travel times for the defined journey-to-work trip file. Stated mathematically:

$$T = \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} \; X_{ij} \tag{4}$$

where

T = total travel time,
a_{ij} = travel time from zone i to zone j,
X_{ij} = trips from zone i to zone j,
m = number of work zones, and
n = number of residence zones.

Complete indifference was simulated by allocating workers to homes on a proportional basis. Total travel time, T, was as above, but interchanges were redefined as:

$$X_{ij} = \frac{J_i \; H_j}{\sum_{j=1}^{n} H_j} \tag{5}$$

where

X_{ij} = trips from zone i to zone j,
J_i = workplaces in zone i,
H_j = homes in zone j, and
n = number of home zones.

Absolute system minimization was obtained using a form of linear programming commonly known as the transportation problem. The solution to the transportation problem allocates linkages between supply points and demand points in a manner that minimizes the total cost of the linkage. This technique requires that the total number of supplies and demands be equal and that all supplies and demands be used (Eq. 4), so that:

$$\sum_{j=1}^{n} X_{ij} = J_i$$

and

$$\sum_{i=1}^{m} X_{ij} = H_j$$

with all terms as previously defined.

The supplies and demands in the journey-to-work study were, respectively, workers at place of work and homes. Therefore, the transportation problem solution was an allocation of workers to homes which minimized the total travel time.

The data processing required to determine the points for each indifference index for the real world and the complete indifference points were performed on the Studies' own computer installation, an IBM 1401, using locally written programs. Each minimization was performed with a modified version of the Dennis Transportation Code, as distributed by SHARE for use on an IBM 7090/94.

JOURNEY-TO-WORK RESULTS

Table 1 gives the results of the analysis of journey-to-work by income class. The index of indifference ranges from 0.39 to 0.63 for the income classes and is 0.39 for all classes. This indicates that persons are not indifferent to travel time, but it does not demonstrate that they minimize aggregate travel time. Since an index value of 0.5 is midway from complete minimization to complete indifference to travel time, the results suggest that minimization is a potent influence.

This conclusion is reinforced by consideration of the nature of the travel minimizing linkage set. Like any ideal construct, the time minimization linkages are quite unrealistic. The mathematical solution is such that workers in each zone select residences on the average in only two of the 435 zones. Actually, workers in each zone are linked with residences in a sizable percentage of all zones. By contrast, the proportional allocation which links workers in each zone with residences in every zone is a much better representation of actual linkage patterns. The results also show that indifference to travel time increases with income. This is as expected.

Table 1 also gives the results of the analysis by race and auto availability classifications. The index of indifference is relatively stable for white drivers, white nondrivers, and nonwhite drivers and the value of the index approximates the previous average. However, nonwhite nondrivers are shown to be relatively indifferent to travel time.

The stratification by race was made originally because it was presumed that the effective location markets were different. This notion can be tested by examining the range between the travel time required for the minimum linkages and for the probable linkages. If either or both the distribution of workplaces and places of residence is constricted, the range will be relatively narrow. In the extreme case, if all residential opportunities were limited to one zone, the travel time required by the minimum

TABLE 1

JOURNEY-TO-WORK ANALYSIS

Class	No. Workers	Total Travel Time (hr)			Avg. Travel Time (min)			Indifference Index
		Indifference	Actual	Minimum	Indifference	Actual	Minimum	
(a) Income[a]								
1	51,242	21,820.9	9,973.8	3,223.0	25.5	11.7	3.8	0.36
2	108,696	50,806.6	25,358.0	9,059.3	28.0	14.0	5.0	0.39
3	92,750	32,595.4	24,498.8	10,709.1	21.1	15.8	6.9	0.63
Total	252,688	117,379.4	59,830.6	22,411.0	27.9	14.2	5.3	0.39
(b) Race and Auto Availability								
White driver	247,099	87,140.2	45,827.9	18,954.9	21.1	11.1	4.6	0.39
White nondriver	45,536	12,846.1	6,625.8	2,545.6	16.9	8.7	3.3	0.40
Nonwhite driver	10,616	2,565.2	1,839.1	1,341.0	14.4	10.3	7.6	0.41
Nonwhite nondriver	6,919	3,254.7	1,716.9	755.6	11.8	9.1	6.6	0.65
(c) Sampled and Factored Linkages								
Sample	9,236	3,254.7	1,716.9	715.9	21.1	11.1	4.6	0.394
Factor	247,099	87,140.2	45,827.9	18,954.9	21.1	11.1	4.6	0.394

[a]Does not include samples with nonreported income.

linkages would equal that required by the probable linkages. A dispersion index constructed as the ratio of the difference between probable linkage travel time and minimum linkage travel time to probable linkage travel time measures this influence. If dispersion is small (minimum and probable times are equal) the ratio approaches zero. As dispersion becomes large the ratio approaches one. The dispersion values are 0.78 for white drivers, 0.81 for white nondrivers, 0.47 for nonwhite drivers, and 0.44 for nonwhite nondrivers. The differences between the white and nonwhite values are sufficiently large to support the assumption of difference in the dispersion of spatial opportunities of the two groups.

The possible influence of auto availability is less clear. It makes no significant difference among the white group. However, it appears to make a great deal of difference among the nonwhite group since there is no significant difference in the dispersion index for nonwhite drivers and nonwhite nondrivers. The results suggest that other factors, not controlled in this analysis, provide the correct explanation. Chief among these might be the household status of the worker, i.e., whether head of the household or secondary worker such as a working wife.

The effect of using the factored number of work-home linkages instead of the actual sampled number in the transportation problem was questioned. Two indifference indexes were determined for the white driver set, one using the factored number of linkages and one using the actual sample number (Table 1). The two indexes are equal.

SUMMARY

This paper has described an index which permits meaningful comparisons of spatial arrays of urban activity. The index simultaneously standardizes a spatial distribution of linkages against the time minimum and time indifferent linkage sets.

The use of this index has been illustrated with journey-to-work data from the Niagara Frontier Transportation Study. The analysis showed that people overall are not indifferent to time. They do not, however, organize their linkages so as to expend the minimum amount of time in travel, although they tend to exhibit more minimization than indifference.

When the data were stratified into income classes, those in the highest income class tended to be indifferent to travel time as measured by the index. Both the middle- and low-income groups appeared more sensitive to travel time than the high-income class, although the lowest income group tended to be only slightly less indifferent than the middle-income class. When the data were stratified by race and auto availability, inconclusive results were obtained.

Additional analysis of the home and workplace linkages are planned with special emphasis on the assumption of equal substitutability of jobs and residences. The distributions will be standardized for differences in family size, car ownership, occupation and industry of employment, and other socio-economic differences beyond income itself.

The use of the index will be extended beyond the area of the journey-to-work. Analysis of market areas of different activity types, such as retailing and recreation areas, may profit from the application of this measure. Another linkage which may be studied is that of school-home.

The ability to plan for the arrangement of human activities in a region is heavily dependent on the planner's understanding of the way the region is currently organized and, more importantly, his understanding of why the region is so arranged. It is felt that this index will be useful in measurement and, therefore, verification of theories of urban spatial structure.

Planning the Metropolitan Airport System

GORDON EDWARDS, Federal Aviation Agency, Washington, D. C.

In the past airport planning was carried out on a project-by-project basis. Problems of crowded skys and air safety in the rapidly expanding metropolitan areas led to the creation of systems planning and ground-to-air control of air traffic. Now problems of interurban transportation, the expansion of existing airports, the planning of new airports and conflicts between the airport and its neighbors have underscored the need for coordinating airport system planning with metropolitan planning programs.

This paper suggests procedures for planning the metropolitan airport system. The objective is to integrate airport system planning with highway and mass transit planning within the context of a long-range comprehensive planning program. The suggested planning approach is a short-range (5-year) airport system development plan based on the long-range comprehensive planning program for the entire metropolitan area. The operational short-range development plan is composed of three elements: (a) changes in scheduling, (b) expansion of existing airports, and (c) the addition of new airports to the system. The short-range plan should also be coordinated with the highway development plan, the mass transit development plan, and local development and land-use plans for the specific area or political jurisdiction in which existing and planned individual airports are located.

•THE PURPOSE of this paper is to suggest procedures for the planning and development of a metropolitan airport system. The objective here is effectively to integrate airport system planning with highway and mass transit system planning within the context of a long-range comprehensive planning program. As President Kennedy said in 1961: "increasingly, community development must be a cooperative venture toward the common goals of a metropolitan region as a whole." This goal was carried forward by President Johnson in 1964 as necessary to assure that "the taxpayer's dollar is to be wisely used and our communities are to be desirable places in which to live."

The Harvard-MIT Center for Urban Studies recently completed a report (1) for the Senate Subcommittee on Intergovernmental Relations in which it concludes that:

> Metropolitan planning offers strong advantages for the Federal Government in facilitating the efficient administration of oversight and review that is close to the local scene, and can foster wise local use of Federal programs on a coordinated basis; moreover, it does so without necessitating an expansion in the number of Federal personnel in the agencies affected.

The approach suggested in this paper is rather ambitious and farsighted. It encourages metropolitan planning agencies to take the initiative in metropolitan airport systems planning. It outlines a new direction in functional planning which metropolitan planning agencies must seek to undertake if metropolitan plans are going to influence urban growth effectively.

Paper sponsored by Committee on Transportation System Analysis.

In terms of airport system planning, this means that the metropolitan agency must shoulder the burden of operational systems planning in addition to long-range comprehensive planning. Clearly, this is no mean task. In the past, planning agencies have not had the necessary staff, skills, or resources to do the job, but now the Federal Government through the Housing and Home Finance Agency (HHFA), the U. S. Bureau of Public Roads (BPR) and the Federal Aviation Agency (FAA) is prepared to provide substantial financial and technical assistance for this important task. The procedures outlined here suggest the direction in which planning agencies should be moving. The FAA is prepared to provide the necessary assistance and technical skills for planning the metropolitan airport system, but the planning agencies themselves must take the initiative in the preparation of system plans.

HOW THE FEDERAL GOVERNMENT ASSISTS TRANSPORTATION PLANNING

On March 8, 1964, the President signed into law an amendment to the Federal Airport Act requiring that airports built with Federal assistance be reasonably consistent with planning programs for the area in which the airport is located. The first sentence of Section 9 (d) (1) of the Federal Airport Act (49 U. S. C. 1108 (d) (1)) was amended to read as follows:

> All such projects and advance planning and engineering proposals shall be subject to the approval of the Administrator, which approval shall be given only if he is satisfied that the project or advance planning and engineering proposals are reasonably consistent with plans (existing at the time of approval of the project or advance planning and engineering proposal) of public agencies for the development of the area in which the airport is located and will contribute to the accomplishment of the purposes of this Act.

With that action, the Federal-aid Airport Program joined the Federal-aid Highway program and the recent Urban Mass Transportation Act in recognizing the necessity of coordinating functional planning programs with comprehensive urban planning programs. The Federal-aid Highway Act of 1962 requires that after July 1, 1965, all Federally aided highway projects in urban areas of more than 50,000 population must be "based on a continuing comprehensive transportation process carried on cooperatively by states and local communities." Long-range highway plans and programs are to be "properly coordinated with plans for improvements in other affected forms of transportation," and are to be "formulated with due consideration to their probable effect on the future development" of the urban area. Under the Urban Mass Transportation Act of 1964, except as specified in the Emergency Program (Sec. 5), no Federal assistance shall be provided unless the HHFA Administrator finds that such assistance is essential to a program proposed or under active preparation for a balanced transportation system as part of the comprehensive metropolitan planning program.

But recognition of need does not automatically assure coordination. Our metropolitan planning programs must now take action to coordinate the transportation planning to meet the challenge of this new airport, highway, and mass transit legislation. In each case, the new legislation requires coordination of functional transportation planning programs with comprehensive planning programs. It does not spell out the form or content or the quality of the required urban planning programs. What it does do is provide a framework for achieving effective coordination of functional transportation planning, perhaps the first step in making metropolitan planning programs effective.

Over the past 10 years, planners have quite properly become increasingly concerned with "effectuating" planning programs. In 1956, Meyerson outlined how long-range planning could be made more effective through the middle-ground community planning function (2). One of the key steps was the "detailed development plan function" to phase specific private and public programs as part of a comprehensive course of action covering not more than 10 years:

> The gap between the developmental policies of government discussed above and a long-range master plan for future development can be bridged by the preparation of short-run plans of five to ten years time span. The Development plan would link measures to deal with current problems with long-range proposals to attain community goals.

What Meyerson suggested 8 years ago is, in effect, required by these new transportation assistance programs today.

The President's 1962 message on transportation called for "balanced transportation systems" which are planned and programmed as part of an overall community planning program. Obviously, in the large urban regions which will emerge in the next 20 years, a balanced transportation program must include airport systems planning. Therefore, airport planning should not be viewed simply as land use but also as a transportation function.

Transportation facilities should be balanced economically and socially, providing freedom of choice in transportation to all people. Each mode of transportation serves particular configurations of functions and people should have the opportunity to choose the mode best suited to their needs—highway, rail or air. The need for choice and a flexible transportation system has become increasingly important in the large, complex metropolitan areas which have emerged in recent years.

While almost everyone in the transportation industry now agrees with the traditional planning goal of a balanced transportation system, the difficult questions of what constitutes a balanced system and how we build it persist. One of the key problems in developing such a system is that airports, highways, railroads, and subways are not built at the same time. To coordinate the various transportation modes, it becomes necessary to plan the entire transportation system. But preparing a plan and effectuating a plan are two different things—a future airport which is generally located on a comprehensive metropolitan plan may or may not be seriously considered by the state highway department or transit authority when decisions are made actually to acquire rights-of-way and build a highway system and transit network. The problem is further complicated by the fact that much of the system is already in place. We must maximize the usefulness and efficiency of the existing system. However, if there is a short-range development plan for each of the functional systems —coordinated within the context of a long-range comprehensive planning program—the critical problems of timing transportation investments can be successfully resolved.

The growth of computer technology has proven very helpful in scheduling actions and investments in the highway building program. These same techniques have also been used in the preparation of metropolitan transportation studies. Techniques for planning the metropolitan airport system should be developed and included in transportation studies.

HOW THE FAA ASSISTS PLANNING AND DEVELOPMENT OF AIRPORTS

Airport planning has traditionally been oriented toward serving the individual community. The metropolitan airport systems approach, suggested here, considers the airport needs of the entire metropolitan region. The metropolitan planning agency should take the initiative in preparing a short-range airport development plan based on the long-range comprehensive metropolitan plan. The FAA will work as closely as possible with the planning agency. The planning agency should request the assistance of of the FAA's District Airport Engineer at the outset of the development of the airport system plan. The objective should be to include each of the individual airport projects in the National Airport Plan (NAP). The NAP is the first step in gaining approval for the project under the Federal-aid Airport Program (FAAP). The basic FAAP provides up to 50 percent matching grants to the local airport sponsor.

The FAA is charged with the responsibility for long-range planning to facilitate the safe and effective use of airspace and landing areas, the formulation of a NAP, and the administration of a FAAP to bring about, in accordance with the NAP, the development of a national system of public airports.

To be eligible for Federal aid, ownership in the airport must be vested in a public agency and the airport must be included in the NAP. The NAP is revised each year and submitted to Congress by the Administrator. The plan specifies, in terms of general location and type of development, the projects considered necessary to provide a system of public airports adequate to anticipate and meet the needs of civil aeronautics. These projects include all types of airport development eligible for Federal aid under the Act (6) and are not limited to any classes or categories of public airports. (In 1964 eligible projects were limited to the following: land acquisition, site preparation, runways, taxiways, aprons, lighting, runway distance markers, fire and rescue equipment building, snow removal equipment building, utilities, roads on airport site, parking, landscaping, turfing, erosion control, fencing, sidewalks, obstruction removal and relocation or modification of navigational aids.) The plans have been based on projected needs over a variable period of time. Before Fiscal Year 1953, the plans were based on needs over a 3-year period. In 1953 the plan projected needs over a 7-year period, and in Fiscal Years 1954, 1955, and 1956 the plans were based on an 8-year period. The 1959 and 1960 plans are based on a 4-year planning period. The 1962 plan is based on a 5-year planning period. Of the funds that are appropriated each year by Congress, approximately 75 percent[1] are apportioned to the states in proportion to area and population ("one-half in the proportion which the population of

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[1] "Sec. 4. Section 5(d) of such Act (49 U.S.C. 1104 (d)) is amended by adding at the end thereof the following new paragraphs:

"(4) For the purpose of carrying out the 1964 amendments to the Federal Airport Act in the several States, in addition to other amounts authorized by this Act, appropriations amounting in the aggregate to $199,500,000 are hereby authorized to be made to the Administrator over a period of three fiscal years, beginning with the fiscal year ending June 30, 1963. Of amounts appropriated under this paragraph, $66,500,000 shall become available for obligation, by the execution of grant agreements pursuant to section 12, beginning July 1 of each of the fiscal years ending June 30, 1965, June 30, 1966, and June 30, 1967, and shall continue to be so available until expended.

"(5) For the purpose of carrying out this Act in Hawaii, Puerto Rico and the Virgin Islands, in addition to other amounts authorized by this Act, appropriations amounting in the aggregate to $4,500,000 are hereby authorized to be made to the Administrator over a period of three fiscal years, beginning with the fiscal year ending June 30, 1965. Of amounts appropriated under this paragraph, $1,500,000 shall become available for obligation, by the execution of grant agreements pursuant to section 12, beginning July 1 of each of the fiscal years ending June 30, 1965, June 30, 1966, and June 30, 1967, and shall continue to be so available until expended. Of each such amount, 40 per centum shall be available for Hawaii, 40 per centum shall be available for Puerto Rico, and 20 per centum shall be available for the Virgin Islands.

"(6) For the purpose of developing, in the several States, airports the primary purpose of which is to serve general aviation and to relieve congestion at airports having high density of traffic serving other segments of aviation, in addition to other amounts authorized by this Act for such purpose, appropriations amounting in the aggregate to $21,000,000 are hereby authorized to be made to the Administrator over a period of three fiscal years, beginning with the fiscal year ending June 30, 1965. Of amounts appropriated under this paragraph, $7,000,000 shall become available for obligation, by the execution of grant agreements pursuant to section 12, beginning July 1 of each of the fiscal years ending June 30, 1965, June 30, 1966, and June 30, 1967, and shall continue to be so available until expended."

each state bears to the total population of all states, and one-half in the proportion which the area of each state bears to the total area of all the states.") and the remaining 25 percent, known as the discretionary funds, may be used by the Administrator for expenditures on approved projects in the several states as the Administrator may deem most appropriate for carrying out the NAP.

The maximum Federal grant for any specific project is 50 percent of the total project costs, except in those states where there are large areas of land owned by the Federal Government. In such cases, the 50 percent is increased up to 62 ½ percent:

> In the case of any State containing unappropriated and unreserved public lands and nontaxable Indian lands (individual and tribal) exceeding 5 per centum of the total area of all lands therein, the United States share under subsection (a) (1), and the maximum United States share under subsection (a) (2), shall be increased by whichever is the smaller of the following percentages thereof: (1) 25 per centum, or (2) a percentage equal to one-half the percentage that the area of all such lands in such State is of its total area. (3)

Large airports like those of New York, San Francisco, Los Angeles, and Chicago require runway lighting of very high intensity. These lights are more expensive than the ordinary medium-intensity lights installed at the majority of the airports. Congress, recognizing that high-intensity lighting, runway distance markers, in-runway lighting and land for approach light systems is in a sense a part of an integrated instrument landing system financed and operated by the Federal Government, increased the Federal share of the cost of purchasing and installing these types of lighting to 75 percent. The Federal share for the installation of medium-intensity lights remains the same as for all the other eligible items in the project.

If the projects in a particular state are not able to make use of the entire apportionment to that state within 2 years from the time the funds are appropriated, the entire balance is placed in a discretionary fund.

DEVELOPING AIRPORT SYSTEM PLAN AS INTEGRAL PART OF COMPREHENSIVE PLANNING PROGRAM

The need for the advanced planning grants authorized by the 1964 amendments to the FAAP is underscored by the basic changes that have occurred in the airport planning as a result of changes in (a) aeronautical technology including the dynamic growth in both commercial air commerce and general aviation, (b) the size and complexity of modern airports, and (c) the rapid expansion of metropolitan areas.

These same changes have also created a need for metropolitan airport systems planning. The need for airport facilities is not confined to the municipal boundaries of a particular airport sponsor. In many cases a facility serves several neighboring communities and approach zones, and takeoff patterns extend beyond municipal boundaries into neighboring political jurisdictions. In future years, many of the metropolitan areas included in the NAP will be based on regional airport systems. It is the responsibility of each metropolitan planning agency to take necessary steps to prepare an airport system plan in advance of program implementation. Sufficient lead time should be allowed to permit review and approval by the FAA and local public officials who will be primarily responsible for financing and developing the airport system.

The question of how and by whom the airport plan is going to be carried out is very important. If the development plan for a metropolitan airport system is to be realistic, the character and content of the plan will reflect the way it is to be implemented. Critics have emphasized that planning studies too often become hopelessly entangled in a web of socio-economic theory to the point that they lose sight of their original objectives and that there is the danger of such studies turning into an abstract socio-economic "goals rush" of limited practical value. Now, it must be remembered that the comprehensive metropolitan plan is by necessity an abstract statement of socio-economic goals and objectives. The short-range development plan for a single metropolitan function such as airports can provide a bridge; it can translate the comprehensive plan into a practical, action-oriented development program.

The FAA is in the process of changing its procedures to require that local government sponsors in metropolitan areas coordinate airport development with metropolitan planning programs. Further, the FAA will provide technical assistance to metropolitan planning agencies in the preparation of areawide airport plans. It is apparent that review by the metropolitan planning agency will be much more meaningful if the Agency has in advance prepared a short-range (5-year) airport development plan. The functional development plan then becomes a yardstick for evaluating the specific airport proposal. A 5-year development plan is suggested because that is the project forecast period used for the NAP. The coordination of metropolitan airport systems with the NAP looks to the time when the NAP will be composed of a series of metropolitan systems which will provide a refinement of the present FAA "hub" concept.[2] The NAP designates large, medium and small hubs. The 21 large hubs coincide with major metropolitan areas. Over the next 20 years, most of the Nation's economic growth is expected to occur in metropolitan areas. The value of integrating metropolitan development plans with national development is immediately apparent because it is how the cash flows that determines how development projects are carried out. However, it is through the functional development programs that metropolitan plans are implemented.

Problems of airspace congestion created the initial thrust behind metropolitan airport system planning. Unlike most metropolitan problems which are either dealt with or ignored on a piecemeal basis by "fragmented" government, control of airspace is the responsibility of the Federal Government, specifically the FAA. The FAA is responsible for air control everywhere in the United States, including metropolitan areas. Air control must be dealt with on an areawide basis. Therefore, the metropolitan airport system must be planned on an areawide basis.

Airports in and around metropolitan areas must be planned and operated as a system so that their interactions (airspace, etc.) are not detrimental to their capacities and so that their functions are complementary. Furthermore, as air traffic continues to increase, more of these airports will approach and exceed a practical operating limit. Therefore, each airport in a metropolitan area should be planned as part of a system of airports to obtain the most efficient traffic flow and the most effective use of facilities.

But it is not enough to create an efficient air transport system that will simply transfer the congestion to the terminal area and ground transportation. Therefore, the FAA is now emphasizing the importance of comprehensive metropolitan planning to achieve a balanced transportation system. As FAA Administrator Najeeb E. Halaby stated in his testimony in the 1963 FAAP hearings before the Aviation Subcommittee of the Senate Commerce Committee:

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[2]The air traffic hubs are the cities and metropolitan areas which the airlines serve. These communities are classified in terms of percentages of the national domestic airline passenger total as follows:

Large,	1.00 percent or more;
Medium,	0.25 to 0.99 percent;
Small,	0.05 to 0.24 percent; and
Nonhub,	less than 0.05 percent.

FAA uses the air traffic hub structure to measure the concentration of all the social and economic factors that determine a community's ability to generate air carrier or general aviation traffic. The hub structure is constructed from airline data because these constitute the longest, most reliable series of air traffic facts available. It is expressed in terms of passengers since they are the principal source of airline revenue and since the distribution of passengers, mail, and cargo by types of communities is well correlated. A community's air traffic hub classification is based on its percentage of the scheduled domestic enplaned airline passengers within the conterminous United States. The hub designation is based on the community's share of the air passenger market of the United States rather than on a fixed number of passengers for a given time period. Of the 21 large hubs, nine have two or more air carrier airports.

We could go ahead with airport layout planning in the absence of comprehensive metropolitan planning. However, we hope that those instances would be rare because what we are all interested in is safe, convenient, and efficient transportation from door to door.

The traveler really does not care how much time he spends afoot, on wheels, or on the wings. He does not analyze it that way. He wants to get from here to there safely and quickly. We will need, as the metropolitan population centers expand, a great deal more regional and metropolitan planning that will provide for rapid transportation from door to door. We hope that these can move forward in formation with airport development.

We will come later to a point where we say, and I think with conviction, that the problem has already become so serious, not to mention how much more serious it will be in the supersonic era, where as much time is spent on the ground as in the air on several different transcontinental flights. Therefore, we are going to look very carefully and may, in certain selected instances, exercise judgment in withholding Federal-aid-to-airport grants where the community has taken no steps to provide for accessibility to and from the airport.

The objective here is a metropolitan airport system developed within the context of a continuing comprehensive metropolitan planning program. In theory, the general procedure for planning the metropolitan airport systems is as follows: (a) prepare the long-range (20-year) comprehensive metropolitan plan; (b) prepare a short-range (5-year) operational plan for airport development including basic inputs from the long-range plan; and (c) make necessary revisions to the long-range plan based on the short-range plan. In practice, however, most metropolitan planning agencies have not yet developed long-range plans. Therefore, the short-range operational plan for airport development should be integrated with highway and mass transit development programs to create a short-range metropolitan transportation plan. This plan is, in effect, the primary method of implementing the initial phases of the long-range transportation plan. This, in turn, is a key part of carrying out the long-range comprehensive plan. In terms of the continuing planning programs, operational planning influences the long-range plan and the long-range plan provides the basic development goals for operational planning. Again it must be emphasized that most planning agencies have not yet achieved the degree of sophistication necessary to perform both long-range and operational planning functions. As was stated at the outset, this represents a rather ambitious and hopefully farsighted view of the direction in which metropolitan planning agencies should be moving to make metropolitan planning programs effective.

The next question is how does the metropolitan planner develop an operational systems plan? Since all major metropolitan areas are presently served by one or more air carrier and general aviation airport, he must first analyze the existing airport system. The methodology outlined here is presented as an example of one way in which the airport system can be analyzed. Like most methodology, it should be reviewed in terms of the transportation requirements of the individual metropolitan area and changed to meet the needs of both the area and the metropolitan planning program. The methodology was developed for the FAA by Warskow and Wisepart of the Airborne Instruments Laboratory, and does not necessarily reflect the official views or policy of the FAA.

METHODOLOGY FOR ANALYZING CAPACITY OF AIRPORT SYSTEMS

Many of the large metropolitan areas and their suburbs are now served by several airports. Because of the interactions between these airports, they should be examined as a system to insure their most reasonable and economic use by: (a) determining when the airport will become congested, (b) finding ways to relieve congestion, and (c) minimizing the need for new facilities.

Method of Analysis

To determine if an airport is to be included in the airport system, it must be decided whether the activity level in the present or projected period warrants its consideration. In general, an airport is part of the system if:

1. An FAA control tower is or will be established (that is, it has attained an activity level sufficiently high for air traffic control), or
2. Its airspace requirements conflict, in either Visual Flight Rules (VFR) or Instrument Flight Rules (IFR), with those of any other airport (civil or military) in the system.

The study of airports for a systems analysis can be limited to aircraft operations. Figure 1 indicates the major items to be considered. These items must be examined to determine the extent of their interaction between airports. Then, each subsystem of each airport must be examined to obtain an overall view of the operation of that airport and its relation to the system. To work in quantitative terms, the methodology used in the analysis evaluates the many items affecting the operation of a system of airports and shows how their effect on the practical peak annual capacity (PANCAP) of an airport can be determined. A technique for determining the PANCAP of an airport is then used to derive the interrelationships between airports and to determine quantitatively when congestion will occur at one airport or in a system of airports. Figure 2

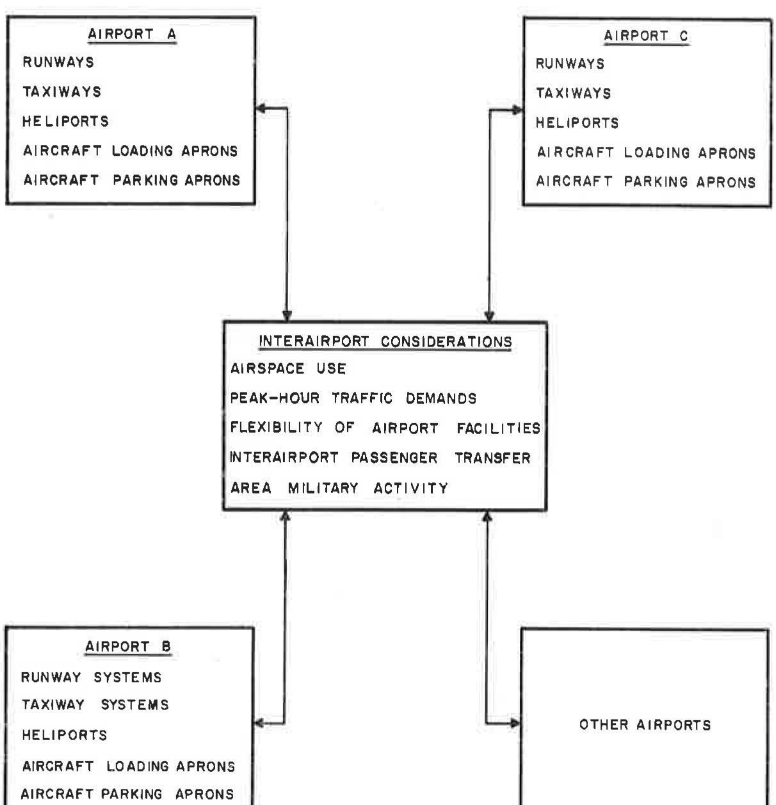

Figure 1. Operational subsystems involved in airport system analysis (source: Airborne Instruments Laboratory, 1964, Contract FAA/BRD 403).

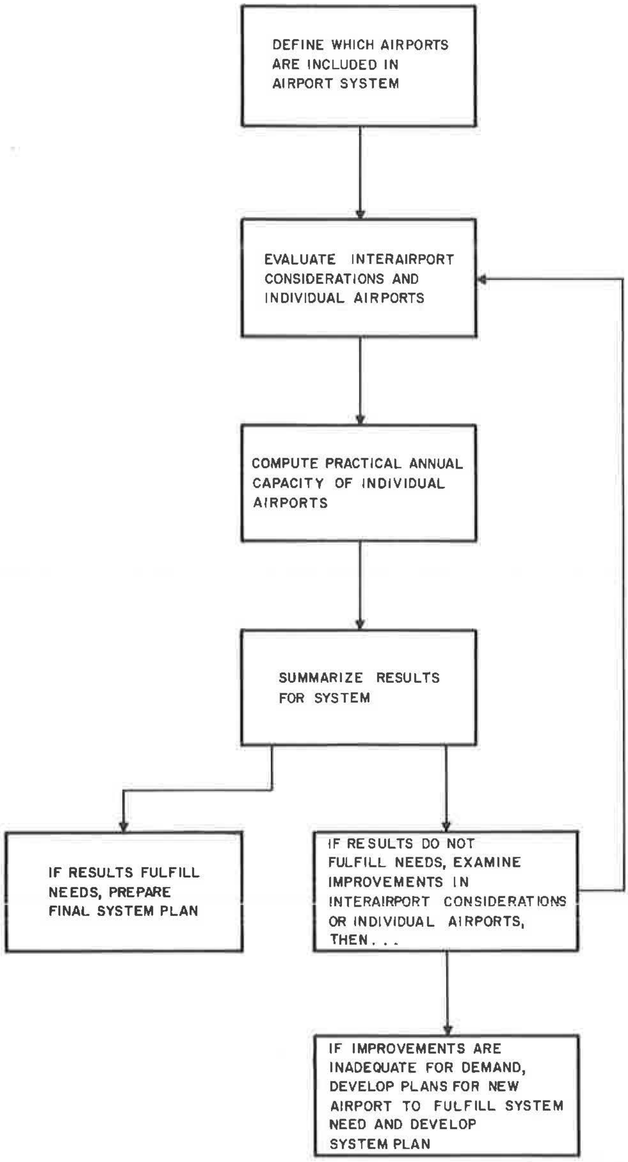

Figure 2. Summary of procedure for airport system analysis (source: Airborne Instruments Laboratory, 1964, Contract FAA/BRD 403).

summarizes the procedures for the systems analysis. It is a cyclical analysis process designed to result in a system plan.

Airport congestion occurs when the annual demand exceeds the PANCAP of that airport. Congestion can be relieved by increasing capacity, shifting demand away from the airport, and redistributing the demand.

Interairport Considerations

Figure 1 shows the interairport considerations that are involved in the analysis of an airport system. Some of these must be examined both as a part of the system and as a part of the individual airport's performance. Their effect on the PANCAP of an airport and the system capacity must be assessed and accounted for appropriately.

Airspace Use.—To establish how a group of airports use, or should share, airspace may involve three distinct analyses:

1. Determining how this traffic at the airport would like to use the airspace, accomplished by examining both the scheduling practices of the airlines and general aviation flow patterns;
2. Determining how the traffic at the airport must use the airspace, for example, by observing and recording the radar pictures of current traffic flow; and
3. Determining where a new airport could be located to have minimum interference with existing facilities; this will require consideration of improvements in air traffic control (such as the common IFR room) and reductions in IFR spacings.

Peak-Hour Traffic Demands.—The hourly traffic distribution for each of the airports in the airport system should be developed to determine whether there is any possibility of sharing the load at the airports during certain hours of the day. If the peak hours coincide and the airports are loaded, this would, of course, not be possible. However, it may be possible to share the traffic between airports until all reach their peak hour capacities, and therefore, some means would have to be developed to shift the demand for each airport. Shifting airline schedules or inducing general aviation to use lightly loaded airports would accomplish this.

Flexibility of Airport Facilities.—If the airports in an airport system are to operate in a complementary manner such that traffic can be moved between airports to satisfy unusual traffic demand or weather situations, it is important that there be some flexibility in the use of facilities. For example, runways must be long enough to satisfy aircraft that usually use airports with longer runways. This would also extend into other areas of airport design such as gate space. The greater the equality between airport facilities, the greater is the possibility of exchanging traffic between the airports.

Interairport Passenger Transfer.—An efficient plan for transferring passengers between the airports must be developed as part of the system plan. This plan should provide for the transfer of passengers between connecting flights—particularly those between domestic and international accommodations to one airport in the metropolitan system. To encourage the system approach to the distribution of traffic between airports, it may be necessary to have a superior means of transferring passengers between the airports. In many cases, current surface transportation is not satisfactory for this purpose. The possibility of using helicopters has great promise for the future.

Area Military Activity.—In many of our metropolitan areas, military activity is conducted from civil airports or from military airports within the system area to provide a convenient training place for reserve personnel. In these cases, military traffic may occur at the peak periods of civil activity. If this can become a problem, ways of controlling or reducing the military activity during these periods must be found.

Individual Airport Considerations

Each airport in an airport system must be analyzed to determine its PANCAP. Figure 1 shows five airport subsystems that must be analysed to determine the subsystem that limits the airport capacity. Although the runway subsystem is the major airport consideration in computing the PANCAP, taxiways, heliport facilities, and apron areas can also be significant factors. Limitations in any of these areas must be accounted for in computing the PANCAP of an airport.

Runway Subsystem.—The most important airport subsystem in an airport-capacity analysis is the runway subsystem. Congestion occurring in the other operations subsystems can usually be relieved to the point where the runways become the limiting factor. A runway subsystem involves several factors (Table 1) that should be clearly specified for the capacity analysis. A wide range of procedural and physical improvements can be implemented to increase airport capacity.

Taxiway Subsystem.—Certain phases of taxiway design affect runway operation, such as turnoffs from the runway and the holding-apron capacity. Other phases of taxiway design that can cause congested situations at the airport include:

TABLE 1

FACTORS FOR RELIEVING AIRPORT CONGESTION

Factors	Procedural Improvements	Physical Improvements
Runway layout		More runways; lengthen runways to remove operating restrictions; modify thresholds and/or intersections; modify runway/taxiway crossings; add and improve turnoffs.
Taxiway layout	Use runways as taxiways.	Improve bypass areas, use runways as taxiways.
Airspace layout	New and additional departure fixes; share airspace assigned to other airports.	New and additional departure fixes.
Operating procedures	Remove any restrictions on runway use.	
Traffic demand	Reschedule air carrier; reduce general aviation; reduce military.	Reduce general aviation.
Navigational aids	Provide more flexibility for approach/departure routes; provide IFR dual-approach capacity.	Provide more flexibility for approach/departure routes; provide IFR dual-approach capacity.

1. The lack of a two-way taxiway capability around the terminal buildings and between the terminal and the runways or hangars;
2. The lack of proper space for taxiing around parked aircraft at terminal locations;
3. Taxiway layouts that use runways as taxiways (thereby limiting the use of the runway wherever this is necessary); and
4. Taxiway layouts so close to a runway that exiting aircraft must mix with aircraft on the parallel taxiway.

The delay resulting from these situations should be evaluated to determine whether it affects annual capacity and can be decreased. The evaluation involves comparing the delay and taxi time of the present system with the delay and taxi time of the improved system. The computation of PANCAP must make appropriate allowances for taxiway problems that reduce runway capacity and cannot be solved.

Heliport Facilities.—In an airport system, the means of interconnection between airports becomes more important as traffic increases, particularly as the airports approach capacity. The rapid means of interconnections that are so important in some cases can most readily be satisfied by helicopters. Since they operate in the same airspace and the same operating parts of the airport as fixed-wing traffic, helicopters should be considered in planning airport operating facilities for metropolitan areas. In general, heliport facilities should be planned to avoid, if possible, any interference with fixed-wing runway use, yet be located for passenger convenience.

Apron Areas.—Aircraft loading and parking areas for general aviation airports are a necessary facility and, in general, do not limit airport capacity because these areas can usually be adequately provided around the operational runway areas. If the parking areas for air carrier aircraft on terminal aprons are inadequate, congestion can occur. Directly observable results will be the tie-up of adjacent taxiways and possibly a delay of scheduled arrivals and departures.

An evaluation should be made to insure that a reasonable level of service is provided and that the delays are not excessive. The number of gate positions required at any specific future date can be determined in relation to the growth in enplaned passengers forecast for a particular airport. The first step is an analysis of present gate use and requirements (Fig. 3).

The results of the analysis of current gate requirements in conjunction with the forecast of enplaned passengers are used to determine the future gate requirements.

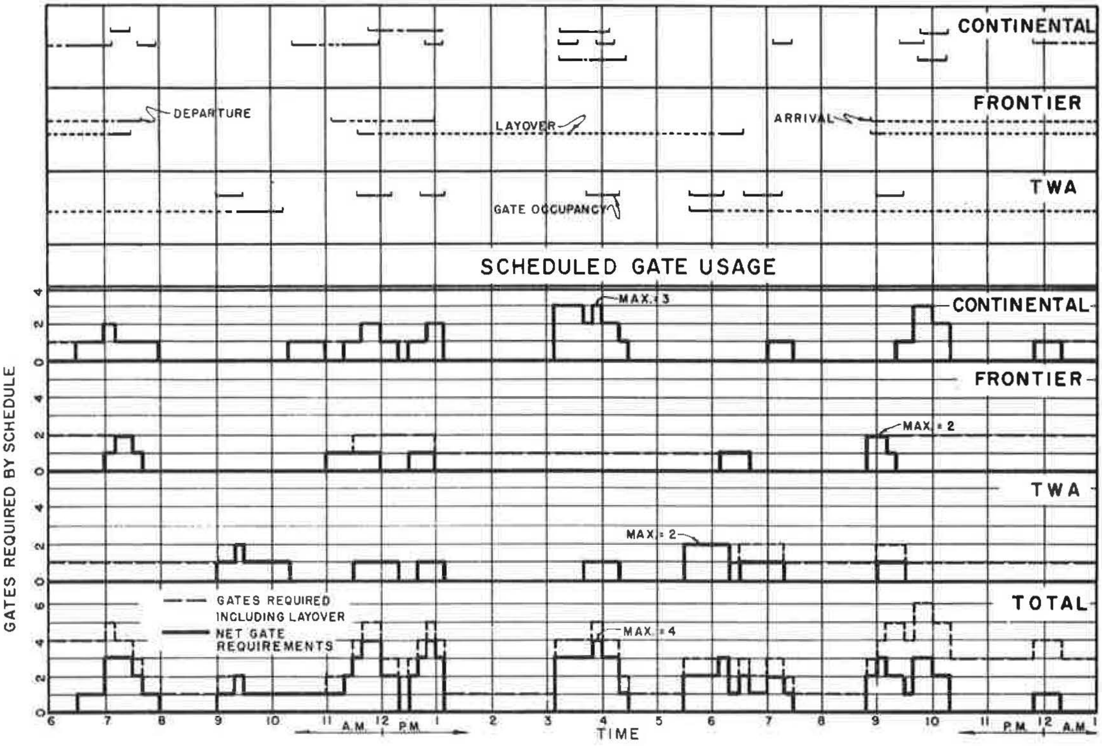

Figure 3. Scheduled gate occupancy, Alburquerque, December 1961 (source: Airborne Instruments Laboratory, 1964, Contract FAA/BRD 403).

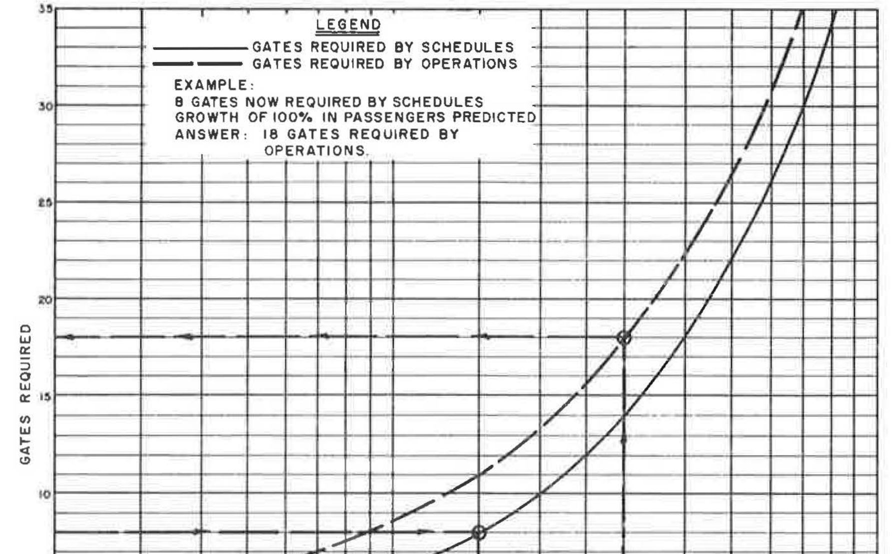

Figure 4. Example of gate requirements (source: Airborne Instruments Laboratory, 1964, Contract FAA/BRD 403).

The procedure illustrated in Figure 4 is used to determine gate requirements and will permit operations with only 2 percent or less of the flights being delayed for an available gate.

It may be necessary to analyze gate requirements more than once to accommodate various traffic demands projected as part of the overall airport system study. There may be valid reasons for examining alternative approaches to assigning or distributing traffic between the airports. When gate requirements use all areas available for terminal building development, it may be necessary to reverse the procedure and determine the effect of this on the total traffic at the airport.

This material can be applied by maintaining a correlation between gate development and the increase in enplaned passengers. The equivalent demand in annual movements must then be obtained and accounted for in determining the PANCAP of the airport.

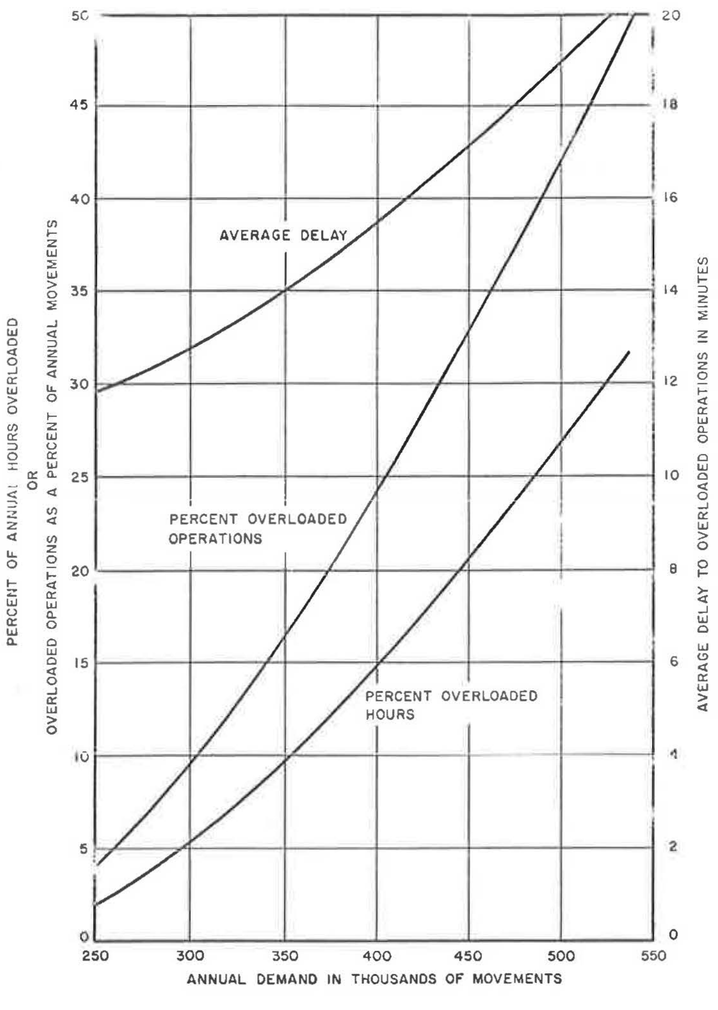

Figure 5. Data required to determine practical annual capacity (source: Airborne Instruments Laboratory, 1964, Contract FAA/BRD 403).

Practical Annual Capacity of Individual Airports

The PANCAP of an airport is determined by comparing the demand (existing or anticipated) on that airport with its capacity. This comparison is accomplished using a technique that examines, for a period of 1 year and for various annual traffic demands, the following factors:

1. Percent of hours during the year that the hourly demand exceeds the hourly capacity (called percent overloaded hours);
2. Percent of annual operations occurring during the overloaded hours (called overloaded operations); and
3. Average delay to overloaded operations.

Note that the analysis considers only those hours of the year when the airport operates in an overloaded condition. These hours determine, for the most part, the quality of service that an airport provides.

The PANCAP is computed using the technique shown in Figure 5. The input data to the PANCAP computation consists of the following:

1. Variation of daily demand levels throughout a year—There are nine VFR levels and nine IFR levels. The nine VFR levels relate to VFR demands on peak, average,

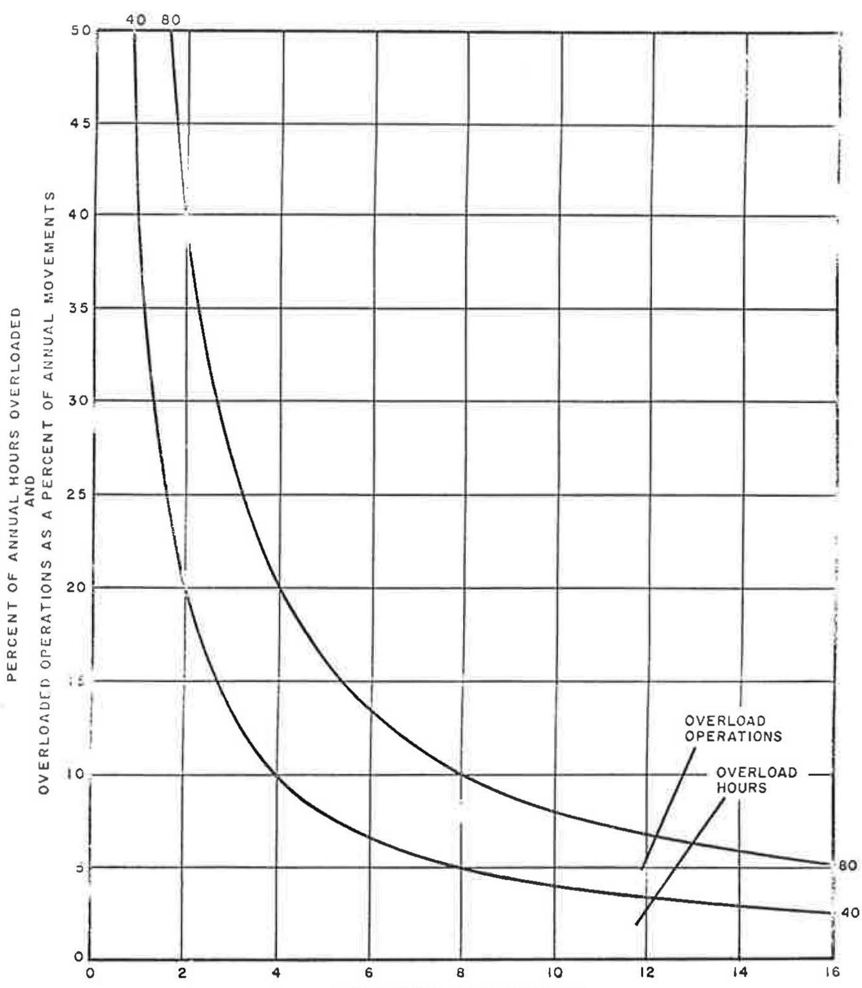

Figure 6. Determination of practical annual capacity (source: Airborne Instruments Laboratory, 1964, Contract FAA/BRD 403).

and low days of peak, average, and low months; the nine IFR levels are similarly classified.

2. Occurrence over a year of each of the relative levels of hourly demand.

3. Typical hourly distributions of demand throughout the day—Different hourly distributions are used for VFR and IFR weather.

4. Ratio of landings to takeoffs for each hour.

5. For each possible combination of runway use, the capacity (for example, at a 4-min average departure delay in VFR) and amount of use during the year.

6. Test demands—These are expressed in terms of the number of aircraft desiring to use the airport runways in a peak hour of a peak day of a peak month.

After these results have been obtained for all of the six hourly test demands, they are curve fit (least squares) and plotted as shown in Figure 6.

Data obtained from Figure 6 are replotted on Figure 7. The average delay at the intersection of the percent overloaded hours curve with the constant-40 curve is noted. The average delay at the intersection of the percent overloaded operations curve with the constant-80 curve is also noted. The PANCAP of an airport is the annual demand that yields the smaller average delay.

Figure 7 is based on the following reasoning. Suppose that we plot the percent overloaded hours as a function of average delay from curves such as shown in Figure 6. We have found that good airport operation exists at annual demand levels representing the portion of the curve below and to the left of the constant-80 curve. The constant-80 curve represents the hyperbola obtained by setting the product of the two axes equal to 80; for example, 10 percent of annual operations occur during overloaded hours and experience an average delay of 8 min.

The procedures used for determining the PANCAP are summarized in Figure 8. The starting point is the existing airport with the runway, taxiway, airspace layout, and the operating procedures and navigational aids in use. If the annual capacity is greater than the current annual demand, then the only need for reexamination is for future conditions. If, however, the analysis shows that the annual demand is greater than the annual capacity, then the analysis must continue by considering improvements to the runway system (Table 1), recomputing the annual capacity, and comparing the revised annual capacity with the annual demand. Thus, the cycle continues until either the annual capacity exceeds the annual demand or all possible ways of increasing the annual capacity have been examined. If it is still impossible to provide adequate capacity, then an attempt should be made to decrease the demand by encouraging the excess demand to use other facilities.

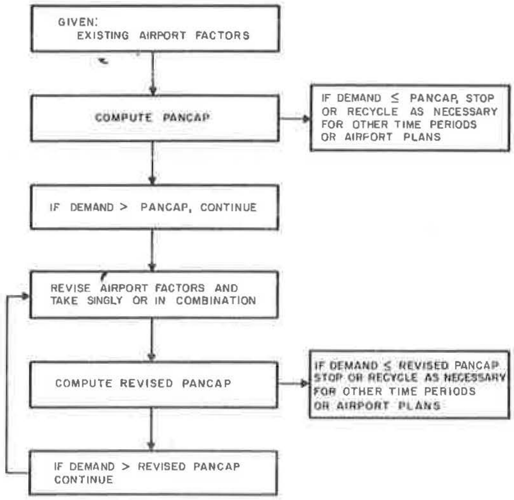

Figure 7. Flow chart for analysis of practical annual capacity (source: Airborne Instruments Laboratory, 1964, Contract FAA/BRD 403).

Capacity of Airport System

After determining the PANCAP of each airport in the system, the system capacity can be derived. A system of airports is congested if one or more of the airports is congested after all reasonable and economic ways of relieving the congestion at the particular airport have been tried. Thus, the comparison of individual airport capacity with the demand of that airport is most important. The systems approach to analyzing the individual airports is vital in order to include airport interrelationships. However, it may be more meaningful to treat the airports individually when comparing the demand with the capacity.

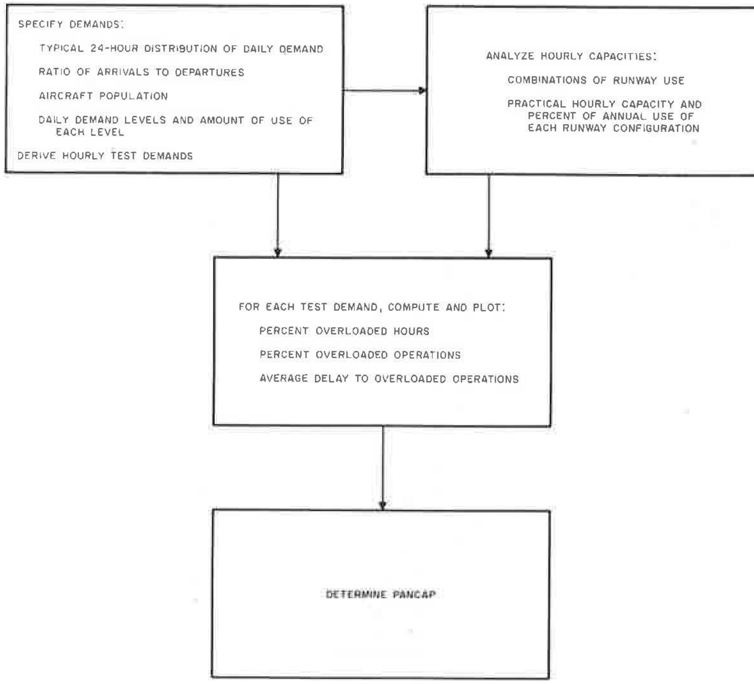

Figure 8. Computation of practical annual capacity of airport (source: Airborne Instruments Laboratory, 1964, Contract FAA/BRD 403).

A suggested procedure for analyzing the meaning of the annual capacities and the airport system capacity is as follows:

1. The cyclical process of Figure 8 should be completed, if not already done. In this step, either adequate capacity is or can be made available or the ultimate capacity has been determined.
2. The capacity analysis will have been based on annual demand, probably both current and forecast. These demands must be compared with the computed capacities to determine which airports will become congested.
3. The demand for the congested airport is analyzed to determine whether demand can be lowered by diverting traffic to airports with excess capacity.
4. If diversion is not practical or if the amount of diversion is so small that a capacity problem still exists, new airports must be provided to relieve capacity.

OPERATIONAL SHORT-RANGE DEVELOPMENT PLAN

After completion of the analysis of the existing airport system, the next step is the preparation of the operational short-range (5-year) development plan. The plan is composed of two parts: (a) planned expansion of the capacity of existing airports, and (b) the addition of new airports to the system based on the long-range comprehensive plan.

Almost all of the growth of the United States is occurring in metropolitan areas. Further, most of our urban expansion is occurring at the periphery of metropolitan areas. This poses some particularly difficult problems for airport planning because airports are large consumers of land for runways, approach zones, takeoff patterns, etc. With more and bigger jets they will also become an increasingly noisy neighbor. Such problems have underscored the need for airport system planning. The short-range plan is a practical device for pinpointing where conflicts between the airport and its neighbors are likely to occur. Moreover, by coordinating airport expansion and development with local city and county planning programs, these painful and emotional conflicts can be resolved before the dollars are committed for construction. The short-range plan represents an opportunity to provide service to the whole metropolitan area without negotiating with each individual community. It is an opportunity to plan the system on a rational basis, providing a guide for future investment in the system.

The use of air carrier service, air cargo transportation, business flying, and pleasure flying have all been expanding in recent years. Since the demand for air transportation facilities will probably be accelerating in the future, the need for operational, short-range development planning becomes particularly important. It seems evident that both elements of the short-range plan will need to be expanded to accommodate the demand for airport facilities. The nature and degree of the changes will, of course, depend on the increase in each of the different kinds of air traffic which are forecast for the 5-year planning period. The FAA has developed methods for forecasting air traffic demand and will provide guidance and assistance to airport system planners.

The analysis of the capacity of the existing system will identify the factors causing congestion in the existing system. From the analysis the planners can determine what kind of rescheduling, expansion, or new facilities will be needed to resolve current problems and to avoid future problems in the metropolitan airport system. For instance, in the Atlanta metropolitan area, there are 20 scheduled flights for 5:00 p.m. at the major air carrier airport. Needless to say, this creates severe congestion around 5:00 p.m. The obvious solution is to reschedule, but because of the nature of the workday and the demand for business commuting by air, none of the airlines wants to give up its priority position on the demand schedule. Therefore, additional facilities might be necessary to handle peak hour loads, but the cost of additional facilities must be weighed against the cost of the convenience to the air passenger, the business community, and the airlines. The consequences, both intentional and unintentional, of these decisions can be clarified and defined within the short-range development plan. Thus, wiser decisions can be made. Wiser decisions mean greater benefits for the community, the passenger, and the air industry.

One of the key objectives of the short-range development plan is a "balanced transportation system." All expansion and new airport development must be coordinated with metropolitan highway and mass transit planning. Peak hour traffic at airports often coincides with the congestion of rush hour commuting. The decisions relating to one transportation mode will influence the planning of other modes. The need for coordination of short-range transportation planning is clear.

Although this kind of coordinated transportation planning has not yet been achieved in any metropolitan planning program, the promise of greater financial support, increased responsibility, and improved technological skills point to more effective metropolitan planning agencies capable of coordinating transportation planning within the context of comprehensive planning programs.

INFLUENCE OF NEW AIRCRAFT TECHNOLOGY ON DESIGN OF METROPOLITAN AIRPORT SYSTEMS

Changes in aircraft technology have influenced airport design in the past. New aircraft technology will influence the design of the metropolitan airport systems in the future. The helicopter, the vertical and short takeoff (VTOL, STOL), etc., will introduce new planning requirements but they will not replace the need for old-fashioned airports with long runways.

The implications of rapid changes in the technology of air transport were explored with considerable imagination and insight by Branch (4), who points out that:

> Use of commercial helicopters in cities is expanding rapidly. Continued growth in this use and the development of other means of aerial travel could create a new set of city planning problems.

The new aircraft technology presently foresees the future development of VTOL, STOL helicopter, and the SST (supersonic transport). Looking at the future prospects for each of these new developments, we can foresee a demand for a greater variety and specification of "airports." The subsidies for commercial helicopters have not changed much over the last several years. The commercial operation of helicopters is actually less than it was a few years ago. The problems are high costs, reliability, and maintenance of schedules in all weather. If the helicopter is confined to speeds of 60 to 80 knots, economical transportation may be possible. The improvement of jet engines might also lead to lower costs. More research is needed to improve the flying and handling qualities of the helicopter to achieve all-weather operation. The objectives of such research are to improve the utility of helicopters for short-range transportation in urban areas.

At present, there is no aircraft that adequately provides short- and medium-haul needs. American industry has the technology to provide such vehicles, costs of development are high. Here again, more research is needed. Aircraft with short-field takeoff may be developed utilizing modern turbine engines, the latest developments in high-lift devices and perhaps the application of boundary layer control. Such a vehicle could reduce airport traffic control problems.

At present, all types of aircraft—short-haul, long-haul, propeller aircraft, and jet transport—use the same runway, causing a large part of the congestion problem. Using the same runways, they come in over the same approach zone and leave the airport in the same direction. The shorter haul aircraft, perhaps with cruise speeds of 350 knots, can be designed to operate in and out of new shorter runways separate from existing low-speed characteristics. With improvement in airborne collision detection equipment and improvement in tower air traffic control systems, much congestion can be avoided.

G.E.M.'s (ground effect machines) merit special discussion. They appear to have several fundamental problems. As the speed of these vehicles increases, their efficiency is seriously limited. When the speeds exceed about 30 to 40 knots, the proportion of the momentum of the incoming air which is required to support the machine becomes a very small proportion of the total momentum of the air handled. At 100 knots, not more than one-fifth of the total momentum of the incoming air is used in the production of lift. At lower speeds, on the order of 30 knots, the efficiency is much better. Because this problem is inherent in the G.E.M., it might represent a fundamental technological limitation. The FAA and the Civil Aeronautics Board (CAB) have jointly determined that G.E.M.'s are not considered to be aircraft.

The long-haul aircraft are far more highly developed than the short- and medium-haul aircraft. There is a growing long-haul air transportation market in most of our larger metropolitan areas. Ninety percent of all transcontinental trips are made by air. The latest advance in the long-haul air transportation is the development of supersonic transport or SST.

The United States is now engaged in a multimillion dollar design and study program aimed at development of a supersonic transport. Initial design proposals from industry were evaluated early this year by a government team and the airlines, and improved designs are currently being studied.

The SST would serve the long-haul air market, that is, 800 mi or more. Shorter hauls will probably continue to be served by subsonic commercial jets. The SST will probably command large economic market areas. Therefore, it is anticipated that relatively few strategically located SST capability airports will be needed to serve the entire long-haul air market of the United States. If asked to define "relatively few," I would say that they will probably be limited to 20 to 30 large hubs; and further, there will probably be only one SST capability airport to serve each of our major metropolitan areas. This means that all modes of medium- and short-haul transportation will play an increasingly important role in providing connecting service to long-haul supersonic aircraft.

Several different kinds of transportation in addition to a well-developed highway system may be needed to provide the passenger with adequate total trip transportation. For instance, connecting transportation to an SST flight originating in New York might require both a rapid transit connection to serve passengers originating in Connecticut and a short-haul aircraft connection to serve passengers originating in Albany.

Similarly, an SST flight originating in Los Angeles might require rapid transit service to Riverside and a short-haul aircraft connection to Las Vegas. Obviously, developments of this nature will have planning implications for highway and transit planning as well as airport planning.

Business flying will also be affected; management will probably make even greater use of privately owned aircraft to provide direct connections from the office or the plant to the SST airport. If the SST is going to serve a large regional market, it will have planning implications for several types of transportation.

From this brief review of new aircraft technology, it is apparent that the new aircraft will supplement but not supplant the existing aircraft. Therefore, we will continue to need the traditional type of airports as well as new kinds of airports for the VTOL, STOL, and helicopters. The use of these new aircraft for interurban transportation is dependent on the development of power plants that are far more efficient in terms of power-weight ratio than the present models. They will also have to be far more compatible with the highly sophisticated air traffic control and navigation installations that are responsible for directing air traffic in the growing metropolitan areas. Major modifications in ground installations, pilot procedures, and airborne electronic equipment will be necessary if any significant amount of helicopter, VTOL, or STOL traffic is to be properly coordinated with existing types of aircraft.

NEED FOR RAPID TRANSIT SERVICE TO METROPOLITAN AIRPORTS

In the past, ground transportation to the airport has been predominantly highway oriented, largely because there is no direct rapid transit service to major airports. With the passage of the 1964 Urban Mass Transportation Act and the prospect of fast, safe, comfortable, and economic transit service, mass transit may provide a practical alternative to the auto, taxi, and limousine.

Fixed rapid transit, such as rails, subway, or monorail with its heavy costs per mile and the considerable number of miles to be traversed, cannot be justified as a facility to serve the airport alone. However, in major metropolitan areas such as New York, Detroit, Chicago, Cleveland, San Francisco, Los Angeles, and Boston, airports are part of a total urban complex. Within such consolidated metropolitan areas, the best opportunity for the economic success of rapid transit service to the airport will be where a new metropolitan transit line can be extended from an existing system to the airport. For instance, in Cleveland the Transit Authority is developing a $1\frac{1}{2}$-mi rapid transit extension from the West Side Terminal. With Federal assistance, it will be able to add another $2\frac{3}{4}$ mi to link Cleveland Hopkins Airport to downtown. In Tokyo, a monorail was recently completed between Hannada Airport and downtown. The trip which formerly took $1\frac{1}{2}$ hr by car can now be made in 15 min. The time saved is perhaps equal in significance to the development of the SST.

Transit time from the passenger's point of orgin to the airport is a matter of major concern. In many cases, the ground time exceeds the air time. With the introduction of jet transports, the margin has increased even more. For a journey of 400 mi between two large metropolitan areas, ground times are as much as double air time.

Surveys made of ground transport to the airport indicate that in the United States the majority of passengers, visitors, and airport and airline employees travel by private automobile. Indications are that this trend will continue in the future. Travel desire lines to and from the airport appear to be widely scattered; this is especially so with travelers residing in the area served by the airport. Out-of-town passenger origins and destinations seem to concentrate more in centralized hotel locations near business centers. On the other hand, many of these travelers are making use of rented automobiles.

Because of the lack of concentration of origins and destinations of air passengers in a metropolitan area and the popularity of the automobile as a personal means of transportation, the use of public transit up to now has not been large. However, as air transport keeps growing, the volumes of passengers may be large enough to warrant special means of transportation to the airport. This is especially true in large urban areas whenever the normal peak vehicular traffic periods coincide with the peak traffic periods at the airport (often 5:00 to 6:00 p.m.). In some cities in Europe, such as Brussels and London, a train connects the airport with a downtown terminal. Other cities in Europe are planning similar installations. 'Although these installations are undoubtedly quite expensive and probably cannot be economically justified on the basis of serving the airport alone, they become useful in the future as part of a rapid transit system for an entire metropolitan area, accommodating peak hour traffic at the large metropolitan airport. Transit planners and officials should be encouraged to explore the economic feasibility of serving major airports with an "airport special" during peak ground traffic hours which are often coincidental with peak air traffic hours. The "airport special" could provide a faster, direct, perhaps nonstop trip to the airport from a convenient central city terminal in a comfortable air-conditioned atmosphere. Since the peak airport hours are usually coincident with surface transportation peaks, the transit planners might have to provide additional equipment to serve the airport needs adequately during the critical peak hour periods. Airlines could provide downtown terminal facilities and service to handle baggage from the cab or automobile at the downtown terminal straight through the airport to the destination.

Metropolitan planners should include airport service feasibility studies in their mass transit planning programs. The FAA Regional Office and the District Airport Engineer will provide assistance. It is particularly important to initiate coordination with the FAA, the airport sponsors, and transit officials at an early stage to coordinate airport transportation planning at the outset of metropolitan transportation system planning.

CONTROL OF LAND-USE DEVELOPMENT AROUND THE AIRPORT

The control of land-use development around the airport is the responsibility of the local political jurisdiction in which the airport is located. The metropolitan planning agency should review local plans, but the administration of land-use controls is a function of the local authorities. Therefore, the FAA must rely on the local community to implement the FAA standards for development of land adjacent to airports.

Land-use control is an extremely complex problem. In areas of rapid urban growth, zoning should be regarded as an interim or stopgap measure. It is not the ultimate solution. The FAA has prepared a "Model Airport Zoning Ordinance" to provide guidance for communities, but like any guide it is the implementation of guidance that counts. The power to zone the height of structure around airports is now well established under the state's police power to "promote and protect the public health, safety, morals, comfort, and general welfare of the people." With the introduction of jets, however, noise has become the critical problem.

A recent HHFA demonstration grant project (5) to determine the noise effects of jet aircraft operation on land uses in the environs of a major jet airport (the Detroit Metropolitan Wayne County Airport) concluded that "Land in the area affected by aircraft noise is not suitable for residential development."

If residential development should be restricted in the airport approach and takeoff pattern, how can owners of the land be reasonably compensated? The answer is that they cannot without a massive program of purchasing development rights around airports. Buying development rights is politically and economically unrealistic at this time. Therefore, the best approach is to (a) encourage a vigorous enforcement of zoning regulations around existing airports, (b) encourage public land acquisition at both ends of the runways of existing airports whenever feasible, and (c) require the protection of new airports by coordinating other public land acquisitions with airport development. In other words, land should be reserved at both ends of the runway for publicly owned parks, reservoirs, sewage treatment plants, landscape nurseries, aboretums, riding academies, golf courses, ets. The FAA now provides matching grants to purchase land in clear zones and the HHFA can provide up to 30 percent grants of land in approach zones. The FAA is also working with the Department of Interior to develop procedures for coordinating land acquisition programs which will be assisted by grants from Bureau of Outdoor Recreation under Public Law 88-578.

In areas where new highways are proposed near airports, highway planners should consider the feasibility of running the highway down the center of the airport approach zone for noise abatement purposes.

The purpose of this land-use coordination effort is to maximize the usefulness of the airport by avoiding conflicts between the airport and its neighbors. Guidelines for land-use planning around airports have been developed for the FAA by Bolt, Beranek, and Newman (6). Although it is not the last work in land-use planning with respect to aircraft noise, it does represent the latest state of the art in calculating composite noise ratings around airports.

The HHFA's Open-Space Land Program authorizes the Federal Government to make grants to localities of up to 30 percent of the cost of undeveloped land for recreational and conservation purposes. In the first 3 years of the program, from 1961 to 1964, the $32 million in Federal Grants for open land were primarily concentrated in large fast-growing metropolitan areas. It is also in fast-growing metropolitan areas where the need exists to protect airports from the encroachment of subdivisions and other incompatible neighbors. Clearly, much greater coordination of open space planning with airport planning should be encouraged. It is worth noting that open space grants include a 10 percent additional incentive if open space planning is carried out as part of a comprehensive metropolitan planning program.

With the expansion of airports for jets and the increasing urbanization partly attracted by the airport itself, the control of land use around airports has become an increasingly difficult and complex task. The local community or adjoining community may not be able to do the job by themselves. The Federal Government may have to provide assistance for excess land acquisition or for the preservation of open space around airports. This is one of the many problems which will not be quickly resolved but planners must take the initiative now to explore methods for avoiding conflicts between airports and their neighbors before such conflicts become frozen in place and the only solution is legal action which can only result in marginal adjustments and unhappy homeowners.

SUMMARY AND CONCLUSION

Airport system planning represents a new dimension and a new challenge to the urban planner. Metropolitan transportation planning programs should include areawide airport system planning. The planner should take the initiative in the development of airport system plans. He should seek the guidance and assistance of the District Airport Engineer in developing the airport system plan.

The planning approach suggested here is a short-range (5-year) airport system development plan based on the long-range comprehensive planning program for the entire metropolitan area. The operational short-range development plan is composed of two elements: (a) the expansion of existing airports, and (b) the addition of new airports to the system. The short-range plan should also be coordinated with the highway development plan, the mass transit development plan, and local development and land-use plans for the specific area or political jurisdiction in which individual airports, both existing and planned, are located.

The capacity of the existing metropolitan airport system should be analyzed to determine where problems of congestion are presently occurring and where problems are likely to emerge within the 5-year development period.

To make metropolitan planning programs more effective, the planner should place much greater emphasis on coordinating the short-range development plans of the functional agencies responsible for highways, mass transit, and airports, even to the extent of preparing areawide system plans for such agencies. The HHFA's 701 Urban Planning Assistance Program, which provides up to two-thirds of project cost for metropolitan planning, specifically authorizes airport planning as follows:

a. Determination of the Number, Type, and General Locations of Airports Needed for Both Commercial and General Aviation. and

b. Relationship of Airports to Community Development, Including Consideration of Economic Factors, Land Use Controls, and the Overall Transportation System. (7)

Further, under HHFA's 702 Public Works Planning Program, the local airport sponsor in coordination with the metropolitan planning agency can also receive a 100 percent advance to cover the cost of preparing a detailed design or development plans for individual airport projects, or the local airport sponsor can use the 50 percent planning grant under the Federal-aid Airport Program which, unlike the 702 Program, does not have to be repaid at the time the specific airport project is undertaken.

The Metropolitan Planning Review Bill (S. 855), which has at the time of this writing unanimously passed the Senate and is pending in the House, would require that a number of Federally supported projects, including airports and other transportation facilities, be reviewed by official metropolitan planning agencies for consistency with each other and with general development plans and policies for the area as a whole. However, even if S. 855 does not pass, future legislation affecting functional development programs will require review by metropolitan planning agencies. Metropolitan planning must take the initiative now to make these review procedures meaningful in the future. This opportunity to make planning programs effective has presented the metropolitan planner with a great opportunity and a tremendous challenge to produce the kind of practical and realistic, yet farsighted and inspirational, planning program that is needed to create a more efficient and workable urban environment.

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Minimizing Land Used by Automobiles and Buses in Urban Central Core: Underground Highways and Parking Facilities

GEORGE A. HOFFMAN, The RAND Corporation, Santa Monica, California

Possibilities for reducing the land used for urban transportation in the central city core by providing ample automotive access with deep underground tunnels and parking areas are examined.

The cost of conventional urban highways built through densely populated areas is described in terms of construction costs, right-of-way acquisition costs, and selected operating expenditures. Construction and ventilating costs of vehicular tunnels are presented to permit a comparison with highway costs. The data imply that if existing trends continue, it might be cheaper before the end of this century to move and park passenger cars and buses under ground rather than above ground in the center of many American cities.

Some design features of underground construction and travel are also considered, such as tunneling machines, rock removal, prefabricated lining and roadways, adaptability to mass transit systems, land reclamation, traffic control, and obstacle removal.

The study considers what may be needed if all mass transit ridership were hypothetically transferred to passenger cars in Los Angeles, Chicago, and Manhattan. Recommendations are given for study of the underground highway concept and developments of prototype machines capable of rapid excavation of vehicular tunnels under most rock conditions.

•THE AMERICAN metropolis is steadily expanding, and its inhabitants, as their incomes grow, are acquiring more and more automobiles. Moreover, these trends are occurring not only in American cities but throughout the world. The passenger car is the most surface-consuming transportation vehicle in wide use today and, as a result, access to the central core of the city by individual transportation should be a prime concern to city planners.

If we expect to preserve the central city as we know it today and handle the large traffic volumes required in major cities, innovations in current practices are required. The minimization of land used in conducting automotive and bus traffic on the surface of city streets is the first step, and the possibility of eliminating surface usage for transportation by removing auto and bus traffic from the surface and relegating it to either aboveground or underground facilities is the primary concern of this study. With the choice between elevated highways and high-rise parking structures, and deep underground roads and storage garages, for economic and aesthetic reasons the underground concept was chosen here to be studied, although aboveground facilities should also receive attention.

The purpose of this report is to investigate and suggest further study of underground vehicular travel (i.e., multilane deep subterranean highways and ample parking facilities with outlets to the surface only in the suburbs) as one alleviation of the central

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city's traffic and land-use problems. This vast urban land conservation program involves consideration of some staggering expenditures, but there are benefits that can be reaped in numerous other areas where we now pay dearly for the highway and road designer's practice of using mostly the surface of the city for car, truck and bus traffic.

To be sure, near the hubs of some American cities, vehicular tunnels (such as those leading into Manhattan) or subterranean parking facilities (as in Boston, San Francisco, Los Angeles, and New York) already exist or are being planned (such as the Beverly Hills freeway), but in no instance are the tunnels connected directly to the parking facilities or do the parking areas tend to decongest surface traffic (but rather the opposite); in most situations they account only for a very minute portion of the vehicular volume.

Naturally the city planner cannot consider only subterranean highways without also considering connected subsurface parking garages. If only ample parking were provided, the surface traffic congestion would deny access to such facilities; likewise, with ample underground traffic density but no place to stop and park underneath the destination, the purpose of the tunnels would also be defeated. Thus, no inlet or outlet to the surface, except for passenger and freight elevators, should exist to congest city streets.

The conjunction of the two schemes—road and parking—is essential at all stages of the design: at the conceptual stage (since tunneling machines must be developed as a very first step for both deep underground parking garages and highway tubes), at the engineering stage (where large commitments and expenditures are defined and funds must be procured), at the construction stage (where the huge amounts of excavated material must be disposed of efficiently), and certainly at the initial use stage.

The plan of this study is to plot over a half-century span the cost of constructing and operating selected conventional urban highways and their right-of-way cost. The costs of some automobile vehicular tunnels built in this century are presented for comparison. In the not-too-distant future these costs are observed to merge, giving some economic basis to the underground concept. The operating costs of highways and tunnels are also listed and compared, and those for underground roads are shown to be lower already than those for equal-capacity surface roads in many instances. Since underground urban automotive traffic might not involve much greater costs than surface traffic in the future, the design features and advantages of future urban highways and parking are investigated. It is recommended that a three-lane tunneling borer be developed as a first approach.

COST OF URBAN SURFACE HIGHWAYS

The initial construction cost of selected major roads and highways is shown in Tables 1 and 2, where the entries were arranged neither by date nor by magnitude. The costs are those of the construction contract at the time it was awarded or of the planning estimate, and are distinguished where possible from the cost of acquisition of the right-of-way. Demolition costs are either in land or in construction costs, since they are accounted for differently in various localities; they tend to be the least of the three major ingredients of urban highway prices, varying from negligible amounts in the West to sizable amounts in the East.

The entries in Tables 1 and 2 encompass a wide spectrum of freeways, differing greatly in environment, materials, design criteria, and time of completion. For example, the spectrum extends from the surface highways built in the first third of this century to the grade-separated contemporary freeways, either depressed or elevated, and from the multiple-access 40- to 50-mph roads to the limited-access 80-mph freeways with cloverleaf interchanges. Materials and methods encountered vary from excavation in hard rock to removal of loose soil, and from concrete paving practices to the use of bituminous aggregate. Finally, although some of the highways are austere, essentials only, arrangements common before World War II, others tend to have elaborate bridge crossings and divided medians with landscaping, requiring expensive detouring roads during construction.

TABLE 1

DATA ON SOME HIGHWAYS

	Name and Location[a]	Lanes	Length (miles)	Completion Date	Cost (millions of $) Construction	Lane-Mile	Type of Area[b]	ENR Reference Date	Page	Remarks
o	Capital Beltway, Md., Va., Wash. D.C.	6/8	65	1965	200	0.44	S-R	1/25/62	93	.....
1.	Boston Inner Belt	6	25	1965	180	2-3	UHD	1/25/62	88	Cost multiplied by 2 for contingencies
o	Hartford - Norwich, Conn.	6	74	1961	61	0.14	S	1/25/62	88	.....
o	Palmetto, Miami Bypass, Fla.	4	25	1961	30	0.30	S	1/25/62	88	.....
o	Ohio No. 71	4	44	1962	25	0.14	R	1/25/62	95	.....
o	Danbury-Newton, Conn.	4	24	1962	35.5	0.37	S-R	1/28/62	141	.....
o	New Jersey Expressway	6	32	1962	65	0.34	S-R	1/28/62	142	.....
2.	Crossbronxway, N.Y.	6	5.4	1962	120	3.7	UHD-LD	1/28/62	142	Extension
5.	Embarcadero, San Francisco, Calif.	8	2.6	1960	15.6	1.0	---	1/28/62	49	Right of way acquired at almost no cost on existing roadways
o	Connecticut Turnpike	4/6	129	1959	445	0.69	UHD-S-R	2/19/59	78	.....
6.	Crossbronxway, Phase 1, N.Y.	6	2.3	1958	32.1	2.3	UHD	2/19/59	78	.....
7.	Edsel Ford, Detroit, Mich.	6/8	14	1959	44	0.45	S	2/19/59	86	Not plotted
8.	Chrysler Expressway, Detroit, Mich.	6/8	3.4	1960's	69	2.9	UHD	2/19/59	86	.....
9.	Spokane Freeway, Wash.	6	2.1	1958	11	0.89	UHD-LD	2/19/59	88	.....
10	San Francisco Central, Calif.	8	1.4	1958	7.8	0.7	---	2/19/59	42	Double-decking cut land acquisition costs in half
11.	Central Artery, Boston, Mass.	4/6	4.1	1951-58	100	4.9	UHD	2/13/58	168	2nd portion may include right-of-way cost: plotted only $3.5/lane-mile
12.	Congress Street, Chicago, Ill.	8	9	1957	106	1.5	UHD	2/13/58	180	Has rail line down median divider
13.	Lodge Expressway, Detroit, Mich.	6/8	9.4	1958	90	1.4	UHD	2/13/58	184	.....
o	Portion of Santa Ana Freeway, Calif.	6	42.9	1958	76.5	0.3	S	2/13/58	194	.....
o	Portion of San Bernardino Freeway, Calif.	6	30.7	1958	54	0.29	S	2/13/58	194	.....
14.	Lunalilo Freeway, Honolulu, Hawaii	8	7.5	1965	55	1.2+?	ULD	4/19/62	25	Cost multiplied by 1.3 for contingencies
15.	Hudson Tunnel Approaches, N. J.	4	0.8	1927	1.75	0.55	ULD	4/30/25	733	.....
16.	New Jersey Meadows, Passaic-Hackensack	4	3.0	1933	18	1.5	ULD	6/12/30	973	.....
17.	Ogden Ave. Diagonal Expressway, Chicago, Ill.	6	2.8	1932	12	0.75	ULD	12/17/31	952	.....
18.	Westside Expressway, Canal to 72nd St., N.Y.	6	6.7	1937	24.3	0.6	UHD	10/14/37	616	.....
19.	Proposed Chicago Elevated Road	4	7	1933	18	0.64	ULD	4/27/33	536	Proposed but never built due to Depression
o	Proposed Chicago Surface Road	4	7	1933	20	0.72	ULD	4/27/33	536	.....
o	Sepulveda Pass, San Diego Freeway, Calif.	8	5.7	1962	20	0.44	R	(c)		Portion over Santa Monica mountains
o	Merritt Parkway, Conn.	4/6	45	1938	13	0.06	S	4/27/33	536	Land acquisition costs were 1/2 of construction
20.	Arroyo Seco, Los Angeles - Pasadena, Calif.	4+	6.2	1940	5.2	0.21	ULD	8/15/40	203	Right of way cost 1/2 of construction
21.	Brooklyn Belt Parkway, N.Y.	4/6	33	1940	70	0.42	ULD	7/11/40	60	Estimated cost of 1946 construction: $30 million
22.	East Boston Expressway, Mass.	4	1.9	1951	12	1.6	ULD	3/17/44	121	.....
23.	Major Deegan, Triboro Bridge - City Limits, N.Y.	6	7.5	1956	63.6	1.4	ULD	2/16/56	149	.....
24.	Boston Central Artery, Mass.	4/6	2.8	1953	14.8	1.1	ULD	2/14/52	109	1st phase
o	New Jersey Turnpike	6	118	1951	255	0.36	R	2/14/52	110	.....
o	Penn-Lincoln Parkway West, Pa.	4	9.2	1953	14	0.38	S	2/14/52	110	.....
25.	Embarcadero, San Francisco, Calif.	8	3.9	1954	13.7	0.45	ULD	2/16/56	163	1st portion; free right of way; elevated
26.	Hollywood Freeway, Hollywood, Calif.	6	8.1	1955	27	0.6	ULD	2/16/56	---	.....
28.	Harlem River Drive, N.Y.	4/6	2.5	1956	20.4	1.63	UHD	2/16/56	149	.....
30.	Calumet Skyway, Chicago, Ill.	8	8	1958	106	1.65	UHD	2/16/56	149	.....

[a] Numbers relate to data points on Figs. 1, 2, and 3.
[b] S = Suburban; R = Rural; UHD = Urban, High Density; ULD = Urban, Low Density.
[c] Data from Los Angeles Times, December 1962.

TABLE 2

DATA ON SOME HIGHWAYS (INCLUDING RIGHT-OF-WAY COSTS)

(Numbers in brackets indicate estimated breakdown of total project costs)

	Name and Location[a]	Lanes	Length (miles)	Completion Date[b]	Construction Cost Estimate (millions of $) Total	Lane-Mile	Right-of-Way Cost Estimate (millions of $) Total	Lane-Mile	Type of Area[c]	Remarks
31.	Glendale Freeway, Glendale, Calif.	8	2.7	1963	12	[illegible]	15.5	0.72	ULD	.....
32.	Harbor Freeway, Los Angeles - San Pedro, Calif.	8	--	1954	--	--	--	0.5	ULD	.....
33.	Golden State Freeway, Boyle Heights, Los Angeles, Calif.	8	--	1952	--	--	--	0.38	ULD	Los Angeles Times, Part II, 1/28/63, p. 1
34.	Golden State Freeway, Riverside Dr., Los Angeles, Calif.	8	--	1953	--	--	--	0.46	ULD	.....
35.	Urban portion of Interstate System	5.7	4,200	1961	10,000	0.41	3,600	0.15	ULD-S	House Document No. 54, 87th Cong., 1st Sess.; total re-estimate, 1961: not plotted; very few roads penetrated CBD
36.	Santa Monica Freeway, Los Angeles, Calif.	8	17.1	1965	--	--	98.5	0.72	ULD	Los Angeles Times, 2/9/63
37.	M-1 Motorway, London - Birmingham, England	4	10	1964	32.2	0.8	--	--	ULD	New York Times, 2/12/63; northern London suburbs
38.	Pasadena (East-West) Freeway, California	8	5.9	1966	23	0.5	38	0.8	ULD	California Division of Highways estimates (plotted x 1.5 for contingencies)
39.	Lower Manhattan Crosstown Expressway, N. Y.	6	2.5	1959	47	2.5-3.5	31	1.5-2.5	UHD	New York Port Authority estimates; project abandoned
40.	Mid-Manhattan Crosstown Expressway, N. Y.	6	2.0	1959	38	3.2	33	2.7	UHD	New York Port Authority estimates; project held in abeyance
41.	Prospect Expressway, Gowanus - Prospect, N. Y.	6	2.1	1961	20	1.6	8.6	0.7	UHD	New York Port Authority estimates
42.	Marina Freeway, Culver City, Calif.	8	3.2	1963	15	0.59	--	--	S	Los Angeles Times, 2/24/63 (plotted x 1.2 for contingencies)
43.	Congress Expressway, Chicago, Ill.	8+	16.5	1960	133	0.95	55	0.39	UHD	.....
44.	Northwest and Edens, Chicago, Ill.	8-12[d]	15.6	1961	173	1.2	70	0.5	UHD	Literature from Historical Section, Expressway Office, City of Chicago
45.	South (Ryan) Expressway, Chicago, Ill.	8-14[e]	13	1963	114	0.88	66	0.51	--	.....
o	Foremost Freeways in Los Angeles, Calif.									Status as of January 1962
46.	Golden State	[illegible]	29.6	--	76	0.34	70	0.32	ULD	Not plotted; disagrees with entries 33 and 34
47.	Hollywood	[illegible]	11.6	1959	37	0.40	35.6	0.38	UHD	Not plotted; disagrees with entry 26
48.	San Diego	[illegible]	55.1	--	127.6	0.21	92.7	0.29	ULD-R	Not plotted; part through uninhabited land
49.	Santa Monica	[illegible]	4.8	--	46.8	2.1	82.3	1.2	UHD	.....
50.	Long Beach	[illegible]	19.7	1958	33	0.15	23.2	0.21	ULD	Not plotted; much of land cleared by early 1950's
51.	Harbor	[illegible]	22.2	1959	50.3	0.28	53	0.3	ULD	Not plotted; disagrees with entry 32
52.	Foothill	[illegible]	2.3	--	2.4	0.49	8.5	0.13	S	Right of way not plotted; mostly vacant land
53.	Glendale	[illegible]	2.4	1958	6.1	0.35	6.8	0.31	S	Plotted for time of expenditures (early 1950's)
54.	Ventura	[illegible]	37.3	--	61.4	0.15	44.5	0.21	S	Not plotted
55.	Colorado	[illegible]	2.3	--	6.3	0.34	2.5	0.13	S	Not plotted
56.	Downtown San Diego	[illegible]	1.6	1962	6.0	0.47	2.8	0.22	ULD	Los Angeles Times, 3/10/63, p. A; 4-level exchange
57.	Brooklyn - Queens Expressway, N. Y. (Total)	6	12.3	--	94	1.27	26.4	0.36	ULD	
58.	Battery-Brooklyn Tunnel to Brooklyn Bridge	6	1.8	1940/54	[illegible]	3.2	[10.7]	1.0	ULD	
59.	Brooklyn Bridge to Navy St.	6	1.2	1954/59	[illegible]	1	[3.4]	0.5	ULD	
60.	Navy to Steuben St.	6	1.1	1954/59	[illegible]	1.8	[4.8]	0.73	ULD	
61.	Bedford to Grand Ave.	6	0.5	1952/59	[4]	1.3	[1.8]	0.6	ULD	
o	Long Island Expressway, N. Y. (Total)	6	86	--	169	0.33	48	0.09	ULD	New York Port Authority estimates
62.	Queens-Midtown Tunnel to Brooklyn-Queens Expressway	6	--	1941	4.2	0.47	0.95	0.1	ULD	
63.	Brooklyn-Queens Expressway to Queens Blvd.	6	3.4	1941/50	[25]	1.23	[4]	0.2	ULD	
64.	Queens Blvd. to Grand Central Parkway	6	1.2	1954/58	[3.5]	0.5	[1.6]	0.2	ULD	Right of way not plotted
65.	Grand Central Parkway to 136th St.	6	0.8	1955/59	[4]	0.83	[2.6]	0.54	ULD	
66.	136th St. to Parsons Blvd.	6	1.1	1954/57	[3.5]	0.53	[1.6]	0.24	ULD	Right of way not plotted
67.	Parsons Blvd. to 190th St.	6	1.4	1956/59	[4]	0.48	[2.3]	0.27	ULD	Not plotted
68.	190th St. to Cloverdale Rd.	6	1.9	1958/60	[9.5]	0.83	[4]	0.35	ULD	Right of way not plotted
69.	Gowanus Expressway, Battery - Brooklyn, N. Y.	6/8	5.1	1961	65.3	2.0	18.4	0.56	ULD	
o	Narrows Bridge, N. Y.	12	1.5-2.5	1967	320[f]	13	--	--	--	

[a] Numbers relate to data points on Figs. 1, 2, and 3.
[b] Estimated or actual.
[c] S = Suburban; R = Rural; UHD = Urban, High Density; ULD = Urban, Low Density.
[d] Nine-lane average.
[e] Ten-lane average; 2 miles elevated.
[f] Total construction and right-of-way cost estimate.

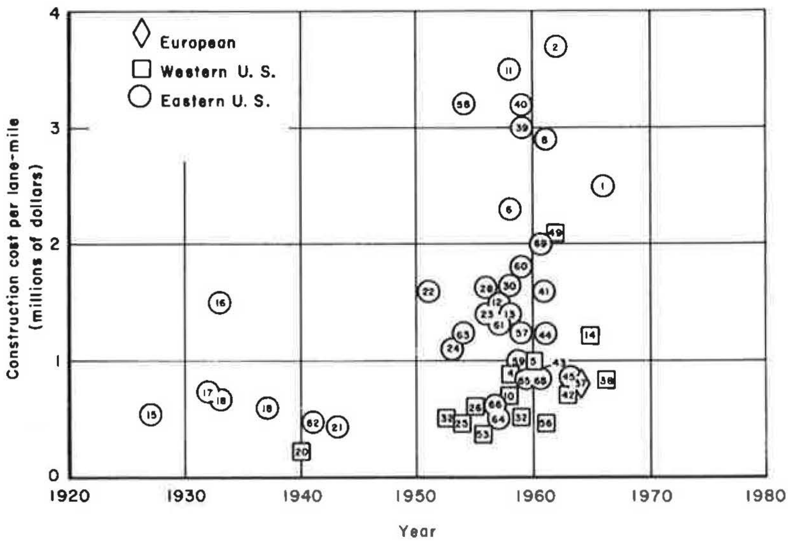

Figure 1. Construction cost of urban highways (numbers keyed to entries in Tables 1 and 2).

It is interesting to plot the data on urban highways and freeways of Tables 1 and 2 through the more densely populated areas—as was done in Figures 1 and 2—leaving out all narrow expressways and suburban and rural highways and roads. The plot of total project costs of urban highways (Fig. 3) appears to be scattered over a wide pattern; nevertheless, it shows a painfully well-known fact, that even the lowest costs of building an expressway through densely populated areas are inexorably rising with the passage of time.

Construction costs of urban highways have exceeded, both in rate of growth and in magnitude, all other analogous costs of general construction and building (Fig. 4) and seem to parallel the wages of construction equipment operators—wages that in the past decade have doubled in magnitude and increased linearly in time. This has come about through the steep rise in the demand for speed, safety, and comfort by the

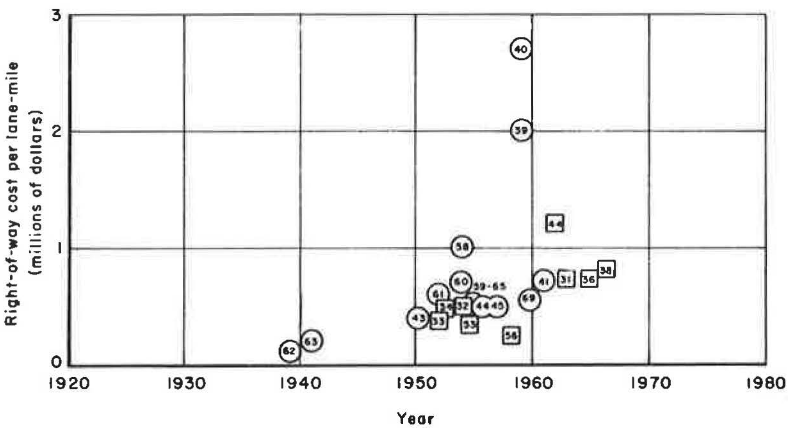

Figure 2. Land acquisition cost of urban highways (numbers keyed to entries in Tables 1 and 2).

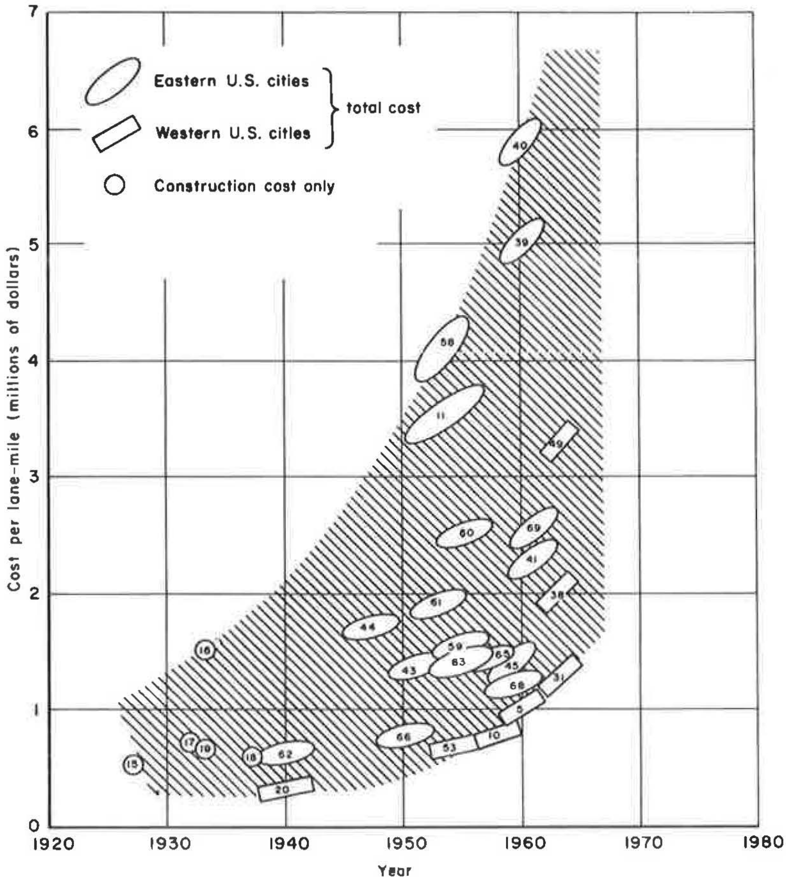

Figure 3. Total costs of some urban highways (numbers keyed to entries in Tables 1 and 2).

motoring public, which is reflected in a widening and upgrading of design specifications for freeways.

Adopting the lane-mile as the common denominator for initial costs of urban freeways is an oversimplification that neglects a large number of other local factors influencing the cost of demolition, land, and construction for surface highways:

1. Emergency parking shoulders—These may vary from no provisions at all (common in some eastern cities) to as much as 8 ft or more (required in some western localities).
2. Median-strip allowance—Again this may vary, even within a single locality, from a meager 2-ft curb with a bounce-back fence to as much as a 100-ft swath, complete with extant rail lines.
3. Slopes on cut or fill—In many instances this necessity of construction requires more than half of the right-of-way of the whole highway.
4. Number, frequency, and elaborateness of interchanges, on- and off-ramps, bridges, and other crossings—In the distant future, as intersecting freeways proliferate, interchange costs might well become a more important cost indicator than the total amount of lane-miles.
5. Unneeded increment in right-of-way—This is caused by the availability of lots and their dimensions in integral multiples.

Highways were classified by dollars per lane-mile because this criterion appeared convenient for vehicular tunnel costs also (as exemplified later by the tighter grouping

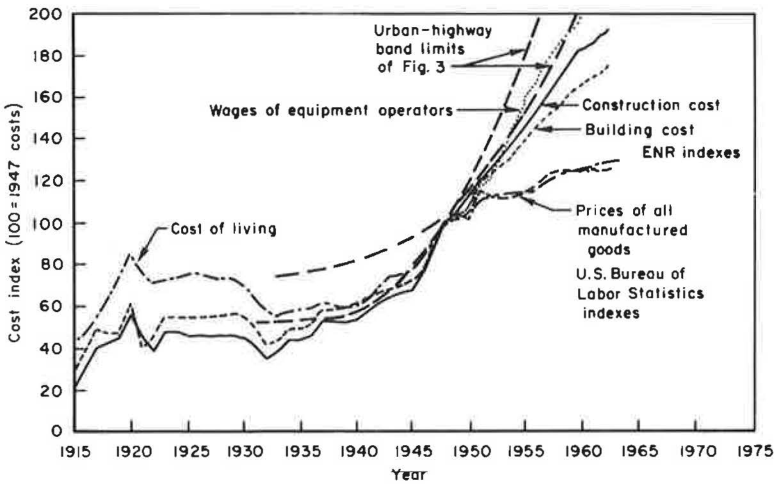

Figure 4. Comparison of some manufacturing and construction costs.

of tunnel cost data when plotted on this basis), and this was a common descriptor for the ultimate cost comparison of surface vs underground highways.

Urban highway costs could be predicted for a couple of decades in the future if desired, since the indicators (mostly vehicle design trends and consumer preferences) are foreseeable and steeply graded upward. For example, automobiles will be far more powerful, maneuverable and economical to operate than today's cars, and each of these sizably upgraded characteristics requires in turn a proportionately more expensive freeway design.

The continuing or running costs of operating urban highways may be divided into two groupings:

Group I—Policing and patrol, debris and wreck removal, pavement repair and painting, sign maintenance, emergency call system, traffic control and pacing, and miscellaneous; and

Group II—Snow and ice removal, fence and guardrail repair and upkeep, and maintenance and landscaping of medians, borders, and lighting.

The first group comprises expenditures common to both conventional on-the-surface and underground highways. Since these costs may be nearly equal for aboveground and subterranean urban expressways, they need not be evaluated in a comparison, even though they are quite significant in other contexts. The second group consists of some of the continuing operational costs of highways that may be avoided in driving cars under cities, rather than on their surface. The loss of tax revenue from property and land wiped out by a freeway has not been included in the continuing costs of highways, since it is seldom associated with expressway operation and might actually be redistributed to outlying areas in the form of derivatives from driver benefits.

Considering then only Group II expenditures, winter maintenance looms as a major item in non-California localities, and in Southern California landscaping maintenance costs constitute the major portion of operational costs. This portion of conventional maintenance costs has been lately between $500 and $2,000/lane-mi/yr and could be eliminated if freeways were to be operated underground (though other costs, such as for ventilation and lighting, to be discussed later, would arise that are not encountered on surface roads).

COST OF VEHICULAR TUNNELS AND UNDERGROUND HIGHWAYS

The initial capital project costs of some vehicular tunnels were compiled in Table 3. Projects outside the United States were included in this listing to show the disparity

TABLE 3

DATA ON SOME VEHICULAR TUNNELS

	Name and Location[a]	Lanes	Length (ft)	Completion Date	Cost (millions of $) Project	Cost (millions of $) Lane-Mile	ENR Reference Date	ENR Reference Page	Remarks
1.	Allegheny No. 2, Pa.	2	6,070	1964	8.2	3.5	9/20/62	107	Competent rock; excavation, $10/yd^3$; complete job, $60/yd^3$
2.	Norfolk - Portsmouth, Va.	4	4,200	1962	22	6.9	1/25/62	94	Soft rock under river
3.	Sasago Mountain, Tokyo - Kofu, Japan	2	9,750	1959	3.6	0.97	3/19/59	130	High mountain rock; lowest labor costs (1/8 of U.S.)
4.	Fort Lauderdale, Fla.	4	864	1959	6.5	10	2/19/59	88	Under river; not plotted; data unreliable
5.	2nd Lincoln Tube, Midtown N. Y.	2	6,000	1940	29	12.7	8/26/37	330	Shield-driven; see 22 for 1st tube
6.	Harvey, New Orleans, La.	4	1,080	1957	4.5	5.5	2/13/58	161	.....
7.	Sumner Tunnel, Boston, Mass.	2	5,440	1934	25	12.2	4/24/30	702	Competent rock
8.	Callahan Tunnel, Boston, Mass.	2	5,500	1960	29	14	1/25/62	94	Cost assumed 40% lower than price; plotted as $10,000,000
9.	Patapsco River, Baltimore, Md.	4	7,650	1957	130	22	2/13/58	161	Much trench and fill; not a "driven" tunnel; not plotted
10.	Fort Pitt, Pittsburgh, Pa.	4	3,430	1957	10	3.8	2/13/58	174	.....
11.	Mt. Washington, Pittsburgh, Pa.	4	5,000	1957	17	4.5	2/13/58	174	.....
12.	Mont Blanc, Italy - France	2	38,050	1963	40	2.7	5/31/62	56	Unstable protogine; low labor cost (1/2 of U.S.)
13.	Kanmon, Honshu - Kyushu, Japan	3[b]	11,420	1958	22	4.1	(c)	--	150 ft below sea level; assuming 2-1/2 lanes
14.	IJsselmeer, Amsterdam	4	8,200	1967	39.5	6.3	4/19/62	47	Below sea level; prefab caissons
15.	Coentunnel, Amsterdam	4	4,710	1966	17.5	3.7	5/19/62	47	Below sea level
16.	Grand St. Bernard, Italy - Switzerland	2	19,000	1962	16	2.2	5/12/62	23	Highest tunnel; low labor cost (1/2 of U.S.)
17.	Viaduct under Dallas-Fort Worth Airport	6	813	1963	1.4	1.5	5/5/62	--	Cut and fill; trench and fill; not plotted
18.	Holland Tunnel, N. Y. - N. J.	4	3,100	1927	48	20	6/3/20 5/24/30	1127 697	Sunken sections; first under water in U.S.
19.	Liberty, Pittsburgh, Pa.	4	5,890	1930	30	6.7	5/7/25	764	Semicompetent geology
20.	Narrows, Brooklyn - Staten Island, N. Y.	4	10,400	1930	34	4.3	22/12/25	280	Proposed date; cost could be as high as $6,000,000
21.	Mersey River, Liverpool, England	3	11,300	1935	30	4.7	11/16/33	58	Under river
22.	1st Lincoln Tube, Midtown N. Y.	2	6,000	1937	37	16.3	3/1/34	304	Under Hudson River; see 5 for 2nd tube
23.	Transmanhattan (under 37th St.), N. Y.	6	7,000	1930	50[d]	6.3	9/9/37	444	Proposed date; tunnel never built
24.	Queens, Midtown, N. Y.	4	5,000	1941	21.3	5.6	7/8/37	42	Under East River
25.	Brooklyn-Battery, N. Y.	4	9,200	1951	82	11.5	3/17/49	123	.....
26.	Broadway Tunnel, San Francisco, Calif.	4[e]	1,620	1953	5.2	4.2	3/17/49	127	Competent rock; San Andreas and Hayward Faults
27.	3rd Bore, Broadway Tunnel, Alameda - Contra Costa, Calif.	2	3,300	1964	10	8	(f)	--	Incompetent geology
28.	Hazelview Summit, Crescent City, Calif.	2	1,890	1962	4	5.6	(g)	--	Competent rock
29.	San Bernardino, Italy - Switzerland	2	21,000	1964[d]	9-15	1.1 - 1.9	3/26/59	34	Competent rock; not plotted; plans only so far
30.	Splugen, Milano - Zurich, Italy - Switzerland	2	30,000	--	18[d]	1.6	3/26/59	34	Competent rock; not plotted; plans only so far
31.	London Transport System, Finsbury Park Segment, England	2	5,300	1961	2.8	1.4	(h)	--	Clay and mud; a drilled subway; not plotted

[a] Numbers relate to data points on Fig. 5.
[b] Two car lanes and one bicycle lane.
[c] Data from the Consulate.
[d] Estimated.
[e] Two bores with two lanes each.
[f] Data from California Highways and Public Works, July - August, 1960.
[g] Data from California Highways and Public Works, May - June, 1961.
[h] Data from City and Suburban News, Issue 36.

in costs between tunnels in the United States and others (due primarily to labor wage differentials). The costs here include the complete turn-key project (excavation, lining, pavements, lighting, ventilation equipment, turnarounds, etc.).

As with highways, the plot of the data from Table 3 (Fig. 5) exhibits a sizable scatter in the costs of tunnels, and only hints that the trend, in general, might be downward for American projects and uncertain for other countries. But, as before, there seem to be definable, though broad, bounds on vehicular tunnel costs in the United States, the lower of which tends to be some $2 million/lane-mi higher than costs outside this country. The upper bound generally represents shield-driven or sunken-type tunnel construction, and the lower bound represents driven tunnels.

The rate of decrease and the relative magnitude of vehicular tunneling costs can be explained in terms of ever-increasing mechanization of excavation and haulage, steady improvement in anticipating geological problems, and increased productivity in the country. That the costs seem to have bottomed is also explainable by dissecting the components of tunnel project cost. A comparison of entries 3, 12, 13, 15, 16, 29, 30, and 31 with American tunnels in Table 3 indicates that wages still constitute one-half of the capital tunneling cost in Europe and three-fourths of the United States tunneling costs. In other words, there is much to be gained by increasing the mechanization of tunnel boring, as recommended later. In addition, there is evidence that the cost of nonvehicular tunnels seems to be made up of two-thirds for excavation and one-third for lining, whereas for vehicular tunnels, the proportions might be one-half for excavation, one-fourth for lining (if lining is required), and one-fourth for roadbed and utilities.

The continuing or operating costs of vehicular tunnels may be divided into two groupings as was done for surface highways; the first comprises expenditures that are met on surface highways as well and the second comprises expenditures unique to vehicular tunnels:

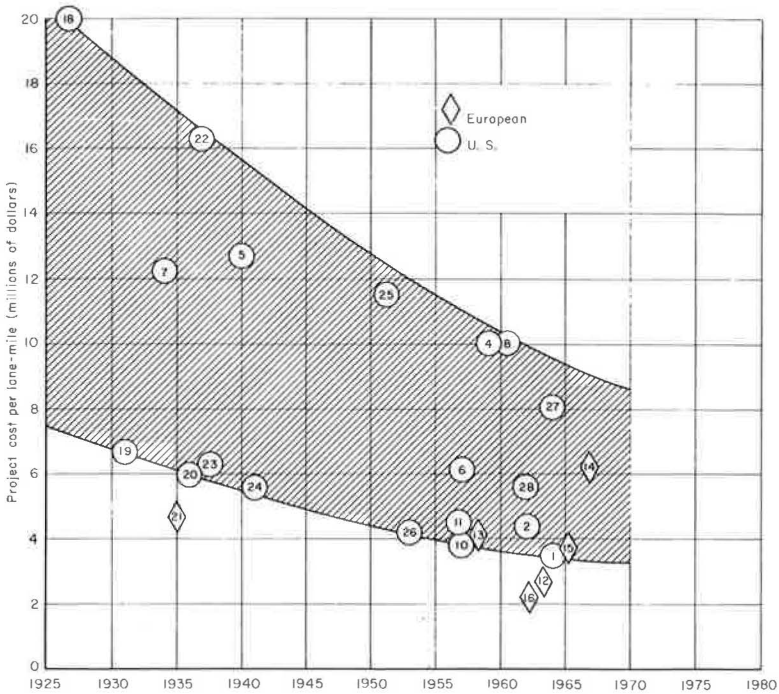

Figure 5. Cost of vehicular tunnels (numbers keyed to entries in Table 3).

Group I—Policing and patrol, nighttime lighting, debris and wreck removal, pavement and lining repair and maintenance, sign maintenance, emergency call system, traffic control and pacing, and miscellaneous; and

Group II—Daytime lighting, and ventilation.

As was done earlier for highways, only Group II costs need to be evaluated in this comparison between surface and subsurface highways, since comparable Group I costs are being incurred in surface highway operation. Lighting costs amount to a small fraction (1/20 to 1/10) of ventilation costs, leaving only ventilation costs as the major operational expenditure to be evaluated vis-a-vis the Group II costs of surface highways.

The ventilation provisions for long vehicular tunnels average at present about 80 to 90 cu ft of air per vehicle-mile, though in most cases this fresh air supply is grossly inadequate. Probably 150 cu ft/veh-mi would be a more satisfactory supply in the future; this corresponds to a ventilation power expenditure of about 6 w-hr/veh-mi. Assuming a tunnel traffic utilization of 5×10^6 veh/lane/yr (the recent integrated average for Manhattan access automobile tunnels) and an electricity cost of $0.015/kw-hr, the power costs for ventilating a modern tunnel would be (6 w-hr/veh-mi) $\times$ (5×10^6 veh/lane-yr) $\times$ ($0.015/kw-hr) $\times$ (10^{-3} kw/w) $\times$ 10^{-2} = $450/lane-mi-yr. The total ventilating costs, including personnel, blower maintenance, and replacement, are double to quadruple the power costs alone and, thus, probably amount to some $1,000 to $2,000/lane-mi-yr by good and ample ventilation standards. These numbers are comparable to the Group II maintenance costs for surface highways.

Having observed that the operating costs of underground and surface highways are comparable, it might be worthwhile to summarize and compare capital costs of automotive tunnels and freeways. Replotting the entries and the bands of Figures 3 and 5 as in Figure 6, one notices that (a) the bands tend at present to merge, (b) cost differences between tunnels and new urban surface roads may be indistinguishable before the end of this century, and (c) tunnel unit costs are presently still decreasing, whereas highway costs are increasing.

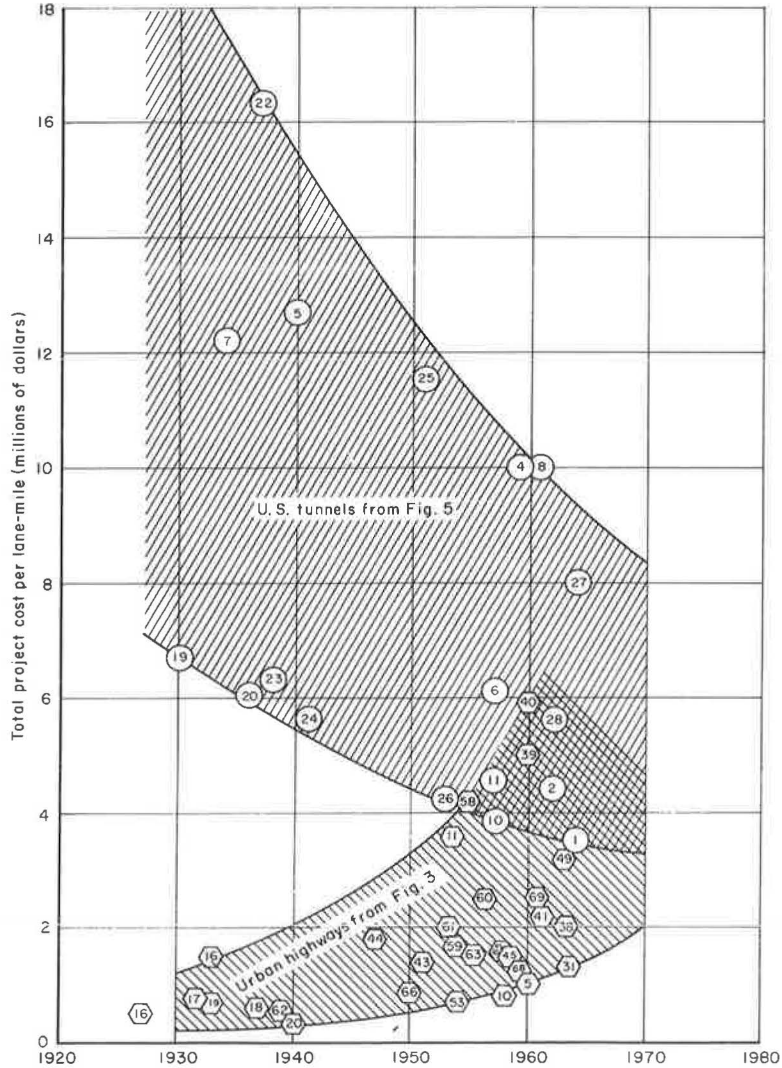

Figure 6. Cost of aboveground and underground highways in the United States.

The causes for these cost trends need careful investigation because they imply that automotive and bus travel and storage may soon be cheaper when conducted deep underground, below the central city. Our prediction is tempered only by factors that might seriously alter cost-curve slopes in the time period while underground systems are being considered. For example, it is clear that highway costs rise with increases in land values, demand for accessibility by car to urban areas, performance and convenience of passenger cars, wages of skilled operators of construction equipment, and general inflation.

Similarly, though tunnel construction cost is at present decreasing because of mechanization of tunnel driving and new boring technologies, this may only be a temporary situation, and in the future tunnel construction costs may also start going up for the very same reasons that highway costs are increasing today.

SOME DESIGN CONSIDERATIONS OF FUTURE URBAN-HIGHWAY TUNNELS

As an illustration of the features of future hypothetical underground urban highways and parking spaces, it might be interesting to imagine the construction of an eight-lane throughway, four lanes each way in each of two separate tubes or a more modest six-lane expressway of two tubes with three lanes each, as shown in Figure 7.

The assumption was that tunnels are machine drilled by a rotating mole rather than by the older manual labor-oriented procedure of pilot-hole drilling, blasting, benching, and muck removal. A 15-ft clearance is provided for the 12-ft wide lanes plus a 2-ft curb at the walls. These tunnels require prior development of counterrotating rock-boring machines, 21 to 27 ft in diameter, a technological feat that could be accomplished in the late 1960's, given enough research and funding impetus, and whose design is the main recommendation in this report.

The excavated cross-sections may vary from about 1,200 sq ft for the four-lane tube to around 750 sq ft for the three-lane arrangement. Both cross-sections are less than the 1,600 sq ft of a machine-driven outflow tunnel for the Mangla Dam in West Pakistan; the lower number is comparable to the 700 sq ft already driven in competent rock in the United States.

To excavate these tunnels in deep competent rock by present-day quasi-manual techniques might cost from $15/cu yd for, e.g., the Chicago subsurface to $20/cu yd for the Eastern littoral, whereas the finished tunnel (i.e., all debris removed and disposed of, tunnel roof lined, and roadways and utilities installed) could easily run to

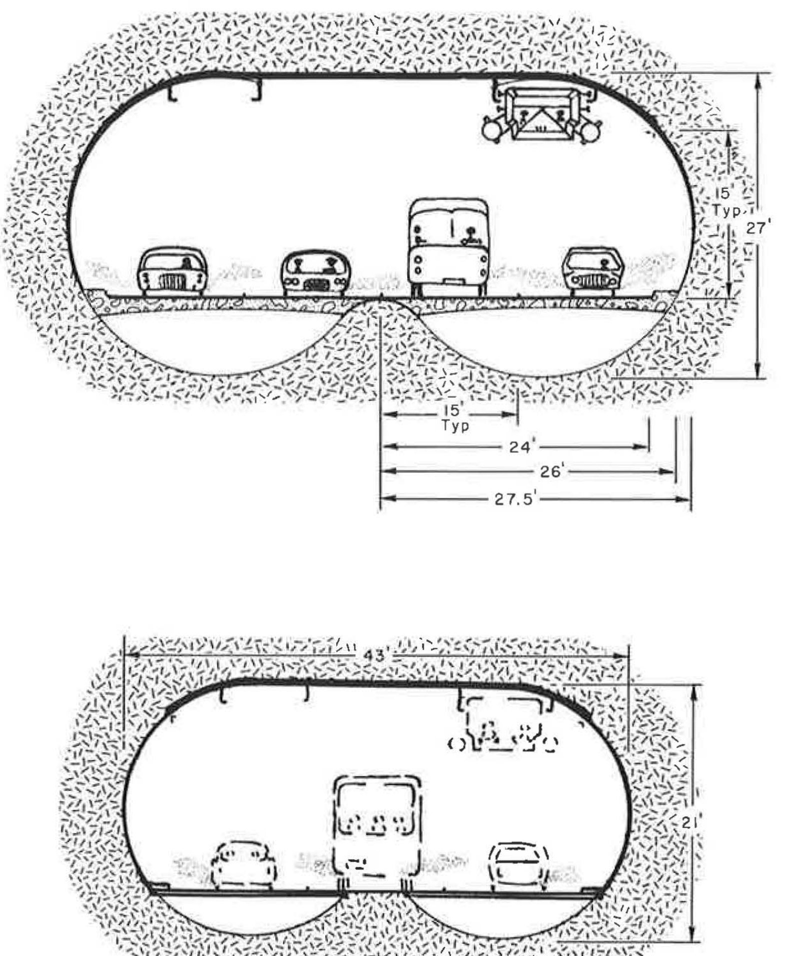

Figure 7. Layout of three- and four-lane machine-tunneled highways.

three times as much. So, in this decade, without machine boring, vehicular tunnels would cost about (\$15 to \$20/cu yd) × 3 × (250 to 300 sq ft/lane) × (5,280 ft/mi) /27 cu ft/cu yd or about $\$2.2 \times 10^6$ to $\$3.5 \times 10^6$/lane-mi—near the lower band limit in Figure 5. With a well-planned, long-range development program under the proper incentives and funding directed toward highly automated tunneling in hard rock, it would be logical to assume that the costs shown in Figure 5 could continue to drop in time, rather than to level off. The objectives of a tunneling machine research program aimed specifically at cost reduction (as recommended here) might encompass the design of:

1. Tunneling machines with counterrotating "bootstrap" drills (prototype example, Figure 8);
2. Continuous belts for conveying broken rock (muck) to prepared sites;
3. Lining and/or roof reinforcements for large-size bores that can be continuously emplaced by moving rigs closely following the drill; and
4. Prefabricated and standardized roadway slabs, fed continuously in long sections to a progressing machine that locates, levels, aligns, and firms them into place.

Though tunneling machines cannot at present bore vehicular tunnels in hard rock, they have a potential of halving excavation costs and could drive vehicular tunnels at satisfactory speeds, possibly as high as 1 mi/mo.

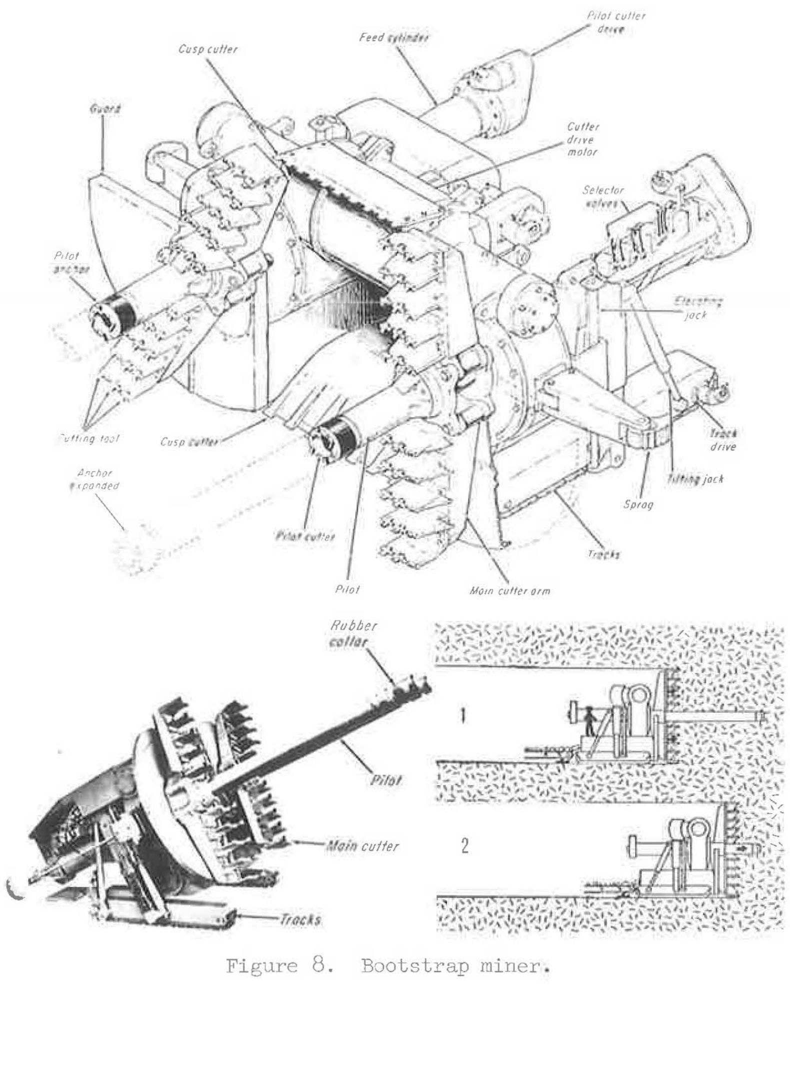

Figure 8. Bootstrap miner.

These recommendations for designing vehicular tunneling machines may be compared with present-day capabilities of single-hole boring machines ("moles"). The larger of these machines provide these advantages:

1. Safety beyond the drill-blast method—The smooth, round, and unshattered opening is inherently stronger than the equivalent blasted hole, and rockfall and lining requirements are greatly reduced. Also cutting, rather than blasting, minimizes the damage and faulting on the roof and sides of the hole and avoids damage and tremor inconvenience to surface property above the tunnel.
2. Precise excavation—In a concrete-lined tunnel, large amounts of concrete can be saved that would otherwise have to be used to fill the highly irregular and jagged voids beyond the required dimensions.
3. Low labor costs with the smaller crew needed—These have resulted in excavation costs as low as $10 to $12/cu yd in shale.
4. Rapid tunnel advance—Cutting rates as high as 150 ft/day have been recorded, and operating times as high as 50 percent have also been achieved in sedimentary rocks.
5. Better muck removal—The uniformly broken rock from the borer improves haulage and permits belt conveyal.

It must be remembered that these characteristics have already been demonstrated by tunnel borers of rather modest specifications. For example, most borers made in the United States and the Soviet Union are less than 10 m in diameter, powered with less than 1,000 hp, capable of advancing less than 12 ft/hr in limestone, shale or sandstone, and cost less than $\$10^6$.

Besides the suggestion for designing, fabricating and testing an automated tunneler, liner and roadway installer hopefully to cut further the costs of urban underground highways and parking facilities, some thoughts are offered on making these complexes more pleasant, safe, efficient, convenient, and cheaper to operate than surface roads by exploiting the subterranean environment.

Adaptability to Mass Transit Systems

Since these tunnels duplicate the desired route of mass transit systems, one or two of the lanes can be used for bus operation, or if the demand develops, for convoys of interlocked buses, or even for rail mass transit. The downtown visitor could be given at least the choice of driving his car and paying for fuel and underground parking fees or of riding more cheaply but inconveniently in a collective-transport vehicle. Traffic experiments on each route could quickly and continuously determine the optimum mix of private and mass transit vehicles.

Construction Without Interruptions

Tunneling does not disrupt the established patterns of surface activities in congested areas. Bores and parking caverns placed well below the network of utilities (water mains, power lines, sewers, gas and telephone conduits, and building foundations) do not necessitate expensive road detours. Work in underground facilities progresses steadily in all seasons and is immune to the vagaries of weather.

Possibilities for Land Reclamation

The broken rock that is drilled out of the bores can reclaim much urban land in the form of causeways, swamp fills, new airports on fill, beach-stabilizing jetties, etc.

Traffic Control Through Television

Central traffic surveillance and control by closed-circuit TV should be easy in the closed loop of subterranean freeways and parking facilities, since observing cameras installed almost at will above and along each lane and parking area open many possibilities for economical and efficient operation. One can think of the automated billing and collection of toll fees and parking charges, the opening and closing of on- and off-ramps to the suburban surface and to the parking facilities, instruction to motorists as to safe speed, shifting of directional signals, and the instantaneous detection of accidents, vehicle breakdowns, and location of roadway debris.

Overhead Patrol Cars

Policing and patrol cars could be designed for high-speed travel in either direction, suspended from electrified rails in the tunnel ceiling and traveling above clogged and jammed lanes to points of obstruction (Fig. 7). Such electrically driven capsules, containing patrolmen knowledgeable in first-aid, and fully equipped with extensible ladders, stretchers, grappling hooks, and medical supplies, could reach a disabled vehicle on the road, render medical or other assistance, and lift or tow the vehicle to the first turnoff by means of the telescoping arms.

Access to Surface

Freight loading and pedestrian exits must be provided in abundance, since there are no surface exits to the inner city core from the underground system. Each building complex would have to provide large-capacity freight elevators directly to these docks and truck turnoffs. Moving stairs, ramps, and unattended passenger and freight elevators would service groups of buildings from the parking caverns by vertical elevator shafts drilled from below.

Lighting and Perception

Lighting intensity in the tunnels could vary gradually from very bright near the suburban exits and inlets to rather dim in the middle of the travel areas, letting the driver's eyes adjust to the variation and cutting down the lighting bill. Driver-stimulating murals might be considered to relieve claustrophobia, loss of perceptual awareness and monotony.

Wind and Weather

The absence of ice-melting salt sprays will be beneficial to automotive underbodies. The ventilation system should be designed to exploit the piston effect of all vehicles moving in a single direction in each tube and to save the motorist's fuel with greatly reduced windage losses.

Exhaust-Gas Processing

It would be technologically desirable to wash the ventilated air by water spray at the outlets, thus removing the water-soluble contaminants. Whatever insoluble pollutants are left (e.g., uncombusted hydrocarbons) could probably be removed quite profitably by standard waste product recovery schemes, such as appropriate filters, precipitators, and separators. The recovered tonnages of hydrocarbons might be startlingly high—enough perhaps for some enterprising private company to undertake the purification and recovery process.

Underground Parking Costs

Since parking spaces hundreds of feet under the CBD are connected only to the freeway tunnels as shown in Figure 9a, there would be no vehicular exits to the surface. Boring of parking spaces—a task as great as tunneling the roadways—should employ the same tunneling machines that would be used for the freeway. The schematic diagram in Figure 9 indicates that a million cars would require almost 1,000 mi of tunnel for parking, plus maybe another 500 mi of approaches, distribution roads, and interchanges for a total of about 1,500 mi. If such tunnels can be bored and finished for $3 million/mi, providing underground parking would then cost $4,500/car, requiring a daily parking fee of about $1.50 to $2.50.

High-Rise Garage Buildings

Multistory parking garages cost only $3,000/space, exclusive of land costs, to build, suggesting as a more economic possibility for large-capacity parking in the CBD a high-rise parking structure connected directly to the tunnels by being dozens of stories below as well as above ground.

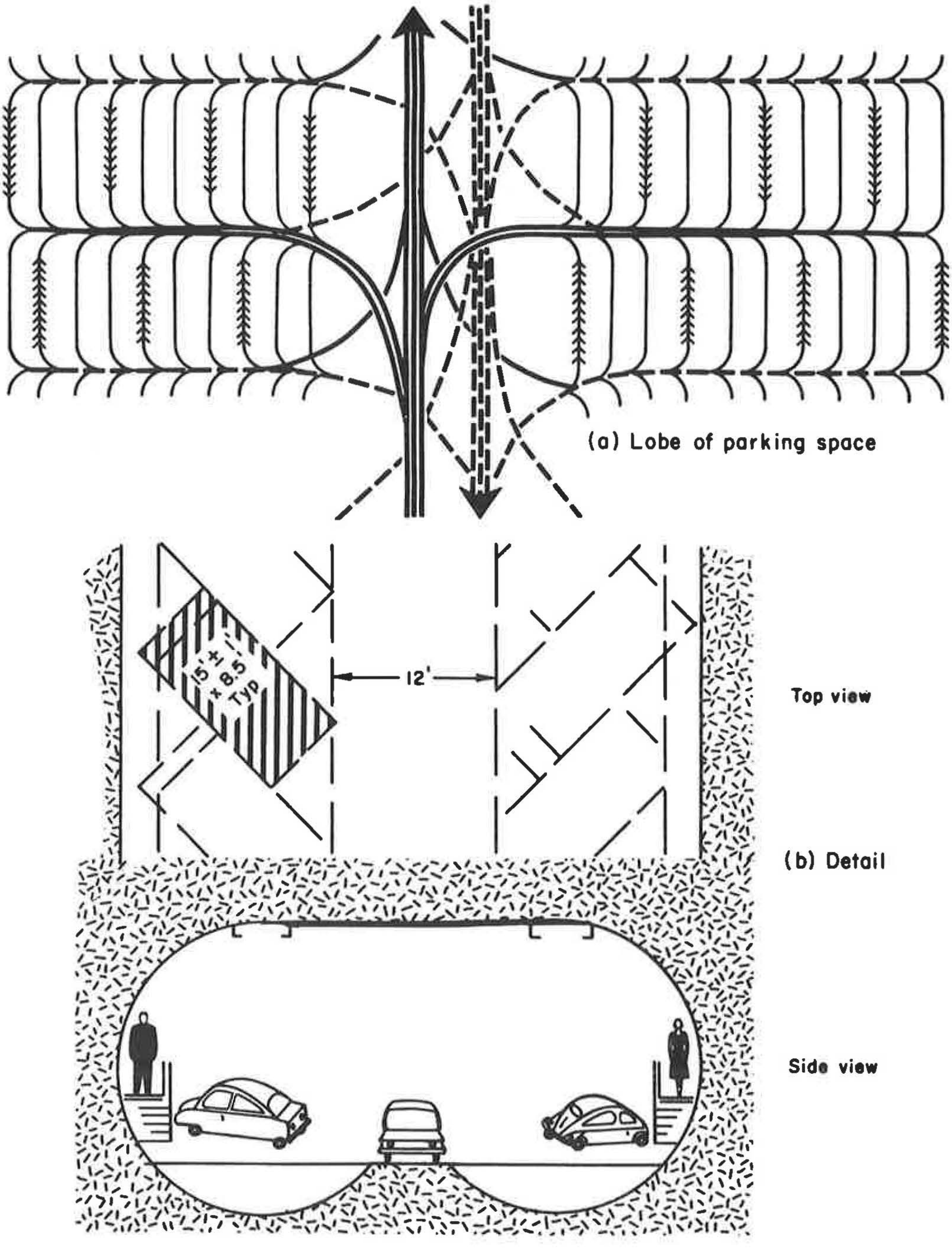

Figure 9. Underground parking space for small and compact cars.

A FEW EXAMPLES

Here we shall consider three cities, assuming that most mass transit riders into Los Angeles, Chicago, and Manhattan have acquired automobiles by the mid-1970's and insist on using them at all costs to commute to work. This is a purely hypothetical example and is the most extreme future concept that could be envisaged in the automobile-vs-public transportation debate. It provides an enlightening endpoint in calculating the cost and other aspects of total take-over by automobiles, taxis and trucks of all urban travel in the three largest metropolises in the United States. At the present time in Los Angeles, 80 percent of the trips to work are made by passenger car and the urban complex is closest to the "all out for cars" situation. In Chicago, only half of the trips to work are by car, and on Manhattan, only 8 percent of the work trips are by car or taxi. Tokyo would have been a fascinating example, since less than 0.5 percent of the million daily trips to the CBD are by auto.

A more detailed description of topics discussed here has been previously published (1).

Los Angeles

The population density patterns of Los Angeles mismatch the geology favorable to tunnels, requiring tunneling costs possibly higher than the $1 million/lane-mi assumed before. On the other hand, mass transit use in Los Angeles by the mid-1970's is the lowest per capita estimated in the three sample cities—at its optimistic best, a million riders per day, i.e., 500,000 round trips vs the recently estimated 700,000 riders per day.

A typical urban highway (such as the Congress Expressway in Chicago) can handle 12,000 veh/lane-day, averaging 1.8 passengers per car. With automotive evolution and population pressures, these numbers will be, by 1975, probably 14,000 veh/lane-day and 1.9 passengers per car; i.e., 27,000 persons per lane-day could penetrate subterraneously any area provided with sufficient parking space. This estimate agrees reasonably well with the projected number of 32,500 individuals per lane-day using the Santa Monica freeway by the mid-1970's.

Choosing a figure of 30,000 commuters per lane-day, the Los Angeles requirement in a dozen years would be 500,000/30,000 or 16.5 lanes in one direction plus perhaps another 7.5 in the opposite direction (assuming midday lane reversal), for a total of 24 lanes feeding into the elongated CBD of Wilshire Blvd., downtown, and Hollywood. It can be calculated that about 1,000 lane-mi would be required connected to 500,000 parking spaces under ground at $6,000/stall. The cost in Los Angeles of this additional transportation system would be ($$10^6$ to $2 $\times 10^6$/lane-mi) $\times$ 1,000 + ($6,000/car) $\times$ 500,000, or $4 billion to $5 billion, with two-thirds of the cost going into the parking spaces.

Chicago

The central Chicago district is penetrated in the peak morning hour or abandoned in the peak afternoon hour by about 200,000 individuals using public transportation. By the middle of the next decade, possibly ¼ million commuters may be riding mass transit vehicles in the maximum hour. When it comes to utilizing the Congress Expressway, Chicago car drivers seem capable of moving 2,000 veh/lane-hr under the best conditions and usually average very close to 2 passengers per vehicle. By 1975, then, accounting for trends in automotive development, some 5,000 individuals per lane-hour would be saturating the freeway's capacity.

Chicago's geological makeup is almost ideally suited for tunneling; throughout the basin, the bedrock is at the most only a few dozen feet underground, and the rock is well constituted for machine boring—soft enough to cut readily and strong enough to require minimal lining. Thus, we may conceive of the hypothetical transfer of all Chicago public transportation to individual automobiles and buses driven and parked underground.

Converging on the CBD might be 250,000/5,000 or 50 lanes one way and possibly 10 lanes the other way with midday lane reversal, for a total of 60 lanes into the center of Chicago feeding into ¾ million parking spaces. If this underground network were to parallel the present mass transit facilities and parking were provided to serve the present daytime inhabitancy peaks, some 1,300 lane-mi would be required (at a finished cost between $$10^9$ and $2 $\times 10^9$), plus $3 or $4 $\times 10^9$ for the parking spaces. Again, as in Los Angeles and Manhattan, parking room is the major component of the system in costs and bored space, amounting to two to three times the freeway tunneling costs.

New York

Under most of the New York City area there is competent bedrock, harder to bore than Chicago's bedrock but cheaper to line and repair. Many New Yorkers are conditioned to high-speed travel in tubes; traffic densities in the Brooklyn-Battery and Queens-Midtown tunnels even exceed the local bridge traffic experiences of 5 million veh/lane-yr, and occasionally automobiles have achieved the transportation of some 30,000 persons per lane-day assumed in an earlier example.

About 1.5 million people go to work in Manhattan; almost one million do so in the peak hour, and only 7 to 9 percent of these people use their automobiles or a taxi. Since about one-third of these workers reside in Manhattan proper, it may be assumed that only 1 million commuters might want to use their car to go to work—if given ample (but costly) roads and parking facilities close to their destinations—and could use some ½ million automobiles in their commuting trip. Projections for the next decade do not indicate a radical change in these numbers, indicating that the ½ million parking spaces that would have to be created would require about 800 mi of three-lane tunnels, costing \$2.5 to \$3.5 × 10^9—one-tenth of the cost of putting an American on the moon. Some 500 to 1,000 lane-mi would be required by 30 to 50 lanes and total system costs (parking and roads) would be between \$3 × 10^9 and \$6 × 10^9. This underground automotive system could be paid for by taxing each car about \$0.005 per tube-driven mile, plus a charge of \$2/day for downtown parking.

CONCLUSIONS AND RECOMMENDATIONS

A conclusion to be drawn from this study is that in the not-too-distant future it may be advantageous to place highways and parking hundreds of feet under the city core rather than on its surface or above it. Another conclusion is that the costs of providing all-automotive urban transportation and access to the central core are very high: though the multibillion dollar initial investment cost could be paid off by highway taxation and parking fees, the capital required for even a modest underground system is still well beyond the fiscal capability of local and state agencies. One may also conclude that only a major Federal agency could cope with the numbers, the cost-benefit considerations, and preliminary estimates of the economic attractiveness of urban land saving and reclamation, reduced construction costs, and increased income from renewed lane use, or exercise the engineering imagination and daring needed for testing the concept.

A final conclusion was that for every mile of new road into a densely inhabited area, a consistent requirement springs up for two or three times as much more area for parking. Since balanced planning would call for two-thirds of the total system cost to go to parking facilities, this might require a radical reorientation of the scope of highway agencies from primarily public road builders to include the role of public parking providers.

It is recommended that a thorough study be carried out of subsurface highways and parking, from the technical, cost-vs-utility, social, aesthetic, and institutional viewpoints. If such a study is to substantiate the promised efficiencies indicated in this analysis, it is also recommended that a design team of civil and mechanical engineers be given the task of developing and fabricating a three- or four-lane tunneling machine for hard rock. This boring machine should have integral provisions for fast and low-cost muck and broken rock removal to a prepared site, and for an automatic lining installer. A roadway installer would also have to be designed and constructed. This would keep pace with or be coupled to the tunneler, so that prefabricated half-tunnel-wide slabs could be emplaced at the proper rate.

On completion of the prototype tunneler, a car-critical urban site should be picked for a demonstration experiment. An eight-lane (two tubes) link between the Lincoln and Queens tunnels seems a most likely candidate, if a modest (e.g., 100,000 car) parking space without surface exits were jointly considered. The experience in boring, finishing, and operating this demonstration line might establish whether or not urban traffic of the future should be carried on the surface of our cities (and choke them with traffic) or underground and preserve them.

Our estimates of the price of these recommendations are as follows:

1. Feasibility study of deep underground highways and parking—less than $\$10^6$;
2. Design and fabrication of prototype tunneler—from $\$10 \times 10^6$ to $\$20 \times 10^6$; and
3. Trans-Manhattan connector and mid-Manhattan 10^5 -car park—less than $\$10^9$.

REFERENCE

1. Hoffman, G. A. Urban Underground Highways and Parking Facilities. RAND Corp., Memo. RM-3680-RC, Aug. 1963.