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84 Urban Transportation Systems

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# Foreword

Transportation systems analysis is a rapidly growing field. Historically, one of the most significant streams of development was that represented by the models and analysis techniques used in urban transportation planning. Other directions of multimodal transportation systems modeling have been the Northeast Corridor Project, the Harvard Transport Research Program model of Colombia, and a variety of specialized analyses of containerization, air cargo, V/STOL aircraft systems, and others. Of course, these developments in problem-oriented models are paralleled by even more rapid developments of fundamental techniques, such as network flow algorithms, simulation languages, economic analysis techniques, and the like.

These developments in analysis tools have been driven by, and have driven, increasingly broader conceptions of the transportation problems that must be addressed. We now talk glibly of multimodal transportation systems; of coordinating pricing, scheduling, and other policy elements with construction of facilities; and of regional and national, as well as urban, transportation studies. There has been a wide proliferation of modeling approaches and identification of policy problems as targets for analysis. There have been significant achievements—and significant disasters—in this field. Because many of these studies have been done for public agencies with high pressures of time and visibility, or for private firms with competitive need for keeping results proprietary, there has been less debate and discussion of these analyses than might be desirable.

It is now appropriate to pause, to reflect, to review, to question, and to explore new directions. What are the advantages and disadvantages of alternative modeling approaches? Now, with the virtue of hindsight, how would we approach a problem differently? Have the models used addressed the policy questions that should have been addressed? What policy judgments were implicit in the very structure of the models used? Where should we be concentrating our future efforts—in model development and in the policy questions to be studied by analysis?

With questions such as these in mind, the Task Force on Equilibrium Models was constituted. This Task Force grew out of an informal meeting in January 1969 at which a number of serious questions were raised about present modeling approaches.

The papers in this RECORD were presented at the first formal session of the Task Force on Equilibrium Models, entitled "Transportation Analysis: Past and Prospects". The objectives of this session are reflected in the format of the program. First was an appraisal—what we have learned from the use of models, particularly in urban transportation planning. In the first paper, Martin describes the models used in developing London's transportation plan and reports problems encountered in using the conventional methods and also techniques that were developed to try to overcome these problems. Kochanowski and Wickstrom, experienced in several U. S. urban transportation studies, appraise the conventional approaches and identify possible improvements. The next paper, by Orski, reports the consensus reached by an international panel of experts in an appraisal of the urban transportation planning process.

The second part of the session was designed to suggest new directions. Harris explores some fundamental notions about static and dynamic equilibria in the urban system and in various approaches to modeling that system, particularly the interrelationships of transportation and urban form. In the final paper, Roberts draws on his experience with three model systems—the Northeast Corridor Project, the Harvard model of Colombia, and urban transportation planning in general—to identify hidden assumptions in existing models and new directions for future developments.

The third part of the session was a general discussion, with participation of the audience and the panelists.

The Task Force hopes that the papers presented at this session will stimulate reflection on analysis tools and policy questions. There are lessons to be learned from the past, but we must also look to the future, without blinders. As the Orski report put it,

> The system of urban transportation models developed to date should be seen as a starting point for further work, and not accepted without questioning. Building on this base, second-generation analysis models must be progressively developed that are more appropriate for the problems facing OECD member countries.

This comment can be extended to all areas of transportation systems analysis, not just urban transportation.

Clearly, many of the opinions expressed here are debatable; let there be debate. The Task Force on Equilibrium Models hopes to continue to stimulate discussions about analysis tools in relation to policy questions in all areas of transportation. This is essential if transportation systems analysis is to truly illuminate the significant policy questions that must be addressed.

—Marvin L. Manheim

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# Transport Planning Models: The London Experience

BRIAN V. MARTIN, Alan M. Voorhees and Associates, London

•TRANSPORT PLANNING in London has existed for many years. The first recorded general plan was drawn up in 1634 and was concerned with improving the streets for the passage of coaches, carts, and horses and with providing for the convenience of pedestrians. But it is the 20th century that has brought about a continuous stream of studies; including a Royal Commission in 1903-5, the Arterial Road Plan in 1910, the General Road Plan in 1911, the Highway Development Plan in 1937, the Greater London Plan in 1944, the LCC Development Plan in 1951, and the Nugent Report in 1959. All of these studies were conducted along traditional lines, in which an eminent engineer or planner heads a small inquiry team that takes evidence from other experts, sieves the limited factual information, and finally makes informed judgments and recommendations. This procedure was almost inevitable because no single administrative body existed over the London metropolitan area and no more scientific methods of analysis were known.

During the 1960s things changed dramatically. Transportation planning models were developed in the United States and Europe that appear to permit a more thorough and comprehensive analysis to be made of urban transport problems. Also the whole administrative structure in London has been changed, so that in 1965 the Greater London Council (GLC) was formed as a metropolitan authority with strategic planning responsibilities.

Transport planning models were first discussed in London during 1960. They were viewed as essentially an American planning tool and, as such, were the subject of some skepticism. By the mid-1960s the possibilities of transport planning models were more generally recognized, although their proponents almost certainly oversold their advantages and the solutions that would flow from using them. Today, transport planning models are firmly established as an analysis tool available to a metropolitan authority. It is recognized that they do not generate transport solutions but evaluate alternatives and that there are still technical improvements to be made. But decision-makers now want to know what a transport planning model analysis reveals about the alternatives open to them.

This paper is concerned with the lessons learned in London as the use of transport planning models has matured. As with many other technologies, their development has been influenced by the institutional framework of government and by the planning issues of the time. These are discussed first, followed by an account of the models used and the technical issues that have arisen.

## THE PLANNING CONTEXT

In 1960, when a comprehensive traffic survey was first being considered, the administrative responsibility for transport was divided among more than 100 authorities. In the center the London County Council was the largest, covering 118 square miles and having a population of 3.2 million. The conurbation had an area of about 730 square miles and a population of 8.2 million. Responsibility for the road system was the most divided function. Public transport was principally the responsibility of the London Transport Board (LTB) for buses and subway and the British Railways Board (BRB)

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for suburban and intercity railway services. The main sponsors of the initial traffic survey and studies were therefore the London County Council and the national Ministry of Transport, which represented all of the other authorities. Both bodies were primarily responsible for highways in London, and it was increasing concern about the road system that led to the suggestion of conducting a comprehensive survey. The London Traffic Survey (LTS) Phase I was therefore predominantly concerned with movement by road, even though a great deal was also learned about public transport. Apart from the intrinsic value of each major item of data, the whole collection of information was of immense value because it had all been collected at the same time and could therefore be more easily related.

The home interview was the heart of the data collection process: 38,539 car-owning households were interviewed, representing 3.5 percent of all car-owning households; 10,042 non-car-owning households were interviewed, representing 0.6 percent of all non-car-owning households. The results provided a full account of all traffic flow characteristics in 1962, and even today these prove useful for many purposes. A great deal of information was gathered and correlated on the development characteristics of London. The data on employment were unique at the time. The passage of time has revealed deficiencies, and the Greater London Council employment survey provides a better basis. But for 5 years the socioeconomic data collected as part of the LTS provided the main basis for strategic planning. The characteristics of person journeys were probably the most valuable data collected and the most revealing.

The survey provided useful data on the movement of goods vehicles. Freight is a difficult aspect of transport studies because the movements, although not large, are so numerous that they cannot be ignored. On the other hand, to study the problem comprehensively requires a seemingly disproportionate amount of resources. The compromise adopted in London, and many other studies, provides adequate data on commercial vehicle movements but hardly appears sufficient to provide a behavioral explanation equivalent to person movements. Nevertheless, the movement of goods vehicles, in terms of quantity and location, was put into proportion by the survey.

The LTS Phase I has provided the basis for all the transport planning models that have been developed in London. Arrangements are being made to update some of the basic transport information in 1971. The first series of transport planning models was developed during Phase II of LTS. The objectives of Phase II followed directly from Phase I: (a) to develop models from which reliable estimates of future traffic can be prepared; (b) to provide planning data for 1971 and 1981; and (c) to provide estimates of 1971 and 1981 traffic using the traffic models, the planning forecasts, and provisional road networks for 1971 and 1981 provided by the London County Council.

It should be noted that the objectives did not include recommendations on a future road system or costing of the systems tested. Public transport was not to be considered in any detail at this stage, but the travel forecasting process did in fact produce some useful information about public transport.

The LTS was started in the midst of a period when London was debating the future form of its administrative structure. The final decision was to create a strategic authority, the GLC, and 33 local authorities that would work in the strategic framework provided by the GLC. The GLC, initiated in 1965, covers an area of 616 square miles and had a 1966 population of 7.9 million. The number of authorities was reduced by this reorganization. More significant, however, was that, by creating two tiers of government, the relationship between the remaining authorities was more clearly defined.

In the transport field all authorities have some responsibility for roads, but the GLC has to plan, maintain, and construct the main road system, including any future urban motorways (freeways). When it was created the GLC had no specific powers or responsibilities for public transport. The GLC was, however, required by statute to produce a strategic development plan for London and as part of this to make a "statement indicating proposals with regard to special roads, trunk roads, and metropolitan roads, having regard to all other methods of transportation, including public transport," as well as "a statement indicating the major traffic interchange points which form, or should form, part of the Greater London pattern of communications," and "a statement of general policy with respect to the relationship of road proposals and traffic movement to other forms of land use."

The emphasis during this period was therefore to broaden the considerations behind the proposals made for new roads. The institutional framework provided, however, does not require the GLC in its Development Plan to make proposals for any other form of transport. Furthermore, the GLC was not given any power over the public transport boards, who remained responsible for planning and operating the buses and trains. The scope of the traffic studies was extended to embrace the broader considerations, and Phase III of the work (called the London Transportation Study) involved both LTB and BRB as partners with the GLC and the national Ministry of Transport.

The results of transport studies all over the world have emphasized the need to treat the urban system as a whole. Very often institutional barriers exist that are more difficult to overcome than the technical issues of transport integration. This is certainly the case in many American cities. In London the creation of GLC was a giant stride forward, but in 1969 the potential of that first difficult step was further exploited by new legislation that made the GLC both financially responsible for London Transport and also the transport planning authority for all forms of transport in London. These new powers were effective January 1, 1970.

The 10 years in which transport planning techniques have matured are also ones in which the administrative framework in which they are used has also changed dramatically. To look for cause and effect here would be to overstate the case, but there can be no doubt that the spur to technical development has been aided by the creation of a better institutional setting. Likewise the changes in administrative structure have been eased by the knowledge and understanding flowing from the technical studies.

## THE PLANNING ISSUES

While the administrative structure sets the scope of the type of studies that can be financed and executed, the planning issues define the problems studied, which in turn will also affect the type of transport models developed. Undoubtedly, the planning issue of the 1960s and probably of the 1970s has been whether London should build an urban motorway system. The benefits of a motorway system have been better understood both as the nature of the transport problem has been analyzed and as the consideration of other planning issues such as the deterioration of the urban environment has been encompassed in the studies.

In the 1950s the problem was defined in the rather restricted terms of congestion on city streets. How can this congestion be removed and provision be made for future growth of traffic? This was certainly a major consideration in defining the initial objectives of the London studies in 1960. Car ownership was expected to increase rapidly, but there was no basis to estimate how large the increase in road traffic would be and how the nature and pattern of travel would be influenced. There were few people who thought that the demand for road travel could be fully met. Until some estimate was available of what that demand might be, it was impossible to assess what proportion could be satisfied, given the measures available to authorities for controlling levels of demand. Phases I and II of the LTS were primarily concerned with these issues.

The results of these studies demonstrated that both the planning implications and the financial costs of meeting the potential demand for road travel were unacceptable. There were only a limited number of locations where large urban motorways could be built without totally destroying community life. Even many of these locations would require great engineering and planning skill if satisfactory results were to be achieved. But if motorway construction posed great difficulties, the studies also clearly implied the even greater problems of doing nothing.

The requirement, therefore, was to determine the level of demand to be met by combined motorway and public transport systems, given that only certain levels of restraint of demand are administratively and technically feasible and that investment resources are limited. Phase III of the LTS had to give guidance on this issue. The well-tried and traditional transport models were not sufficient because the demand could not be related to the level of network service offered. A restraint model was therefore developed and this is discussed in the next section.

Phase III of the LTS did not demonstrate that one particular course of action was conclusively the best. It is not likely that any study of this kind ever has, ever will, or even should. The LTS did provide insight into the costs and benefits of alternative levels of road investment and the level of restraint implied by each. The impact and relationship of road and public transport investment was explored. The background was provided, in fact, for the GLC to put forward a specific motorway plan.

## THE PLANNING MODELS

The LTS was conducted for the GLC by the consultants Freeman, Fox, Wilbur Smith, and Partners who have described the Phase II and Phase III models summarized below in more detail elsewhere (1, 2, 3, 4). The LTS Phase II traffic model had four main elements:

1. Trip generation,
2. Modal split,
3. Trip distribution, and
4. Traffic assignment.

The first three of these elements were developed to suit London conditions from the Phase I data. The fourth element, traffic assignment, was imported directly from the United States. The whole approach was, of course, derived from earlier American studies. Trips were classified under three general headings: internal, external, and through; by three purpose groups—work (to and from), other home based, and nonhome based; and where appropriate by four modes—private transport (driver), bus, rail, and other passengers (mostly car passengers). Goods journeys were treated separately by light and heavy classifications. All analyses were made on a 24-hour basis.

The trip generation model was based on regression equations developed from the survey data. These equations very adequately reproduced the 1961 situation (as would be expected if the regressions were any good), but the equations did not contain parameters that reflected the level of service provided by the transport network. The equations were sensitive to socioeconomic changes, which were the largest relative changes expected over the forecast period, particularly income and car ownership.

To estimate road traffic generation it was obviously necessary to deduct public transport trips from total travel expectations. The modal split calculation was made using category analysis. The categories were as follows:

1. Cars owned (0, 1, 2, or more);
2. Household income—low (up to £1,000), medium (£1,000 to £2,000), or high (over £2,000);
3. Employed residents (0, 1, 2, or more);
4. Rail accessibility (low, medium, or high); and
5. Bus accessibility (low, medium, or high).

For forecasting purposes, rates were calculated for each category by travel mode and by trip purpose, and for Central London and the remainder of the survey area. The modal split for attractions was obtained by regression equations using the previous category analysis and regression results as control totals.

The traffic model included distribution functions for private and commercial vehicle trips. The basic form was the Interactance Trip Distribution Model, a version of the gravity model, with travel time being used in the distribution function. The model was calibrated against survey data by trip purpose, and three distribution functions were derived depending on the attraction zone. This represented a simplification and, in my view, an improvement over separate functions for each zone as used in some studies.

The final element of the model is the traffic assignment process. An "all or nothing" approach was adopted, the U.S. Bureau of Public Roads program suite being used. The use of unrestrained assignment techniques does introduce a number of fundamental problems. It has been argued (a view once held by me) that unrestrained techniques are of little use because it is likely that congestion in some form will always be present in large cities. The experience in London does show, however, that unrestrained assignments are of use in the very first tests undertaken on a network, particularly if the travel demand is in excess of the network capacity. In these conditions capacity-restrained techniques tend to spread the traffic across the network but, because of the imbalance of supply and demand, loadings still exceed capacity. The net result is that the true demand pattern is obscured at the early stage of the analysis when it may be more important than the absolute level of loadings.

The Phase II model forecasts indicated that either very large sums of money had to be spent on roads, the demand had to be "managed" in some respect, or, more likely, a combination of these policies was required. Whichever way the problem was finally approached, the implications for the technical work were the same. The techniques had in some way to reflect the effects of congestion on trip generation so that guidance could be given on the main issues raised by the Phase II results. For example, what effects would different parking policies have and how would road pricing change the situation?

Although the Phase II results did not provide detailed information on public transport, the overall estimates indicated that, even in the free demand situation for roads, significant movements by public transport were forecast. This led to further questions being asked; for example, how would improvements in public transport affect the situation, and how would different road policies affect public transport? The issues raised were not only confined to transport networks but also included the land use pattern. For example, if large investments were made in transport in the context of the present land use, would they hold good in the future if land uses changed?

The issues raised by the planning models had outstripped the technical capability of the models being used in London. The Phase II traffic model could not directly provide technical information that would give the more detailed guidance now demanded. A revised traffic model was therefore developed for Phase III of the work. The traffic model developed for Phase III had seven main elements, as follows:

1. Trip generation,
2. Trip distribution,
3. Modal split,
4. Traffic assignment,
5. Speed reduction,
6. Restraint procedure, and
7. Economic analysis.

The analyses were made with the same trip purposes and modes as Phase II and were made on a 24-hour basis except for public transport assignments, which were for the peak hour (these were derived from 24-hour estimates). Early in the development work, it became clear that the model should be based on traffic districts (186) instead of traffic (933) as used in Phase II. (An exception to this was the assignments to public transport, which were made on a zone basis.) This was because of the complexity of the process and the size of London, but it introduces the use of a model heirarchy in which each level is more detailed and deals with fewer alternatives.

The trip generation procedure estimated the total travel demand by car-owning and non-car-owning households. Generations were obtained from a category analysis, the groupings being as follows:

1. Cars owned—0, 1, or 2;
2. Household income—low (up to £1,000), medium (£1,000 to £2,000), or high (over £2,000);
3. Employed residents—0, 1, or 2; and
4. Density (persons per acre)—0 to 35, 35 to 65, or over 65.

The analysis was undertaken for the central area and noncentral area. Attractions were based on the Phase II regression equations, but additional factoring was necessary to divide them between car-owning and non-car-owning households. The car-owning household travel demand was considered separately in the model from non-car-owning households because the modal choice problem is most relevant to the former. For car-owning households, total travel was distributed using an interactance model similar to that used in Phase II. Travel time diversion curves were used to obtain public and private transport journeys. The private transport journeys were then assigned by an "all or nothing" procedure.

The resulting loadings exceeded the capacity of the links, as was the case in Phase II. The fifth element of the modeling is a speed reduction process in which the analyst lowered the motorway speeds by inspecting the loadings, with the objective of obtaining an equal overload condition in which the overload on the primary and secondary system is approximately equal. With the networks tested in Phase III, two speed reductions were necessary to achieve this balance. For each speed reduction a corresponding traffic distribution and modal split were made.

The speed reductions reduce vehicle mileage, alter the modal split, and reallocate demand between routes, but the overall level of trip-making demand is not altered so some overloading may still occur. In reality, the shortage of capacity will limit trip generation, and regulatory measures, such as parking controls, may also be introduced to manage the demand. It is clearly difficult to develop a rational procedure for simulating this process when so little is known about the demand curve for transport. The consultants chose to use a linear programming procedure to relate link capacity and travel demand. The objective function was to maximize the total number of trip attractions subject to the link capacity of the system. The final assignments obtained gave loadings at or within the capacity assumed for links.

The journeys restrained by the capacity of the system are divided into two groups: those made by public transport and those not made at all. This is achieved by assuming that, in total, restrained car-owning households behave as if they were non-car-owning. This is not meant, necessarily, to imply lower car ownership but lower trip generation in all car-owning households.

The public transport journeys estimated during the modal split are re-expressed as trip ends, the public transport portions of the restrained trips are added, and the total is combined with non-car-owning trip ends to give the total public transport demand. These trips were distributed by a separately calibrated interactance model and assigned to a public transport network.

The planning models used in the LTS have been of immense value in providing understanding of the transport situation in London and in the guidance they have given to the selection of a road investment program. The models can still be improved technically, especially for the analysis of more detailed situations, but further technical improvement is unlikely to yield a different strategic answer to the problems of London. In the field of public transport, further developments that would be useful include the ability to analyze multimode situations such as park-and-ride and kiss-and-ride.

## FINAL REMARKS

The purpose of this paper has been to show how transport planning models have been used in London and how their development has been related to the institutional and planning framework of the period. Today the models are used to evaluate the significance on strategic policy of changes in population, employment, and income forecasts; to assess the effects of variations in design standards; and to provide a better basis for engineering design. In other words, the various models have become the tools of the transport planners. Technical problems still remain, ranging from the behavioral explanations the model provides to the often excessive computer time required to use them. As time passes the tools are being made more appropriate to the tasks they have to perform—macromodels for major strategic alternatives, and more detailed models for tactical problems.

Although planning models have assumed a more appropriate role as part of the continuous process of planning cities, the need for the development of new ideas is still urgent. An interesting comment was made in London recently by a group of professionals who oppose the GLC motorway plans: "While accepting that car-ownership will continue to grow rapidly and fully recognizing the advantages of the car we reject any attempt to predict what the pattern of transport will be in the distant future, because we believe that the pattern is largely within the control of the GLC and the government." From this comment one assumes that this group is looking for alternatives and concepts far beyond those that are presently being offered the urban community by engineers and planners.

If this view were right, and there is growing evidence that urban communities throughout the world are seeking better alternatives, we may well be back to placing more emphasis on creating new ideas and environments in the manner of 300 years ago, as was discussed at the beginning of this paper. We are now able to evalute these ideas to a greater extent than ever before. In fact, perhaps the emphasis of our present work should move more toward the creation of new ideas and alternatives for the future urban environment and less on the precision and sophistication of urban models.

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# On Improving the Transportation Planning Process

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•IN SPITE OF what many transportation planners believe, the history of architecture holds some lessons that may be of value to us in contemporary planning. Some of the most venerated architectural forms were conceived with functional beauty and simplicity. As the form became known and established, schools of admirers began to embrace its principles, and gradually the form became institutionalized in the social process. Then, as time passed, each practitioner of the art sought to improve the form by adding his own modifications and embellishments. As this process continued, the simple art form began to lose its original function and identity. Finally, a creation that once held appeal and beauty was rejected by the public as baroque or even grotesque. Subsequently, a renaissance was reached that resulted in the evolution of a complete new art form.

In many respects, the transportation planning process as it is applied today has evolved in a similar fashion. When the process was conceived some 15 years ago, it represented a fresh approach and introduced an element of science into the art of planning. For the first time transportation facilities could be planned on a systems basis, using an objective, quantifiable, and replicable approach. Even though the scope and accounting included in the process were limited only to transportation (and some will argue that only highways were given fair consideration in the earliest transportation studies), the step was a significant one because, for the first time, practitioners began to seriously consider transportation facilities as part of a future total system of facilities and not as a series of individual projects. In spite of its contribution, the process was still not totally embraced, and it was viewed by many administrators with a mixture of awe and suspicion during the late 1950s and early 1960s.

Then, as more and more responsible people began to see the value of planning transportation facilities on a systems basis (and other people became disenchanted with the way highways were being planned), pressures began developing for a more universal application of the transportation planning process in urban areas. Culmination of these concerns was the passage of the 1962 Federal-Aid Highway Act, a step that was to institutionalize the transportation planning process. This Act generated nationwide interest, and substantial research was undertaken on all elements of the process. Although some of this work in the years immediately following passage of the 1962 Act served to improve each of the elements of the transportation planning process, the process itself remained essentially unchanged from its original form.

Then, in the mid-1960s a new dimension was added to urban transportation planning. As the U.S. Department of Housing and Urban Development (HUD) became involved in transportation planning, it was mandated that transportation planning be couched within comprehensive planning in urban areas. In effect, transportation planners could no longer "do their own thing" in isolation from other urban systems planning. Transportation systems were no longer to be suboptimized but were to be developed as integral elements of the total urban system, with full consideration for transportation's influence on development and its interactions with other urban systems. But instead of

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redesigning the entire planning process to meet this new charge, the transportation and land use planning tools were conveniently combined and labeled "comprehensive planning."

The result of this merger is an eclectic set of tools that are not in accord with prevailing planning philosophy. Although we have mandates to plan long-range transportation facilities and urban development comprehensively, our tools are not tailored to this charge. Although we have developed methods to compare the direct costs and performance of alternative transportation systems for one future point in time, we find that the values that we have learned to measure and plan for are but a part of the total factors that society requires us to consider in order to implement the plan.

## HOW HAVE WE BEEN DOING?

An evaluation of the large-scale land use and transportation studies of the last decade was recently made by Boyce and Day (1) of the University of Pennsylvania for the U.S. Bureau of Public Roads. In their report they state:

> Experience. . .indicates that the data requirements and data management problems in these programs, particularly those employing mathematical models, are immense. . . . Consequently, the number of alternatives tested and the differences among them were severely limited in the programs reviewed. Work schedules have been drastically revised, often resulting in a loss of credibility for the planning effort. Alternatively, agencies have resorted to crude short cuts, interim plans, or dropped the use of mathematical models altogether to stay somewhat close to schedule. The dilemma posed by this situation is particularly perplexing. While the use of computer methods is demanding of time and staff resources, important advances in metropolitan planning capability cannot be achieved without utilizing computer techniques. Because of the above problems, the evaluation phase of these programs has typically been hurried and too narrow in its scope. In addition, evaluation has been less meaningful than it might have been because of the narrow range of differences among the alternatives being evaluated.
>
> The experience of the past few years also indicates that the growing understanding of metropolitan processes on the part of professional planners outstrips their ability to communicate this understanding effectively to public officials or to the general public. This situation has clear implications for evaluation methods and public participation. The decision process too often appears to have been a matter of sophisticated analysis versus blunt political or subjective reaction. In retrospect, the primary emphasis in these programs over the past few years has been the development and testing of planning methods, leaving insufficient time for a complementary emphasis on their application in fostering, examining and supporting creative ideas about the form and values of the future metropolis.

Urban transportation planning agencies and their sponsors must also struggle constantly at the other end of the scale. Transportation systems are not built instantaneously, and highway and transit project planning and programming are too often a world apart from long-range comprehensive planning. The values of individual projects that can relieve short-term problems can be substantially different from the values of a total transportation system that is 20 years or more away. More often than not transportation administrators and public officials responsible for project programming and implementation do not want to hear of the abstract benefits and costs of the "some day" total system; they are more concerned with the pragmatic details of a project's short-term impacts. A major problem is that transportation planners are not equipped to provide rapid and reliable analyses and information that would assist in making decisions on such projects.

## IMPROVING THE PROCESS

How can we reorient the transportation planning process (and its methodologies and tools) so that it can be a more meaningful part of long-range comprehensive planning and also a more effective guide in individual transportation project decisions? First, we must recognize that transportation facilities will have impacts and effects on urban areas that will extend far beyond our present ability to define and measure. Entire new urban forms and structures will grow around the transportation corridors that are planned today. Unfortunately, we know little about the indirect values and benefits that, because of the urban forms resulting from present transportation decisions, will accrue to society over time.

To become more effective, we believe that the transportation planning process must be broadened in terms of both planning scale and time horizon. At the regional scale, we must relegate to a lower level of significance the present methodologies and tools and search for sincere answers to complex, far-reaching questions that extend beyond the horizon of transportation alone. In effect, we must learn to do comprehensive region-wide planning before we can do a good job of regional transportation planning.

To date, we have spent most of our resources producing detailed forecasts of traffic volumes on every significant link in an assumed future transportation system or systems. It is perhaps the one thing that all of the approximately 200 land use and transportation planning programs have in common. The assumptions, data requirements, data processing and analysis, forecasts, models, and computer programs designed to produce these forecasts are legion and need not be elaborated here.

We believe it is impossible to forecast accurately the travel demand that will exist in 20 years on each transportation link at the regional scale. We further submit that the estimation of traffic volume for 20 years or more into the future should not be the overriding concern of the urban transportation planning process.

Transportation systems, unlike single facilities in rural areas, are dependent on and interact with all other links (and modes) in the system. Aside from the obvious difficulties of forecasting future small area population and employment, assumptions made concerning the system are crucial. All parts of the system must be built exactly as assumed if the forecast link volumes are to occur, even if the forecasts made and the models used are 100 percent accurate. Similarly, the economic analysis as now performed is at best only a measure of a portion of the benefits and costs in a system that may not materialize entirely as planned.

We presently have some measure of how transportation facilities will affect development patterns, but little has been done to determine how human values vary with alternative region-wide forms and development patterns. Is it, as has been alleged, cheaper to provide public services (including transportation) to a densely developed region? If it is, do people wish to live and work at such densities? It may be that there are no strong differences in the costs or values of alternative development forms over long periods of time at the regional level but that these factors are only meaningful at a finer scale such as a neighborhood.

## REGIONAL TRANSPORTATION PLANNING

Transportation facilities constructed in urban areas will serve as facilities for movement by some mode throughout decades and even centuries. When viewed at this scale, factors such as link volumes in 20 years or attempts to optimize service for short-term demands lose their importance. Two parameters of regional transportation system planning then stand paramount—spacing and continuity. If the long-range plan for transportation facilities has good spacing and continuity, it will stand the test of time regardless of shifts in technologies, modes, or development patterns. However, if spacing and continuity are comprised for shorter range objectives, the long-range consequences could vary from additional investment in transportation facilities to major urban inefficiencies or disruption when maximum urban development is achieved.

These principles should determine the broad corridors within which individual transportation facilities must be designed and located. The regional scale, then, should establish the overall spacing plan for the highest level of transportation improvement. The development of such a plan does not require the detailed small area data collection, forecasting, and modeling now undertaken at the regional scale. Much simpler, more direct procedures are desirable and badly needed.

## CORRIDOR PLANNING

Within the framework provided by the regional system, corridor or subarea analysis should be used to study alternative improvement proposals for each mode of travel. At this scale, network assumptions, data requirements, forecasting, and modeling become more manageable. Shorter range projections (e.g., 10 to 15 years) are appropriate. The nature and staging of specific improvements takes on added significance. It is at this scale that our present transportation planning methodology is most applicable. We have spent too much detailed effort in dealing with end-state alternatives, but far too little time testing, evaluating, and recommending improvements to the partial transportation systems that exist today and will still exist 5, 10, or even 20 years from now.

Within these corridors, research efforts also should be directed toward better methods of land use control to ensure that a reasonable level of service is maintained. All too often, the expenditure of funds for highway facilities to improve the level of service has been immediately offset by rapid growth in land development producing subsequently higher travel demands than anticipated. Alternative ways to achieve a balance between land use and transportation in corridors include the following:

1. Restricting land development in the corridor to an amount that can be accommodated by the transportation improvements provided;
2. Controlling the amount, type, and location (or arrangement) of land uses so that the same objective is reached;
3. Modifying the supply of transit facilities and services provided to change the modal split in the corridor so as to maintain a high level of transportation service;
4. Metering the flow of traffic to maintain a high level of service; and
5. Some or all of these four in combination.

The demand as well as the supply side should receive study.

## PROJECT PLANNING

Project planning should also receive more emphasis. At this level, all of the detail and information that we can muster is needed, but only for the specific transportation facilities that have been identified in the corridor planning phase as the earliest action priorities. First, we need to know in considerable detail the peak volume ranges for which we are designing the facility. We should know these design volumes, not only for an arbitrary design year 20 years in advance, but also for the variations in demand that will occur before the design year so that the design and staging can anticipate interim operational needs as well.

Decision-makers want short-range information, and we need to develop improved methods of defining the project's short-term impact on the existing transportation system and its surrounding environs. A major need in this regard is tools to evaluate the transport and other impacts of large-scale developments such as shopping centers, office complexes, and the like. Recommendations must be made by local planning bodies to accept, modify, or reject the proposed development and revise the transportation system as required. Reliable knowledge of nonresidential trip generation characteristics, essential to such analyses, is lacking. Less emphasis on home interviews as a way of obtaining basic data is indicated (with studies made at these sites instead).

Similarly, the definition and measurement of the land use and socioeconomic impacts of individual transportation projects is one of our most profound challenges. We need to have better measure of the disruptive effects of projects, and need to acquire the ability to evaluate how alternative alignments, cross sections, and modes of travel in a corridor can minimize this disruption. Planning for the relocation of people displaced should be included as well.

## SUMMARY

As presently practiced, the regional land use and transportation planning process rests far too heavily on the assumption that the inputs to the process can be forecast with an acceptable degree of accuracy over a 20- to 25-year period. Although some progress has been made in improving the traffic simulation models that utilize these inputs and although some research has been directed recently toward improving methods of evaluating outputs, the process itself remains largely one of testing alternative end-state assumptions. It can be characterized as "what would happen if" art and, as such, is still too far removed from the decision-making process.

It is, therefore, essential that the urban transportation planning process be reoriented from its present overwhelming preoccupation with detailed long-range forecasting and end-state planning at the regional scale. The urban transportation planning process must be made more relevant to decision-making and implementation. Most transportation decisions are not made at the regional scale, but at the corridor and project levels. Much of today's transportation planning methodology can be applied at these finer degrees of planning, but new methods and techniques specifically tailored to these scales need to be developed as well. At the same time, much broader regional studies involving human values, as well as physical and economic considerations, should be undertaken. We badly need more specific, fine-grained tools for short-range planning, and also broader social and economic planning tools to apply at the regional level.

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# The Urban Transportation Planning Process: In Search of Improved Strategy

C. KENNETH ORSKI, Organisation for Economic Co-Operation and Development, Paris

•IN FEBRUARY 1969, the OECD Consultative Group on Transportation Research endorsed a proposal to convene an exploratory meeting to examine and assess the state of the art of the urban transportation planning process. The intent was to lay foundations for a concerted effort to provide OECD member governments with an improved capacity for making sound and sensitive transportation decisions. Depending on the skill with which we exploit its potential, transportation can be either an instrument of desirable social change or a disruptive force against human development. It can both enhance and damage the quality of the environment. It can act either as a stimulus or as a brake on urban growth and development. Thus, the ability to make enlightened transportation decisions may, to a large extent, determine government's success in achieving wider policy objectives.

Two premises served as the basis for the meeting. The first premise was that a new conceptual approach to urban transportation planning is emerging, giving increased emphasis to human values and to the social and economic goals of urban development. In this approach economic and engineering efficiency, demand for transportation, and profitability no longer serve as the only guiding principles for investment decisions. These conventional criteria are weighed against the social, economic, environmental, and aesthetic needs of urban residents, including personal mobility, accessibility to urban opportunities, comfort and convenience, clean air, open spaces, pleasing surroundings, and preservation of neighborhoods and of urban diversity. Underlying this shifting emphasis is the growing conviction (a) that transportation is not an end in itself but a tool for bettering the total condition of urban life; (b) that its objective is not just to move people but to enhance the quality of the cities and to improve the social well-being of their residents; and (c) that planning concerned only with the effects on transportation itself has too often resulted in transportation systems that have failed to contribute effectively to these objectives.

A concomitant premise was that there is a need for a methodology that is more sensitive to the important issues facing urban society and more effective in helping to reach socially responsive decisions. In particular, more sophisticated tools of analysis are required (a) to perceive individual and community preferences and formulate goals and program objectives in the light of evolving technology and changing habits and values; (b) to search for and generate alternative approaches to meet given objectives; (c) to predict, evaluate, and rank the impacts of alternative proposals; and (d) to give adequate recognition to the element of uncertainty in decision-making.

The aim of the meeting was as much to open up new perspectives as to review current work. Particular emphasis was placed on exploring the implications that the convergence of the new techniques of analysis into a continuous and structured systems planning process might have for improving decision-making in the context of the larger urban social system.

The meeting, held on June 30-July 2, 1969, consisted of three one-day sessions. The first was devoted to the presentation of a paper on strategies for transport planning and to discussion of the general subject of the normative principles that should guide transportation policy. The second session heard a paper on maximizing urban transportation

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Paper sponsored by Department of Economics, Finance and Administration and Department of Urban Transportation Planning and presented at the 49th Annual Meeting.

potentials and a subsequent discussion on the gaps between the requirements of rational decision-making and the capabilities of existing methodology. The third and final session provided an opportunity to develop further some of the important themes raised during the first 2 days and to explore the present deficiencies and needed directions for improving the process of planning for urban transportation. This report is based principally on the discussion that took place during that final session.

It should be noted that this report contains the conclusions of a panel of experts. Its contents do not necessarily represent the views or policy of OECD or its Consultative Group on Transportation Research.

In the brief space of 3 days it obviously would have been impossible to explore in depth a subject fraught with so many complexities. The report thus lays no claim to being exhaustive, and the panel should be forgiven if in its treatment of the subject it has been somewhat selective. Also, this report is not a guide to specific improvements in the planning methods. Such improvements are going to be a matter of slow evolution. They must proceed against the background of more profound knowledge of the changing requirements imposed on transportation planning. It is this challenge—a better understanding of the new environment in which the planning process must take place—that motivated the panel's discussions.

## THE SOCIAL CONTEXT OF TRANSPORTATION POLICY

Traditionally, public investment decisions about transportation have differed little in approach from those of any private enterprise. Many government agencies still tend to assess the available options and select the best among them in terms of transportation-specific criteria such as capital costs, satisfaction of observed demand, net user benefits, profitability, engineering efficiency, and reduction of traffic bottlenecks. In so doing, they measure transportation system performance with criteria relevant to the workings of the transportation system itself.

Although this approach allows for the satisfaction of internal, system-specific demands, it ignores the wider, external effects of transportation. Yet transportation is only a part of a larger urban or regional complex, and every change within the transportation system reverberates throughout the larger complex, producing multiple impacts that reach out far beyond the confines of the transportation system.

Today the external impacts are playing an increasingly dominant role in the calculations of the policy-maker. When considering an investment decision to build a new airport from the traditional technoeconomic standpoint, for example, it is sufficient to evaluate the various location options in terms of benefits that the projected investment may be expected to bring to the users of the airport, including additional passenger and freight capacity, reduction in travel and shipping time, and relief of congestion. In this approach, the airport is appraised only against its own internal criteria for success.

We have come to realize that this is an incomplete way to view a public investment; equally as important as the internal effects are the impacts of the proposed airport on the larger system of which the airport is a part. Hence, we try to anticipate the effects of the alternative location decisions on future land development around the airport; on the likelihood of attracting new industry and creating new demand for labor in the area; on the levels of noise, pollution, and traffic congestion in the communities neighboring the airport; on the degree of relocation assistance required; and on the desired economic development of the region.

If, in addition, we are to be sensitive to the social and political consequences of our actions, we should also attempt to trace the impacts of the secondary effects on the different groups that are affected by them and to learn how these impacts are perceived and evaluated by the individuals who make up these groups. Only by so doing can we test the decision's fairness.

In recent years a number of sophisticated studies have attempted to estimate the magnitude of costs and benefits that would be generated by a proposed government investment. A common feature of many of these studies has been the implied assumption that, if the total benefits exceed the total costs, the project is desirable from public policy standpoint. This aggregative approach is oblivious to the redistributional effects of public decisions. Even if overall benefits of the proposed airport site did exceed its overall costs, the decision could nonetheless impose considerable hardship on a large number of people. Which publics are to pay and which are to profit from government's action is ultimately a political decision. To make a socially enlightened and politically sensitive decision, we must explicitly recognize that there is a multiplicity of competing communities of interest, each with its own set of values, preferences, and ideas as to how the benefits should be paid for and distributed. Hence the planner and the analyst should strive to trace and evaluate the incidence of the benefits and burdens of alternative decisions on each of the affected publics, rather than engage in a grand social accounting for some generalized and largely mythical community at large.

Because we have acquired a heightened awareness of the external impacts of transportation and of the social and political significance of their redistributional effects, our approach to transportation planning is changing. Today the best design for a transportation system is no longer necessarily the one that results in the lowest capital costs or in lower user costs or the one that produces the biggest reduction in travel time. Rather, it is the design that yields the highest social return on the investment and that reconciles most effectively the conflicting interests of the individuals and various groups in the community affected by the proposed project. Hence the cardinal challenge facing transportation planning today is not so much to achieve maximum functional efficiency as it is to respond most fully to society's present and future total needs.

What is the nature of those needs? On this there never will be complete agreement. Nevertheless, there is sufficient consistency in human desires and behavior for us to distill a certain workable consensus. As we draw closer to an era of near-total urbanization, a dominant social goal of public policy will be that of preserving and fostering an urban environment drawn to the human scale, with values, services, and facilities that respond fully to the needs of the various groups that make up the urban community. This means, on the one hand, a social environment that provides freedom for all to move up social and occupational ladders; promotes opportunity for all citizens to participate fully in economic, social, and political life; and offers a variety of ways of life with opportunity to choose among them. On the other hand, it means a physical environment that meets the aesthetic and psychological needs of urban residents; protects them from the excessive intrusion of the unintended side effects of changing technology; preserves the historical heritage and beauty of the urban landscape; and promotes a climate in which cities can grow as viable centers of management, commerce, information, knowledge, and culture.

For the analyst and planner the challenge has become that of developing a capacity to assess the effectiveness and productivity of proposed transportation investment in terms of its contribution to these broad societal goals. This, in turn, calls for the development of new, more sensitive measures of transport output. Four such measures have particular significance in present-day transportation analysis and plan evaluation.

## Accessibility to Opportunities

Except for such activities as ship cruises and Sunday driving, transportation has value only insofar as it helps to overcome the friction of space. In so doing, transportation improves geographic accessibility. Accessibility, in turn, opens up new markets, fosters trade and commerce, increases opportunities for contact and exchange, and thereby acts as a medium for economic development. This was the motive behind the huge railroad and canal building era of the 19th century and behind the highway and airport construction programs of the first half of the 20th century. This is also why today developing nations are still investing up to a third of their gross national product in transportation.

For most of the industrialized world, the problem of inaccessibility as an obstacle to economic growth has significantly diminished. We have largely succeeded in integrating local economies into national economies, and we are well on our way to integrating national economies into one world economy. To be sure, the task of improving transportation to foster economic growth is not quite finished. We must continue to use transportation as a means of developing remote regions and reviving economically depressed areas that are the victims of structural imbalances. We will need to enlarge the capacity of the transportation network to keep up with the demands of a growing economy and an expanding population. We will continue to strive to cut down transit time and reduce traffic bottlenecks in order to improve transport efficiency. But all this, relatively speaking, will call for marginal improvements. In urban areas of the industrial world, at least, economic development can no longer serve as the primary justification for large-scale capital investment in transportation. The future objective of urban transportation investment must increasingly be viewed as that of promoting social development and bringing the resources and opportunities of the city within the reach of all citizens.

Today, large segments of population in metropolitan areas are denied convenient access to urban services and facilities because they lack personal mobility. Their freedom to move may be impaired because of poor public transportation service, because they cannot afford an automobile, or simply because they are unable to drive. Whatever the reason, people whose personal mobility is impaired are barred from the enjoyment of what the city has to offer. Also, they are placed at a disadvantage as regards access to the more basic things in life, such as opportunities for employment, education, decent housing, medical care, and recreation. Thus, the extent to which transportation can serve to lower the barriers to urban opportunities, by offering those who are disadvantaged improved personal mobility, may well become one of the chief measures of transportation's performance.

## Environmental Effects

Transportation activities have always adversely affected the environment. But until recently transportation impinged on relatively small portions of man's environment, and therefore its impact was not widely felt. Today, the ubiquity of modern means of transport has made escape from their external effects no longer feasible. All who live in metropolitan areas are the unwilling sufferers of noise and fumes emitted by automobiles. Increasing numbers of people are being exposed to noise from aircraft, and soon millions might become exposed to sonic booms from supersonic transports. More and more neighborhoods suffer disruption through urban freeway construction, and few of us are protected against the unsightliness, obtrusiveness, and ugliness of a variety of transportation-related or transportation-induced phenomena: automobile junkyards, elevated highways, parking lots, billboards, and the like.

The undesirable, unwanted side effects of transportation activities have reached a point where society can no longer ignore them. Increasingly, criteria for evaluation of transportation investment must include environmental quality considerations; increasingly the analyst will be called on to answer the question: To what extent will the transportation system impinge on the environment in terms of noise and air pollution, visual impact, land consumption, disruption to the surrounding area, and risk of accidents? In our increasingly crowded society, environmental quality will inevitably become a highly important criterion for evaluating total transportation effectiveness.

## Long-Term Impacts on Land Use

Changes in accessibility and in the levels of environmental quality can, in turn, cause profound and lasting changes in the character of land use. One of the most striking examples of this phenomenon has been the effect of the construction of radial and circumferential highways in the vicinity of some of the large cities. By offering improved access these highways have triggered intense development of the adjacent land and have become a magnet for an ever-growing array of industrial parks, shopping centers, recreational facilities, and housing developments.

To be sure, the need for large parcels of land—induced by exogenous factors such as technological change in manufacturing processes, the shift from vertical to horizontal integration of production lines, and changes in merchandising methods—may have been at the source of the massive shift to the outlying areas. But without the improved access offered by the new highways, this shift would at best have required a much longer period of time; often it could never in fact have occurred.

Similarly, there are numerous examples where transportation facilities have been responsible for depressing the character of land use. The effect of urban freeways, for example, has often been to condemn a formerly viable and attractive area to the status of a second-class neighborhood because of the adverse environmental effects associated with their use.

In the past, transportation planners have all too often been oblivious to the external impacts that their decisions produce on the surrounding land. Increasingly, however, transportation investment is viewed as a conscious instrument for promoting orderly land use development and desirable urban form and growth patterns. Increasingly, too, the test for transport effectiveness will include a test of its influence to preserve and shape the character of the neighborhoods and regions that it is supposed to serve in a way that satisfies the community's sense of basic values and aspirations.

### Quality of Service

For a long time the amenities of urban travel played a subordinate role in the planning and design of public transportation. The result has been that the quality of urban transportation service often falls far short of that expected by the transport user. The city bus is an example of unmet aspirations of the urban dweller. Although the bus is a model of engineering reliability and economic efficiency, it has fallen into public disfavor (as witnessed by falling patronage) because it fails to provide the kind of service that the riding public demands. Although the bus loses part of its appeal because it gets caught in traffic jams, much of the reason the bus projects a poor image stems not from its slow speed but from poor service: infrequent and irregular runs, unreliable schedules, poor riding comfort, uncertain arrival times, long waits at bus stops, crowded vehicles, and inadequate shelters.

As improvements in the amenity of other forms of travel and rising living standards push the expectations of the urban traveler even higher, the qualitative aspects of urban transportation will assume increasing importance. Factors such as comfort, convenience, frequency of service, and reliability will take on new significance and will figure importantly in the evaluation of overall transportation systems performance.

These four elements—accessibility to opportunities, environmental effects, the resulting long-term impacts on land use, and quality of service—have joined the more traditional criteria in the evaluation of transportation investment. If the basic assumptions are valid that transportation has value only insofar as it satisfies the broader social purposes, and that the test for transport effectiveness, therefore, must be a test of its external, social effects, then these four measures may emerge as the principal factors that will shape future public decisions about urban transportation.

## THE PROCESS OF GOAL FORMULATION

Fundamental to the planning process is the initial step of setting goals. Goals provide the necessary direction for the planning effort and furnish a means by which the effectiveness of the effort can be measured. However, in a society dominated by rapidly evolving knowledge, technology, and culture, goals will need to be revised and replaced as new needs and opportunities present themselves. Whether the goals are arrived at by the reflection of the planner, by surveying the opinions and attitudes of the local citizens, or by the dictates of the political decision-maker, they are likely to be abstractions or broad generalities. Strategies must be developed to translate such goals into statements about specific objectives that are truly attainable, if goal-oriented planning and evaluation methods are to be effectively introduced.

As in all areas of broad public interest, setting goals for transportation involves choices between competing and conflicting interests and scales of values, and must be viewed in terms of a comprehensive policy in which all the pertinent considerations—social, legal, aesthetic, and political, as well as economic and technical—are weighed, evaluated, and reconciled.

Some innovations in the policy-making apparatus may be required to achieve these purposes. Present governmental structures are not designed to deal with broad issues of social development and environmental quality in a comprehensive manner. Although decisions can be made on the basis of arguments and considerations formulated by agencies with specific goals and missions, there often is no mechanism for trading off the benefits against the disadvantages and for taking distributional effects into account.

New institutions may have to be created that cut across the jurisdictional lines of existing agencies in order to provide a forum in which goals for transportation development can be brought forward, argued, weighed, and decided on with the widest possible interplay of interests and values and in light of the total needs of society.

## PARTICIPATION

Now that we have come to view transportation as an activity that produces multiple external impacts that fall unevenly on the various groups in society, we want to know what trade-offs among the alternatives and impacts are necessary to reach socially desirable decisions. To gain this knowledge we need to consult the affected groups in the community and to allow them a voice in the formulation of decisions. All too often planning efforts have been characterized by inadequate contact between the planner and the public and between the planner and the politician, leading to the criticism that planning has insulated itself too much from the political process.

One of the important roles of transportation planning is to help clarify in the minds of political decision-makers, as well as the community, the range of options open to them, as well as the implications of these options. There are a number of fruitful directions for development of more effective interaction between the technical process of transportation planning and the real-world political process.

Within the technical process itself, there should be continuous attention given to identifying each of the different interest groups that might be affected by the alternatives being studied. The technical team should spend considerable effort evaluating how these effects might be perceived by the groups, and should search for technical means of minimizing negative effects—redesigning alternatives, providing adequate compensation, and searching for more equitable solutions.

The technical process itself should be open to the public. Considerable effort should be devoted to communicating with a variety of interest groups not only when presenting the final technical recommendation, but also at the beginning of the project. It is very important, therefore, that the technical team, from the earliest stages, seek out groups that may be affected, learn about these groups and their desires and attitudes, build effective communication, and present to them through the planning process technical information on the alternatives and their impacts. To get all points of view fully and adequately expressed, it may be desirable in some circumstances to provide resources to particular community groups to enable them to obtain technical assistance for a thorough evaluation and for articulate support of their position.

Effective communication presumes not only a thorough understanding of the plan on the part of the planner, but also an ability to convey its meaning and explain its consequences to the public. The development of more effective methods of presentation, as well as intelligent and persuasive advocacy of desirable planning alternatives, is essential for establishing a meaningful interaction between the planner and those for whom he plans.

It is inevitable that transportation plans will raise controversy; some interest groups will always be hurt. Every effort must be made to confront clearly the social choices that are called for and to involve those affected in the decision-making process. The planning process may cost more and take longer as a result, but the final product is more likely to reflect the overall interests of the metropolitan area.

## INNOVATION, UNCERTAINTY, AND EXPERIMENTATION

If transportation is to continue to serve effectively the needs of urban residents, it must be alert to changing urban conditions and have the capacity to respond rapidly to the resulting changes in the nature of travel demand. Existing modes have shown themselves unable at times to cope with the multiple requirements of urban travelers. As cities and urban population continue to expand, traditional transportation systems will find themselves less and less capable of accommodating the increasingly dispersed patterns of movement in the suburbs and the growing concentration of trips in downtown areas, while maintaining levels of personal mobility, accessibility, service, and comfort that meet the expectations of modern urban dwellers.

Although a temporary solution may be obtained from incremental improvements and from a more efficient use of available facilities and technologies, entirely new transportation solutions may be required in the long run to satisfy urban travel needs and to save urban areas from total strangulation. A necessary condition for the emergence of such solutions is a vigorous and sustained level of technical innovation.

Unfortunately, quite the opposite has been the case to date; the level of innovation in urban transportation has been generally quite modest. The explanation for this poor performance can be found in a number of legal, financial, institutional, organizational, and planning constraints. Foremost among the obstacles to orderly innovation, however, has been the element of uncertainty and risk that surrounds the introduction of major changes in transportation systems.

Risk is always present when ushering in innovative ideas, but this is particularly true in the field of transportation. Massive resources will be required for research and development to carry new transportation systems from concepts to operational prototypes, to test them, to refine their design, and to produce working operational systems. As with any untried technology, there will be uncertainty about actual construction and operating costs and engineering performance. There will be uncertainties about the new systems' environmental side effects, their effects on property values, and their compatibility with existing transportation networks. Most importantly, there will be uncertainties about the degree of public acceptance, passenger response, and the resulting magnitude of the market for the new transportation service.

In the face of the large uncertainties and capital investment requirements, municipalities and transport companies have been hesitant to innovate because the risk of loss is high in relation to potential pay-offs and because failure of a new system or policy might involve political repercussions as well as loss of money. The financial and political risks, in fact, may be so unacceptable that transportation authorities will forego the introduction of major system changes unless they involve fully developed and tested technology. Private industry, however, in the absence of clearly identifiable markets for such technology, is not likely to risk its own capital to develop "off the shelf" operational systems.

To some degree, uncertainties can be reduced through the application of analysis. Thus, because of steady improvements in simulation methodology, the innovator is obtaining increasingly reliable estimates of the probable technical and economic performance of new systems. However, even the best models and predictive techniques cannot overcome all of the uncertainties associated with new technology, particularly the crucial uncertainties concerning response of the consumer and the resulting demand for the new service. The most effective and perhaps the only sure way to dispel these uncertainties—and hence to provide greater confidence in critical decisions—is to test the innovation in a real-world situation before beginning detailed design and construction of the full system.

Increasingly, the concept of large-scale experimentation is recognized by governments as a powerful device for reducing the risk of loss and for lessening the constraints that inhibit successful development and implementation of new systems of urban transportation. Until now the concept of the transportation demonstration has been associated principally with testing and evaluating new technology. Nothing in its nature, however, prevents the demonstration from being used as a vehicle for evaluating a variety of nontechnological innovations: improvements in service, in operating and promotional techniques, in design, in pricing policies and financing arrangements, and in organizations and institutions.

The art of design and conduct of transportation demonstrations is still in its infancy. A concerted effort should be made to refine the methodology so that the transportation demonstration can assume the role it rightfully deserves in the managerial decision-making process.

## ADAPTIVE PLANNING

Transportation planning takes place in a context of continuous evolution in demand, technology, people's preferences, and objectives. Because there are significant time lags in the implementation of transportation systems, the planner must build into his plan an opportunity to review and revise his strategy in order to accommodate the changing conditions.

In considering a comprehensive long-range transportation development plan for a metropolitan region, we can expect that even by the end of the first 5 years things will have changed. Demand patterns will have evolved as a result of urban growth; new technologies and new ways of using existing technologies will have been developed as a result of research and development efforts; behavioral research and data collection activities will have produced new insights into people's needs and wants, which in turn will have altered the planner's view of community goals and objectives. The conditions would no longer correspond to the planner's initial set of assumptions and, therefore, would call for a modified plan of action. If changes have been relatively minor, the actions to be implemented in the subsequent stages of the planning strategy may stay the same; more likely, however, the later stages of the plan will likewise have to be revised because of further changes in critical conditions.

The planning process described involves an iterative or sequential approach. The transportation plan is conceived as a sequence of staged actions; at the conclusion of each stage, the planning strategy is reviewed and possibly modified in the light of fresh data acquired through observation and appropriate demonstrations.

An even more general formulation is that of the "open-ended" planning process. Here the process is one of constant iteration and feedback, with the goals and objectives being redefined and modified as new alternatives and strategies are conceived. These are tested and compared against the background of advancing technology, changing human needs and habits, and evolving community aspirations and values. The result is a dynamic process of continuous assessment of future conditions and continuous search, evaluation, and refinement of alternative solutions.

## ALTERNATIVES AND INNOVATIONS

One major reason why urban transportation investment and management policies are not always fully effective is that the alternatives considered for analysis and evaluation are often severely and prematurely limited. This premature restriction of potential options arises from inadequacies in both the institutional setting within which urban transportation studies are conducted and the planning methodology that is used.

Most transportation studies are conducted within an institutional context that tends to emphasize a single mode and that almost invariably excludes serious consideration of truly innovative technologies or practices. Furthermore, present transportation planning models and procedures are designed to analyze a limited number of alternatives in great detail. The expense and time required to acquire the necessary data and to simulate large and complex networks often preclude evaluation of more than a few candidate systems.

To broaden the spectrum of transportation alternatives that can be analyzed and evaluated for potential implementation in urban communities, the following principles should be observed:

1. Transportation planning and investment studies should not be tied to any single mode but should be conducted within an institutional setting that encourages the comprehensive analysis of several modes.
2. The potential of various forms of transportation—pedestrian, automobile, transit, and multimodal systems—to provide a broader range of integrated services should be more systematically analyzed. Particular attention should be given to the interface among the several components of urban transportation systems and between urban and intercity systems.
3. A mixed strategy should be employed in which short-run improvements based on available technology and practices are instituted within a framework of more comprehensive and longer run programs that might include unconventional technology.

4. In view of the very rapid rate of technological and social change, preference should be given to improvements that can be introduced incrementally so as to avoid "locking in" the future with massive fixed investments.

5. Systems engineering studies that explore the potentials of new technologies should be made an integral part of the urban transportation planning process so as not to base transportation plans on or continue to encourage the adoption of outdated or obsolete technologies.

6. Transportation systems analysis techniques should be developed and adopted that allow for a rapid screening of a wide range of candidate systems in terms of both level of service and community impact. These overview techniques should not rely on massive accumulations of data but should serve to suggest the most effective directions for subsequent, more intensive data collection and analyses.

7. Research should be encouraged in formal design and search techniques, including systems optimization and mathematical programming models. Both community impact criteria and transportation service objectives should be made an explicit part of the model system.

8. Because land use is part of the system, any selection of alternatives should include those that vary land use arrangements as well as transportation facilities.

## EVALUATION OF TRANSPORT SYSTEM ALTERNATIVES

To make sound choices from among several transport system alternatives, a procedure must be employed to give the decision-maker information about the relative merits of each proposal in terms of the goals they are expected to fulfill. In the typical case where investments being considered are relatively small and the alternatives have much in common, the evaluation procedure is conceptually simple, and existing methodology is fully satisfactory.

Some of the major studies undertaken in recent years have attempted to extend this procedure by adding to the analysis other readily quantifiable measures of transportation system performance, such as travel time, accident incidence, and direct costs of travel incurred by the user. In some cases, the operating benefits associated with a proposed new policy have been converted to monetary equivalents and compared to the estimated capital cost in order to derive a percentage return on investment or a benefit-cost ratio.

Although this procedure can be illuminating if knowledgeably applied, the decision-maker should be made aware of the important considerations ignored in the analysis and of the tenuous assumptions employed. Arbitrary values of time are often used and distinctions are seldom made in this regard among different categories of travelers. Major systems costs such as traffic control, emergency services, and facility maintenance are often not included in the analysis, a practice that can be justified if alternatives considered are basically similar, but one that becomes a significant deficiency if multimodal alternatives are being considered or if the scale of alternative investments is very different. Many performance characteristics important to the user are not considered explicitly (e.g., security, privacy, reliability, and comfort), thus severely limiting the application of existing methodology to the comparison of alternatives employing different mixes of modes.

It is particularly important for the decision-maker to recognize that analysis techniques now in use do not take into consideration a broad range of important environmental impacts that fall on nonusers or on the community as a whole. Therefore, the rate of return or benefit-cost ratio associated with each proposal must be only one of several factors weighed by the decision-maker in the process of selection. Other factors to be considered include noise, pollution, aesthetic intrusion, land consumption, economic impact, social disruption, and relocation.

Analytical procedures can be modified to throw additional light on many of the system characteristics mentioned so as to assist the decision-maker in the comparison of alternatives. The nature of this analysis must be influenced by the political realities in each situation, so that those system impacts considered most important by the community will receive attention by the system designer and the analyst. For example, it should be possible in many instances to determine the degree to which target populations in a community—such as the young, the old, or the poor—would be affected by any proposed transportation investment.

In some cases it may be possible to simplify the comparison of alternatives by determining the cost to society of compensation for certain undesirable aspects of each transportation system. By utilizing the insight of social scientists, engineers, and analysts, we could introduce the cost of correction, abatement, or compensation as a bona fide system cost and adjust the rate of return calculation accordingly for each alternative. However, it should not be assumed that this process can in all cases be safely applied in a comprehensive manner to convert all system characteristics and impacts to a monetary equivalent. Such an effort, leading to the creation of a single performance index for each transportation alternative, probably is an impossible goal for the analyst and could pose a danger for the decision-maker by obscuring critical assumptions.

Existing methodology has an important role in evaluation of transport plans in spite of obvious weaknesses and shortcomings. However, the decision-maker must understand the limitations of what the analyst has to offer and recognize the critical gaps in analysis that must be compensated for by astute, politically informed judgment.

## THE SYSTEM OF MODELS USED FOR ANALYSIS

A repertory of models has been developed for use in analyzing alternative transportation systems. This system of models has been utilized by many urban transportation studies. The development of this system represents a major achievement in placing transportation analysis on more rational grounds. However, the system suffers from the following significant limitations:

1. In theory, analysis of transportation systems should predict the flows in the networks by finding equilibrium between supply and demand. In practice, the existing system of models makes a number of simplifications, resulting in a segmented series of computations with internal inconsistencies.
2. There may be certain biases introduced by the simplifications that have hitherto been found necessary. For example, the technique called "all-or-nothing assignment without capacity restraint" may significantly overestimate the demand for private automobile transport, as also may the assumption that the total number of trips originating in a zone is independent of the level of congestion in the network.
3. No wholly satisfactory system of models exists that (a) analyzes multimodal systems (particularly with new technologies); (b) tests a wide range of operating, financing, and pricing policies as well as network alternatives; (c) takes into account the influence on consumer choice of transportation mode and route attributes other than total trip time and cost (such as reliability, number of transfers, privacy, flexibility, and other difficult-to-measure aspects of quality of service); or (d) considers explicitly alternative time sequences of investment and uncertainty.
4. Many significant nonuser impacts are difficult to predict and are not included effectively in present model systems (e. g., the effects of relocation of residents and businesses and air and noise pollution). Prediction of land use changes arising from alternative transport systems, although the subject of some study, is highly uncertain, partly because of the lack of detailed land use data at several different time periods. As urban development decisions become concentrated in fewer hands, the use of urban development models as a tool of prediction may become even more open to doubt.
5. The system of models and the whole process in which the models are developed, tested, and used in a particular metropolitan area may be out of proportion. It is important to achieve a basic level of planning capacity through initial data collection and model construction efforts. However, achievement of this capability is only the first step, not the final target; the data and models must be used to analyze a wide range of alternatives. Sufficient time and resources must be budgeted to allow this analysis after data collection and model construction. The present system of models may be more detailed and thus more expensive and difficult to use than necessary; the degree of precision in the numbers produced may be more than is justified by the underlying population, employment, and trip-making behavior assumptions. Many more alterna-

tive systems and policies should be analyzed than most present studies have been able to do. This may require development of new model systems that are less detailed, easier to use, and more relevant to the issues to be studied.

6. There is a strong concern about behavioral changes over time and their effect on the accuracy of long-term forecasts and forecasts of consumer response to new types of systems and services not previously experienced. The present model systems generally forecast travel patterns based on simple extrapolations of present trip-making behavior. What is required is a more behavior-oriented approach to demand modeling and a change in emphasis in data collection. For example, there should be continuing collection and analysis of demand data with a more varied mix of survey approaches. In addition to the typical cross section studies (such as an origin-destination survey), there should also be periodic selective sampling of particular market segments and travel groups (e.g., airport-user and transit-rider surveys), consumer panels, and a variety of other means of continuously observing and sampling the travel market.

Thus, the system of urban transportation models developed to date should be seen as a starting point for further work, and not accepted without questioning. Building on this base, second-generation analysis models must be progressively developed that are more appropriate for the problems facing OECD member countries.

# Change and Equilibrium in the Urban System

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•A SYSTEMS VIEW of urban problems should be much more than a catalog of interactions or a platform from which to launch highly specific proposals for action or research. Systems considerations as such are of little more than trivial interest if they do not provide major insights into problems through some general theoretic concepts. These theoretic concepts should have the property of sustaining new deductive conclusions.

I propose to discuss two or three concepts having to do with urban modeling and, more particularly, having to do with the relationships between various urban policies and the goals of urban development in the context of system equilibrium. The principal topics that are discussed have to do with problems of form (or morphology), problems of change, and problems of measurement.

Before taking up these topics, let me comment briefly on my view of the city as a system. We know, naturally, that nearly every system is a subsystem or an element in some larger system, and frequently the degree of interaction with the external environment is so strong that the independent study of it is fruitless. Sometimes we have to distinguish different aspects of this central problem. For example, man is a self-contained biological system in many respects and can be studied as such. But it is almost useless to study a man as a social system, even though he is a major element in any such system. Similarly, it may be argued that cities are far from independent of the national and world economies, that their import-export relationships are powerful and even dominating, and that, therefore, the economic life of the city is too open usefully to be considered as a system. I would agree that this is the case regarding culture, technology, economic function, and national politics. On the other hand, as a labor market area, a pattern of settlement, a dense concentration of land development, and a site for daily social interaction, the metropolitan area functions as a coherent and identifiable system. From this point of view, the other considerations become a part of the long-term development that impinges on, but is to a considerable extent independent of, the metropolis as a system. This paper should indicate that I regard this second aspect of urban affairs as deserving systems study.

## FORM OF METROPOLITAN AREAS

In discussing the form of metropolitan areas, I refer to the patterned distribution in three-dimensional Euclidean space in a metropolitan area of artifacts, people, and their attributes. Form is not necessarily plainly visible because, for example, the relative distribution of occupational groups or religious groups might be a significant element of form but would not be immediately obvious to the observer. Form also includes in a sense flows and interactions, because these are attributes both of people who occupy an urban area and of their artifacts.

Urban form in its most general sense is an important object of policy manipulation; it implicitly controls many of the aspects of the quality of life that people appreciate (positively or negatively). The cost, location, and quality of housing, the amounts of private and public open space, the length of the journey to work, the social environment, pollution or its absence, and public safety are all aspects of urban form that affect people's lives and that are more or less subject to public control. It is therefore

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important to know, among other things, how form is determined, so that the cost-effectiveness of public policies can be improved. This needed knowledge implies some understanding of the urban system.

There are essentially two complementary ways of looking at the genesis of urban form, static and dynamic. It is tempting and indeed useful to note the similarities among a wide variety of cities and to speculate that these similar forms represent the conclusion of an equilibrating process, an end state toward which, under present circumstances, many large urban conglomerations converge. If this were correct, the problem of emerging tendencies in urban form could be studied as a problem in general equilibrium, and this is a view to which I tend to subscribe.

This view is frequently counterposed to the picture of the metropolis as an evolving organism, in which the processes of change are more important than the states that exist at any particular time. In addition, it is suggested that the dynamic moving forces that motivate this process of change are so strong, so persistent, and themselves so changeable that the system never can achieve equilibrium. I agree that this view is true in its most literal sense, but I am inclined to believe that, in spite of external shocks and stimuli, any particular exemplar of the urban system is always tending toward equilibrium. With a proper definition of that equilibrium and with a proper understanding of lags, we can use the equilibrating tendencies to explain much of the dynamic picture.

These two views of urban equilibrium play complementary roles in the evaluation of policy. In the theory of general equilibrium in economics, equilibrium is frequently identified with optimality, and probably we should examine the extent to which this is true of spatial equilibrium. The opposite proposition also has considerable merit—that a study of the dynamic properties of systems operating over time will illuminate their anticipated behavior under a variety of policy assumptions. The static view neglects the path by which some desired equilibrium might be achieved, whereas the dynamic view tends to neglect ultimate objectives and to focus principally on the immediate implications of policies. The dynamic view also turns out to be a very clumsy way of testing paths of arriving at desirable configurations.

A certain note of caution must be struck regarding the optimality implications of competitive spatial equilibria. The Hotelling problem regarding the location of two hot dog vendors on a beach is the simplest possible example of a general and pervasive spatial problem. Competition leads the two vendors to locate side by side at the center of the beach, even though social welfare would dictate their being located one-fourth of the way from each end, where they would equally divide the market. This example indicates that globally optimal solutions are not necessarily reached by "natural growth processes" as replicated in models, especially when there are indivisible units and spatial monopolies.

## SPATIAL DISTRIBUTION MODELS

There are two very broad classes of urban models of spatial distribution. One class provides an equilibrium description of urban distributions in the static sense without arriving at this conclusion by way of an examination of the equilibrating process. Three examples of this type of model might be mentioned with varying degrees of explicitness in their definition of equilibrium. First, Lowry (1) defines an equilibrium distribution of population and service activities for Pittsburgh based on the transportation systems, travel patterns, and location of export or "basic" industry. The equilibrium implications of this model are difficult to determine, but they reflect some stability in travel patterns. A second group of equilibrium models belongs to a class of gravity models used in the location of retail trade. These models if applied to a uniform distribution of purchasing power and a uniform class of commodities will, like central place theory, arrive at a distribution of equal-sized market areas. It can also be shown that this type of model tends, in a somewhat indirect way, to minimize total travel time for shopping subject to certain constraints and to a stochastic distribution of shopping trip lengths. The equilibrium that exists is quite explicitly between spatially located supply and demand, and if an equilibrium were disturbed, it is implied that some centers would be more prosperous than others. Finally, we may mention the Herbert-Stevens model (5) of residential location, which is based on the Alonso theory of the land market and which uses linear programming to achieve a Pareto optimum that is also a behavioral, competitive, market-clearing solution and therefore a form of equilibrium.

The second case of static equilibrium has a certain number of interesting properties. It connects ideas about the statistical behavior of users of a transportation system with ideas about the equilibrium of land use and location. At the same time, it may seem to produce an optimal situation from the point of view of the users. But it turns out that the equilibrium and the optimum are not exactly the same thing. This finding suggests that spatial behavioral models with equilibrium-seeking properties may not possess all of the same optimality properties that nonspatial economic models have.

The model in view here is one of the location of retail trade that has been extensively discussed in earlier literature by Berry, Garrison, Huff, Carroll, and others. Recently somewhat similar ideas have been applied without any equilibrium properties by Lowry (1), and the equilibrium model was developed simultaneously by Lakshmanan and Hansen (2) and by me. Because the Lakshmanan and Hansen model is simpler and more directly related to the problem that I wish to discuss, I will use that rather than my own model. All of the models mentioned produce results that are very similar to the results of central place theory. Each marketplace is surrounded by an area of market dominance, and the areas of market dominance exhaust a plane. Unlike central place theory, however, these models, which are based on gravity models of trip interaction, admit of overlapping trade areas, and if the trade centers are of unequal size, the boundaries between their areas of dominance are neither straight nor equidistant between the centers.

The model developed by Lakshmanan and Hansen assumes that we are dealing only with a uniform type of subregional shopping centers with floor areas in the vicinity of 500,000 sq ft. Repeated applications of the model yield estimates of the number of tripmakers who will be attracted by each center as it competes with other centers. (Hypothetical center locations are an input to the model.) If the purchasing power of a center exceeds some predetermined average (say, $55 per sq ft), then the center is expanded on the next iteration. Centers that become too small are dropped out, and centers that become too large may be split in two if hypothetical sites are available. The outcome of this process is a form of equilibrium in which nearly all centers have an equal level of sales per square foot of floor area.

Lakshmanan and Hansen found, as a by-product of their procedures, that the pattern of centers produced by this process also appeared to involve the minimum total miles of travel for the users of shopping centers. If this observation were absolutely correct, it would provide a useful consequence of the equilibrium aspects of the model. However, it may readily be seen that the equilibrium postulated in the model is primarily a producer's equilibrium. Sales at less than $55 per sq ft are uneconomic and cause some firms to go out of business, whereas sales at over $55 per sq ft on the average are excessively profitable and cause new firms to enter any particular center, thereby expanding its floor area and attractive power. There is a large element of consumers' or users' preferences involved in these equilibria in that, owing to the convenience aspects of shopping as reflected in the gravity model of trip-making, it is impossible for all shopping to become concentrated in one center, and the distribution of centers becomes fairly even. This evenness produces the apparent optimality from the point of view of the user, but it must be stressed that there is no guarantee of such user optimality built into the model.

A simple way of viewing the paradoxical nature of this model may now be presented. The following three assertions have been made:

1. Purchasers or consumers tend to behave as in a gravity model for any particular class of trips, e.g., food shopping.
2. Producers achieve a spatial equilibrium by adjusting the size of their activity to serve just precisely the level of activity that it will attract.
3. This arrangement represents a minimum travel cost scheme from the point of view of the consumer.

It is not difficult to show that only in very restricted circumstances can all three of these assumptions be true. Consider the layout of market areas along a radial axis with a declining density gradient. It is apparent that if two centers are of equal size they will not have equal radii of service under the second assumption that the size of the center adjusts to the available market. If, on the other hand, they have equal radii of dominance, they will have unequal total markets and therefore be of unequal size. We must note, however, that under the gravity model formulation of trip distribution a market area boundary, defined as a line of equal probability, will be equidistant from two centers only if these centers are equal in size, inasmuch as the interaction probabilities are generally proportional to the size of centers at equal distances. Finally, to a good approximation, it is evident that equal radii of market areas are necessary and sufficient for consumer travel times to be at a minimum. If, as a consequence of unequal sizes of centers, market boundaries are shifted toward one or another center, a substantial proportion of consumers will make trips longer than those to the nearest center. This contradicts the hypothesis of consumer optimality.

With this line of reasoning, we are usually constrained to give up at least one of our three original hypotheses. There is, however, one condition that seems to permit us in part to escape this trilemma. We can assume that centers are of equal size, but unequally spaced. At the same time, the lines of equal influence are perpendicular bisectors of lines joining the centers. Thus centers will have radii of influence that are shorter on the "up-hill" side of the density gradient and will not be located in the center of their service areas. This seems to be the usual pattern of shopping center location, and Lakshmanan and Hansen seem to have been fortunate in their selection of potential sites, making it possible to arrive at a configuration that would approximately satisfy this set of conditions.

This solution, however, still contains a residual paradox. In the postulated configuration, the shopping centers are not necessarily at the centroids of their service areas. Within any one area, if a center could relocate and retain its customer allegiance, it could reduce total travel cost. But some customers would be disadvantaged in their choices of centers, and their consequent shift of allegiance would result in a change in center sizes. The equal size condition could no longer be maintained.

The model therefore permits all three assumptions to hold only on an isotropic, equal-density configuration. It thus seems that this example raises serious questions about the rationality and reality of the gravity model of trip-making, or of this family of retail trade models, or of the assumptions of optimality implicit in the equilibrium model. This line of inquiry is thus a powerful means for exploring certain aspects of models.

## DYNAMIC MODELS

A broad class of dynamic models that have equilibrium and final state implications is becoming very popular in metropolitan planning circles; it goes under the general name of urban or regional growth models. The general form of such models is a system of differential or difference equations, not necessarily linear and sometimes quite large.

A recent publication by Forrester (3) makes quite clear the structure of a system of simultaneous differential equations applied to urban phenomena. These systems of equations have the properties of embodying many feedback loops, of possibly providing contra-intuitive results, and of producing projections that for any particular phenomenon are not necessarily monotonically increasing or decreasing. All of these features have some considerable attraction in that they correspond with our intuitive views of the real world. Nevertheless, Forrester's presentation has a number of difficulties, most particularly in the nature of the assumptions regarding interregional change and the lack of detail regarding intra-urban distributions. Forrester also suggests that his ideas in their application to cities are novel, although this is clearly not the case.

At least three major modeling efforts have been made in which an interacting set of models, used recursively in steps of 5 years or less, provides a much larger and richer mix of feedbacks than appear in the Forrester system. The argument is not essentially changed by the fact that these models are all based on difference equations rather than differential equations and that their results are cruder, but computationally more convenient. Models of this type include the EMPIRIC model for Boston (which had a short-lived companion in the differential equation formulation, POLIMETRIC), the Penn-Jersey Transportation Study model package, and the Time-Oriented Metropolitan Model developed by Crecine (4) for the Pittsburgh community renewal project and later further expanded. We might also include the Dyckman-Robinson model for the San Francisco community renewal project.

There is thus no shortage of relevant dynamic models, but very little attention has been paid to their properties. I now propose to explore some of these by illustrating a number of points. First, I will look at the connection between equilibrium and dynamic models, and I will suggest that these ideas immediately provide another powerful means of examining both policy issues and the construction of the models themselves. Second, I will develop in brief a particularly simple model of urban location patterns and examine the properties of its equilibrium solutions in slightly more detail. Finally, I will look at a group of statistical problems that arise in connection with these ideas and, indeed, in connection with a great deal of urban research.

## Relationship Between Equilibrium and Dynamic Models

The role of feedback and dynamic performance of systems in relation to homeostasis and equilibrium is complex, subtle, and not understood in sufficient detail. For example, the models that I will discuss have linear feedback loops. If these loops were nonlinear or discontinuous, it is probable that in many cases the equilibrium tendencies of any particular system so described would depend on the initial state of the system as well as on its structural characteristics. Such dependency is common in biological systems and must exist in some social situations—indeed, quite commonly at least in any situation that has to do with matters of life and death. I will, however, investigate only linear and generally continuous systems.

Positive and negative feedback are of course distinctively different in their influence on dynamic systems. Positive feedback implies positive and self-reinforcing experiences and, consequently, leads to growth and to extended exploitation of the environment. Negative feedback, on the other hand, leads to decline or to equilibrium-seeking performance. It is important to realize that positive feedback and exponential growth cannot continue to operate indefinitely. Systems possessing this characteristic ordinarily encounter one of two modes of change that limit the growth. The ordinary or "liberal" solution results from a shift in relationships either internal to the organism or between the organism and the environment such that positive feedback is converted into negative feedback. Typically this happens when expansion is limited by the increasing cost of resources, or when the agglomeration economies begin to be offset by the diseconomies that result from congestion or pollution. The "radical" or less automatic solution arises when basic changes resulting from the growth of the system create conflicts or problems that necessitate new laws and new institutions. In the first case, the growing system reacts to changed circumstances. In the second case, either the system or the larger system in which it is embedded adapt by change of form. In society these changes of form are changes in institutions, laws, and social relations.

## Models of Urban Location Patterns

As a consequence of this distinction between positive and negative feedback, we can logically and practically ask two questions about models of urban systems: Do they generate any unlimited tendencies and do these tendencies in fact correspond to those that can be observed in the real world? Unlimited growth, decline, concentration, or dispersion would in general seem to be contrary to our intuitive view of urban arrangements, but, were they realistic, they could in any case be expected to create various types of severe institutional stress. Systems that behave in this way have no equilibrium or homeostatic tendencies except when they have reached boundary conditions such as the concentration of national population in a single or very large city, ultrahigh urban densities or uniform densities, or giant corporate monopolies. If an exploration of a model leads to the conclusion that it does not imply any normal equilibrium, it will be a matter of considerable delicacy to decide whether the abnormality lies in the construction of the model or in the true behavior of the system.

It seems much more likely that for well-constructed models a set of equilibrium solutions will be available for most inputs of policies and environmental conditions. Such an equilibrium is, for example, displayed by the long-term solutions of the Forrester models of urban dynamics (3). More generally, various types of equilibrium probably exist corresponding to no change (or a steady-state turnover of individuals, households, or firms), or to variously defined conditions of equiproportional growth. As I have suggested, in the case of linear models these equilibria are probably independent of starting conditions and rates of initial growth, but in the event that there are long lags such as may be identified with respect to the redevelopment and redeployment of the urban capital investment, the ultimate equilibrium might take a long while to achieve in any realistic growth situation.

Evolution and Equilibrium

When we explore the possible equilibrium positions of urban systems implied by dynamic models, we must take account of the many aspects of the relationship between equilibrium and dynamic performance. Not only do actual physical investments tend to persist over long periods of time, but agglomeration economies, once established, may long outlast their original impetus. Thus, for example, urban financial centers are typically located near the original port centers of major cities, even though these may no longer be in the central business district. Given this resistance to change, it is my view that cities probably tend toward their equilibrium position. This, however, may be constantly changing as a result of external impulses, and thus the homeostatic mechanism is aiming at a moving target. Tendencies that affect the rate of movement of the target are most particularly the rates of growth of metropolitan regions, the rates of change of economic function, the rates of increase or decrease of personal income, and the rates of change of technology—particularly in building, transportation, and communication.

It is attractive to consider that the manifest form in which cities are cast is a joint product of the evolutionary tendencies and their underlying equilibrium tendencies. Such a view might at the same time accommodate an explanation both of the convergent similarities of cities and of certain specific and evident differences. It is also attractive to compare this process, if it exists, with processes of biological morphogenesis and evolution. These comparisons are perhaps more dangerous than helpful, especially as long as our knowledge of both biological and metropolitan morphogenesis is so qualitative and so inadequately explored.

Aside from long-term speculations in the philosophy of science, the relationships that we have sketched between equilibrium and dynamics suggest that at any particular point in time the equilibrium that could be achieved for given environmental conditions, existing sunk capital, and policy determinations might tend to represent some sort of optimal arrangement. Actual anticipated development that takes into account short-run decisions that will result in capital investment and therefore foreclose some aspects of the long-term equilibrium would then be by definition less than optimal. In making use of this hypothesis we must constantly bear in mind the qualifications developed earlier regarding the possible mismatch between equilibrium and optimality. We must also recognize that avoiding currently attractive decisions that in the long run are less than optimal will usually impose costs on either government, investors, or users. Given all these qualifications, the equilibrium condition for dynamic systems may be extremely useful for the exploration of ideal future states and the policies that are related to their attainment.

## EMPIRIC MODEL

To give this statement some realistic content, I should like to discuss briefly a modified version of the EMPIRIC model, originally developed by Donald Hill and his associates (6) for application in the Boston region. This model, as mentioned, is a multiple-equation, multiple-variable difference equation model that will be considered here in a modified form for simplicity of discussion. The dependent variable in the EMPIRIC model is a large set of area-specific and locator-specific rates of change—actually deviations from regional rates of change. The right-hand variable in these equations falls into four classes. First, the changes in all other locator quantities in a given area are assumed to affect the rates of change on the left. For example, if during a given period the volume of manufacturing in an area increases greatly, the rate of increase of residential location will be depressed. This formulation is necessary for a difference equation formulation, especially one with a time interval as long as 10 years, but because it is not relevant to a differential equation formulation, we omit it from further discussion. The second class of variables defines the density of each locator variable in each area. In most cases it is anticipated that high densities discourage additional location. In the original EMPIRIC model these densities appear in a concealed form in relation to zoning policy variables, but we will consider them explicitly. The third class of variables has to do with accessibility, a constructed variable that, in this case, is calculated by weighting the locator volumes in all other areas by a declining function of time-distance from the area under consideration. Although the distance functions are nonlinear, the weighting process is linear and the locators in various areas enter into the calculation in a linear way. Ordinarily, except possibly for conflicting land uses, the signs of the coefficients of accessibility are positive, thus differing from density. The fourth and final group of variables has to do with neighborhood qualities. These in principle may be both variables that are exogenous to the planning process—such as those having to do with slope, elevation, microclimate, and the like—and control variables such as water and sewer service and many other planned neighborhood characteristics.

Given this general description of the model, if we have N areas and M locators, we have MN equations for MN locators. Owing to the construction of the accessibility variables, all of the variables appear in all of the equations, or everything influences everything else, and there are MN feedback relationships involving all the variables. There are of course many less than $(MN)^2$ basic parameters in the model, because of the manner in which the accessibilities are calculated. Here the network conditions, which are themselves policy variables, generate a large number of coefficients. In general, each equation will contain some positive and some negative coefficients so that, for a properly selected vector of locator groups of length MN (with all elements positive), it may be possible to force all rates of change to zero. There are in fact two different cases under which this might occur. If the left-hand side of this MN equation is set to zero, we have on the right-hand side a set of terms involving the locator groups and a set of terms involving neighborhood conditions. The dual problems are as follows:

1. Given a certain set of neighborhood conditions, what would be the equilibrium distribution of locators?
2. Given a desired distribution of locators, what would be the necessary configuration of neighborhood conditions?

In both of these cases, certain mathematical difficulties arise.

Equilibrium Distribution of Locators

In the first case, there is almost certain to be a unique solution. Not only is the number of unknowns equal to the number of equations, but the combined neighborhood conditions provide a nonzero vector of constants. It seems unlikely on somewhat cursory examination that the (very large) matrix of coefficients applying to the locators would be singular. Such singularity could arise, however, in a case where the behavior of a locator is exactly similar to the behavior of any other locator (that is, where its coefficients are proportional to another locator), or indeed if any locator's coefficients can be defined as a linear combination of any other locators. From a certain point of view this might be taken as reason for reducing the number of locators to be considered. From a different point of view, however, it makes considerable sense to say, for example, that banking is indeed 50 percent retail trade and 50 percent business services and to analyze its behavior accordingly. This may be so even if it does not make very much sense to use the algebraically equivalent statement that business services are equivalent to banking doubled less retail trade.

These problems, though somewhat novel, are a perfectly legitimate field of inquiry in locational models, and they suggest that other methods for dealing with this type of problem need to be explored. It is obvious, for instance, that for iterated solutions such as have actually been used for the EMPIRIC model and by Forrester the singularity of a coefficient's matrix may not create the same type of difficulty.

Another problem that may arise in this first case is that certain constraints on the solution have not so far been built into our formulation of the problem. The first of these constraints is that none of the values of the locator groups shall be negative. The second is that the total volume of each locator must exactly match some predetermined or input value of population or business that has to be accommodated. The second problem can be converted into the first by eliminating M equations and M variables—for instance, replacing the Nth subarea variable for each locator by the predetermined total less the sum over all other areas. This calculated quantity itself cannot be negative. The existence of negative locator values in such a solution would indicate that the system described has no equilibrium, because if the negative values are replaced by zeros, various rates of change will be nonzero.

Necessary Configuration of Neighborhood Conditions

The second case in this dual problem has to do with the circumstance when we have projected a possible pattern of equilibrium of locators and wish to know what public policies could bring this equilibrium about. We will not discuss the subcase of the influence of transportation networks via accessibility on the equilibrium, because this leads into the solution of a problem that involves not only nonlinear functions, but also the combination of links into least-cost paths in a network. Given a network configuration, however, it seems practical to ask what levels of other government services are necessary to ensure a certain pattern of development, short of direct controls. Where such controls are everywhere binding, the notion of equilibrium is no longer applicable. The mixed case where some controls are binding and others are not is most vexatious, not only as applied to solution methods, but also with respect to the observation of "natural" locational tendencies.

The first thing to be observed is that there are apt to be many more locator variables (and hence equations) than policy variables influencing location. This will always be the case if there are more types of locators than there are policy variables. Thus, the equation system for determining what policies are necessary may be overdetermined. There are two general ways out of this dilemma. One of these is to make a least-squares fit of policies to the desired configuration. In this case, the RMS error could be interpreted as a measure of the lack of realism in the policy. The second means of dealing with the problem is to reduce the number of equations by combining locators. This could be done along the lines discussed earlier or by any other reasonable procedure based on past locational behavior.

No matter which method is followed in solving this dual problem, the same difficulty regarding potential negative (or, more generally, unrealistic) policy values will probably be observed. In this case, the implicit advantages of an iterative scheme are not available, and it is necessary to conclude that the desired configuration cannot be achieved by way of influencing the behavior of the locators, but only by outright regulation. It seems likely that such regulation of locators implies some departure not only from equilibrium, but also from optimality. In other words, the imposition of a preconceived pattern of location may satisfy certain planners' goals, but does not necessarily best serve the interests of the locators.

## STATISTICAL IMPLICATIONS OF EQUILIBRIUM MODELS

My last major point in this discussion has to do with certain statistical implications of equilibrium models. In dealing with spatial location and perhaps even more with dynamic spatial processes, we often find that statistical problems are gravely complicated by aspects of multi-collinearity. Statisticians sometimes argue that this problem should be avoided by reducing the number of variables, because it is "quite evident" that some of these variables must measure the same thing. This approach suggests the desirability of step-wise regression methods among others, but in my view is not entirely satisfactory. It seems to me that the preceding discussion leads directly to some conclusions that are at variance with this interpretation of multi-collinearity.

First, to clarify the situation somewhat, we must refer to the earlier discussion of the uniqueness and linear independence of locational behavior. If, in fact, some locational behaviors can be represented as linear combinations of other locational behaviors, and if the system is approaching equilibrium, then the corresponding consequent locational patterns may be linear combinations of other locational patterns. Because the locational patterns enter uniformly into the variables of density and accessibility that make up many of the independent variables of this model, these variables will in turn be linearly dependent and the correlation problem is in principle not soluble. There may be some difficulty in identifying this case separately from the more difficult and more important case that follows. A simple way to deal with it, however, would be to component-analyze the locational patterns of all the locators over all areas. The locators themselves could then be replaced in the model by a set of component scores that would ordinarily be less than the number of locators. We have used this type of analysis to reduce the dimensionality of measures of accessibility, without sacrificing any of the information provided by taking a rich and detailed view of this set of variables.

The second and more serious difficulty arises out of equilibrium considerations. Even assuming that each locator entering into the model is truly independent, a correlation analysis might still break down. Consider the circumstances that arise when an urban system has either reached equilibrium or has approached it and is "tracking" equilibrium in a relatively uniform way. In this case, for each locator the rates of growth for areas on the left side of the difference equations are zero or uniform. In a regression analysis to determine the coefficients of these equations, the vector of correlations between the dependent and independent variables is zero. In this case, the equation for the coefficients yields only a trivial solution if the matrix of correlation coefficients for the independent variables is nonsingular. We may justifiably generalize this situation slightly by saying that the closer an urban system approaches equilibrium, the more likely it is that any analysis of the rates of change will create a singular correlation matrix.

We may put the same problem in more intuitively attractive terms. The model we have outlined depends on the interaction of factors that attract and repel the locators, e.g., accessibility and density. For any particular size of city and location within it, there is some appropriate balance between these, indicating that their weighted algebraic sum is zero. (This discussion, of course, assumes a linear model.) If this condition is satisfied everywhere, the system is in equilibrium and has no impetus to change, yet this condition of a zero weighted sum of two or more vectors is precisely the condition for linear dependence in a set of variables. In practice in correlation analysis, we observe this phenomenon in the form of a very small determinant of the correlation matrix, followed by high and "unreliable" B values. Alternatively, if we correlate the dependent variable with component scores for the independent variables, we find that components with very small eigenvalues play a very large role in the analysis.

It is quite evident in this situation that throwing out variables is not the appropriate solution, although I hasten to add that the exact selection of appropriate methods is not altogether clear to me. However, it is clear that throwing out one of two highly correlated variables may be a disaster if in fact some phenomenon of locational change is closely related, for example, to their difference. Because density and accessibility (as illustrative variables) obviously measure quite different phenomena, the original assumption of overlapping concepts and variables is no longer applicable. In other words, equilibrium provides an alternative explanation for collinearity.

From the preceding discussion it is quite evident that the stronger the equilibrating forces and the more responsive the system is to them, the less confidence statistical measures would give to the coefficients describing growth relationships. For example, if I observed an SMSA in which accessibility and density were very highly correlated, I would take this as a confirming instance of my basic view of urban dynamics; yet if I used these variables in a correlation analysis of change in the same urban area, statistics would tell me that the influence of these variables is measured in a highly unreliable way. I must say that I cannot accede to this view, and I think that the problem of sorting things out is up to the statisticians. It is important because it is closely related to the predictive power of models.

## SUMMARY

In this brief case I have tried to develop in an illustrative way a cluster of ideas about how the relationships between dynamics, equilibrium, and optimality could be used to explore more fully our understanding of models and of urban phenomena. I think that the ideas presented are perhaps somewhat naive and oversimplified, but I am confident that further exploration in greater depth would be more rewarding. I trust that these explorations will be widely undertaken.

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# Model Systems for Urban Transportation Planning: Where Do We Go From Here?

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•URBAN TRANSPORTATION PLANNING seems to be approaching some kind of maturity. The concept of planning transportation using computer models, introduced in the mid-1950s, is now well established. The procedures for carrying out these studies are technically advanced with support from thousands of scientific and engineering references giving the mathematical derivation, the empirical testing, the use, and the limitations of these models. The procedures are carefully documented and established by law. Cities of over 50,000 population must base their requests for federal highway funds on comprehensive plans established using these general techniques. Manuals detail the step-by-step procedures to be followed (1). From a financial point of view the urban transportation planning process is comparatively well endowed, with funds provided from the Highway Trust Fund. Initial planning reports from most urban areas were completed in the middle to late 1960s and the fairly large staffs that most of the transportation studies had at the outset have now been trimmed to more modest sizes. There is, however, a general recognition that the studies must be continuing in nature if the transportation problems of the cities are to be solved and the necessary funding is to be provided.

However, all is not well with urban transportation planning. The freeway plans for many cities are running into severe opposition. At a time when the public's attention is being increasingly directed to the problems of the city and when public funding for the massive urban transportation expenditures needed could potentially be at hand, the planning establishment and its plans have been largely written off by the public as a failure.

Although the wisdom of past planning attempts has yet to be vindicated and is not likely to extricate us from our problems in any event, this is a good time to pause, to reflect on the planning models and procedures that have been used, and to ask the questions: Where do we go from here? Are the models adequate? Should they be larger, more elaborate, and more richly financed? Should we drop them as being ineffective or study them to improve their effectiveness? Does the planning process need attention? This paper will necessarily examine these questions from my point of view, which is that of an academic with an interest in transportation planning and its application. However, I have had the good fortune to be a part of the study team on two large-scale applications of transportation system modeling at the regional scale, the Harvard Transport Research Program study of Colombia (2) and the Department of Transportation Northeast Corridor Project (3), as well as more typical experience in modeling traffic problems in a number of urban areas. I intend to call on these experiences for illustration where appropriate.

As I survey the urban transportation planning efforts of the past and those currently under way, I see a number of hidden assumptions that appear to underlie the entire planning process and about which I have some doubts. I would like to elaborate on five of these underlying assumptions and their implications for the validity of models and their results. Although I would argue that these assumptions have deleterious consequences that lie at the heart of our problem, there are those who would disagree with

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me on some, if not all, of the points. In return for allowing me to be critical, I hope to justify my negative outlook by advancing what I consider to be better approaches and more attainable goals.

The five hidden assumptions are as follows:

1. The purpose of the planning process is the selection of a design for the urban transportation system that supports the land use anticipated for the design year.
2. Land use is not affected by the location of transportation facilities or, at least, it can be assumed so for the purpose of building transportation planning models.
3. In evaluating alternative transport system designs the desirability of a particular system can be determined by comparing flows on alternative designs and analyzing the net costs and benefits of the systems.
4. System simulation results must be used to help size facility design ramps and plan traffic control installations, inasmuch as they are the best figures we have. System dynamics can be ignored in the planning process because they affect the design of the facilities relatively little.
5. Citizen participation is extremely difficult to incorporate into the technical aspects of transportation planning. The best that can be done is to give lip service to broadly participatory planning but avoid it wherever possible.

Obviously, there will be some who will disagree with my choice of these five premises and charges by others that the accusations are unjust. I must therefore elaborate on each in order to make my point.

## THE PLANNING PROCESS

The first assumption states that the urban transportation planning process is a design process whose purpose is the selection of a single recommended system from among those systems investigated. Problems arise here with the initial statement of goals. Goals may vary from case to case, but a frequent goal of the transportation planning process is the selection of that network plan that supports the land uses anticipated for the design year.

The difficulty arises in conjunction with the concept of a design year. Designing urban transportation systems is a complex job that must be simplified to be accomplished. One of the easiest methods of simplifying is to select a target year and then aim for it. The finiteness of the planning budget, the slow speed of computers, and our inability to program them has led us to this use of the design year concept. Because there are so many possible futures, it is very comforting to be able to select one design goal as that utopia to which we aspire. The concept of a design year is well established not only in urban transportation planning but also in engineering, city planning, and government policy-making.

The question that immediately arises is how the land use will be determined for the design year. Because land use has a lot to do with trip origins and destinations, it is obviously important to transportation planning. In Manhattan, for example, 700,000 trip destinations per square mile are possible (4). In other urban areas trips may be attracted at a rate of less than one-half trip per acre. Because land use is so important to transportation planning, obtaining a statement of the land use for the design year is imperative. Some possibilities for obtaining this land use statement are as follows:

1. If you believe that land use can in fact be effectively controlled, then decide what the land use should be and state this as a goal to be achieved. The final statement will appear in the form of a land use plan.
2. If you view land use as the aggregated decision of many individual decision-makers and beyond the control of any single planning authority, then the land use for the target year should be predicted.
3. Some combination of these two may be adopted.

Obviously, the third point of view is more correct than either of the other two, because all land use plans will contain some elements of central control and will typically involve some decisions by others that are beyond central control. In an urban society like ours, current land use is probably best viewed as a manifestation of past policies rather than as the product of some plan. The control variables, therefore, are the policies pursued by government, not the statement of land use (Fig. 1).

The frequent ploy of transportation planners is to abdicate the responsibility for this land use plan for the design year as being outside of their authority. Frequently the plan is furnished by another agency or authority. Another approach commonly found in practice is to embrace several alternative land use plans and to design transportation systems to support each. The assumption, which underlies the use of a design year in the case of either a predicted or a projected land use plan, is that we can move from the land use we have now to that anticipated for the design year, and the major question to be resolved by the transportation planning process is the selection of the transportation system that will best support the design plan.

The use of a design year and the testing of alternative systems for this design year is appealing because of its simplicity. However, I cannot accept the oversimplifications involved. The design year is just not a realistic conception. It is, after all, just an artist's rendering of what the world could be like if everything went the way we wanted it to. However, it is only one possibility out of millions. It is not clear for more extreme cases whether the design year land use plan can even be achieved. By this I mean to question whether it is sufficiently within the control of the planning and decision-making group that it can be achieved. "It may be," as the old-timer from Maine said to the tourist asking directions, "that you just can't get there from here." Even if we could get there from here, the intermediate steps would still be important. In fact, I would argue that how you get from here to there is actually more important than where you are when you get there. The time value of money offers an analogy that is valid in this context. The economist discounts each year by the factor $1/(1 + i)^n$. Therefore, money available in the first years of the series contributes more importantly than that available later. For any time series in which the interest rate is fairly large the 20th year may be inconsequential. This suggests that the sequencing of a transportation plan may be more important than the final plan itself.

Furthermore, in our world it is naive to believe that any plan can be constructed exactly as conceived. The best laid plans sometimes go awry, and we must plan for that occurrence. In extreme cases the inability to finish important links in a freeway system will render the entire system useless. In all cases the benefits measured for the completed system are quite different from those for the incomplete system. Therefore, to select a strategy promising early benefits from where we are now is better than to plan on being able to build an entire system as conceived.

I am not arguing that it is fallacious to attempt to complete entire systems, including ring-roads, innerbelts, and bypasses. I am merely pointing out that to plan for a design year is starting at the wrong end of the process. The design year plan can be argued, and usually is. It can be obstructed, and usually is. Finally, it can be modified, and usually is. Therefore, to base our entire planning on the benefits achievable for a completed plan, whether the plan is predicted or prespecified, is fallacious.

A better approach would be to start with today's system and to introduce changes. These changes can and should be time-sequenced steps toward some long-range plan or, better, alternative plans. The emphasis, however, must be on the short-term future and on achievable first steps, with flexibility left for alternative future steps. These first few steps are, or should be, realistic, achievable steps based on solving today's needs. They should add up to longer range goals as

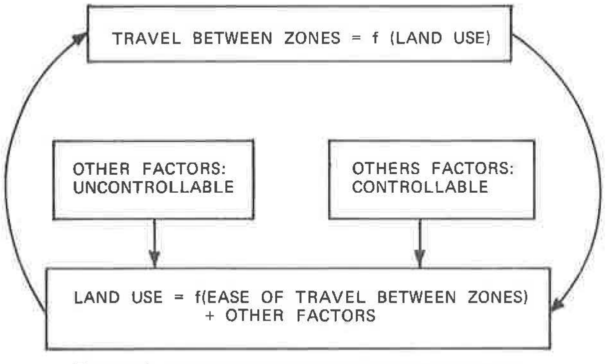

Figure 1. Land use and travel interrelationships.

well, but by concentrating the planning efforts on the achievable, we introduce realism into the process. This also reduces the chance of being seduced into believing that the unachievable can be had by merely wishing for it. Showing how these first steps are related to the long-term goal makes it more achievable. Many a planning report is gathering dust on a shelf because it did not indicate the first steps toward the recommended long-term utopia.

A point that must be understood for any planning process to be put into practice is a careful definition of the control variables and who holds them. It cannot be assumed that an enlightened group of decentralized decision-makers will convene and act in concert for the public good. One must instead take the more limited view that only those control variables that are in the hands of the authority doing the planning can actually be manipulated. This was dramatically illustrated for me by comparing the Colombian Transport Plan prepared for the Minister of Public Works of the Republic of Colombia with the Northeast Corridor Study, which, although prepared for the U.S. Secretary of Transportation, is really more for Congress. During the course of the Colombian model studies, actual construction projects were recommended, and the Minister could initiate construction activities almost immediately. In contrast, for the Northeast Corridor Study, the recommendation is only the beginning.

## LAND USE AND TRANSPORTATION

Most transportation planning processes and models involve implicitly or explicitly the assumption that land use is not affected by the location of transportation facilities. This assumption is the obvious corollary of using the concept of a design year. Many transportation planners know that the assumption is not true. Others adamantly refuse to admit it. If the design year land use plan could be influenced by the way transportation develops during the interim, the whole concept of a design year would be in trouble. Furthermore, this fact, if faced directly, would render today's planning models inadequate. Thus, it is easier to believe that transportation is incapable of causing a change.

It is clear, however, that transportation does influence land use by affecting the choice of location for various enterprises. Some establishments, such as gasoline stations and restaurants, depend quite directly on highway traffic for their livelihood. Where these establishments have been bypassed by controlled-access facilities, many have become unprofitable and failed. Certain industry types appear to favor locations along expressways. Interchanges, in particular, are sites for industries requiring access to skilled employees over a large portion of the urban area and large parking. Likewise, large suburban shopping centers appear to favor locations near freeways.

The major arterials are the primary locations for a number of establishment types, including automobile sales and service, strip commercial, and other service-oriented industries. Residential locations also require some form of access, although direct access to freeways is not as important. Multifamily dwellings by contrast are almost always located near some form of public transportation. Service industries are frequently located in the central city, replacing older industry forms such as warehouses and manufacturing. At the margin of the urban area, land is either unoccupied or occupied by lower intensity land uses such as agriculture, forestry, or recreation. This margin is clearly related to transportation.

If, as we believe, land use is a function of transportation, this has a number of important implications both for the system and for the planning process. Let us first examine the real world process set in motion by introducing a change in the system.

Once a transportation facility is installed in the real world, there is then a certain amount of adjustment to it. This phenomenon is typically obscured by the overall growth of the system, but there is always a sort of dynamic equilibrium between use of the transportation system and land use. When trips are easy and cheap more trips are made. Trips divert from other paths and other modes, and relocating parties find it to their advantage to avail themselves of the relatively cheap commodity—transport—by changing locations. As trip-making becomes more difficult and costly, trips are curtailed or rescheduled to off hours, and finally changes are made in location.

Similarly, if a poor choice of transport facility location is made, initially there is a certain amount of healing that goes on within the system to correct this poor choice location. The nation's commuter railroads offer one case in point. It was not anticipated at the time of the location of most of these facilities that they would become unprofitable to operate. The residential location decisions made by many individuals place a tremendous pressure on the authorities to maintain this uneconomical service long after it should be discontinued. Although it is not clear what the economic impact of discontinuing this service would be, it is clear that it would be substantial.

The dynamic equilibrium that is set up between land use and transportation is in all probability a very imperfect one. The relocation of industries and residences takes time, and the nature of the fixed facilities associated with some industries may make them unusable for other occupants. It may therefore be necessary for an industry to completely amortize its present equipment before it can move to a new location because there is no market for the old facility. Transportation is obviously not the only factor of importance to the location of industry and individuals, but it is clearly one of the factors and could therefore be used as one force helping to establish a particular land use.

Our current transportation planning processes do not account for land use that changes in response to the transportation facilities provided. Although there are a number of studies and reports that acknowledge the fact that land use is shaped by accessibility, there are only a few urban transportation planning efforts that have explicitly incorporated this into the basic model structure in an operational way (5, 6, 7). Most of these treat land use in a one step, design-year fashion. Current procedures are more like those shown in Figure 2 (8). The steps indicated in this figure include

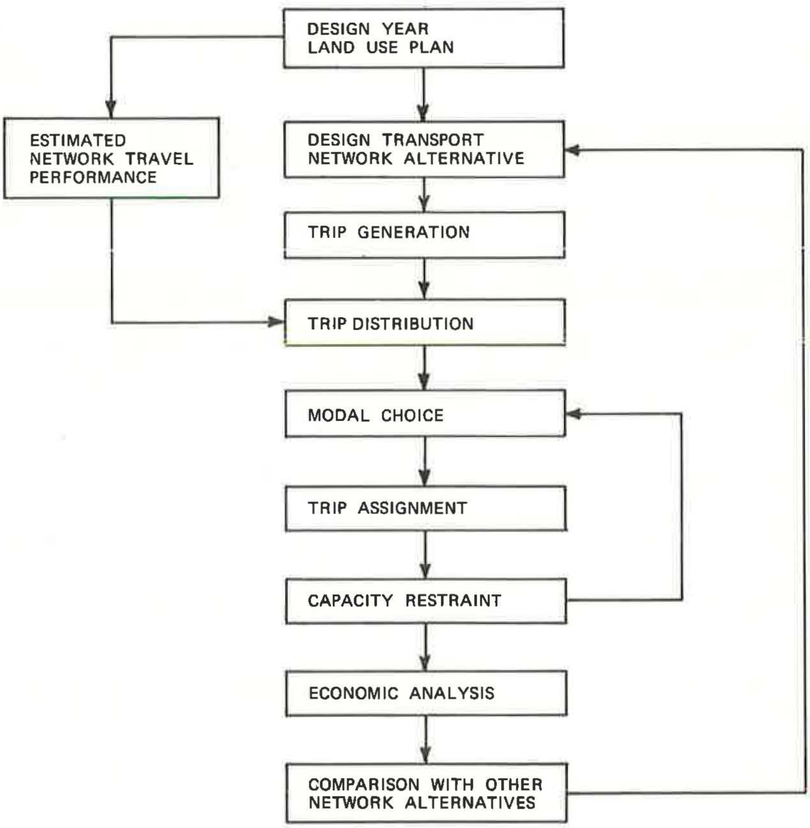


Figure 2. Simplified current transportation planning procedures.

land use forecasts typically for the design year, trip generation based on empirically determined generation rates found in current land uses, and trip attraction based on estimated network travel performance. This last step involves use of one of the traffic assignment models, such as the well-known gravity model or something equivalent. This is followed by modal choice, traffic assignment, and capacity restraint routines for most studies.

Although it is generally recognized that the capacity constraint portion of the assignment must be iterated until the traffic volumes assigned to each link remain fairly stable over several iterations, it is not generally appreciated that the same kind of iterative procedure must hold for the trip attraction portion of the assignment process. The gravity model must use as input the estimated network travel performance from point to point, sometimes known as "skim trees". Yet, there is usually no attempt made to check final travel performance on each link of the network with the estimated network travel performance used as input to the gravity model. Presumably if a different set of skim tree inputs were given to the gravity model, the assignments could turn out to be quite different. At present, good practice does not iterate until a consistent set of outputs has been achieved.

Another point on which the current procedures could be greatly improved is the elimination of the assumption that trip-making is independent of the level of traffic service provided. This is the direct consequence of separating trip generation and attraction. Models for accomplishing this improvement already exist (9) and could easily be incorporated into the existing structure. They would replace both trip generation and trip distribution models. They have the advantage of possessing behavioral parameters, thus obviating the need for separate calibration in every application. The inputs for such "econometric travel demand" models would be supplied by descriptions of land use on the one hand and travel performance on the other and, like the suggestion of the previous paragraph, should not be iterated until all outputs are consistent.

The concept of introducing a model to predict changes in land use arising from changes in accessibility into the procedure and running the model on a year-to-year basis complicates the process and to date has been untried in practice. Yet, this appears to be a logical next step.

For me, the implications for urban transportation planning models are quite clear. First, we must have models that show how the entire urban area will grow over time in response to changes in the transportation system. The models must link together the urban economy, the land use, the travel patterns, and their influence on the future location of industry and residences. The overall structure of the model would be somewhat as shown in Figure 3. Here, the overall operation of the model shown would occur once during every period of time simulated. Thus, if the time increments were years, the entire process would be run for every year of a simulation. The status of both transport network and land use would be maintained internally and updated yearly as exogenous changes were introduced.

The comprehensive nature of such models must not deter us from their exploration. The models may turn out to involve as much effort on the housing market portion of the model as in the transportation portion. The nature of the spatial competition for land and between industries must also be involved. It will be impossible to have practical planning results available from the first uses of such models to meet specific planning deadlines. It therefore appears that it would be unwise to organize model-building efforts in such a fashion that they would be called on to produce detailed planning studies for actual implementation in the real world as a prime responsibility. This unfortunately is what happened to the Penn-Jersey study, in which many of the scientific aspects of that work had to be neglected and eventually abandoned (10). At the same time practical planning was severely shortchanged and much criticism was lodged against the overall study for that reason. It will, however, be crucial to have these studies directly associated with real cities and with real decision-makers.

Although the models proposed here are meant to be comprehensive, everything cannot be done with the same set of models. Each set must be relatively policy-specific. Because the subject of interest here is transportation, these models must be transportation-specific. That is, they must include those aspects that bear directly

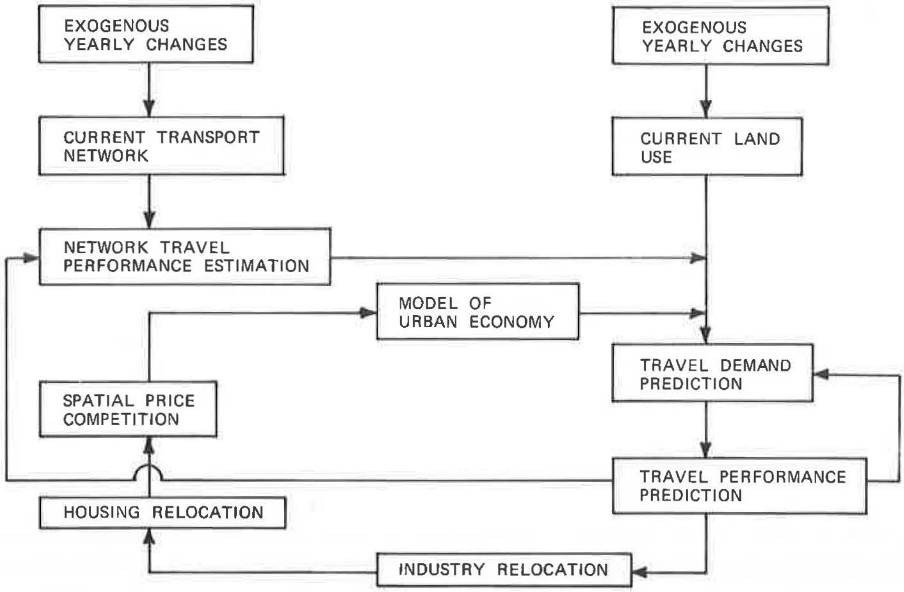


Figure 3. Simplified proposed urban growth model for use in transportation planning.

on transportation planning, but must necessarily ignore other aspects that may be of broader policy interest, e. g., the social aspects of the ghettos.

Examples of the type of models that I am proposing are suggested by both the Harvard work in Colombia and the Northeast Corridor Study. Both use integrated economic and transport models. Both involve multimodal multiattribute transport networks. Both embody the concept of a system that grows over time with feedbacks from one time period to the next. The elements of the Colombian model were so tightly interconnected that it was possible to make 10-year runs in the computer without manual intervention. Both studies, however, are concerned with interregional travel, location, and spatial equilibria instead of the more difficult process within the urban area.

## SYSTEM EVALUATION

A common misconception is that the desirability of a transportation plan can be determined by comparing flows on alternative designs using the output of the transportation simulation models. If, in fact, the only changes in the entire system under evaluation were those in the transport system, there would be some measure of truth in this approach (11). However, if the total environment in which the transportation system is functioning is allowed to change with industry and residence relocations, changes in the trip-making propensity of the public, and shifts in the nature of the urban economy, then there can be trade-offs in which higher transportation costs are traded for lower costs somewhere else in the system. In this case it is no longer possible to treat transportation as a separate entity, if in fact it ever was.

In fact, the purpose of the transport system will always be found outside the system itself. The transport system can be used to promote more efficient production, to allow easier access to goods and services by individuals, or to create a more pleasant environment. Increases in any of these goals cannot be measured on the transport system alone. This was obvious from the start in the case of the Colombian study, and evaluation in terms of the state of the economy were substituted for the more conventional cost-benefit studies, although comparisons between the two approaches were illuminating (12). This was also recognized in the corridor project, and studies of comparative evaluation strategy were undertaken (13).

The fact is that the external effects are extremely difficult to measure and to evaluate. For example, it appears that one of the benefits of increased freeways is to allow industry to move to low-cost, more efficient, one-story plants with easily available parking. Families have been motivated to move to the suburbs to achieve the amenities of more open space and individual housing. Likewise, commerical retailers have found that one-story shopping plazas with easily provided parking are also more efficient than the downtown location. Although we have yet to measure these savings in a careful way, they are undoubtedly partly the product of improved transportation.

Finally, the whole question of environmental quality is becoming increasingly more important as our society grows in affluence and complexity. In the same fashion that a family may choose to use its income to secure a home with special amenities, as opposed to one that provides housing at the most economical level, so may an urban population decide that it wishes to have an environment that is somewhat nicer or one that emphasizes characteristics different from those in other urban areas. At the moment we do not have sufficient mechanisms whereby this kind of public decision can be made. Nevertheless, it is clear that the transportation system offers one of the most powerful tools for shaping the urban environment from an aesthetic point of view.

One of the problems in this regard is that at the moment transportation planning authorities are not delegated responsibility for planning the total environment of the city. Rather, they are charged only with the responsibility for providing an efficient transportation system. Legally, they probably could be found guilty of manipulating the transportation system to produce a given form of land use. Although this appears to be a legitimate goal, it is certainly not the intent of the legislation under which most transportation planning authorities are currently working.

Our society could decide (and portions of it have) that the noise, pollution, and frantic activity involved in urban living are just not worth the benefits received, and they could revert to a somewhat more aboriginal existence. The alternative is to seek to improve the quality of urban existence. In this endeavor, the transportation system is likely to play a major role. Urban growth models will be indispensable to this type of planning. These models will be used to find how to grow the city in a more environmentally acceptable way. The problem may be akin more to gardening than to engineering.

## ACCURACY OF RESULTS

Current planning models produce an exceptionally large amount of output. The traffic flows for every major link in the system are typically produced, including turning movements for each intersection. These flows are frequently factored to give peak hour and off-peak hour volumes as well. Because these figures are produced for the design year, they are invariably used by the designing authority to help size the facilities being designed. For planning new freeways, these figures are frequently used to determine the number of lanes, the placement of ramps, and the timing of traffic signal devices. Although most planning authorities recognize that these figures are not sufficiently accurate to be used in this fashion, there are no alternative figures, and it is difficult to admonish the design engineers that these figures should not be used.

In spite of the fact that these are the only figures available, there are major distinctions between the planning models and the real world. Within the planning models there are no traffic queues. Within the real world queues, both traveling and stationary, are perhaps one of the most noticeable aspects of an urban transportation system. When a traveler arrives at a constricting point, it is necessary for him to wait his turn before using that portion of the facility. There is, to use the words of the hydraulic engineer, "ponding in the system". Current planning models do not involve system dynamics, and relatively little work has been expended on developing them.

My general feeling is that limited use should be made of the output of the planning models, if they are used at all. It would be far better if the facilities were designed from the point of view of maintaining consistency for the using volumes. If, for example, the input to a particular road segment is metered, then all flows downstream can use this figure as an upper bound on flows, unless it is anticipated that the input constraint will someday be eliminated. Conversely, by metering inputs, we can guarantee travelers a given level of service in this section. Adequate thought must be given to these effects of backup and ponding during the design phase.

For use in design, it would be extremely beneficial to have models that were dynamic in time over very short time increments, perhaps as short as 2 to 5 minutes. These models should treat subareas or corridors of the transport system, not the entire network. They should show the places where queues will build, their lengths and dispersal times, and queuing statistics such as the average holding time and maximum holding time. Instead of developing these models for design, we have concentrated on building large networks. We talk now of networks with 10,000 or more links. Such networks are extremely difficult to work with, from the standpoint of both computer time and programming, as well as in the data collection and use phase.

It is extremely doubtful that using such large networks does much for us in the way of planning. A great deal of effort is required to define the network and all the inputs, yet the principal planning on design effort is being directed toward only a few links in the overall network. An infinite number of technical difficulties manage to keep us from focusing sufficiently on these critical links. It would, in my estimation, be more productive to redirect the time and effort spent on working with large networks to working on smaller networks treated in a dynamic fashion.

It is possible to develop simulation programs that handle traffic flow in a time-dynamic sense. These programs would simulate the behavior of traffic flowing over street systems or freeways in which queue formation and dispersal could be studied and design alternatives explored. Of necessity, the programs would involve considerably more detailed input in geometric design and in terms of signal timing, parking, and off-highway interference. Nevertheless, the exercise would be extremely beneficial for both freeway designers and transport system analysts. Although there have been a few good starts toward the solution to this problem, nothing really practical has resulted to date.

Experience with the transport networks involved in the Northeast Corridor Project suggests that we will have some problems in extricating the corridor of interest from the larger network. One approach to handling this problem is to use a spider network covering the overall system within which important systems interactions occur and superimposing the detailed network within the area of most intense interest. By this device the trade-offs between the system of interest and the remainder of the environment can be captured while preserving a manageable-sized system overall. Other techniques will have to be evolved for detailing some systems components while allowing others to remain only grossly defined. With more experience this will become easier.

Using these techniques, we can concentrate more of our attention on the planning phase and the design phase as separate endeavors. It should be possible to redirect some of the efforts of the planning phase from overconcern with the very large networks we are presently using to smaller networks studied in a more comprehensive manner. This would allow room in the broader scale planning effort to concentrate on such topics as sequencing over time, land use, and industry location as an explicit part of the planning process.

## CITIZEN PARTICIPATION

The problem with trying to involve more citizen participation in the planning process is that there are at present too many actors controlling too many control variables. From a model-building point of view the number of combinations of alternatives is extremely large. To have a group of uninformed citizens entering into the process, each with his own set of biases and without the right organizational mechanism for incorporating suggestions, appears to be inviting chaos. For planning purposes it would be far simpler if decisions could be centralized.

There is no denying that increasing the number of participants in a decision makes the decision that much more difficult to achieve. Yet, it is also clear that planning is a sociopolitical process. Changing the transport system in the real world will undoubtedly affect some people more and some less, some adversely and some beneficially. The silent (and only slightly affected) majority has a stake in the planning process, but so does the highly vocal minority that is being affected in a major way.

It is important to recognize that the people who are displaced by a transportation facility improvement are compensated for their inconvenience, although the compensation is in many instances less than the damage, particularly for the old and the poor. The loss of housing does pose a threat to many. Families that can least afford it may be affected in an adverse way and marginal businesses may be closed. The people who are left behind, however, are frequently affected adversely without compensation. Although it is difficult to provide adequate compensation in all cases, in the interest of equality some kind of compensation should be arranged for this group. Although larger payments to affected parties may be in order, even more important is a sensitivity on the part of planning officials to the effects that transportation changes can bring.

To be useful at all in a broadly participatory planning process, the planning models we devise must be able to trace the incidence of benefits within the system. It will not be enough to know the total net benefits of a particular plan; we must know that one group will be net losers while others realize a net gain. Only then will it be possible to design adequate compensation schemes and to preview the political repercussions of various courses of action. This proved to be true in the Colombian study in terms of trade-offs between both regions and industries. I would therefore argue that instead of a reduction in planning models, it will be necessary to increase the scope and usefulness of these models and that they will be applied more and more to study the sociopolitical consequences of an improvement or change to the transport system.

In summary, then, urban growth models of the type I have advocated appear to be a useful addition to our planning repertory. Having appropriate facts at hand may not make political decision-making any easier but, by the same token, it is unlikely to affect it in an adverse manner. By clarifying the complete set of consequences that will result from a transportation improvement, we can improve public confidence in the planning process.

## CHALLENGES FOR URBAN TRANSPORTATION PLANNING

Urban transportation planning has come a long way from the days of the Fratar model, but it still has a long way to go if it is to contribute to the solution of the major problems in our cities. The next decade promises to be the era of the city. It is clear that this is where the major growth in our economy will lie. Money for urban development may eventually be forthcoming. Even then, however, there will never be a time when efficiency and economy can be ignored. The planning model and the computer will be immensely useful if we have developed the needed models and if we understand their use.

The greatest challenges to effectively performing our role as urban transportation planners are, therefore, as follows:

1. Recognizing that current urban transportation planning has stagnated in the building of new models and is failing to adequately address the pressing model-building issues of the current time;
2. Admitting that, although today's models are useful, they could be made more useful if we restructure them to eliminate the hidden assumptions outlined in this paper;
3. Recognizing that future models must be based on a true desire to understand the urban growth phenomenon (this may require subordination of transportation until its role is better defined);
4. Developing future planning models that are dynamic over time and that incorporate submodels of industry and residential location along with models of the urban economy;
5. Ensuring that our preoccupation with models does not hinder our search for new technology and ways to apply it and realizing that new technology can solve our problems only if we understand what its full impact will be on the urban growth process; and

6. Seeking more effective ways in which the planning process can be integrated with decision-making and allow grass-roots participation.

The challenge to urban transportation planning is a challenge to how effectively we can utilize the model-building capability we are slowly acquiring, the computing power we have developed, and the understanding of the nature and purpose of planning we have discovered to explore the possibilities that the technology of the future holds for the city.

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