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Practical Planning Techniques: Review and Rethinking

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This paper emphasizes improved understanding of practical, operational techniques that are responsive to current and short-term issues. Included are (a) documentation of issues; (b) documentation of the state-of-practice for identifying and measuring economic, energy, and environmental indexes; and (c) operational guidance for the use of validated techniques. Major findings are that most earlier and current planning is of a single mode, single discipline nature. Multimodal state and regional planning, pricing, or policy formulation is rarely attempted. The literature contains very little on truly integrated economic, social, environmental, and energy evaluations. The indicators to address these current and changing issues are poorly organized, and techniques for measuring the indicators are rarely evaluated or validated. Consequently planners and decision makers have poor understanding and use techniques and approaches that are faulty.

The current transportation literature is flooded with publications titled, "social, economic, and environmental impacts." Indications are that a meaningful change is taking place and that this flood of articles reflects the depth of the change. In the past, any action that facilitated the transportation of goods and passengers in greater numbers or more quickly appeared to represent a contribution to the public interest. In the new age of increasingly scarce resources and critical pollution thresholds, this is no longer the case. Basic factors critical to transportation planning are also changing. The birth rate has fallen below the basic replacement rate despite the highest household formation rate in history. Equally important, the recent growth in small cities and towns has signaled one of the most dramatic changes in population location in this century. The rate of growth of nonmetropolitan areas is exceeding that of the big cities and suburbs. Continuation of these shifts could have a profound effect on state and regional transportation planning.

Transportation improvements have become, whether actively or passively, vehicles of public policy. Proof that volume, safety, or speed will be increased, or even that direct costs to users will be reduced is no longer adequate evidence of the desirability of a transportation project. If the best overall public interest (1) is truly to be served, many other factors must be considered, particularly since an aroused citizenry have the legal tools to delay and possibly stop projects that are detrimental to either the human or the physical environment.

This is not to say that transportation improvements are not socially desirable or, in fact, essential. We, as planners, must consider the more subtle and far-reaching impacts a proposed project might have and not just the immediate benefits to be derived. Transportation improvements should no longer be assessed apart from the broader context of societal goals.

Changing conditions, attitudes, and values place tremendous new pressures on state and regional planners and decision makers. Techniques for evaluating transportation improvements in light of these changes are not readily available. An improved understanding of practical and operational impact identification and measurement techniques must be developed for the regional land use-transportation planner who is strongly influenced by new social mores, energy shortages, environmental problems, and the current state of the economy. Techniques are needed that are applicable to pricing, regulation, and policy formulation, as well as to planning.

While some improvements are proposed in this paper, I have not developed a single approach that is universally applicable, easily applied, and based upon quantifiable criteria alone. This paper attempts to contribute to improved understandings and to identify techniques relevant to short-term conditions for this range of decision-making activities. The following discussion is directed primarily toward state and substate regional planning, program development, and policy analyses. Because of strong relationships, urban considerations are also included. The discussion focuses on methods broadly applicable to all modes of movement of passenger and goods and covers all levels of capital investment (new construction, low capital investments, no build, and abandonment), operational improvements, and pricing and regulatory measures. The scope is broad, but no broader than that faced daily by most planners and decision makers.

ISSUES, INDICATORS, AND TECHNIQUES

Transportation planning and decision-making processes have improved rapidly over the past decade, stimulated in part by National Environmental Policy Act of 1969 (NEPA). This type of legislation has raised the awareness of issues outside of, but closely related to, transportation planning. In fact, techniques used by some states in creative policy formulations have, in turn, led to successful, multiagency planning and budgeting efforts (2, 3). These and similar recent improvements are overshadowed, however, by the basic changes taking place in the traditional response-to-growth type of transportation planning. Hammer (4) gives an excellent summary of the increasing use of normative planning or managed growth approaches:

> The emerging policymaking is a welter of crisscrossed lines. On one hand the new [U.S. Department of Housing and Urban Development] HUD Act is testimony of the acceptance of a new federalism that admits the limitations of top-down approaches to the management of physical development. On the other hand, the new [U.S. Environmental Protection Agency] EPA and [Federal Energy Administration] FEA regulations are startling in their reassertion of federal force in the face of new environmental and energy crises.... Now the states, for the first time in U.S. history, are asserting their constitutional power over land use and settlement patterns. Most important are the emerging actions of local jurisdictions and their plans and implementation programs dealing with the management of growth.

Instead of merely upgrading traditional, single-mode techniques for comparing alternatives after the decision to build has already been made, we now have techniques to determine whether transportation improvements or some other improvements are needed to support broader socioeconomic and land use goals. If transportation improvements are needed, we choose which combination of capital investments and pricing or regulatory mechanisms will be most effective in accomplishing those goals. The traditional response-to-growth approach is not yet a thing of the past. Fortunately, most of the

findings regarding impacts and techniques apply equally well to the response-to-growth, normative, and growth management approaches.

The results of earlier work on improving techniques indicate that still more monitoring and postevaluation work are needed. For example, economic research by Harral and others in the transportation research program of the Brookings Institution (5) provides an excellent base in that discipline. This is supported by recent work by Llewellyn (6) in the socioeconomic area; by Wolf (7) in the social area; by Yukubouski of the New York State Department of Transportation (8) or Manheim (9) in the citizen participation area; by the state of Oregon (10) in the energy discipline; and by the state of Georgia (11) and the Smithsonian Center for Natural Areas (12) in the environmental area. Most of these works have not been organized into an overall framework for planning, pricing, and policy formulation that uses multimodal systems assessments and integrated economic, social, environmental, and energy (ESEE) evaluations.

The issues that state and regional transportation planners must deal with were assembled from direct contacts with planners and decision makers and from some excellent recent references (13, 14, 15). Most were old issues, many as old as transportation itself. During the last three decades, planners responded to tremendous growth pressures and found little time to respond to energy or environmental issues. As a consequence, responses (in the form of alternative approaches and techniques) are poorly developed for issues such as:

1. Developing meaningful state goals,
2. Learning to deal with change and uncertainty,
3. Planning for multimodal systems, and
4. Pricing and regulatory mechanisms for coordinating private and public sector investments and operations.

Major new issues include state and local attempts to manage growth, energy problems and the corresponding issue of resource management, and reliability problems in predicting socioeconomic trends. Each of these issues is drawing transportation planning and decision making out of the transportation field and into the complex field of land use and socioeconomic planning. ESEE relations are poorly understood in this larger field. For example, land use is often used as a surrogate for social and economic issues. While an important consideration in itself, land use is a poor surrogate for issues such as energy conservation or neighborhood cohesion. Similarly, environmental impacts are frequently labeled as indirect and thereafter ignored, even though indirect impacts are among the most important to informed decision making. Also, terms used in economic analyses, such as externality or financial versus economic analysis, are often used incorrectly.

All of these factors have contributed to the existing state-of-practice in state and regional transportation planning. Systems planning is minimal in this country. Most state and regional plans are sum-of-projects by mode and then sum-of-mode efforts; little or no analysis is made of economic, energy, social, or environmental relations. This situation is changing as more states adopt policies regarding land use. An example is Colorado's goals in redirecting economic and population growth (16).

Some techniques are so well understood and documented that we can identify issues, document impacts, identify operational methodologies, and develop guidelines for their use in various decision-making activities. These techniques include those for finance, fuel consumption, transportation accidents, and noise assessments. A relatively high level of confidence can be placed in predictive techniques in these areas.

With the exception of those mentioned above, impacts and techniques currently employed to address major issues are at very uneven stages of development. Generally, they combine single-mode and single-discipline assessments, which rarely discuss system or discipline relations, and offer short-term evaluations almost to the exclusion of long-term considerations. Frequently, the techniques are methodologically incorrect or used incorrectly. Almost no postevaluations have been performed to validate the reliability of recent, observable impacts or of currently used techniques. One recent postevaluation of highway impact methods, completed for the Federal Highway Administration (FHWA) (6) summarizes, "The results of this study indicate that a large proportion of the research on highway impacts is poorly conceived, lacking in substance, and replete with errors in methodology and research design." Most postevaluations are either harsh condemnations of the techniques in use or such poor evaluations themselves as to be inadequate to establish the reliability of the techniques in question.

Indicators comprise the logical link between issues and measurement techniques. They are key characteristics of major issues that can be measured quantitatively. Unfortunately, decision makers rarely agree on issues, indicators, and techniques. Thus the National Cooperative Highway Research Program (NCHRP) (17) proposes organizations in this regard for the economic, social, environmental, and energy disciplines (Table 1 is an example).

PRACTICAL TECHNIQUES AND IMPLICATIONS TO DECISION MAKING

Generally, our understanding of how to use economics for state and regional transportation planning and evaluation is poor. Most earlier economic analyses were (a) justifications rather than evaluations; (b) single-mode projects rather than multimode systems oriented; (c) predominantly short-term instead of short- and long-term considerations; and (d) often of a financial instead of economic nature. For example, most economic analyses of airports, pipelines, ports, and railroads are, in fact, financial assessments of costs and revenues needed for investment purposes. Employment and related benefit data are used for justification purposes. Costs and revenues are necessary analyses for a broader economic assessment, but they are only fragmentary inputs to that broader assessment.

Table 1. Energy issues, indicators, and techniques.

Issue	Indicators	Measurement Techniques
Fuel energy consumption	Modal energy intensiveness	1. Sketch and detailed analyses 2. Models of existing systems
	Operating fuel consumption	1. Multiply modal energy intensiveness by number of seats and total distance traveled
Capital energy consumption	Energy costs for such things as vehicle manufacture, traveled way and facility construction, manufacture and operation of traffic control, and signals	1. Sketch analysis 2. Multiply project dollar cost by total U.S. energy consumption for year in question and divide by GNP for the same year 3. Detailed analysis 4. Input-output

Waterway development evaluations provide an example of invalid economic or financial analyses. Current practice is to compare rates for heavily subsidized waterway carriage with regulated rates for the same cargo on a real or imaginary parallel rail line. Economic analyses for regional systems are rarely performed. The most widely recognized technique, benefit/cost analysis, is used primarily for project evaluation instead of for state or regional system planning, and then only to select between highway alignments once the decision has been made to build a highway. This technique has valid uses; however, it can provide only a part of the input required for economic analyses of concern to planners. Other findings are that:

1. Requirements for economic assessments are changing so that many traditional terms such as externality, second order, and indirect are less relevant than they once were;
2. Economic analyses, subject to data availabilities, are equally applicable to all modes—no major economic techniques are mode specific; and
3. Multiple techniques are needed for overall economic evaluations; rarely is a single technique adequate to address more than one issue nor will a single technique provide useful information for all decisions about planning, pricing, regulation, or policy formulation.

The technical requirements and limitations of economic analyses must be better understood. These include (a) the use of with and without analyses, (b) the establishment of causal effects, (c) the understanding that tax analyses merely reflect internal transfers in an economy, and (d) the delineation of clear boundaries for economic analysis.

The implications of the state-of-practice in economic analysis are twofold. The first implication for state and regional transportation goals confirms Hand's findings (18, p. 4):

> State development policies and planning, including transportation, need to reflect a common base of population, economic, and resource information and analyses. State governments need to be encouraged to move more in the direction of a goals definition that is part of a systematic consideration of overall objectives, targets, needs, deficiencies, implementing programs and projects, and the periodic recycling of these judgments.
>
> Functional elements will always compete for priority of attention and support, e.g., transportation versus education and welfare versus environment. But if each functional element is to be viewed and understood as fitting into a total structure rather than as being the umbrella for the solution to all questions, then overall definition and direction must gain the same recognition and support...
>
> This larger context is important for transportation decisions. It is essential to intermodal judgments. This larger context is important and is essential to transportation decisions and intermodal judgments, among other reasons, because these decisions and judgments should be used by society in shaping what it determines it wishes to be.

The second implication is that state and regional transportation planners will require inputs from trained economists. These economists should have a societal viewpoint rather than view transportation as an economic activity in itself. Further, the economist, according to Munger and Edwards (19):

> ...will have to spend the time and effort required to determine what people want and how they go about satisfying those wants. He will have to abandon exclusive reliance on an analytical tool designed... to maximize income and to develop, instead, tools capable of guiding public decisions aimed at achieving multiple objectives, some of which are subjective in nature. And, most important, he must remember that the search for acceptable alternatives is a political bargaining process which he can assist by providing needed information and withholding personal value judgments.

Energy issues are relatively new to planning in this country. Except for scattered works, like that in Oregon (10), few energy assessments have been completed at the statewide, multimodal planning level. Energy assessments are largely the application of well-known physical laws. Issues in the energy discipline do not have numerous or highly qualitative indicators. Because of the strong relationships between energy and economic, social, or environmental assessments, future energy assessments will be critical

1. To state policy formulation, pricing, regulation, planning, and financing of multimodal operations;
2. To an understanding of a state's energy balance, to the need for energy imports (into a state), and to related long-term effects on the state's economy; and
3. To planning the modal balance for new systems and, more importantly, to the organization of priorities for marginal improvements to existing systems.

The indicators and techniques for fuel energy consumption are well developed and are a direct counterpart to dollar costs for transportation operations. These techniques, which are easily understood and applied, are currently part of many state-level analyses.

Capital energy costs are less well understood and rarely used. They have their direct counterpart in dollar costs for such things as transportation facilities and equipment, and therefore, may be as important to long-term transportation decisions as fuel energy analyses. For example, capital energy requirements will be very important to future decisions on the trade-off between short-haul air service, which is highly energy intensive but may have minimal capital energy requirements, versus high-speed rail, which is not nearly so energy intensive, but could have enormous capital energy requirements. Energy implications to land use, economics, resource management, and social subsystems are so strong that energy assessments of the future may force vastly improved interagency planning and budgeting activities. Further, modal energy comparisons may be easier to develop than cost comparisons, and the economic implications may be more easily understood.

Much work remains to be done in relating energy assessments to those for economic, social, and environmental analyses. Because their economic implications are easily understandable, capital and operating energy assessments will have an immediate, long-lasting, and pervasive impact on transportation decisions. Energy and economic evaluations will be of particular importance in times of uncertainty and scarcity.

Social assessments are used as the underlying basis for many court suits against transportation projects. But, the social discipline appears to be the least well developed and the most lacking in terms of an overall understanding of how social considerations can be used in transportation decision making. By far, most information about social impacts is related to highways. The predominant need for value judgments in social assessments may make the development of good understandings difficult and the assembly of a comprehensive body of reliable social assessment techniques even more difficult. Value judgments vary so much from person to person over time; the development of predictive analytical techniques for interrelated social issues, therefore, appears to be an unrealistic goal. Several considerations indicate that social assessments may be even more important in the future than they are now.

1. Strong socioeconomic ties contribute to a growing consensus among planners that social considerations may

be the most important of future ESEE evaluations; and

2. Energy considerations indicate that future transportation developments may have key social implications, such as on the quality and distribution of state and regional growth.

An effective community participation program may be the most reliable central mechanism for addressing social issues; however, participatory programs at the state and regional level are not yet well developed. Thus, the testing and development by individual states of alternatives identified by Yukubousky (8), Bigelow (20), Ortolano (21), and Manheim (9) should be a priority item—particularly if the findings of Llewellyn (6), Crane (22), and Wolf (7) regarding the inadequacy of current social techniques prove to be correct.

Participation programs alone will not be adequate to address social and related issues. A long-term, well-organized program to verify social impacts and develop techniques for their prediction will be necessary if social considerations are to be given meaningful consideration in transportation decision-making processes. Until these techniques are available, the use of an effective citizen participation approach appears to offer the best potential for reliably incorporating social concerns in state and regional decision-making processes.

Existing noise level standards reflect a consensus on the importance of noise issues. A long history of research has resulted in the development of relatively reliable predictive techniques for noise impacts. Also, validations have been performed on the effectiveness of noise techniques. More work on noise techniques is needed to make them universally applicable to all modes and conditions and less costly to perform.

Air pollution impacts on humans, biota, and buildings are fairly well documented. In addition, predictive techniques are available for the generation of pollution by all transportation modes. However, dispersion and concentration of air pollutants in rural air basins are not well understood, and the available techniques for their practical reliability are unvalidated.

Water pollution impacts are not well documented because the generation and dispersion of transportation-related pollutants have not been thoroughly researched. In particular, the dispersion of transportation-related pollutants in groundwater supplies is not understood. Thus, while some of these pollutants are known to be highly toxic (such as asbestos and mercury), only sketch techniques are available for generation and dispersion predictions.

Ecological considerations are less well understood and ecological impacts of transportation systems are not well documented. Impact indicators are not agreed upon and analytical techniques are neither well developed nor easily documented in the literature. No meaningful validations of currently used techniques were found in the literature.

While ecological issues were primarily responsible for the NEPA legislation, most environmental assessments have been little more than inventories of species (particularly endangered species) or climatic and soil conditions. Key ecological considerations, such as community, food webs, and triggering factors are rarely mentioned. Work for the Georgia Department of Transportation is an exception (11).

The implications for state and regional transportation planners are that, although existing techniques can be used to perform noise and energy assessments with a relatively high level of confidence, reliable air and water pollution and ecological assessments will require the further development of predictive techniques. Until such techniques are developed, the identification and monitoring of critical areas (air basins, water resources, or ecological areas) appear to be an excellent alternative for considering these impacts at the state level. The U.S. Department of the Interior initiated such a program based on work initiated by the Smithsonian Institution (12). Given the difficulties in developing predictive techniques, the identification and monitoring of critical areas may be the only practical short-term approach available to planners.

CONCLUSIONS

Some of the newer issues, such as growth management and energy, provide opportunities to deal more effectively with the older issues of risk and uncertainty. However, techniques to address related issues and impacts need to be better organized. Most state planning is done on the basis of summing regional or local projects by mode and then summing sets of modal projects. Multimodal system planning is rare; therefore, little documentation exists on the impacts of system planning. Reliable impact documentation is even more rare. Most impact documentation ignores relationships, is too narrow in scope, or is faulty. Post project evaluations are frequently justifications of earlier decisions rather than evaluations of the reliability of the planning techniques. Thus, a common finding of reports of planning or evaluation techniques is that monitoring programs and postevaluations are among the highest priority needs.

Available techniques can significantly improve decision processes, but reliable techniques do not exist to address some major issues or for measuring some relationships. Currently available techniques are broadly applicable to decisions on capital versus operating investments, abandonments, pricing, regulation, and policy formulation. Six years of experience with the NEPA legislation shows that ESEE assessments and community participation must take place at the outset of planning rather than after plans are complete and public approval is sought. Thus, we are approaching the point at which the distinction between planning and impact assessments may disappear.

As a reflection of earlier single mode and single discipline assessments, the ESEE disciplines are at very uneven stages of development and critical discipline relationships are poorly defined. New issues give policy makers the responsibility of balancing ESEE trade-offs, but the poor state-of-practice leaves them without adequate information for doing so.

Energy and economic techniques are among the most reliable and well developed. Environmental and social impacts are the least well organized, documented, and developed. Energy assessments and community involvement techniques appear to offer the best alternatives for improving understanding of ESEE relationships. Both can be employed by the existing staff of state transportation agencies. Most current impact evaluations are negative in character, largely as a reflection of the inadequate use of available procedures. For example, the use of the without alternative (a technical requirement for the valid comparison of alternatives) can significantly add to planning understanding.

The five modes plus the ESEE disciplines and relationships, when placed in the existing institutional and financial context, result in a complex network of considerations that confront state and regional transportation planners and decision makers. As planners, we must learn to deal with this complexity and not avoid it by searching for easy answers or fast solutions.

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Transportation and Land Use Planning to Achieve National Goals: the Netherlands

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The Netherlands is one of the most densely populated countries in the world. The Dutch people have a long history of rigid land use controls; urban sprawl is unknown there. High-rise apartment complexes generally mark the boundary between urban and agricultural land uses. Urban expansion and some decentralization of urban activities since World War II have placed a difficult burden on transportation. The number of passenger automobiles has increased fivefold between 1960 and 1970. Transportation policy goals for the Amsterdam region call for public transportation in the future to accommodate about 60 percent of the journey to work traffic (it now accommodates about 25 percent), bicycle and pedestrian trips will be 30 percent, and the private automobile will account for the remaining 10 percent. To help achieve the

latter goal, parking will be provided for no more than 10 percent of central city employees. The key to land use control in the Netherlands is municipal expropriation of land ripe for development. The three-tiered land use planning process (national, provincial, municipal) is described in some detail, as well as the process of land acquisition, the provision of funding, and the installation of public facilities prior to private development. The manner in which highway planning is incorporated into and becomes an integral part of the overall planning process is described. The nature and degree of public participation in highway planning and the method of resolving disputes is discussed. The moderate effectiveness in coordinating highway development and land use activities to minimize adverse effects and enhance beneficial effects of highways is more an indirect result of the intensive overall land use planning process than the result of specific controls for such purposes. The Netherlands system of land use controls might not be as effective if not for the extremely high financial costs involved in preparing sites for construction (draining, removing peat and top soil, sand layering, and installing piles). Moreover, their land use control system does not appear to be politically or institutionally acceptable in the United States at this time. The remarkable success of the Netherlands in controlling a very scarce and valuable resource, land, has probably led to a more stable economic and social system for the country as a whole, but it has not been without some trade-off costs—restrictions of freedom of private land ownership and an almost total constraint on private gains from land value appreciation.

TRANSPORTATION PERSPECTIVES

One of the most striking features of the Netherlands' landscape, besides its flatness, is the very intensive use of land. The Netherlands is one of the most densely populated countries in the world; consequently, idle use of land simply is not economically feasible. The usual pattern of single family home development that marks the urban fringes of American cities is almost totally lacking around the major urban complexes in the Netherlands. Multistory apartment buildings usually provide the demarcation between urban and rural uses of land. Livestock are commonly seen grazing, crops are planted in the shadows of apartment buildings, and goats and sheep are seen tethered and grazing on railroad and limited access highway embankments. Urban sprawl, as we know it in this country, is nonexistent in the Netherlands.

Modern cities could not have developed in the southwestern portion of the Netherlands without the construction of seawalls and subsequent draining of the land, yet this is where most urban development has occurred. Over the centuries, about 607 000 hectares (1.5 million acres) have been recovered from the sea or from tidal marshlands. In 1970, about 8 percent of the land area in the country was in urban use. By the year 2000, this is expected to increase to 16 percent, mostly because of a declining density in housing. Within the Amsterdam region, there are now about 2.5 million people. By the year 2000, the total population in the Netherlands is expected to reach 13.5 million.

Although residential density is decreasing, it is still extremely high by our standards. Land has always been a scarce resource in Western Europe, particularly in the Netherlands, and so residential density in the older portions of the cities was, and still is, extremely high. However, the rapid rise in personal incomes and the adoption of modern technologies have resulted in a decentralization of the cities and a movement of both people and industry to urban fringe areas.

Such decentralization has placed a particularly difficult burden on transportation. Between 1960 and 1970 the number of passenger cars increased fivefold, from 0.5 million to 2.5 million. By the year 2000, 6 to 7 million passenger cars are anticipated. Public transport during the 1960s showed a strong relative decline in terms of passenger kilometers. Its share of total passenger transportation in 1960 was 47 percent; by 1970, it dropped to 18 percent.

In Amsterdam, as in the other major cities, traffic problems are severe. Older streets are very narrow, and during rush hours congestion is extremely heavy, even though 60 percent of all journeys to and from the central area are made by bicycle. Heavy bicycle traffic, in fact, accounts for part of the congestion. City streets are marked with well-defined bike lanes on which automobiles must not intrude.

Urban expansion in the last few decades has resulted in some dispersion of work places. Both industrial and service establishments are appearing in city extensions. Such spatial changes in activity have altered traffic flows. In addition to more radial traffic, there are now tangential flows. Increased distances to the city center because of suburban expansion have discouraged the use of bicycles, contributing to increased congestion.

From an intensive study of the expected development of the city and future transportation needs, specific policies have been formulated (1, 2, 3). The automobile will be unable to absorb a larger share of the journey to work, despite a national road-building effort to provide more radial and secondary roads. Reliance on public transportation appears to be the key to the future transportation policy of the Netherlands; transportation planning and physical planning are very closely related.

At the present time, public transportation by bus and tram carries about 25 percent of the rush hour traffic and private cars about 10 percent (bicycles and pedestrians account for the remaining 65 percent). Future policy goals call for public transportation to accommodate about 60 percent of the rush hour traffic and for the private automobile's share to remain at 10 percent. To help achieve this latter goal, parking will be provided for no more than 10 percent of those employed in the central city. Little has been written about the relations between transportation and environmental quality and the means by which adverse effects might be mitigated or beneficial effects enhanced. However, both implicitly and explicitly, social, economic, and environmental effects as related to highways are recognized by officials and the public.

LAND USE PLANNING AND CONTROLS

Land use and land development are strictly controlled in the Netherlands. Every hectare in the country is under some land use plan. The key to public control of land use is the right of expropriation, as formalized in the Expropriation Act, which gives the municipality the power to designate land for future development and subsequently provides for compulsory purchase of such lands.

There are three levels of government in the Netherlands, and all play a role in the planning process. An overall national plan recognizes and mandates specific uses of land. Communities are responsible for providing the planning details and plan implementation, but such plans must conform to the overall national plan. Plans formulated by the communities must first be approved at the provincial level and then approved at the national level. The provinces, however, have no legislative power in land use; they only provide an advisory and review function. The first national plan was formulated about 50 years ago. In 1965 a new law, separate for housing and community planning, emphasized the role of municipalities in the planning process, although the national development plans still are overriding.

In its local expansion plan to meet the demands for new growth, a municipality will designate certain adjoining undeveloped land (in almost all cases, land now in agricultural use) as tracts suitable for development.

It may acquire those lands once the plan has been approved by the provincial authority and by the Crown (through the Minister of Housing and Physical Planning in the federal government). When the lands cannot be purchased by mutual agreement between the landowner and the municipality, a judge issues an expropriative order and decides what compensation shall be paid by the municipality to the landowner. In this way, land is acquired for new development for any purpose (housing, commercial or industrial uses, highways, recreation areas) and development can take place only on such appropriated lands. Once the land has been acquired, it is then made ripe for development by the municipality. The relatively heavy layers of top soil and peat must be removed and the site covered by a layer of sand. A sand and water slurry is pumped to the site. Often the sand has been recovered from the North Sea. This is a very expensive operation, so only comparatively large tracts are prepared. Usually, only the government can afford such undertakings. After the sand has drained of excess water, it is leveled and streets, sewers, waterworks, canals, bridges, roads, and other utilities are constructed by the municipality.

Because of the swampy nature of the soil, virtually all buildings have to be constructed on piles. Also, throughout much of the southwestern portion of the country, bedrock is 3000 m (9800 ft) below the surface. Piles are usually 6 to 12 m (20 to 40 ft) in length, all within the sand layer. Thus, the cost of site preparation, even for single-family houses, is extremely high. This is why about ⅔ of the cost of most housing, which is high-rise apartments or row condominiums, is subsidized by public funds.

Building sites prepared by municipalities are not sold to developers or private landowners, but are rented under long-term lease arrangements. The long-term lease system was introduced in Amsterdam in 1896. A system of perpetual leaseholds was introduced for private residences in 1915. A system of moving leasehold terms for industrial sites was introduced in 1937, but in 1966 this was changed to a system of perpetual leaseholds.

The costs of making the land ripe for development are shared among the individual building sites according to the use assigned each of these sites in the development plan. A ground rent on a particular site is then levied by the municipality; this rent is fixed at from 4 to 6 percent of the cost of site preparation. Ground rents are adjusted every 5 years to correct for changes in land values, and at the end of each term of the long lease agreement (50 years) adjustments in ground rent are made to reflect changes in the real value of land.

Under the procedures outlined above, the government exercises very close control over the kind and location of various land use activities. Because municipalities purchase and prepare all tracts for future developmental needs, there is virtually no land speculation in the Netherlands. Speculative interest in land is further discouraged by the fact that the municipality, when purchasing land previously designated on the approval extension plan as land for future development, pays to the landowner a price only slightly higher than the present value of agricultural land.

Municipal capital funds for land acquisition and site preparation come largely from bank loans, which are guaranteed by the federal government. Such loans are generally made at normal market interest rates. The municipality recoups the principal of the loan over time and is able to meet interest charges through the ground rents it subsequently collects and through taxes. Ground rents are determined by the costs the municipality has absorbed in land acquisition and preparation, giving the municipality the flexibility to establish ground rents sufficient to meet its loan obligations. Moreover, increases in the value of land resulting from both inflationary forces and the interaction of supply and demand determine, over the long run, future ground rents. Thus, over time, the municipality, not the private landowner, captures the benefits of public improvements capitalized into land values.

Most of the Dutch do not consider the procedure of state-mandated and approved planning, expropriation of land and subsequent site development, and lack of private land ownership to be socialistic. There are perhaps two reasons for this. First, the process is not strongly tied to politics. Seldom is it a political issue at the national or provincial level. At the local or municipal level, some long range plans may have political overtones and thus indirectly contribute to the election or defeat of present or aspiring council members. But the usual ongoing planning decisions of housing, commercial, or industrial expansion seldom become political issues.

Second, the Dutch have a long history of government intervention in land development. In fact, without government involvement in seawall and canal construction and subsequent draining and preparation of polder lands, the country could not have been developed. Moreover, a large population, dependent for survival over a long time upon a very limited land resource base, could not have maintained itself in the absence of strong public authority and intervention in land use decisions.

LAND USE AND HIGHWAYS

Highway planning in the Netherlands is incorporated into and becomes an integral part of the overall planning process. At the national level, the Ministry of Transport provides two basic kinds of plans: a structure plan, which covers 30 to 40 years into the future, and a national plan. The second national plan was formulated in 1966; the third came out in 1977. Each national plan, which resembles more a program of development efforts, contains a structure plan. Until the last national plan, highways were included in a structure plan.

The Ministry of Transport may designate a highway between two cities in a national plan. Such a future highway must then be incorporated into the plans of each municipality and province, and together with the other community needs and extensions comprise the comprehensive plans for the communities. Thus national highway planning gets integrated into urban and regional planning at an early stage and there are no surprises at the local level. The corridors for primary national highways are designated by the Ministry of Transport at the national level, but more precise alignments are left to the discretion of the municipalities, subject to final approval by the province and the state. There is no legal basis for public participation in the highway planning process, nor are environmental impact statements required.

Although the public has no legal way to stop highway planning or construction, such as recourse to the courts as used in this country, conflicts and disagreements do arise and must be resolved. For example, residents in a municipality may object to a certain highway corridor as suggested in the national plan. Since municipal plans must be approved by the municipal council, members of which are locally elected, and since most council members are aware of the opinions and desires of their constituents, voting at the local level is not disassociated from local issues, of which highway planning is one. If the council will not accept a highway plan formulated by the local planning agency in conformance with the plans as handed down from the national level, then a locally

acceptable plan is prepared. But the new, locally acceptable plan, in turn, must be approved by the provincial and national governments. The new municipal plan, however, may not conform to other national goals, such as containment of growth, saving agricultural land, or location and provision of public utilities, and so the national government may reject the municipal plans. In this case, then, an appeal is made to the Crown to settle the dispute.

The hearing or adjudicating body that handles such appeals is the State Council, which is really an administrative court. Their decisions are generally binding. At the present time there are about 4000 plans awaiting decision by the State Council, only some of which involve highway planning disputes.

Once highways are opened for use, the same planning process and land use constraints exist for abutting or nearby lands as exist for all other lands. It does not appear, however, that very much explicit attention has been directed toward ameliorating adverse highway effects through controlling land use, or enhancing the positive effects. The long existing strict controls on development and its spatial dimension would in and of itself prevent the patterns of roadside development we so commonly find in the United States. In the Netherlands there is no strip development as we know it. There are very strict access controls to all roads and highways, although at times political pressure does get some changes and exceptions made. But one finds virtually no motels, quick food service establishments, or other businesses catering to motorists' needs along the Dutch highways. Service stations are far less numerous than in the United States (preponderance of small cars and lower commuting and travel distances required would contribute to this). At major highway interchanges, one is as apt to see cows as high-rise apartments. Large shopping centers or malls are just now becoming popular.

One of the principal beneficial effects of highways in the United States is the increase in land value caused by improved accessibility. In the Netherlands, land value appreciates from improved accessibility, but the private sector does not benefit, because all development land is expropriated by the municipality. The shifting of such economic incentives from the private to the public sector has removed much of the pressure, both speculative and real, for unplanned and uncoordinated development of a multitude of land use activities near highways.

For some time, a law has been in effect preventing building within 100 m (328 ft) of the edge of expropriation lands, although in certain circumstances exceptions are granted. A gentleman's agreement prevents the construction of structures closer than 200 m (656 ft) to the center of the highway. There are no billboards in the Netherlands. The government purchases land adjacent to the highway for landscaping purposes.

There is no noise legislation in the Netherlands at present, although such a law is now under consideration. This law, if adopted as now written, would establish norms for different land uses. The noise level within a residential structure could be no greater than 35 dB(A), and noise outdoors in residential areas should be no more than 55 dB(A). The indoor norm would have to be satisfied, but the outdoor noise level norm is only suggested, but one must have good reasons not to satisfy it. Structures to alleviate highway noise within heavily developed areas are being planned, but none have been installed to date.

PLANNING EFFECTIVENESS AND GOAL ACHIEVEMENT

The moderate effectiveness in coordinating highway development and land use activities to minimize adverse effects and enhance beneficial effects of highways has come about more as an indirect result of the intensive overall land use planning process than through specific controls designed for such purposes. For example, residential land uses are not excluded from sites adjoining the highway, and in redevelopment of downtown areas can be right next to the right-of-way. The 100-m restrictions in new expansion lands on the urban periphery are more for aesthetic purposes than to ameliorate the effects of air and noise pollutants. The rigid access controls and land development controls, however, have been highly effective in preventing unsightly strip development and preventing a gradual reduction in traffic flows and capacity. Public expropriation of land, however, has effectively denied one major beneficial effect from highways, that of the capture of land value appreciation by the private sector, but at the same time has probably enabled a wider segment of the populace to benefit from improved accessibility.

The Dutch approach to controlling land use does not appear to be applicable to the United States at this time. The extremely strong and long-held beliefs of the American people in the desirability and right of private land ownership would make the current land use planning and control techniques of the Netherlands unacceptable. Most American landowners cherish their rights in land and adamantly oppose strong governmental intervention. The ability of the Netherlands' municipalities to expropriate land from private ownership, make it ripe for development, retain ownership into perpetuity, and insist that all new development can only take place on such expropriated lands seems far beyond fiscal, social, political, and legal reality in the United States. Fiscally, over the long run, such a program is probably self-amortizing, but Americans lack the legislative or institutional framework to launch such programs.

Although a direct cause and effect relationship between the spatial distribution of land use activity and the strict approach to land use planning and control in the Netherlands seems to be apparent, it is interesting to speculate whether such a pattern of land use is caused by strict land use controls or whether it might also be due in part to economic factors. When one considers that agricultural land, because of its high productivity, is worth about \$1600/hectare (\$4000/acre), the high cost of land preparation through removal of topsoil and replacement with sand, and the cost of piling, which alone represents about ⅓ the cost of a house, high density becomes necessary in order to recover costs. The cost of a single family home on an individual lot becomes prohibitive for all but the very wealthy. In the absence of the economic constraints surrounding new development, the Netherlands system of land use controls might not be as effective as it now appears to be.

Overall, the Dutch have achieved remarkable success in controlling the use of a very scarce and valuable resource—land. There is no idle land, no waste land, and no urban sprawl such as we know. The Dutch realize that if they are to survive and prosper in a modern age they must exercise strict control over how their land resource is to be used. The land must be used in a manner most beneficial to the community and to society, and not necessarily in a manner most rewarding to the interest of a private landowner. Over time a system has evolved that achieves this goal to a remarkable degree, a system based on integrated multijurisdictional planning, strong municipal authority, and economic realities.

This achievement, however, has had some trade-off costs to the individual. Full land ownership rights are

not possible for most Dutch citizens. Consequently, the gains to wealth originating from appreciation of land values are largely constricted in the Netherlands. Only the very wealthy can own a home on an individual lot. One must balance such restriction of freedom in private land ownership against the situation that might have evolved over the years had there been no such restrictions. Basically, what is involved is the trade-off of one kind of freedom for another kind of freedom. The loss of freedom of land ownership for the majority has probably meant a more stable economic and social system for the nation as a whole—hence higher national output and total personal income, a higher standard of living for the majority, and freedom from economic want.

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The Effects of Urban Structure on Automobile Ownership and Journey to Work Mode Choices

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This study documents an investigation of the effects on automobile ownership and use of intermetropolitan differences in transit and highway service levels and overall urban development patterns. Specifically, we present models of the determinants of automobile ownership and mode choice for 163 488 white, single-worker households from the largest 125 standard metropolitan statistical areas in 1970. Indexes of highway capacity, transit service levels, and overall residential density for each area as well as each household's socioeconomic characteristics, workplace location, and residence choice, are used to explain the number of automobiles owned by each household, and, given that, each household's work trip mode (automobile driver; automobile, bus, or rail passenger; or walking). The models offer a framework for considering the effect of alternative urban development scenarios on automobile ownership and use, and for comparing alternative development and infrastructure policy options. Because the models were estimated using households from different areas, they are particularly appropriate for investigating changes in spatial structure.

Forecasts of automobile ownership and use are crucial inputs to the transportation planning process. Attempts to model these decisions based on disaggregate probabilistic techniques have recently received much interest. Typically, these studies focus on a particular metropolitan area, take each individual's workplace and residence zone as fixed, and characterize the ownership or use decision as dependent on various socioeconomic factors and the costs of alternative modes of travel.

This study has a similar approach in its disaggregate probabilistic framework and in its selection of variables that influence the ownership and use decisions. The analysis, however, addresses a range of questions that studies of a single metropolitan area are not designed to answer, such as how the overall arrangement of land uses (the density, location, and juxtaposition of workplaces and residences, in combination with the transit and highway systems serving them) affect the level of automobile ownership and mode choices of urban households.

Statistical studies of a single metropolitan area cannot capture or quantify the effects of the overall spatial structure and transportation systems on automobile ownership and travel behavior. However, these aggregate effects are required to evaluate the effects of major transportation investments or of extensive changes in land use patterns. A household whose sole or primary wage earner works in Manhattan must choose from a different set of housing and mobility choices than an otherwise identical household whose primary wage earner is employed in the suburban New York area, in the Phoenix central business district (CBD), or at a suburban workplace in Phoenix.

MODEL OVERVIEW

The analyses presented in this report consider the determinants of two interrelated decisions: (a) the number of automobiles each household owns and (b) the modes of travel employed members of the household use to commute to work. The statistical model employs a three-stage method of estimation that analyzes automobile ownership and modal choice decisions of urban households within a recursive model structure. The procedure first estimates the expected probabilities of owning zero, one, or more than one automobile based on the socioeconomic demographic characteristics of the sample households. Similarly, we obtain estimates of the expected probability that households in each automobile ownership class use each mode, again based solely on socioeconomic demographic characteristics.

The second stage of the analysis incorporates the

estimated expected probabilities of owning zero, one, or more than one automobile (obtained from the first-stage national probability model) into a multivariate linear probability model of automobile ownership. The six equations of the automobile ownership model consider (a) whether the employed household member works in the CBD, (b) the location and other characteristics of the household's residence, (c) a series of variables that quantify the principal aspects of urban spatial structure of the 125 metropolitan areas included in the study, and (d) several measures of the extent and quality of the competing transportation modes available in each standard metropolitan statistical area (SMSA). Estimates of independent effects of each type of variable are obtained by using a multivariate linear probability model. The automobile ownership and modal choice equations presented in this report are estimated by ordinary least squares (OLS).

The third stage is similar to the second except that the dependent variables are the probabilities that the employed household member commutes to work as an automobile driver; an automobile, a bus, or a rail passenger; or by walking. The conceptual framework requires a separate modal choice equation for each of three levels of automobile ownership, for each of three workplace locations, and for each of five modes. Stratification of the mode choice equations by both workplace and automobile ownership reflects the recursive or conditional nature of the model. Each equation evaluates the independent effects of the several household characteristics, of residence location, of the overall measure of urban spatial structure, and of the measures of urban transportation supply on the household's modal choice, given its workplace and automobile ownership. Equations 1 through 4 provide a compact description of the three-stage model used in this study.

<u>Stage 1</u>

$$\hat{A}_i^n = H_i \qquad (1)$$

$$\hat{M}_i^m = (H_i, A_i^n) \qquad (2)$$

where

$\hat{A}_i^n$ = expected probability of owning n automobiles,
$\hat{M}_i^m$ = expected probability of using mode m,
H_i = a vector of household characteristics consisting of race of head, number of employed workers, family size, age of head, and household income, and
i = sample households.

<u>Stage 2</u>

$$A_{ij}^n = (\hat{A}_i^n, R_i, W_i, U_j, T_j) \qquad (3)$$

where

A_{ij}^n = the probability of owning n automobiles,
R_i = vector of dummy variables depicting residence occupied by the ith household,
W_i = vector of dummy variables describing workplace location of the ith household,
U_j = vector of variables intended to describe the overall urban structure of each of the 125 sample metropolitan areas, and
T_j = vector of variables describing the characteristics of the competing transport modes in the 125 metropolitan areas.

<u>Stage 3</u>

$$M_{ij}^m = (\hat{M}_i^m, R_i, W_i, U_j, T_j) \qquad (4)$$

where M_{ij}^m = the probability of using mode m.

NATIONAL PROBABILITY MODELS

The national probability model used to estimate the proportion of white, single-worker households owning no automobiles is displayed in Table 1. Identically structured models were used to estimate the proportion of one- and multi-automobile households. The family size and age of household head dimensions represent differences in automobile ownership preferences. Economic theory and a large number of previous studies also indicate that household income has a large independent effect on automobile ownership and modal choice.

Careful examination of the three national probability models reveals that all three variables have an important independent influence on the probability of owning a specific number of automobiles. For each family size and age of head category, the probability of owning at least one automobile increases with income. When income and family size are held constant, the proportion of households owning at least one automobile tends to be greatest for those households whose heads are younger than 35 years of age and lowest for those whose heads are older than 65 years of age.

In the first stage of the modal choice analysis we estimate the proportion of workers choosing a particular mode. The sample used to make the estimates is only 151 059 households rather than the 163 488 used in the

Table 1. National probability model: proportion of households owning no automobiles by family size, age of head, and income.

Family Size	Age of Head	Income ($000s/year) 0	0 to 2	2 to 4	4 to 6	6 to 8	8 to 10	10 to 12	12 to 15	15 to 25	25+
1	Under 35	0.35	0.39	0.33	0.27	0.21	0.18	0.11	0.14	0.15	0.12
	35 to 65	0.43	0.48	0.47	0.40	0.32	0.25	0.20	0.15	0.14	0.13
	65+	0.50	0.63	0.56	0.49	0.46	0.35	0.36	0.26	0.26	0.31
2	Under 35	0.27	0.25	0.18	0.17	0.11	0.08	0.06	0.04	0.02	0.03
	35 to 65	0.22	0.26	0.26	0.22	0.15	0.10	0.06	0.04	0.03	0.03
	65+	0.37	0.43	0.29	0.25	0.21	0.17	0.14	0.11	0.08	0.06
3	Under 35	0.25	0.24	0.18	0.12	0.07	0.04	0.03	0.02	0.02	0.05
	35 to 65	0.15	0.20	0.24	0.19	0.13	0.08	0.05	0.03	0.02	0.01
	65+	0.39	0.37	0.29	0.28	0.21	0.19	0.15	0.10	0.06	0.06
4	Under 35	0.20	0.15	0.18	0.12	0.06	0.02	0.02	0.01	0.01	0.02
	35 to 65	0.11	0.16	0.23	0.17	0.10	0.05	0.03	0.02	0.01	0.01
	65+	—	0.44	0.18	0.27	0.21	0.17	0.17	0.11	0.10	0.00
5+	Under 35	0.26	0.16	0.20	0.16	0.08	0.04	0.02	0.01	0.01	0.01
	35 to 65	0.20	0.19	0.24	0.18	0.10	0.05	0.03	0.01	0.01	0.00
	65+	—	0.45	0.41	0.21	0.22	0.15	0.05	0.00	0.03	0.08

calculations of automobile ownership probabilities. The discrepancy between the two samples is caused by households that have a member of the labor force who was unemployed, worked at home, or did not report the mode used to commute to work.

Fifteen national probability models were used to predict the proportion of zero-, one-, and more than one-automobile households driving an automobile to work; commuting to work as automobile, rail, or bus passengers; or walking to work. By far the most striking feature of the national probability models for modal choice is the importance of automobile ownership stratification. Households that have no automobiles are the principal users of the bus, rail, and walking modes. In contrast, one-automobile households, for the most part, use one of the automobile modes. The automobile driver mode is almost universally chosen by households that have at least two automobiles available.

There are subtle but important systematic variations within automobile ownership categories, which are correlated with income, age of head, and household size classifications. For example, the proportion of those walking to work from households that have no automobiles tends to decline as their incomes increase. Automobileless households tend to make more use of the two transit modes (bus and rail) as their incomes rise.

Labor force members from households whose heads are aged 65 or older are less likely to commute to work by automobile and are more likely to use some form of public transit. Between the two transit modes, they are more likely to use bus than otherwise similar households whose heads are younger. These findings may be the result of a tendency for households whose heads are older to be in older and more dense neighborhoods, which have especially good bus service. Family size also influences modal choice: When one automobile is available, larger households tend to make a smaller proportion of automobile driver trips and a larger proportion of automobile passenger trips.

The national probability model results are interesting in their own right. The determination of how household characteristics are related to automobile ownership and use for SMSAs as a whole is an important first step in understanding how intermetropolitan variations in land use and transportation supply affect automobile ownership and modal choice decisions. In addition, national probability models provide estimation efficiencies in two ways:

1. The prediction, when used as an independent variable, replaces 149 dummy variables that would be required to represent an equally complex interaction structure; such a problem would be expensive to solve through computation.
2. The remaining explanatory variables are discrete categorical variables: households are classified by workplace, residence type, and SMSA location.

In a single pass of the household microdata tape, we can sort households by class to produce actual and predicted values of the appropriate dependent variable. SMSA-specific variables can be tested by fitting regression lines using the cells of the classification scheme as observations, weighted by the number of households contained in each cell.

Regression runs on grouped data, using a much smaller number of independent variables, produce large efficiencies in fitting the multivariate linear probability models of automobile ownership and mode choice at the cost of a somewhat restrictive model specification. Specifically, we cannot incorporate interaction effects among individual household variables and the remaining variables included in the models. Obviously we consider the price worth paying.

Second Stage Model

The multivariate linear probability models of automobile ownership in this section were estimated using a sample of 124 050 households. The sample excludes approximately 25 percent of the households that were represented in the national probability models because data describing transit and highway systems were incomplete. Table 2 gives estimates of the probability of a household owning zero, one, or two or more automobiles as a function of (a) an expected probability computed from the national probability model; (b) the workplace location of the household's employed member; (c) certain characteristics of the household's residence; (d) the level of highway and transit service prevailing in the SMSA where the household resides;

Table 2. Regression results for automobile ownership categories.

Item	Automobile Probability if CBD Workplace (n = 12 820)			Automobile Probability if Other Area Workplace (n = 113 749)		
	0	1	2 or more	0	1	2 or more
Constant	+0.26^a	-0.13^a	+0.13^a	+0.19^a	-0.08^a	+0.16^a
Expected probability	+1.16^a	+0.69^a	+0.77^a	+0.60^a	+0.89^a	+0.80^a
Residence type						
Built 1960 to 1970						
1 to 4 units	-0.07^a	+0.26^a	-0.21^a	-0.01^a	+0.17^a	-0.15^a
5 to 19 units	-0.07^a	+0.25^a	-0.21^a	-0.02^a	+0.20^a	-0.18^a
20+ units	+0.06^a	+0.13^a	-0.24^a	+0.02^a	+0.17^a	-0.18^a
Built 1940 to 1960						
Single family	-0.02^a	+0.10^a	-0.09^a	-0.01^a	+0.07^a	-0.16^a
1 to 4 units	+0.01^c	+0.21^a	-0.26^a	+0.03^a	+0.19^a	-0.22^a
5 to 19 units	+0.09^a	+0.09^a	-0.24^a	+0.06^a	+0.17^a	-0.22^a
20+ units	+0.16^a	+0.01	-0.23^a	+0.14^a	+0.10^a	-0.22^a
Built before 1940						
Single family	-0.00	+0.15^a	-0.17^a	+0.02^a	+0.13^a	-0.13^a
1 to 4 units	+0.07^a	+0.13^a	-0.25^a	+0.11^a	+0.14^a	-0.24^a
5 to 19 units	+0.25^a	-0.11^a	-0.22^a	+0.25^a	-0.01^a	-0.22^a
20+ units	+0.25^a	-0.11^a	-0.21^a	+0.34^a	-0.10^a	-0.21^a
Mobile home	-0.10^a	+0.22^a	-0.16^a	-0.02^a	+0.16^a	-0.13^a
Single family (%)	-0.41^a	+0.25^a	+0.15^a	-0.28^a	+0.09^a	+0.19^a
Rapid rail available	+0.04^a	+0.07^a	-0.09^a	+0.03^a	+0.01^a	-0.04^a
Highway route miles/mile^2	-0.18^a	0.09	+0.18	-0.14^a	-0.05^a	+0.20^a
Bus vehicle miles/central city population	-0.02	+0.05^a	-0.03^a	-0.03^a	-0.03^a	+0.00^a
R^2	0.79	0.32	0.73	0.80	0.56	0.85

Notes: The above was done in U.S. customary units; therefore, no SI units are given.
Superscripts indicate statistical significance levels (a = 0.01, b = 0.05, c = 0.10).

and (e) the average density of the county or county group where the household resides.

As is evident from Table 2, our model specification requires six equations for workers employed in the CBD and three for workers employed outside of the CBD. The decision to estimate separate equations for CBD and non-CBD workplaces reflects our conviction that workplace and residence choices are important influences in household decisions to own a certain number of automobiles and to use a certain mode to commute to work. The CBD versus non-CBD distinction reflects large differences in the extent and quality of transit services serving the workplaces located in these areas. In subsequent analyses we plan to explore the roles of workplace location and differential transportation access to the workplace in more detail, as well as disaggregate other workplace locations into central city outside the CBD and the suburban ring of each SMSA.

All six automobile ownership probability models explain a large part of the variance in their dependent variables (Table 3); ranging from 32 percent for the equation that explains the probability of CBD workers owning one automobile to 85 percent for the equation that explains the proportion of non-CBD workers owning at least two automobiles. All but a small fraction of the individual regression coefficients are significant at the 1 percent level and have signs that are consistent with our a priori expectations. Stratification by workplace does not add substantially to the explanatory power, but individual coefficients are significantly different across workplaces. Moreover, given the recursive structure of the overall model and the importance of the stratification to the mode choice equations, the stratification for automobile ownership equations is useful and important.

Table 3. Analysis of variance of the overall multivariate linear models of automobile ownership.

	Probability					
	No Automobile		One Automobile		Two or More Automobiles	
Item	n	%	n	%	n	%
Total sum of squares	3973		3164		5418	
Variation explained by stratification by workplace	244	6	67	2	55	1
Variation explained by regressions	2972	75	1576	50	4492	83
Variation unexplained	757	19	1521	48	921	16

Overall Model of Modal Choice

The multivariate linear probability model of mode choice consists of 45 equations estimated by OLS. The specifications of the modal choice equations are similar to those used to estimate the multivariate linear probability models of automobile ownership, except: (a) The expected probability of owning zero, one, or two or more automobiles used in the automobile ownership equations is replaced by the expected probability of using the appropriate travel mode; (b) the number of automobiles owned by the household is added to the model and is used to stratify the sample. Separate mode choice equations are calculated for each level of automobile ownership; and (c) the sample is stratified by workplace [CBD, central city (CC), and suburbs] instead of the two used for the automobile ownership analysis. Table 4 displays results of the six equations used to predict automobile driver and automobile passenger commutes for households that have more than one automobile available.

Table 5 gives summary statistics for the multivariate linear probability models of mode choice. The first row in the table gives the sum of the squared deviations from the overall sample mean proportion using each mode for the entire sample of 124 050 households. For each mode, the total sum of squares is the yardstick against which to measure the performance of our multivariate linear probability model. The R^2, or coefficient of determination, is the proportion of total variance explained by the model and measures how well we have done.

The importance of the sample stratification by workplace and automobile ownership levels is clear from

Table 4. Multivariate linear probability models of mode choice for automobile driver and automobile passenger trips for households owning two or more automobiles.

	Probability of Automobile Driver Commute			Probability of Automobile Passenger Commute		
	Workplace			Workplace		
Item	CBD (n = 3376)	CC (n = 16 907)	Other n = 20 331)	CBD (n = 3376)	CC (n = 16 907)	Other (n = 20 331)
Constant	+0.19	+1.03[a]	+0.90[a]	+0.01	-0.03[a]	+0.01[a]
Expected probability	+0.90[a]	-0.08[a]	+0.02	+0.82[a]	+0.80[a]	+0.84[a]
Residence type						
Single family						
Built 1940 to 1960	+0.01	-0.01[a]	-0.01[a]	-0.02[a]	+0.00[a]	+0.00[a]
Built before 1940	+0.01	-0.04[a]	-0.05[a]	-0.02[a]	+0.01[a]	+0.01[a]
1 to 4 units						
Built 1960 to 1970	+0.07[a]	-0.02[a]	+0.01	-0.00	+0.00	+0.00
Built 1940 to 1960	+0.02	-0.03[a]	-0.03[a]	-0.02	+0.02[a]	+0.01[a]
Built before 1940	-0.03[c]	-0.06[a]	-0.04[a]	-0.01	+0.02[a]	+0.01[a]
5 to 19 units						
Built 1960 to 1970	-0.05[c]	-0.00	+0.00	+0.01	-0.00	-0.00[c]
Built 1940 to 1960	+0.02	-0.08[a]	-0.02[a]	-0.06[a]	-0.01[c]	+0.00
Built before 1940	-0.25[a]	-0.11[a]	-0.09[a]	-0.06[a]	-0.02[a]	+0.00
20+ units						
Built 1960 to 1970	-0.00	-0.03[a]	-0.05[a]	+0.01	-0.00	+0.02[a]
Built 1940 to 1960	-0.04	-0.08[a]	-0.02[a]	-0.03	-0.00	-0.00
Built before 1940	-0.09[b]	-0.34[a]	-0.10[a]	-0.06[a]	+0.08[a]	-0.01
Mobile homes	+0.00	-0.04[a]	-0.01[c]	-0.02	+0.01[a]	+0.01[b]
Rapid rail available	-0.44[a]	-0.10[a]	+0.01[a]	-0.01	+0.01[a]	-0.01[a]
Bus vehicle miles/central city population	-0.08[a]	-0.01[c]	-0.01[a]	+0.01[b]	+0.01[a]	-0.01[a]
Highway route miles/mile^2	-0.15[a]	-0.02	+0.10[a]	-0.00	+0.04[a]	-0.06[a]
Proportion single family	-0.12[a]	-0.02[a]	+0.00	+0.02	+0.03[a]	-0.00
R^2	0.50	0.22	0.06	0.02	0.04	0.05

Notes: The above was done in U.S. customary units; therefore, no SI units are given.
Superscripts indicate statistical significance levels (a = 0.01, b = 0.05, c = 0.10).

Table 5. Analysis of variance of the overall multivariate linear probability models of mode choice.

Item	Automobile Driver n	%	Passenger Auto-mobile n	%	Bus n	%	Rail n	%	Walking n	%
Total sum of squares	10 916		1241		2853		3022		1365	
Variation explained by stratification	8 544	78	225	18	1510	53	799	26	453	33
Variation explained by regressions	898	8	132	11	327	11	1567	52	178	13
Variation unexplained	1 474	14	884	71	1016	36	656	22	734	54

the second row in Table 5, which is the amount of variance explained by the stratification. The fifth row provides this information as a percentage of the overall sum of squares. In the case of automobile drivers, for example, the workplace and automobile ownership stratifications explain 78 percent of the total variance in the probability of commuting to work as an automobile driver. The percentage of variance explained by stratification is largest for the automobile driver mode and smallest for the automobile passenger mode.

The overall explanatory power of the multivariate linear probability model of mode choice is, however, given by the combined total of the variances explained by stratification and by the 45 regression equations. As the sixth row in Table 5 indicates, the share of total variance explained by the nine regression equations for each mode varies from a low of 8 percent for automobile driver trips to a high of 52 percent for rail passenger trips.

The share of total sample variance explained by the nine mode choice regression equations as a whole should not be confused with the explained variance of coefficient of determination (R^2) for the 45 individual regression equations presented in Table 6. The explanatory power of individual equations varies widely from 2 percent for the probability of automobile passenger trips by CBD workers who have at least two automobiles available, to 78 percent for the probability that CC workers will commute by rail if they do not own an automobile.

The statistics summarized in Table 6 cannot be compared directly to those in Table 5 because different means are used to calculate the variances. The sums of squares presented in Table 5 are all computed using the overall sample means, but the coefficients of determination in Table 6 refer to the variances of each of the nine workplace-automobile ownership samples, which are computed using the means of each of the nine samples. The individual regression equations explain the total variance that remains after stratification. This statistic, which is given in the fourth row in Table 5, is only 14 percent of the original sample variances in the case of automobile drivers, but 71 percent of a much smaller total variance in the case of automobile passengers. One interesting observation is that the proportion of total variance explained by our entire multivariate linear probability model, including both the stratification and the nine regressions for each mode, increases with the aggregate size of the total sum of squares.

As Table 6 illustrates, the fit of the individual mode choice equations varies widely. The lowest R^2, 0.02, applies to the probability of multiple-automobile, CBD workers commuting to work as automobile passengers and the highest, 0.78, applies to the probability of CC workers who do not own automobiles commuting to work by rail. The final row in the table provides a summary measure of how well the equations for each mode as a group explain whatever variance remained after strati-

Table 6. Percent of variance explained by individual multivariate linear probability models of mode choice.

Number of Automobiles and Workplace	Automobile Driver	Passenger Automobile	Bus	Rail	Walking
0					
CBD	8	18	44	67	31
CC	24	31	20	78	20
Suburb	17	7	11	48	13
1					
CBD	57	9	20	77	15
CC	47	5	20	65	25
Suburb	10	4	14	28	15
2+					
CBD	50	2	13	67	8
CC	22	4	10	43	16
Suburb	6	5	3	22	9
Weighted average	38	13	24	70	20

fication. According to this summary statistic, the nine regressions for the rail passenger mode had the most overall success: In combination they explained 70 percent of the variance in the probability of using rail transit that remained after stratification by workplace location and automobile ownership. The nine automobile passenger equations were least successful using this criterion; they explained only 13 percent of the total sample variance that remained after stratification. The overall success of the rail passenger equations is not particularly surprising and is undoubtedly due to the explanatory power of the rail transit dummy, which distinguishes SMSAs that have extensive rapid transit systems.

PREDICTIONS

To demonstrate the potential use of the model as a tool for policy analysis, we made a few sample predictions of household automobile ownership and modal choice decisions for a typical household in Boston and in Phoenix. The two cities have widely different urban spatial structures and transportation systems: Boston is an older, denser, automobile-oriented city and has a well-developed public transportation system; Phoenix is a newer, more sprawling, automobile-oriented metropolitan area. Our predictions illustrate how a household's residence and workplace orientation within the two metropolitan areas affect decisions about automobile ownership and mode choice, as well as the way these decisions are influenced by differences in overall spatial structure and the general character of the transportation systems. At least one use of our model for policy analysis is to examine how alternative forms of urban development affect automobile ownership and transportation use. The model is capable, moreover, of assessing the independent effects of changes in the spatial distributions of residences and jobs within each metropolitan area, as well as changes in SMSA development patterns and transport infrastructure.

Table 7. Predicted probabilities of owning zero or more than two automobiles by workplace and type of residence.

Number of Automobiles	Residence Type	Workplace CBD Boston	CBD Phoenix	Non-CBD Boston	Non-CBD Phoenix
0	Single family built 1960 to 1970	0.09	0.02	0.06	0.00
	20+ units built before 1940	0.34	0.27	0.40	0.34
2+	Single family built 1960 to 1970	0.50	0.64	0.64	0.71
	20+ units built before 1940	0.29	0.42	0.43	0.50

Table 7 gives the expected probabilities for a typical white, single-worker Boston or Phoenix household, whose worker is employed inside or outside the CBD. The age of the head of household is 35 to 64 years and the annual income is in the $10 000 to $12 000 range. In evaluating these data, note that single-family units built between 1960 and 1970 accounted for 29 percent of Phoenix's houses in 1970; structures of more than 20 units built before 1940 were only a negligible portion at that time. Similarly, single-family units built between 1960 and 1970 were 13 percent of the sample Boston households in 1970, and structures of more than 20 units built before 1940 constitute 3 percent of Boston's houses in 1970.

Table 7 reveals important differences in the probabilities that comparable Boston and Phoenix households would own zero or two or more automobiles. Estimates indicate that a Boston worker employed in the CBD and residing in a new single-family home would have a 0.50 probability of owning two or more automobiles; the same probability for a comparable Phoenix worker would be 0.64. A Boston worker employed outside the CBD and living in a new single-family home would have the same probability of owning two or more automobiles as an otherwise identical Phoenix resident employed in the CBD. This same Boston worker would, however, have a considerably lower probability of owning two or more automobiles than a comparable Phoenix worker who is employed outside the CBD.

Comparison between the estimates for residents of new single-family and old multifamily units, also shown in Table 7, illustrates how residential choices of urban households have a major influence on automobile ownership levels. Differences in structure type and its age have a large effect on automobile ownership levels in both SMSAs. For example, the probability of a typical Boston CBD worker owning two or more automobiles is 0.50 if she or he chooses a new single-family unit, but only 0.29 if the same worker lives in a structure with 20 or more units built before 1940. For Phoenix, the comparable probabilities are 0.64 and 0.42.

These calculations clearly demonstrate that for the household's workplace location, the type of housing chosen, the level of transit and highway service available to workplace and residence, and overall SMSA density all have large impacts on the levels of automobile ownership. We now consider how these factors affect the journey to work mode choice of the employed member of these households. Our estimates were obtained by first solving the appropriate modal share equations for the predicted probability that a representative Boston or Phoenix household working in one of three workplaces and living in one of two types of residences would use each mode if it owned zero, one, or two or more automobiles. These conditional probabilities of using each mode for each level of automobile ownership are then multiplied by the probability that the representative household would own zero, one, or two or more automobiles, obtained from Table 7. The resulting values are then summed to provide the mode choice probabilities displayed in Table 8.

The predicted probabilities of using alternative modes for the journey to work are remarkably consistent with our a priori expectations. The overall model predicts that 84 percent of Phoenix CBD workers who reside in new single-family units would commute to work as automobile drivers and that an additional 10 percent would be automobile passengers. Only 6 percent would use buses to reach work, and none would walk. The predicted probabilities based on Boston values of the explanatory variables are sharply different. Only 33 percent of Boston CBD workers who live in new single-family structures would commute to work as automobile drivers; another 6 percent would be automobile passengers. In contrast, 12 percent of such households would reach work as bus commuters and an additional 48 percent would arrive by rail.

The differences between the modal share estimated for Boston and Phoenix suburban workers are relatively modest. The model predicts that 85 percent of Boston's suburban workers that have the characteristics assumed for these comparisons would commute to work as automobile drivers, but 89 percent of the Phoenix suburban workers who possess the same characteristics would drive automobiles to work. Three percent of the sample Boston suburban workers would commute by rail and 2 percent would commute by bus. In Phoenix, 1 percent of comparable suburban workers would commute to work by mass transit.

Within each SMSA and workplace, differences in residence type also have the expected effects. For example, 76 percent of Boston's CC workers of the kind assumed for the analysis who live in new single-family units commute to work as automobile drivers. Only 34 percent of Boston CC workers who live in old multifamily structures, however, drive to work. The comparable

Table 8. Predicted probabilities of using alternative modes to work.

Residence Type	Travel Mode	Workplace CBD Boston	CBD Phoenix	CC Boston	CC Phoenix	Other Boston	Other Phoenix
Single family built 1960 to 1970	Automobile driver	0.334	0.844	0.761	0.906	0.852	0.894
	Automobile passenger	0.059	0.096	0.050	0.024	0.045	0.055
	Bus passenger	0.121	0.060	0.054	0.039	0.019	0.014
	Rail passenger	0.483	—	0.104	—	0.034	—
	Walk	0.000	0.000	0.009	0.000	0.002	0.001
20+ units built before 1940	Automobile driver	0.128	0.531	0.343	0.464	0.533	0.600
	Automobile passenger	0.018	0.050	0.092	0.073	0.051	0.079
	Bus passenger	0.240	0.242	0.234	0.214	0.134	0.152
	Rail passenger	0.530	—	0.162	—	0.114	—
	Walk	0.037	0.082	0.158	0.094	0.061	0.038

numbers for Phoenix workers are 91 percent of those CC workers residing in new single-family units and 46 percent of those in structures of more than 20 units built before 1940.

FUTURE MODEL DEVELOPMENT

A recursive model structure subsumes a number of important conceptual and theoretical questions. The household's choices of workplace location, residence location, automobile ownership, and mode to work might be made simultaneously; therefore, both the structure of the model and the estimation methods used should reflect this. We plan to develop models that analyze the interrelationships between residential choices and automobile ownership as well as models, like those considered here, that relate automobile ownership and modal choice.

Although our models capture the gross effects of transportation supply and urban form variables, their lack of precision is equally evident. They show the considerable importance of transit and highway service levels and variations in urban spatial structure in determining automobile ownership levels and the modal choices of urban households, but they also raise questions about the interrelationships between land use and transportation. We expect to consider these issues in the next phase of our research.

We also plan to extend the models described in this report, or improved versions of them, to households having no members in the labor force, multiple-worker households, and black households. The decision to estimate separate models for these households is based on the hypothesis that the land use and transportation variables have a different effect on the automobile ownership and mode choice decisions of households having different numbers of labor force members. We chose single-worker households for the first stage of the analysis (rather than households without a member in the labor force) because we wished to study both automobile ownership and the mode used to commute to work. We also anticipated that workplace location would have an important influence on both automobile ownership and modal choice, and decided to deal first with the choices of single-worker households before modeling the far more complex choices of multiple worker households. Finally, black single-worker households were excluded because previous research has shown that housing market discrimination and segregation have large impacts on the workplace location, residence location, and travel behavior of black households. These are issues of great research and policy significance; we therefore deferred the analysis of these questions to a time when we can accord them the careful attention they deserve.

Discussion

Anthony James Catanese, School of Architecture and Urban Planning, University of Wisconsin, Milwaukee

This analysis of national data from 1970 is a welcome addition to our base of empirical knowledge on urban structure and land use as related to the journey to work and modal choice. It develops precise national models of modal choice and automobile ownership.

The findings are not surprising. They show that the wealthier, suburban residents tend to live in newer, single-family homes and to have much higher levels of automobile ownership and automobile commuting than several other groups. This was expected from previous research and a priori. That the trend is strong is clear from the sample data, which used white, single worker, four-person households whose heads were aged 35 to 64 and had incomes of $10 000 to $14 000. In short, the policy analysis example discussed in the conclusions was a rather typical suburban group, and the results were predictable.

If good research is meant to raise more questions than it answers, this research is very good. It demonstrates that such models, at a large level of aggregation, can predict automobile ownership and modal choice as related to residence and workplace. The policy questions implied, however, are far more interesting. The paper states that the next level of research will delve into the roles of workplace location and transit accessibility and level of service as contributing factors. I suspect these will be a strong set of factors for urban structure and land use patterns. Similarly, the research may go into other groups not presently included, such as multiworker households, single-person households, and minority households, where we expect some variation to occur.

The policy questions raised and implied are most interesting. If these are the trends, and they do have application in a given urban region, what costs and benefits are implied? What are the economic consequences of this pattern of automobile ownership and modal choice? What variations can be determined from these findings in cities that have undertaken massive transit programs to change such patterns? And finally, what are the long-term prediction strengths of the model that may be useful to planners attempting to project trends in land use?

The obvious question to ask is, What effect, if any, have the post-1970 gasoline embargo and higher prices had on these patterns? A recent Southeastern Wisconsin Regional Planning Commission study used a questionnaire to measure this and found essentially no effects, yet other researchers have found significant effects and behavioral changes.

This research points out trends and conditions. We should remember, however, that such findings may reflect major problems that need change. Such an empirical basis should bolster our imagination and intuition as we seek new solutions to transportation problems and innovative planning for urban structure.

Anthony R. Tomazinis, Transportation Studies Center, University of Pennsylvania, Philadelphia

The paper presents essentially two models—one on automobile ownership and another on modal choice for home to work trips. The population considered is restricted to only white families that have only one worker per household from the 125 larger standard metropolitan statistical areas (SMSA) of the country in 1970. The automobile ownership model is developed in two steps. In the first step the authors divide the households in their study into 150 groups by separating them into 10 income groups and 5 family size groups. Each of the 50 groups is further divided into 3 groups according to the age of the head of the household. For each of the 150 groups, the researchers establish the proportion of households owning no automobile, one automobile, or two or more automobiles.

The sample population includes 164 000 households. The proportions of households owning zero, one, or two or more automobiles are first called by the authors the national probability model. Later the proportions are assigned to each household in each group as the expected probability of owning zero, one, or two or more automobiles. In the second step the model assumes the expected probability of each group on the national scale and tries to improve this estimate by correlating the actual automobile ownership of each group in each SMSA with variables that express the housing characteristics of each household, and other variables that express the availability of mass transit and highways in each city. In order to improve the accuracy of the model, the correlations are made separately for household by workplace. The second step of the model has six regressions (three by automobile ownership level and two according to the workplace of the head of household) and 17 independent variables.

The modal choice model has a similar structure. In the first step the households are stratified into 450 cells. The initial 150 types were further divided into three groups according to automobile ownership level. For each of the 450 groups the proportion of automobile driver; automobile, bus, and train passenger; and walker commuting trips is estimated (2250 proportions) on a national scale for the household included in the study. The second step improves the national scale modal split rates by introducing characteristics of each city and subdividing the total into three groups according to the workplace of the worker. The step involves the estimation of 45 regression equations, of 17 independent variables each, for the five modes of travel, the three levels of automobile ownership, and the three types of workplaces. The 17 variables are, again, descriptive of types of housing occupied by the household and of the availability of mass transit, rapid transit, and highways.

Major Characteristics

Three major characteristics of the models deserve attention:

1. The striking amount of stratification of households required and the number of proportions that need to be specified at the first step;
2. The cross-sectional approach, based in this case on the 1970 census; and
3. The need in the second step to incorporate many variables that describe accurately and meaningfully the housing aspects of the households and the highway and transit availability in a SMSA.

Even though the authors focus on a small minority of the households in the urban areas, the model still specifies their stratification into 150 cells. In a universal approach, thousands of cells would have to be specified just to complete the first step. The models add the need to measure 450 proportions of ownership rates and 2250 proportions of commuting trips of the selected 150 household groups.

Cross sectional correlation models can work only with what is present and measurable at the time of data collection. They capture or match existing relations and may lead or mislead the researcher, depending on what they include or exclude. Recalling the numerous automobile ownership and modal split models that have reproduced reality at a given moment might be helpful for all of us. For this reason, I believe caution and reserve are required in reviewing the results.

Attention also needs to be paid to both the number and the format of the variables, whether dummy or real values. The culmination of data inputs takes place at this stage and the limitations of correlation analysis and of multiple sets of data must be kept in mind.

Strengths and Weaknesses

The automobile ownership model has several strong and weak points. Among its stronger points is the emphasis it places on the three sociodemographic variables (income, size of household, age of head of household), stressing the intrinsic significance that these household characteristics have on automobile ownership decisions. A second important point in its favor is the emphasis the model places on improving the estimates of nationwide proportions through the use of variables characterizing the types of housing situations and the relative availability of transit and highway facilities. The watershed is reached at this point because its further stratification according to the workplace is partly a strong point in terms of additional accuracy but a weak point in terms of additional stratification and restriction required.

Among the weak points that the model demonstrates, of particular signficance is the degree of household stratification that it prescribes. Every cell created in the first step of the model would need to be associated with urban pattern variables later on in step two of the model and then projected in case the model is to be used for projection purposes in a SMSA. Both steps are extremely risky; no guarantee exists of a relationship between the automobile ownership rates of all types of households and urban pattern variables. And projection 10, 20, or 30 years hence for that many household types in each small district of urban regions is just impossible. Also, there is the problem of the cross sectional data that the model utilizes. Such models can easily misread incidental, temporary occurences, as time-honored relationships. For instance, for most types of households in Philadelphia, the physical relationships stayed almost the same; even the sociodemographic characteristics stayed almost the same between 1960 and 1970. Yet the automobile ownership rate increased by almost 25 percent over these 10 years. The same has probably happened in Boston and in many other SMSAs. Clearly the trend of higher automobile ownership levels far exceeds changes in density, and in the provision of highways and transit. This point is also related to the observation that not all of the investigated relationships produced high correlations. In fact, in both steps of the model the one-automobile relationship produced the least satisfactory results. One-automobile households were found in larger numbers in all groups of households than any sociodemographic stratification or urban pattern variable would indicate. Such one-automobile households appear to be influenced more by a continuous trend towards a universal availability of one automobile for all urban households than by any ad hoc household characteristic. Perhaps one automobile per household should be considered the standard expected provision, from which deviations upwards and downwards should be identified, traced, and explained through the use of sociodemographic variables or urban pattern variables or other stratifications.

Another point of concern in the automobile ownership model is the finding that the real policy variables of the model have only marginal statistical importance. The most important variable is the expected probability variable of step one. The variables expressing bus and rapid transit availability are marginably important. Even the highway availability variable is

minimized within the complex of 17 variables used by the model. Interestingly enough, the most important variable in many cases is the age of the household. Unfortunately, the age of the housing units is not a policy variable. In fact, it is only a substitute variable denoting, most probably, the manner in which apartment buildings and other housing units were designed before 1940. A final point in this connection is that the model, as it is presented in the paper, does not always present results consistent with a priori presumptions. For instance, the households in apartment buildings built before 1940 whose workers are employed in central business districts (CBDs) have a lower probability for not owning an automobile than does a similar household in the rest of the region—the opposite of what would normally be expected for Phoenix and Boston in 1970.

Turning to the modal split model for home to work trips, the main strong points of this model are two. First is the separation into two steps and the emphasis placed on the three sociodemographic variables (income, age, size of household) plus the automobile ownership variable. In emphasizing the intrinsic significance of these variables for modal split, the model again offers, as in the case of automobile ownership, a distinct contribution. The second strong point of the modal choice model is the additional stratification of the workplace. The circumstances in both the origin and the destination of the trip play the major role in the choice of travel mode. The level of stratification the model includes and the manner in which it incorporates urban pattern variables need improvement if the model is to add to the present array of modal split models. In addition, the model would need to reach much higher levels of simulation accuracy to compete effectively with other models in the field. Finally, the policy variables (except, possibly, the rail dummy variable) appear to carry only marginal importance in the correlations produced. Again the expected probability of step one is the dominant variable, followed in certain occasions by the old multiple apartment buildings variable.

COMMENTS AND REFLECTIONS

This paper has particular significance for both transportation and land use planners. It presents an innovative, intensive effort to develop new, predictive, and explanatory models for automobile ownership and modal choice. At the same time it explores in more depth the link between the transportation planner and the city planner. Although the title and some of the claims of the paper might be considered as somewhat unwarranted overstatements, the link between characteristics of the urban structure and the consumer patterns of urban residents is placed under central focus in the automobile ownership model. A similar link between urban structure and travel behavior centered on the most important component of urban travel, the home-to-work trip, is also attempted. What strikes me also as very important in these models is the two-step structure of the models and that the influence of the intrinsic characteristics of the household on automobile ownership and modal choice is emphasized first on a national scale, followed by the influence that some specific characteristics of each urban structure exert on automobile ownership and modal choice. Although in my view the models are not yet ready for widespread use, their contribution is clearly evident, especially with regard to the automobile ownership model. I hope that these and other researchers will continue the work in this field so that we may increase the hopes of establishing the frequently claimed but almost always elusive relationship between land use patterns and transportation.

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A Transit-Oriented City

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Cities are designed to accommodate the automobile. A transit-oriented city is one that from inception is designed for public transportation modes rather than the automobile. In such a city, automobile use would be possible but unnecessary. The goal of a transit-oriented city is to make public transportation travel more attractive than driving so that automobiles will be little needed or used. One possible transit-oriented city is described. From this example we see that many of the advantages of current urban and suburban life-styles are attainable without automobiles. The building of a transit-oriented city as an experiment is suggested.

A transit-oriented city is designed to make automobiles little needed and little used; the movement of people is accomplished primarily by modes other than the automobile. Nonautomobile modes would include new and old types of mass transit, constant speed and accelerated moving sidewalks, bicycles, and walking. A transit-oriented city would be an altogether new city (or town or new town-in-town) to be built from the ground up. Travel by automobile would be possible and, in fact, would not be deliberately discouraged. However, the design goal would be to make public transportation faster, safer, cheaper, more pleasant, and more convenient than automobile transportation, so that residents would choose to make most in-city trips by public modes. Public transportation of such attractiveness can be achieved through the integration of land use and nonautomobile movement technologies.

When a conflict occurs in the design of a transit-oriented city between the needs of automobiles (such as close-in parking or direct nonstop routes) and the needs of nonautomobile modes, the latter are given priority.

Similarly, the need for a pleasant urban environment is predominant over that for swift and convenient automobile travel. Except for these two priorities, automobile transportation is not hampered or restricted by artificially low speed limits or by the prohibition of automobile use at certain times, for example.

Transit-oriented cities offer, in the long term, a possible solution to the problems created by urban automobiles. These problems include air and noise pollution; accidents; congestion; excessive consumption of petroleum energy; excessive use of urban land; and unavailability to the poor, aged, handicapped, and young. The conventional approach to these problems is to improve automobiles. This approach is appropriate for the near term in existing automobile-dominated cities and towns. It is the approach that is being taken in the United States, where an effort is under way to make automobiles less polluting and more energy efficient.

The transit-oriented city approach is appropriate for new cities, rebuilt parts of older cities, and new towns—and it is appropriate for the long term, by which I mean 20 years or more into the future. Transit-oriented cities offer alternative life-styles, which are not dominated by the automobile. These nonautomobile-dominated life-styles may be more attractive and cheaper than the automobile-dominated life-style available in contemporary cities and suburbs. Whether new life-styles can, in fact, be more attractive is especially important because of diminishing petroleum supplies.

A transit-oriented city must be designed so that automobile-related problems will not simply be replaced by other transit-related problems. A poorly designed transit-oriented city might suffer from people congestion in its transit vehicles and stations. A congested transit system can be avoided by carefully matching transportation capacity to transportation demand. The public transportation system in a transit-oriented city could be unduly costly and unduly consumptive of energy unless the city is designed to minimize the need for the movement of people. This can be accomplished by locating working, shopping, and other destination places close to living places. The importance of (a) minimizing the need for movement, and (b) matching transportation capacity to demand, have been pointed out by Wilfred Owen (1). Except for a few towns like Runcorn, England, no transit-oriented cities currently exist anywhere in the world.

EXAMPLE TRANSIT-ORIENTED CITY

Figure 1 shows a map of an example transit-oriented city. Each of the square-shaped figures is a cell or community, which has a transit station at its center. The two round areas are the central business district (CBD) (above) and an industrial park (below). Transit guideways (shown as lines) link the transit stations (shown as dots). Circumferential highways and an access highway are also shown.

Not shown are the local roads that thread through the CBD and the industrial park and connect these to the communities. The local roads are intended primarily for service and delivery trucks. The local road system requires indirect routes and is not designed for high speeds. There is limited room for automobile parking in the industrial park and none in the CBD. Automobile drivers destined for the CBD must park at lots on its perimeter and enter by foot. Once in the CBD they can move about by foot, by moving sidewalk, or by the transit system. In the CBD, the second-story level is the pedestrian level, one story above ground; trucks are restricted to ground level. People enter buildings and transit vehicles at the pedestrian level. The moving sidewalk system is on the pedestrian level and pedestrian bridges arc over the CBD's truck streets. The movement of people to and from the CBD and the industrial park is primarily by transit and only to a limited extent by automobile. The movement of goods to and from the industrial park, the CBD, and the communities is by truck.

Figure 2 shows a typical community. It is a picture of a model built by Victor Wong. The community consists of a central doughnut-shaped structure surrounded by four groups of buildings. In the center of the doughnut is a park, and under the park is the transit station. The exterior of the doughnut structure contains townhouses and apartments. The roof of each townhouse supports the yard of the townhouse just above. In Figure 2, one can see the trees in the townhouse yards. Inside the doughnut is a circular mall, which has a circular moving sidewalk running through it. Stores and offices are in the mall.

Consider the four groups of buildings surrounding the central doughnut-shaped structure. Each group consists of high-rise buildings whose bases are arranged in a circle and some lower-level buildings inside the circle. Each circle of high-rise buildings is connected near ground level by a flat ring-shaped structure (of blue plastic in the model). Inside this ring structure is a circular multilane moving sidewalk. The ring diameter is 274 m (900 ft, average

Figure 1. The example transit-oriented city.

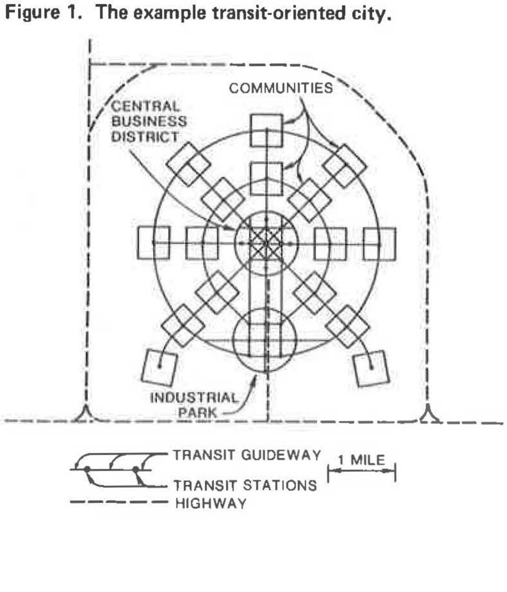


Figure 2. View of one community in the example transit-oriented city.

of exterior and interior diameters), or the size of three football fields.

Figure 3 shows, to large scale, one of the high-rise, ring-linked, buildings seen in Figure 2. The building is shown truncated in height. The Figure 3 high-rise building consists of living units, houses, stacked up in spiral staircase fashion around a central column. Each house looks out on its own yard, which is above the house one step down. A crawl space is between the top of the lower house and the floor that supports the soil of the upper house's yard. The houses are two-story units. As the sun changes position during the day, every yard will be at least partially exposed to direct sunlight. Another of the high-rise buildings seen in Figure 2 consists of single-story dwelling units. The buildings are extensions of the concept used by Moshe Safdie in his Habitat complex in Montreal (2).

High-speed elevators connect the houses to the ground level, where automobiles are parked, and to the level of the moving sidewalk, a circular multilane conveyor, shown in Figure 4. The Figure 4 moving sidewalk does not look circular because the picture is of a model that, for simplicity, was made linear. This type of moving sidewalk is contained inside each of the four blue ring structures. The outermost lane on the right is stationary, as is the outermost lane on the left. The lanes in between the two stationary lanes are all moving in the same direction, toward the observer. The wide lane in the center, which has the benches fixed to it, is the fastest lane. Lane speeds are symmetrically arranged on each side of the center lane. They increase progressively from the stationary lanes to the central lane, as shown by the arrows. The speed increment from one lane to the next is 0.8 km/h (0.5 mph). Thus, the outermost moving lane on the right moves at 0.8 km/h, the adjacent inner lane at 1.6 km/h (1 mph), and the next inner lane at 2.4 km/h (1.4 mph). The speed of the central lane is 5.6 km/h (3.5 mph). If we add to this a typical walking speed of 4 km/h (2.5 mph), a pedestrian walking in the center lane would have a total speed of 9.6 km/h (6 mph).

Figure 3. Large-scale, truncated in height view of the high-rise structures from Figure 2.

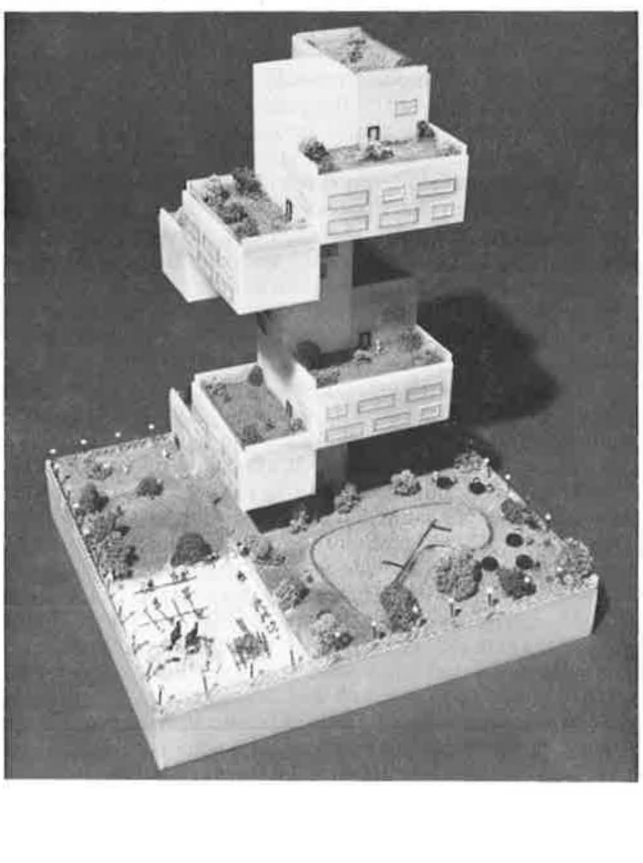


Figure 4. The multilane moving sidewalk in one of the four ring-shaped structures.

Although 9.6 km/h is not very fast, it is sufficient because trip distances are short. At 9.6 km/h, a trip around one of the rings takes only 5⅓ min. By bus, one must walk to the bus stop and then wait for the bus to arrive; on this type of conveyor, one boards anywhere along its length without waiting.

As mentioned, the central doughnut-shaped structure also has a moving sidewalk running through it. The moving sidewalk in the central shopping mall and the four moving sidewalks in the rings are all on the same level. This is to facilitate local trips, especially for shoppers carrying goods. The doughnut's central park is on the level of the moving sidewalk, the third-floor level, and the transit station is on the second story level under the park.

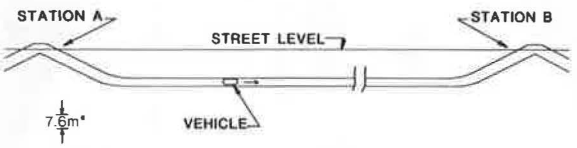
Note the advantages of the circular configuration for a moving sidewalk. A person wishing to travel to an upstream destination can get there by moving downstream; a separate conveyor for each direction is unnecessary. Further, the lanes do not have to bend and so can be made rigid, yielding savings in mechanical complexity and cost over a linear conveyor of equal length. I discussed the advantages and disadvantages of multilane conveyors in another article (3).

The buildings inside each of the four blue rings are apartments, a school, perhaps a hospital, and offices. These buildings are connected by an all-weather pedestrian passageway to the central torus.

The Figure 2 community occupies an approximately square site about 0.7 km^2 (0.3 $miles^2$) in area. The population of each community is about 8000 people, and the population of the entire city is about 140 000 people. In this city, the walking process would be assisted by moving sidewalks and escalators, and the pedestrian environment would be designed to make the walking experience pleasant and interesting. Along the pedestrian ways greenery, sculptures, and vistas through windows would entertain the stroller as he progressed.

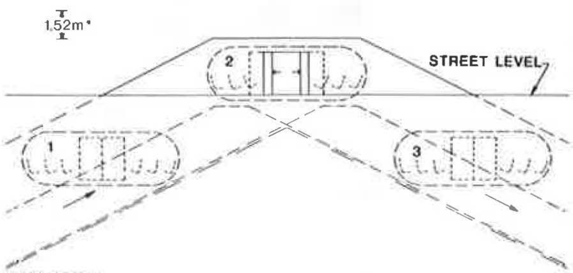
The nature of the transit system that links the communities to each other and to the industrial park and CBD is indicated by Figures 5, 6, and 7. Station A (Figure 5) would be in one of the communities and station B in the CBD, for example. In this case, street level would

Figure 5. The transit system. Vehicles descend from and rise to the stations instead of having the pedestrians descend and ascend.



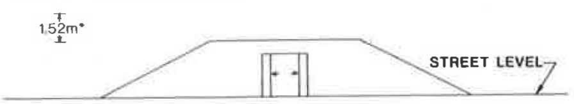
*7.6m=25 feet

Figure 6. A vehicle rises uphill into an entrance-exit chamber (1), discharges and accepts passengers (2), and descends out of the chamber (3).



*1.52m=5 feet

Figure 7. A transit user's view of an entrance-exit chamber.



*1.52m=5 feet

be for station A, the transit station level, and for station B, the pedestrian level.

As shown in Figures 5, 6, and 7, the transit vehicles descend from stations at street level to below-grade tunnels or trenches. Thus stairways and escalators are not needed for access to the level of the tunnel or trench. Further, vehicles are accelerated by gravity as they go downhill from a station and decelerated by gravity as they rise uphill to a station. As a result, energy is not wasted in braking.

The transit vehicles would be activated by demand during times of low demand, functioning as horizontal automatic elevators; during periods of high demand they would depart at regular intervals on nonstop or one-stop trips. Maximum vehicle speeds would be in the 64- to 96-km/h (40- to 60-mph) range. Each transit station would have a number of vehicle entrance and exit chambers, such as the one shown in Figures 6 and 7, rising from its floor. This intercommunity transit system would be an automated guideway system.

ASSESSMENT

The example city is called transit oriented because it was designed to make transit travel more appealing than automobile travel. Whether this goal is actually realized in practice could be determined ultimately only by building the example city and populating it with residents.

A fundamental question is, Can our quality of life remain the same without automobiles? Perhaps life without automobiles may be even better than life with automobiles. If costs of the transit-oriented city are reasonable in the long run and if the quality of life is as good as it is now, if not better, then the implications are profound.

A necessary (but not sufficient) condition for a high quality of life in a transit-oriented city is that travel by public modes be more appealing than travel by automobile. If this is not the case, too many residents will turn to the automobile; automobile congestion will be severe and automobile-created air pollution will not be avoided—in short, the quality of life will be degraded. The way to make public mode travel more appealing than automobile travel is to make the public modes faster (door-to-door), more convenient, safer, cheaper, and more pleasant than the automobile.

To see if the public modes are faster, consider travel times. The estimated door-to-door travel times by the public modes and by automobile are shown below for three trips in the example city (1 km = 0.62 mile).

Trip From a Home in a Ring High-Rise Building	By Public Modes	By Automobile
To the shopping mall in the central structure of the same community	4.7 min	5.2 min
To the CBD of the city (1 km from the origin community)	19.2 min	25.6 min
To a home in a ring high-rise building of another community (2.4 km from the origin community)	27.2 min	20.8 min

The trip times assume that the origin home is in a high-rise building attached to one of the blue rings, and that the high-rise building is located a maximum distance from the central doughnut-shaped structure. The times also assume that few travelers use automobiles. If many were to use automobiles, automobile trip times would increase significantly. Further, in developing the automobile times, the driver was assumed not to unlock his car to get in or to load packages or children, not to wear a seat belt, to start driving immediately after the engine is turned on, and to take less than 0.25 min to park (usually parking time is taken to be 1 min). So the given automobile times are lower limits.

Except for certain trips to the industrial area (those for which the trip maker has access to the few parking spaces within that area) and intercommunity home-to-home trips, the example city's public modes produce travel times that are as short as or shorter than those by automobile. The exceptional trips would be a small fraction of all trips. Thus, for most of the trips in the example city, the public modes are as fast as or faster than private automobile travel.

In the example city, the public modes appear to be at least as convenient as the automobile. They provide rapid, zero-fare service at any time of the day or night, and are accessible from the home without going outside. The traveler on the Figures 5, 6, and 7 transit system gains direct access to the core of activity centers (the CBD or community centers), whereas the automobile traveler must park, often take stairs or an elevator to change levels, and then enter an activity center from its periphery. Children can use the moving sidewalks without the aid of adults. Thus, the need for busing to schools and chauffeuring to extracurricular activities would be eliminated. The example city's public movement system would be designed and operated to provide safer transportation than that available by automobile.

The nonautomobile modes in the example city would be zero-fare systems. This is equitable if most people use public transit rather than automobiles, and such a policy saves users' time and the costs of fare collection. The cost of providing public transportation in the example city is difficult to assess. The three-station personal rapid transit (PRT) system in Morgantown, West Virginia was built at a cost of $60 million, of which $24 million was for research and development (4). Clearly, the cost of the example city's public movement systems would be great, but so too would be the savings due to reduced automobile costs. These savings would prob-

ably amount annually to $1000 or more for each family. The example city would house about 45 000 families, so total annual savings for these families would be $45 million.

Residents of the example city would find the nonautomobile modes more pleasant than driving, assuming there were no threat of crime on the public system and that city residents did not value the privacy of the automobile. Given this situation, would the great majority of trip makers in the example city find the nonautomobile modes more appealing than the automobile?

It is appropriate to seek guidance from existing modal-split models. For the example city, the Washington-Toronto-Philadelphia model (5, 6, 7) predicts that 82 percent of work trips will be made by transit, assuming that all trip makers are in the highest of the model's five income ranges. However, neither this nor any other existing modal split model can make reliable transit-share predictions for the example city. This is because a trip maker's decision to travel by the nonautomobile modes or by automobile reflects his subjective perceptions of the two alternatives, and in the example city the nonautomobile mode travel experience and the experience of automobile travel would both be radically different from the corresponding experiences in existing cities. Transit shares predicted by existing models will be too low. Probably, the transit share of trips in the example city will be sufficiently high, and the automobile share sufficiently low that automobile usage will cause little environmental degradation. Assuming this, an important condition for a high quality of life in the city would be met. There is one other condition, namely that example city residents must find the nontransportation aspects of their city attractive. I feel that this second condition would also be met because the city provides suburban privacy and greenery in the context of urban variety. In my judgment then, the quality of life in the example city would be high. With a high quality of life and an attractive life-style, the example city offers the good life without automobiles. Can the good life without automobiles be even better than the automobile-dominated version thereof (that is, similar to suburbia with two automobiles in every garage) that we have today? Perhaps.

Besides the example city, there are other possible types of transit-oriented cities. Intracommunity transportation could be provided by pedestrian passages, bicycles, horizontal elevators, or electric minicars instead of by moving sidewalks. Types of intercommunity transit could be used that would be different from the type shown in Figures 5, 6, and 7. Housing need not be stacked up spiral staircase fashion, for example.

Automobiles are not the only route to the good life. Indeed, the quality of life without automobiles, in transit-oriented cities may be even better than the quality of life with automobiles. Or, if not better, perhaps more affordable in a petroleum-hungry and space-limited world. But the question of costs is outside the scope of this paper.

A Suggestion

I want to suggest the building of an experimental transit-oriented city in the United States. It should not be identical to the example city, however; better designs are possible. A transit-oriented city would be a transportation energy conserving city; each person would require perhaps as little as 10 percent of the transportation energy now required in existing cities. In view of this and other advantages, new cities and rebuilt parts of old cities should be transit oriented rather than automobile oriented. Such an experiment would be expensive, costing between $5 and $50 billion, but going to the moon was also an expensive experiment.

The suggestion that an experimental city be built is not new. Athelstan Spilhaus put forward the idea of such a city in 1968 in Science (8). In a 1971 article in Saturday Review, Anthony Downs suggested the building of a transit-oriented city as an experiment (9). He stated: "Full-size autonomous new cities offer our best change to try alternative urban forms that might reduce key problems (such as designing a city mainly for public transit to cut air pollution and traffic congestion)." Actually, Runcorn, England, is already an experimental transit-oriented city (10). I am suggesting a more technologically innovative version for the United States.

There is no reason why a city experiment should be limited in scope to transportation and land use; new solid waste disposal technologies and solar energy technologies could be evaluated as well. Indeed, new social and institutional arrangements could also be tried out. Root causes of crime could perhaps be eliminated; new welfare programs could be tested, and an attempt made to eliminate the alienation and loneliness of American society described by the sociologists Bronfenbrenner (11) and Slater (12).

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Models of Urban Development in the Analysis of Transportation Investment: North Central Texas

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This article reports on the theoretical foundations and structure of a model of urban development and its application to North Central Texas. The model has been used to examine the spatial urban development consequences of five alternative regional ground transportation systems that embody varied amounts and mixes of highway and transit investment. The objective is to select and adopt a preferred multimodal system for the period to 1990. The urban development forecasts provided by the model formed the basic socioeconomic inputs to the transportation analysis procedure, and certain of the impact measures that the model produces were used in the evaluation of the alternative systems. This article provides a summary of the work performed in Texas and the conclusions that can be drawn from it in a form that will be of value to urban analysts and policy makers.

STUDY CONTEXT

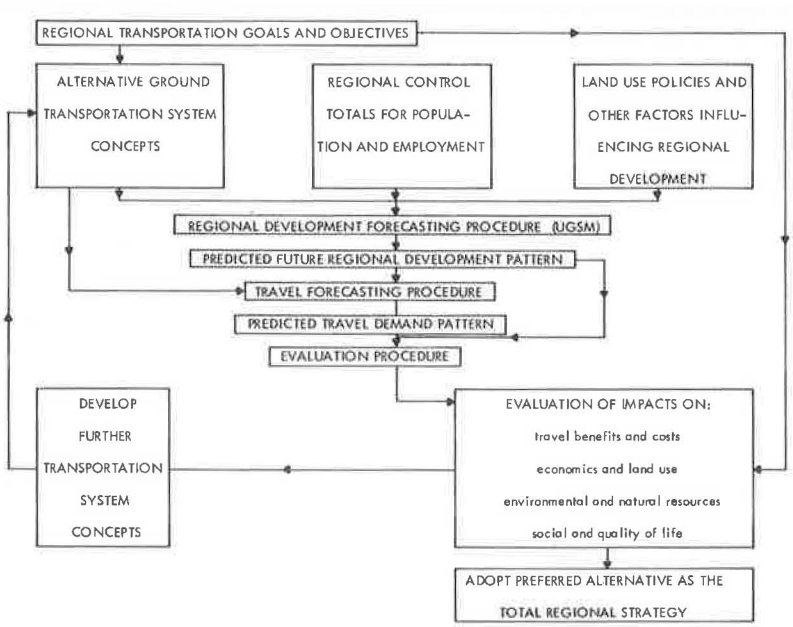
On February 26, 1974, the Regional Transportation Policy Advisory Committee was established for the North Central Texas Region. The committee's goal was to determine a multimodal transportation policy that would be suited to the requirements of the regional community for the period to 1990.

Four multimodal ground transportation system concepts and the do nothing case were considered. The four multimodal alternatives included tests of the extreme situations whereby investment would be channeled entirely into either highways or transit and two tests of different investment mixes of highway and transit. Each alternative was developed to serve the intensive study area of North Central Texas (the Dallas-Fort Worth metropolitan region). These concepts were further defined in terms of regional transportation plans, and detailed descriptions were given of small regional analysis areas' (RAA) highway and transit routes and service levels.

Both predictive and evaluative techniques were needed to measure the performance of the alternatives. Predictive techniques described the future conditions in the region for each alternative in terms of the future intensity and location of urban activities, such as residential development, industry and commerce activities, and travel demands. Evaluative techniques assessed the impact of these future conditions on the well-being of the community in terms of the accessibility of urban resources to different groups and the quality of the environment. This predictive and evaluative process is illustrated by Figure 1. Two additional inputs were required at this stage of the process: (a) future regional control totals for population and employment and (b) land use policies and other major factors influencing regional development.

The estimates of regional population and employment growth were derived from an analysis of the current and predicted economic position of the region relative to that of the Southwest region and the United States as a whole. The basic assumption underlying these population and employment estimates was that the rate of regional population growth and the demand for services are functions of the rate of increase in growth-generating economic activity. Growth-generating activity is defined in terms of either the production of goods or services for export or the goods or services that would otherwise have to be imported into the region. The employment so generated

Figure 1. Simplified regional transportation predictive-evaluative process.



is defined as primary employment; all other types of employment that serve primary economic activity and residential population are defined as service employment.

The land use policies of individual communities within the region were used to establish constraints on the amount and type of development that could occur within each small RAA. In addition, those factors (other than transportation) considered fundamental to the regional development process, such as the availability of land for development, sewer and water infrastructure, and the nature and intensity of existing development and possibilities for urban renewal, were examined on an RAA basis to identify areas for potential development during the period to 1990. Collectively these policies and factors were used to identify the set of fertile RAAs within which economic or residential development could take place.

The function of the regional development forecasting procedure was to distribute the projected regional increase in residential population and employment to each RAA, in response to the different regional accessibility surfaces created by each of the regional transportation system concepts, and subject to the above development constraints on infertile RAAs. The different regional development patterns and socioeconomic characteristics predicted under each transportation alternative and the service level characteristics of each system provided the basis for the subsequent prediction of future travel demands. In turn these development patterns, socioeconomic characteristics, and travel demands were used to evaluate the feasibility, desirability, and utilization of proposed transportation improvements, as well as their potential impact on land use patterns, the environment and natural resources, and accessibility.

This process led the steering committee of the policy advisory committee to select the primarily highway alternative (the mixed investment alternative that emphasized highways) for further refinement and analysis. As a result of that refinement and analysis, the steering committee recommended and the policy advisory committee approved the sixth alternative as the total transportation plan for the North Central Texas Region for 1990 (1).

REGIONAL DEVELOPMENT FORECASTING STUDIES

Our study objectives were considered fundamental to the overall process:

1. To simulate the interaction between the regional transportation system and the development process to provide a consistent description of the future pattern of regional development under each of the transportation system concepts tested and
2. To provide information that would be valuable to the assessment of the impact of each such system on the community.

The conventional transportation planning process fails to take sufficient account of the interaction between transportation and development. In a rapidly growing region such as North Central Texas, which is neither constrained by a lack of developable land nor by the historical investment in infrastructure, such an omission could be critical. Failure to take account of the different spatial development possibilities open to the region through alternative transportation concepts would result in an unrealistic set of future travel demands and impact measures and an inadequate basis for decision making. The urban development studies were, therefore, necessary to formulate and test relationships between the development process and transportation against an historical situation, and to apply the relationships so established to each of the transportation systems generated to predict the future pattern of development in the region.

The methodology of the studies assumes that the demand for travel is a function of the consumption of and interrelationship between different urban activities, such as working, shopping, leisure and recreation, and distributing goods. Within the urban region, consumers come into contact with the suppliers of urban activities through the communications and the ground transportation systems. Indeed, the present location and intensity of activities in the region is, to a considerable extent, a function of historical investment in the ground transportation system and the accessibility surface so created. Changes in either the total amount or mix of investment in the transportation system, therefore, affect the accessibility of production and consumption activities at different locations in the region. Such changes could affect one location's accessibility costs relative to others and cause changes in the amount of activity locating there, or the substitution of new activities for existing ones. Such changes could, in turn, affect the demand for travel between producers and consumers, which would manifest itself in the resulting regional patterns of travel.

The methodology on which the study was based, the urban growth simulation model (UGSM), simulates the interaction between the transportation system and urban development over time. The chronological development of this methodology is illustrated below.

- Theoretical Foundation
  - Lowery 1964
  - Centre for Environmental Studies 1967, 1970
  - Urban Land Market Theory 1961, 1970
  - Central Place Theory 1967
- Subregional Activity
  - Bristol Severnside Subregion England 1970, 1972
- Statewide Activity
  - Connecticut 1974
- Urban System
  - North Central Texas Regional Transportation Study 1972
  - Baltimore Regional Environmental Impact Study 1973
- Urban Growth Simulation
  - North Central Texas Continuing Transportation Program 1974, 1975

The structure of the UGSM is illustrated in Figure 2. The model is based on a conceptualization of the urban region as the culmination of a process by which physical stock (transportation areas, space, and public utilities) and activity centers (homes and places of employment) are distributed spatially (2). The hypothesis is that activity centers are distributed to locations as a function of their interrelationships with other activity centers and constraints imposed by the physical stock. Physical stock locates in response to the activity demands for stocks—for example, for transportation space and infrastructure. The model also incorporates the competition for physical stock among urban activities through an accounting framework that relates the distribution of activities to the availability of physical stock.

Specifically, the model distinguishes between growth-generating employment (primary), residential population, and service employment activities; and between floor space, transportation, and public utility physical stocks. The model simulates changes in the distribution of primary employment, residential population, and service

employment over time as a function of changes in intrinsic locational attractiveness and changes in the availability and quality of the physical stock.

Lowry's contribution (3) is significant because he formalized and tested a stratification of metropolitan economic activity in terms of a basic residential population (export oriented) and a service sector (population serving). These were interrelated regionally through a series of activity rates and population serving ratios and interrelated spatially through a series of zonal activity distribution functions. The definition of the metropolitan economy in Lowry's terms leads to a number of inconsistencies—the most important is that all economic growth is assumed to be export oriented. No allowance is made for growth through either import saving or local market oriented employment. To overcome this problem, our model was designed so that both import saving and certain local market oriented activities (such as local government expenditure or investment in the housing market) could influence the regional economic growth rate (4). This is important because the separate identification of growth-generating economic activities in the study area allows the effects of differences in national economic growth to be traced. For example, changes in national demand as a result of changes in energy availability or price could cause changes in the structure and growth of the region's primary economic activities and in turn affect the demand generated within the region for service sector products. The second influence on the development of the model was the research of the Centre for Environmental Studies, London. This work established a general theoretical framework for the analysis of urban activity distributions (5).

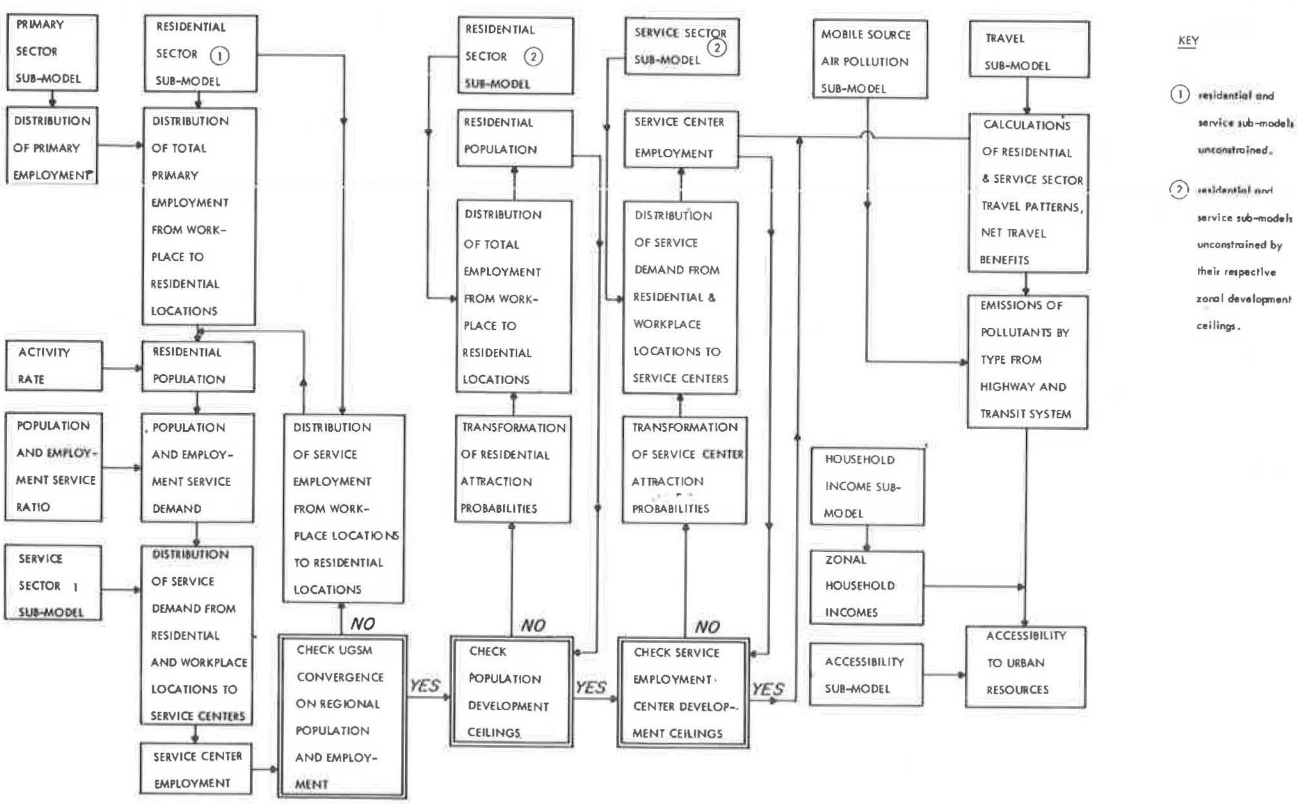
This theoretical derivation is important for the development of the UGSM residential and service employment submodels (Figure 2). The spatial distribution of residential and service employment activities is determined by submodels that distribute employees from work to home and distribute service demand from home and work to service centers, thereby maximizing the entropy of each activity system. This relationship is determined in the model by the amount of travel observed or projected for each activity.

Wilson's theoretical framework also incorporates a procedure to reconcile the demands of competing activities (population and service employment) with the available space at each location. This can be defined as a development ceiling on the location of both population and service employment, in terms of the amount of developable space, maximum density of development, or amount of activity. This procedure has been incorporated in both the residential and service employment submodels respectively, which provide unconstrained and constrained activity forecasts by RAA. Both submodels also incorporate a locational attraction index, in an attempt to represent, albeit crudely, the relative attractiveness of alternative residential and service locations.

Further assumed is that the perceived value of locational attractiveness lags behind its real value at a given point in time. The rationale for this assumed lag in the response of demand to the changing attractiveness of residential and service employment locations is a function of imperfect information and communication, habit, and inertia (6). For these reasons, the zonal attraction indexes used in the residential and service employment submodels are lagged behind their real values for existing and future points in time (7).

The residential sector trade-off decision between transportation cost and locational attractiveness, simulated in the form of a spatial distribution of population, is consistent with the urban land market theories of Wingo (8) and Alonso (9). Similarly, the service sector trade-off decision, simulated in the form of a spatial distribution of service employment centers, is consis-

Figure 2. UGSM structure.



tent with the spatial arrangement of service centers suggested by central place theory (10).

Model Application

The UGSM is based on the prediction of regional distributions of population and employment over time in response to changes in transportation, public utility, land use, and environmental policy variables. This approach (of recursive prediction) requires inputs by discrete time periods of 5 or 10 years from the base year to the end of the forecasting period. For each time period this involves changes in regional population, in primary and service employment, and to the zonal development ceilings or the regional transportation system to reflect policy changes. The model is then run for each time period to forecast a new regional distribution of activities. At the end of each time period, the inputs are revised and the model is run for the next forecast period.

The role of the UGSM was to examine the potential implications of five alternative 1990 regional transportation systems on the pattern of urban and regional development at that date and provide inputs to the travel model procedure.

An intermediate forecast for 1980 was made to provide the necessary inputs for the subsequent 1990 predictions. The specific alternatives tested for 1990 are described previously in this paper:

1. Do nothing,
2. Primarily transit,
3. Primarily highway,
4. All transit, and
5. All highway.

Table 1 summarizes the mean regional trip length results for the two extreme investment alternatives and compares them with the 1970 observations and 1980 estimates. The higher travel costs under the all transit alternative can be attributed to the concentrated pattern of economic activity that the regional rapid transit system would cause. Given the existing dispersed pattern of residential development in the region, this shift toward the concentration of economic activities causes a marginal increase in the work and a proportionately greater increase in the service travel cost.

It is useful to consider these results in relation to the two main factors that cause variance in the residential and service employment distributions within and across the five alternatives. These factors are the RAA development ceilings on population and employment (which, although constant across the alternatives, affect the distribution and intensity of development that would otherwise occur in a completely free market situation) and the five regional transportation system alternatives (which cause the regional accessibility surface to vary and have a differential effect on both the free market and constrained activity distributions within each alternative).

Table 1. UGSM mean regional generalized cost trip length comparison for 1970, 1980, and 1990.

Year	Mean Regional Work to Home Travel[a]	Mean Regional Home and Work to Service Travel[a]
1970	56.2	34.9
1980	56.8	34.9
% change 1970 to 1980	+1	—
1990-all highway	56.3	35.7
% change 1980 to 1990	-1	+2
1990-all transit	56.8	37.5
% change 1980 to 1990	—	+7.5

[a] Generalized cost (in units referred to as Utiles) is defined in terms of the composite highway and transit journey time multiplied by the perceived value of each element of the journey, and added to out-of-pocket expenditures.

Despite the other spatial growth differences observed across the alternatives, little difference was found in the distribution of residential population by functional area. This can be attributed to three factors.

1. Development ceilings were held constant across the alternatives, thus dampening the differences in intensity and location of activity that would otherwise have occurred,
2. The 20-year time period under consideration allows for minimal deviation for the already established residential development pattern and philosophy of urban activities within any given metropolitan area, and
3. The distribution of residential population in the region is already far more scattered than is the distribution of economic activity, thus less scope is provided for further significant spatial change.

The impact of the alternatives on economic activity was marked—significant shifts in the location of employment occurred as a function of the amount and mix of transportation investment. The basic finding is that large-scale investment in a regional transit system would cause the greatest increase in the amount and intensity of service economic activity in the central business districts. This concentration of activity is reflected in the transit alternative's denser pattern of economic development than that of their highway equivalents, resulting in a smaller overall developable land requirement.

Findings

The development model described formed an integral part of the process by which a preferred multimodal transportation investment strategy was adopted for the North Central Texas Region. The urban development forecasts made by the model provided the basis on which the future regional travel requirements were predicted under each of the transportation alternatives tested. In this respect, the patterns of regional development predicted by the model across the transportation alternatives were found to be consistent with and sensitive to the changes made in the level and mix of transportation investment and other major variables influencing the development process.

Several points must, however, be made about the limitations of such models.

1. This type of model is founded on regional rather than local behavioral concepts. Therefore, the accuracy of small area predictions will vary according to the relative influence of regional and local factors on the decisions made at particular locations.
2. The UGSM requires regional primary employment, residential population, and service employment control totals that have been determined independently as a basis for its forecasts; thus, the interrelationship between the predicted spatial development patterns and rate of regional growth are omitted. Consider, for example, the possibility of a particular development alternative so constraining growth in the central business district that primary sector growth in that area is discouraged from locating within the region. This would have ramifications for both the growth and location of population and services, and by definition for the policy alternatives being examined.
3. The model is not explicitly disaggregated by socioeconomic group, although it is disaggregated to some

extent by employment category (i.e., the primary and service employment sector breakdown). The issue is the familiar one of the trade-off between the increased accuracy and the value of disaggregated forecasts and the extra information, technical development, and financial cost that would be necessary for their derivation. The results of modeling exercises that have adopted a disaggregated approach to policy testing do not seem to justify the additional effort and investment required.

FURTHER RESEARCH

Several areas of research continue in regard to the UGSM and its application to the comprehensive regional planning process:

1. Policy design and evaluation;
2. Forecasting techniques for the development of regional control totals (i.e., population and employment) and the allocation of the primary employment activities are exogenous to the UGSM structure;
3. Sensitivity testing; and
4. Policy monitoring.

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Applications of Land Use Models to Strategic Transport Planning

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The nature of strategic land use and transportation planning in Ontario is discussed and the major phases of the typical study are outlined. The structure of a land use and transportation model that may be used in these strategic studies is described as well as two applications of the model. The first set of applications are described for a variety of regional planning problems in the Toronto-centered region of Ontario. These applications include the analysis of the probable impacts of various public sector investments on activity distributions and the analysis of the role of a new town. The second application is described for the Delhi region of India. A version of the model that is disaggregated by socioeconomic group is also outlined.

The metropolitan transportation planning process that emerged during the 1950s and early 1960s was directed primarily toward the formation of long-range capital investment programs for regional transportation facilities. Many cities throughout the world have abandoned transportation plans or critical elements of plans developed by this process. During the past decade two types of new transportation policy responses have been undertaken. Much of the recent effort in the United States has concentrated on programs for improving the efficiency of existing transportation facilities. The transportation system management program is geared to improving traffic flow, encouraging the use of high occupancy vehicles, and maintaining road and public transportation capacity.

In Canada, urban transportation policy responses also embraced the shorter run, but while also focusing on the longer run strategic planning of land use and transportation facilities. This longer run policy emphasis reflects the view that realistic and effective solutions to urban transportation problems may be achieved only through the formulation and implementation of good development plans. These development plans must embrace many of the public infrastructure sectors, including transportation.

PLANNING STUDIES IN ONTARIO

The emergence of strategic planning in Ontario may be traced to the creation of regional governments that have the power and finances to implement regional development plans. Strategic transportation planning studies

have been performed in the major urban centers of the province. These studies vary in detail, but the typical study consists of five major steps:

1. To identify the major travel corridors that exist or are likely to develop during the time period for which the study is forecasting,
2. To establish the transportation capacities that are feasible in each of the corridors for selected screen lines,
3. To estimate the travel demands that are likely to occur by the end of the forecast period in each of these corridors as a result of trends in land development,
4. To compare travel demands to corridor capacities at critical screen lines and to isolate potentially congested corridors, and
5. To identify potential land use and transportation responses that are likely to lead to a balance between demand and supply in the congested corridors.

Most of these studies identified the land use responses subjectively and calculated the transportation demands by using simplified generation-distribution-assignment modeling procedures. This approach is generally unsatisfactory because it fails to identify the public policies necessary to yield the assumed land use configurations. Soberman described the nature of the strategic transportation planning process followed in the metropolitan Toronto studies (1). The required modeling capability allows the testing of the land use and transportation implications of a variety of public development policies.

AVAILABLE LAND USE AND TRANSPORTATION MODELS

A recent U.S. Department of Transportation report identified nine separate models that have been used for planning purposes in the United States (2). These models range from simple techniques designed to improve the reliability of the land use inputs to transportation models to optimization models designed to generate optimal development plans. Several of the models described are derivatives of the Lowry model. A great deal of work has also been conducted outside of the United States in the past decade, but most of the operational models are also derivatives of the Lowry model. Wilson (3), Hutchinson (4), and Batty (5) described many of these models.

The land use and transportation model work described in this paper is also a derivative of the Lowry model. A modeling capability has been developed that allows the household and employment sectors to be disaggregated by socioeconomic group and the population-serving employment to be stratified by employment sector.

The basis of this land use and transportation model is a gravity allocation function of the following form:

$$\ell_{ij} = e_i \left[h_j \exp(-\alpha c_{ij}) \Big/ \sum_j h_j \exp(-\alpha c_{ij}) \right] \quad (1)$$

where

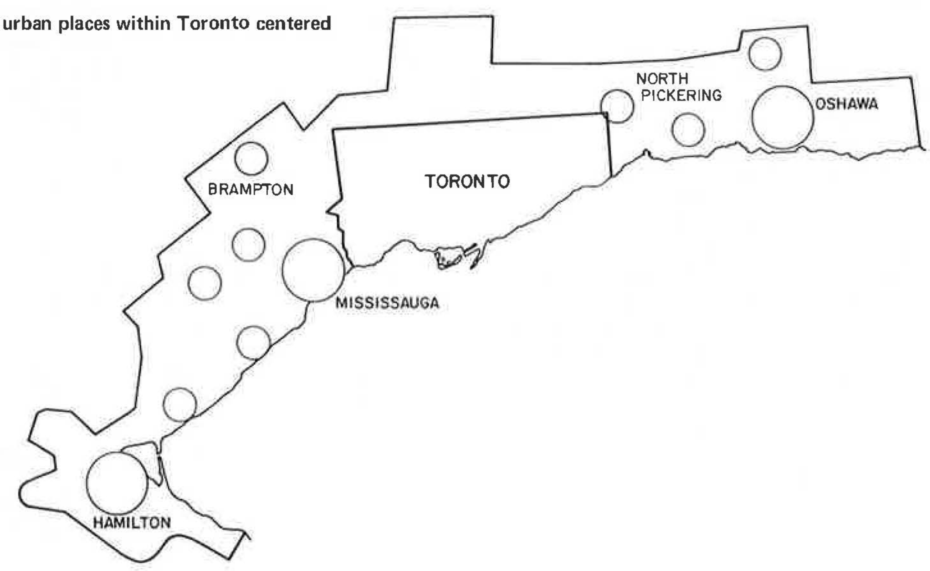
ℓ_{ij} = the amount of interaction between activities of type e in zone i and activities of type h in zone j,
e_i = the total amount of activity of type e in zone i,
h_j = the total amount of activity of type h in zone j,
c_{ij} = the generalized travel cost between zones i and j, and
α = a parameter that reflects the influence that travel costs have on destination decisions for the particular interactivity interaction being considered.

Gravity allocation functions of this type form the basis of the set of allocation models. Hutchinson (6) has described the detailed model structure elsewhere.

Use of Model in Regional Development Planning

In 1970 the government of Ontario adopted as general policy a plan for a large region centered around metropolitan Toronto. The urban part of this structure plan is illustrated in Figure 1. In 1973 the government of Ontario established a task force to refine the structure plan for the subregion illustrated in Figure 1, which was referred to as the Central Ontario Lakeshore Urban Complex (COLUC). The COLUC task force was an interministerial group composed of representatives from the Ontario government ministries of agriculture and food; natural resources; transportation and communications; environment; housing; and treasury, economics,

Figure 1. Distribution of urban places within Toronto centered regional concept.



and intergovernmental affairs. The primary responsibility of the COLUC task force was to refine the Toronto-centered regional concept so that it could be used as a common guideline by regional municipalities and various provincial government agencies in formulating development policies and programs (7).

A second initiative of the government of Ontario in implementing the Toronto-centered regional plan is the North Pickering Project, which is an undertaking of the Ontario Ministry of Housing. The aim of this project is to create a new community on a 100-km^2 (25 000-acre) site located to the northeast of metropolitan Toronto. This new community and the new Toronto International Airport were to represent the first major steps of the structure plan.

COLUC Regional Analyses

The COLUC task force identified a system of 23 urban places within the region. These urban places are grouped into four subregions, which center around Hamilton, Mississauga, Toronto, and Oshawa. Each subregion is intended to be diversified and self-sufficient for service employment, but dependent on Toronto for very specialized services. Each subregion will contain several functionally interdependent urban places of different sizes. Preferred population and employment targets were established for each of the urban places illustrated in Figure 1.

Alternative programs were converted to input variables acceptable to the model. These inputs were used along with the appropriate model parameters to calculate population and employment allocations to each of the urban places and the associated travel demands assigned to a coarsely coded regional transportation network that reflects the principal transportation corridors. This analysis process will be helpful in understanding the probable impacts of the following policy elements on the preferred regional structure plan:

1. The distribution of basic (exogenously established) employment, particularly the location of airport employment;
2. Residential trunk servicing (population serving) policies and the residential densities of the urban places;
3. Urban population sizes and their influence on population-serving employment distributions (endogenously calculated employment distributions) and interurban and service demand orientations; and
4. Regional transportation policies.

The land use and transportation model was used to analyze the potential impacts of these alternative development policies. The model was calibrated for some 1971 transportation data. The behavioral parameters of the functions that impede travel were developed separately for eight subregions within the region to reflect differences in observed behavior between these subregions. The details of the calibration procedure were described in a previous report (8). The majority of the analyses were conducted for expected conditions in 1986, although some analyses were conducted for 2001.

Below are the characteristics of the public development policies analyzed. These policies included variations in the location of the new Toronto International Airport, alternative locations for the major trunk services extensions and alternative commuter rail networks.

1. COLUC base—1968 base condition reflecting some modifications to population and employment trends,
2. No new airport—proposed new Toronto International Airport abandoned and all air traffic uses existing airport,
3. Peel utilities network—a trunk services policy that would accelerate provision of serviced residential land on the western fringe of metropolitan Toronto,
4. York utilities network—a trunk services policy that would accelerate provision of serviced residential land to the northeast of metropolitan Toronto,
5. Oshawa utilities network—a trunk services policy that would accelerate provision of serviced residential land in the eastern end of the COLUC region,
6. All utilities network—simultaneous implementation of servicing policies 3, 4, and 5, and
7. Regional transportation—a variety of changes to the regional commuter rail network.

Changes in population from the COLUC base population allocations were calculated by the model for each of the five subregions for a number of the policy elements listed and transportation flows were assigned to a corridor level network. The concentration of all airport employment at the current airport site, Malton, had little impact on population distribution in the region. Shifting 15 000 employees would influence the residential location decisions of about 32 000 people. The principal residential zones affected are located on the fringes of metropolitan Toronto and within the Oshawa and Mississauga subregions, which are adjacent to the airport sites. The residential land servicing policies had the greatest influence on the distribution of population and employment within the COLUC region. The Peel network servicing policy had the greatest impact on the distribution of population and employment within the COLUC region. This could be expected because land use model analyses of the COLUC base concept showed that residential zones in the western areas of metropolitan Toronto and in the Mississauga subregion were likely to experience continued pressures for development; the provision of serviced land simply strengthened this demand. This servicing policy made Mississauga an important service employment center, which in turn increased the demand of service employees for residential location within the Mississauga subregion. Other servicing policies produced similar effects—residential demand and a certain amount of population-serving employment were encouraged to locate in the areas affected by the particular servicing policy.

The regional transportation policy alternatives tested all represented improvements in the public transportation system, except for the completion of one freeway link within the boundaries of metropolitan Toronto. These policies influenced the populations allocated to only the urban places whose access times to the Toronto central business districts were increased dramatically by the introduction of a high-speed commuter rail service. However, these effects were insignificant when viewed on the regional scale.

An interesting comparison of models is available from this study in that the EMPIRIC land use model was also used. Earlier studies for the regional government describe the EMPIRIC studies and provide some comparison between EMPIRIC and the Lowry model described in this paper (8, 9).

North Pickering Service Employment Analysis

A second series of analyses were performed on interurban place service employment allocations within the Oshawa subregion of the COLUC area. The particular interest of these analyses was the service employment

allocations to the North Pickering new town under three development scenarios for the subregion. The characteristics of these three development scenarios are shown in Table 1. Scenarios A and B have the same population targets for the Oshawa subregion but differ from each other in terms of the activity rate and the proportions of basic (i.e., employment independent of where population lives) and population-serving (i.e., employment required to meet needs of the population) employment. Scenario C has a higher subregional target population and a higher activity rate. Table 2 summarizes the service employment demand rates for each service employment sector. The rates for scenarios A and C are based on 1971 census data; those for scenario B are forecasts developed by the COLUC task force.

A number of development alternatives were postulated for the North Pickering community within each of these subregional scenarios:

1. North Pickering developed to a scale of 34 000 persons in 1986,
2. North Pickering developed to a scale of 80 000 persons in 1986,
3. New Toronto International Airport constructed and a total of 22 000 employed in 1986, and
4. New Toronto International Airport not constructed and all traffic using the existing airport.

The combination of subregional development scenarios and the North Pickering development alternatives and regional transportation policies were analyzed by the land use model using a disaggregated service employment submodel operated at the COLUC regional scale.

Figure 2 summarizes the population and service employment allocations to each of the urban places within the Oshawa subregion for four of the conditions analyzed. This diagram illustrates that under scenario A, when Oshawa provides only 180 000 residential opportunities, the population targets at North Pickering are exceeded for both scales of development of the new town. However, note that the service employment targets for North Pickering are not met. For a scale of development of 80 000 persons, 83 percent of the service employment target is met while only 59 percent of the target is achieved at the smaller scale of development. The service employment targets for Oshawa are just exceeded and Ajax, being the focus of the subregion, receives an overallocation of service employment.

Figure 2 illustrates that under scenario C, when Oshawa provides 300 000 residential opportunities, the population and service employment allocations to North Pickering are of a similar character to those just described for scenario A. Population targets are achieved, but the service employment targets are not achieved and the lakeshore communities of Ajax and Oshawa have been allocated too many service employees. These analyses provide a quantitative confirmation of the difficulties that might be experienced by the North Pickering development as a relatively self-contained service community.

Table 1. Oshawa subregion characteristics for three scenarios in 1986.

Variable	Scenario A	Scenario B	Scenario C
Employment			
Basic	57 660	55 300	70 900
Service	74 090	85 700	131 670
Total	131 750	141 000	202 570
Population	310 000	310 000	431 000
Service employment/population	0.239	0.276	0.305
Population/total employment	2.353	2.199	2.128

Table 2. Per capita service employment demand rates.

Service Employment Sector	Per Capita Service Employment Demand Scenario A	B	C
Retail	0.046	0.055	0.061
Finance and real estate	0.015	0.040	0.016
Education	0.028	—	0.030
Health and welfare	0.030	—	0.032
Business and personal services	0.100	0.160	0.105
Public administration	0.020	0.031	0.022
Transportation	—	0.025	—
Total	0.239	0.311	0.266

Applications to Delhi, India

Metropolitan transportation planning studies have been conducted in most of the large Indian cities. In Delhi, these studies produced recommendations for about 50

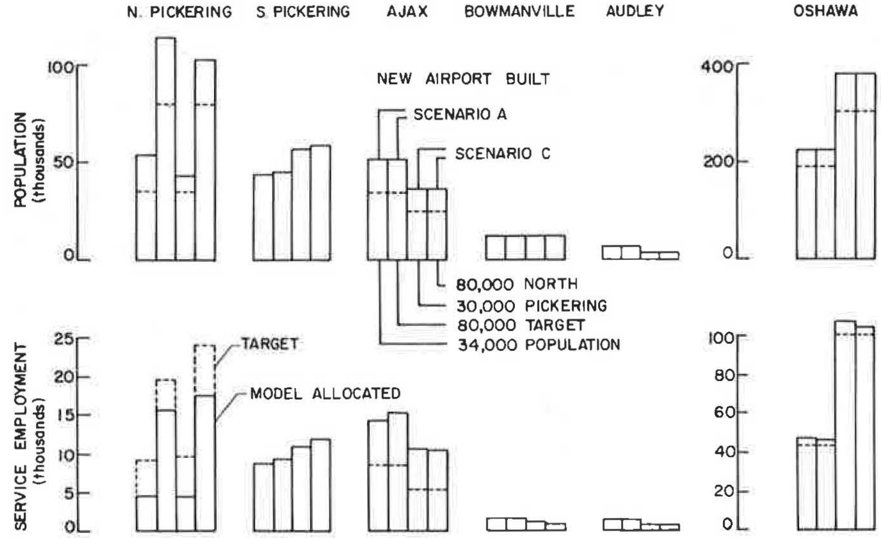


Figure 2. Population and service employment allocations to urban places within the Oshawa subregion for four strategies.

km of rapid transit facilities, which require large capital expenditures. The resources required for subway construction will probably not become available. Land use planning efforts are being directed to developing alternatives to minimize travel demand. Some of the land use development options under consideration include redistribution of the population throughout the area in order to achieve more desirable density patterns and the decentralization of employment.

There is a tremendous range in the characteristics of the socioeconomic groups who live in Indian cities. The spatial distribution of employment and housing opportunities, as well as the transportation services that are compatible with each of these socioeconomic groups, vary widely. An adequate estimate of the activity patterns and associated travel demands that might result from a particular set of public development policies must be conducted in terms of a number of separate socioeconomic groups.

Table 3 shows the distribution of household incomes observed in Delhi in 1969, average family size, motor vehicle ownership, work trip generation rates, and modal transportation choice for the journey to work. The information in Table 3 is based on data collected in 1969 by interviews conducted in homes by the Central Road Research Institute.

This table indicates that about 70 percent of the households in Delhi had monthly incomes of less than Rs (rupees) 500/month ($66.75/month). The information also indicates that motor vehicle ownership is quite low, except in households that have incomes greater than Rs 1000/month. Another feature illustrated by Table 3 is the high proportion of walking trips made by the lower income groups. The modal choice characteristics illustrate that the use of motor vehicles increases systematically with income. Mass transit usage increases with increasing household income and begins to decrease when household incomes are greater than about Rs 1000/month.

Another interesting feature was the proportions of various types of trips made by households in the various income groups. About 52 percent of all trips made were to work; educational and social or recreational trips formed the next most important type of trip. For households whose incomes were less than Rs 500/month, work trips represented more than 60 percent of the total trips made by these households; but when monthly incomes were greater than Rs 1500/month, this proportion dropped to less than 40 percent. The proportion of educational trips varied from a low of about 4 percent for households whose incomes were less than Rs 100/month to a high of about 22 percent for the upper income households.

A version of the land use and transportation model disaggregated by socioeconomic group was selected for calibration because of the need to understand the impacts of alternative development policies on the separate socioeconomic groups. The parameters of this version of the model have been estimated from the data collected in the 1969 Delhi home interview study. Because the Delhi home interview study was based on a simple random sample of households, some of the household income groups are not well represented in the sample and their behavioral characteristics had to be estimated subjectively. The criteria used for model calibration were agreement between observed and model-calculated trip length frequency distributions and observed and model-allocated activity vectors. In addition, model-calculated travel demands, which had been assigned to a system of travel corridors, were also used as a check on the validity of the model calibrations.

Table 4 summarizes the parameter magnitudes estimated from the Delhi home interview data. The table shows the behavioral parameter magnitudes of the residential and service submodels respectively, the work and service trip generation rates, and the modal split probabilities for work and service trips. Note that differences among the behavioral parameter magnitudes of the three income groups are not significant. The home interview study revealed that the trip length frequency distributions of motorists, transit riders, and bicyclists were very similar. However, the spatial distributions of activities compatible with each of the socioeconomic groups are quite different and the disaggregated model is required. Table 4 reveals large changes in the trip generation rates as incomes change. The lower income groups generate a much higher proportion of pedestrian trips, which is reflected in the lower trip rate in Table 4. The modal split probabilities also reveal interesting differences among income groups as well as differences in modal choice within an income group but between trip types. The lower income group households make few service trips, but the majority of these trips are by mass transit rather than bicycle, which is used for the majority of work trips. More detailed analyses of modal choice behavior were conducted, but the coarsely drawn regional transportation network used for the 1969 study prevented transportation system responsive modal choice models from being developed. The calibration of this model is described fully by Sarna (10).

The calibrated land use and transportation model has been used to explore the transportation implications of a number of changes to the 1981 master development plan for Delhi. These concepts varied as to the location of basic employment, housing opportunities, and transportation system properties (10).

CONCLUSIONS

This paper describes several applications of a land use

Table 3. Characteristics of households in Delhi, 1969.

Monthly Income Range: Rs[a]	Monthly Income Range: %	Average Size (persons)	Motor Vehicles[b]	Work Trips: Non-Walking	Work Trips: Including Walking	Modal Transport Choice[c] (%): Motor Vehicle	Modal Transport Choice[c] (%): Mass	Modal Transport Choice[c] (%): Bicycle
Less than 100	3.7	2.7	–	0.14	0.49	7.5	31.4	59.6
100 to 149	8.7	4.2	–	0.28	0.71	0.3	26.3	68.4
150 to 249	25.3	4.8	–	0.47	0.98	0.6	24.0	70.7
250 to 499	30.1	5.6	0.051	0.69	1.20	4.1	36.5	53.3
500 to 749	12.1	6.1	0.189	0.99	1.41	13.7	48.4	32.3
750 to 999	4.1	6.4	0.303	1.20	1.64	18.1	51.1	24.6
1000 to 1499	4.6	6.0	0.500	1.33	1.63	33.0	47.2	11.5
1500 to 2000	2.0	6.1	0.909	1.27	1.51	50.2	31.1	4.1
2000 to 2500	1.5	6.0	0.909	1.45	1.60	53.3	28.1	3.2
More than 2500	1.3	6.3	1.429	1.65	1.75	78.9	9.1	1.2
Unknown	6.6	4.2	0.083	0.20	0.29	25.0	38.7	28.6

[a] In 1969, Rs7.49 = $1.00.
[b] Includes motorcycles, motor scooters, and automobiles.
[c] Percentages are for nonwalking trips only.

Table 4. Parameter magnitudes for socioeconomically disaggregated version of model.

Variable	Income Group[a] Low (less than Rs 500)	Middle (Rs 500 to 1499)	High (more than Rs 1500)
Behavioral parameters			
α	0.112	0.105	0.120
β	0.120	0.140	0.120
Trip generation rates			
Work to home/employee	0.33	0.62	0.84
Home to service/household	0.29	1.02	2.31
Modal split probabilities[b]			
Work			
Motor vehicle	0.03	0.21	0.69
Mass transit	0.33	0.52	0.27
Bicycle	0.64	0.27	0.04
Service			
Motor vehicle	0.04	0.23	0.71
Mass transit	0.61	0.64	0.21
Bicycle	0.35	0.13	0.08

[a]In 1969, Rs7.49 = $1.00. [b] Entries do not include pedestrian trips.

and transportation model to issues encountered in regional strategic development planning. Analysis models used for this type of planning must have modest data requirements, be adaptable to a variety of issues, and have quick computer turn-around time.

The first application of the model was to aid in the formulation of a consistent and desirable set of public development policies. In this application, the behavioral parameters of the model were disaggregated spatially, but the residential submodel was aggregated over all socioeconomic groups and the service submodel was aggregated over all service sectors.

The second application involved detailed analyses of the distribution of service employment by sector within one subregion. In this application the service employment submodel was disaggregated into a number of service employment sectors.

The final application involved the development of a version of the model disaggregated by socioeconomic group for Delhi, India. A disaggregated version is required because of the tremendous range of socioeconomic groups in Indian cities and the very different spatial distributions of employment and housing opportunities available to these groups. This version of the model has been used to explore the impacts of alternative land development policies on the corridor level volumes of road and public transportation trips.

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Impact of Transportation on Urban Density Functions

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A method is proposed for analyzing the variable impact of transportation on urban structure. The varying coefficient model, which uses the negative exponential density function as a theoretical base, provides a means for systematically incorporating hypothesized effects of current and past levels of transportation while holding constant population, income, and other factors identified with current urban spatial structure. The aspects discussed include the following: the theoretical basis for the hypothesized effects of the conditioning variables to be investigated, the development of the model in relation to changing density functions, the estimation of model parameters by use of available cross-sectional data, the application of the model to the generalized problem of the urban density function, and simulated forecasts and analyses of transportation-related changes in urban structure for selected cities.

The relation between density and distance—or, more generally, the density gradient—has been used in recent years to explain urban spatial structure. The standard

functional form assumed for the density gradient is the negative exponential; i.e.,

$$D(u) = D_0 \exp(-ru) \quad (1)$$

where

$D(u)$ = density u distance from the urban center;
D_0 = density at the urban center; and
r = density gradient, the percentage by which $D(u)$ decreases as distance increases.

Previous models of urban economies have focused on explaining the intensity of land use and employment by distance from the urban center, incorporating modifications to include transportation cost, income, past development, and other selected socioeconomic factors. This paper proposes an alternative method for analyzing the variable impact of transportation on urban structure. The varying coefficient model (VCM), which uses the negative exponential density function as a theoretical base, provides a means for systematically incorporating hypothesized effects of current and past levels of transportation while holding constant population, income, and other factors identified with current urban spatial structures. The VCM thus generalizes the simple exponential density function to accommodate more realistic hypotheses about the impact of transportation on urban structure. Because transportation exhibits high secondary relations with time, the VCM also represents a basis for sharpening existing forecasting tools. In addition, because its use requires little additional computation or data collection, it is useful in exploratory statistical analyses of urban structure and other applied economic problems. This study applies the VCM to the estimation of an urban density function conditioned on factors that vary within and among cities.

THEORY AND DATA

The theoretical foundation for the density gradient provided by Muth (6) can be used to determine qualitative effects of transportation on the intercept and the slope of the resulting exponential function. Briefly, housing is produced by using land that surrounds the central business district (CBD). Workers residing in these households are assumed to commute to and from jobs in the CBD. The optimal household location for a cost-minimizing worker employed in a CBD occurs when

$$-\partial p/\partial u(q) = \partial T/\partial u \quad (2)$$

where

p and q = price and quantity of housing services respectively and
T = transportation cost.

Thus, $-\partial p/\partial u(q)$ is the reduction in expenditure necessary to purchase a given q that results from moving u distance away from the CBD. The derivative $\partial T/\partial u$ represents the increase in T that is incurred by making such a move. By using Equation 2 and related formulations of the demand for housing, Muth was able to derive qualitative effects for a number of variables on optimal location. Because the model is well-known, this discussion only reviews the qualitative results as specialized for the variables selected for empirical analysis in this study.

The data consist of a random sample of 43 census tract densities measured u distance from the CBD for each of 39 U.S. cities in 1970. Two corresponding sets of additional data were also used. The first consisted of observations for each of the 43 tracts in the various cities—referred to as tract-specific variables. The tract-specific variables are the percentage of commuters who use public transportation (X_1) and income (X_2). The percentage of public transportation commuters is used to reflect the impact of the introduction and continued use of subways or bus systems on urban structures. Relative costs of private versus public transportation are, of course, difficult to determine. Instead of making statements about relative costs that cannot be tested, this study uses observed behavior to establish the importance of the transportation variable. Muth's model shows that an increase in either the fixed or the marginal costs of transportation decreases the equilibrium distance from the CBD for any household.

The relation between optimal household location and income is important because it determines patterns of housing consumption in different parts of the city. For example, consider a general increase in the level of income for the residents of a city. The increase in income would increase housing consumption and, assuming this outweighed effects of increased transportation cost and housing prices, the equilibrium distance from the CBD would increase for all households. On the basis of this reasoning, the density gradient is expected to vary inversely with the level of income.

The second set of concomitant data is citywide and designed to explain differences among cities attributable to variations in past development. Harrison and Kain (2) have demonstrated the importance of past development on current land use. In fact, they have suggested that the principal differences in urban structures among U.S. cities are attributable to differences in the timing of their development. For example, in the Los Angeles metropolitan area, dwelling units constructed between 1950 and 1960 accounted for almost 40 percent of the total in 1960; in Boston they accounted for only 16 percent (2). Two variables were used this study to capture these effects: relative age of the city (X_3) and city population (X_4). The age of the city, which is based on the last significant spurt of growth, pinpoints the timing of significant structural changes that have occurred in the city. Population levels are used to represent overall scale effects caused by past development. Generally, recent spurts of growth and population increases would tend to reduce the density gradient because of the effect on transportation of technological changes such as freeways and the automobile (6).

THE MODEL

In specifying a model that is consistent with the theory and the data discussed above, the approach was to use the exponential density function but to introduce systematic changes in parameters. That is, the parameters of the density function are hypothesized to vary as a result of the interplay of city- and tract-specific variables. As indicated above, the a priori basis for relating parameters of the exponential density function to city- and tract-specific variables is somewhat limited. Generally, the theory only yields conclusions for signs of anticipated parameter changes.

Because of limited prior information, the VCM proposed is one with a polynomial as the structure for possible changes in parameters. Because the specification locally approximates more complex relations, it is useful for exploratory work. To implement the poly-

nomial specification, let

$$\ln D_o = \ln D_o(X_1, X_2, X_3, X_4) = \sum_{n_1=o}^{q_{o1}} \sum_{n_2=o}^{q_{o2}} \sum_{n_3=o}^{q_{o3}} \sum_{n_4=o}^{q_{o4}} \beta^o_{n_1,n_2,n_3,n_4} X_1^{n1} X_2^{n2} X_3^{n3} X_4^{n4} \quad (3)$$

and, similarly, for the slope coefficient (r) in Equation 1, let

$$r = r(X_1, X_2, X_3, X_4) = \sum_{n_1=o}^{q_{11}} \sum_{n_2=o}^{q_{12}} \sum_{n_3=o}^{q_{13}} \sum_{n_4=o}^{q_{14}} \beta^1_{n_1,n_2,n_3,n_4} X_1^{n1} X_2^{n2} X_3^{n3} X_4^{n4} \quad (4)$$

The parameters $\ln D_o$ and r are thus polynomials of orders q_o and q_1 respectively in X_1, X_2, X_3, and X_4 (the four city- and tract-specific variables). Application of this revised specification to the data is straightforward. $\beta^o_{n1,n2,n3,n4}$ and $\beta^1_{n1,n2,n3,n4}$, as well as values for city- and tract-specific variables that correspond to the data points, determine the exponential density function. The special case $n_1 = n_2 = n_3 = n_4 = 0$ is the constant coefficient, log linear density function.

The advantages of the VCM provided by Equations 3 and 4 combined with the hypothesis for the log linear density function should be apparent. The VCM generates city- and tract-specific results but within the context of a functional form that has theoretical and empirical support. Moreover, the flexibility of the VCM would appear to make the exponential density function more useful in policy analysis and prediction. Since the selected city- and tract-specific characteristics may be subject to control by policy action or may be comparatively easily projected on the basis of time, the model can be used for both forecasting and policy analysis even though it is estimated from cross-sectional data. This feature is not without statistical limitations, but it should prove especially useful given the data bases available for studying density patterns in urban economies.

METHODS OF ESTIMATION

The estimation procedure follows from error assumptions and additional information that restricts the numbers of parameters for the model as expressed in Equations 3 and 4. First, the polynomials that relate $\ln D_o$ and r to the X_1, X_2, X_3, and X_4 variables are assumed to be second order. Even if this is assumed, application of the standard formula for permutations shows that there are 1320 parameters for each of the hypothesized conditioning structures on the $\ln D_o$ and r coefficients. Although the data are extensive in comparison with those used in some other studies, they obviously cannot support this ambitious specification. As a result, the number of parameters required to determine the variable coefficients of the log linear density model was further limited.

The approach used to obtain these restrictions is based on the intended uses of the model and on preliminary tests in the sample data. Although there are some obvious statistical problems with this method (8), no alternative was possible. First, four versions of the model of the density function were estimated; in each version the coefficients were functions of only one conditioning variable. For example, in the case of the X_1 tract-specific variable—the percentage of commuters who use public transportation—the assumption was $q_{o_2} = q_{o_3} = q_{o_4} = o$ and $q_{12} = q_{13} = q_{14} = o$, which implies structures for the VCM that are determined on the basis of six parameter estimates. If i denotes the city and j the tract for this special case, the model given in Equations 3 and 4 can be expressed as

$$\ln D(u)_{ij} = \ln D_{o_{ij}} - r_{ij} u + \epsilon_{ij} \quad (5)$$

for the 43 × 39 observations in the sample. An additive error term (ϵ_{ij}) with a subsequently specified structure has also been included. Applying the special assumptions to Equations 3 and 4 yields

$$\ln D_o(X_1,X_2,X_3,X_4) = \ln D_o(X_1) = \ln D_{o_{ij}} = \sum_{n_1=o}^{q_{o1}} \beta^o_{n_1} X_{ij}^{n1} \quad (6)$$

and

$$r(X_1,X_2,X_3,X_4) = r(X_1) = \ln r_{ij} = \sum_{n_1=o}^{q_{11}} \beta^1_{n_1} X_{ij}^{n1} \quad (7)$$

where subscripts for β^o and β^1 that correspond to the excluded conditioning variables have been omitted for convenience.

The model specified in Equations 5, 6, and 7 includes coefficient restrictions across tracts and cities. It is clear, therefore, that pooling of the data on tracts and cities is necessary to estimate the required parameters. In addition, plausible assumptions for the distribution of the structural disturbance ϵ_{ij} point to the advantages of pooling the data (1, 9, 10).

Based on the results from the four simplified VCMs and prior information to be subsequently discussed, a model was specified that incorporates the effects of all the coefficient conditioning variables. In terms of Equations 3 and 4, the structure of coefficient variation for the density function for this final model is

$$\ln D_o = \beta^o_{oooo} + \beta^o_{looo} X_1 + \beta^o_{oloo} X_2 + \beta^o_{oolo} X_3 + \beta^o_{oool} X_4 \quad (8)$$

and

$$r = \beta^1_{oooo} + \beta^1_{looo} X_1 + \beta^1_{2ooo} X_1^2 + \beta^1_{oloo} X_2 + \beta^1_{o2oo} X_2^2 + \beta^1_{oolo} X_3 + \beta^1_{oo2o} X_3^2 + \beta^1_{oool} X_4 + \beta^1_{ooo2} X_4^2 \quad (9)$$

It should be apparent that final specification concentrates on variation in the density gradient (r). By using an argument analogous to that made for Equation 5, this structure can be substituted to reparameterize the model of the exponential density function, and generalized least squares methods can be applied to obtain estimates with desirable asymptotic properties. In addition, based on the procedures just described, the central and noncentral F-statistics can be used to test the null hypothesis (the density function model with constant coefficients) for appropriateness given the sample data.

EMPIRICAL RESULTS

Results from an application of the density function model with constant coefficients on a city-by-city basis are given in Table 1. These estimates provide a source of comparison for estimates derived from the alternative VCMs. The results in Table 1 demonstrate a concern about the appropriateness of the exponential density hypothesis with constant coefficients. Both $\ln D_o$ and r are statistically significant for most of the 39 cities. But there are important differences in their magnitudes, especially for r. In addition, the estimated density function for the pooled data did not explain a high proportion of the variation that was observed in the de-

Table 1. Ordinary least squares estimates of coefficients for exponential density function for 39 cities and pooled city data.

		r					r		
City	$\ln D_o$	Estimate	t-Statistic	R^2	City	$\ln D_o$	Estimate	t-Statistic	R^2
Akron	9.273	-0.202	-2.86	0.167	Pittsburgh	9.689	-0.121	-2.14	0.100
Baltimore	9.767	-0.186	-12.37	0.783	Portland	9.193	-0.139	-4.75	0.355
Birmingham	9.017	-0.190	-6.38	0.498	Providence	9.090	-0.135	-4.54	0.335
Chicago	9.745	-0.039	-1.60	0.059	Richmond	8.716	-0.221	-6.71	0.523
Cincinnati	9.669	-0.162	-4.78	0.358	Rochester	9.845	-0.327	-10.32	0.722
Dayton	9.245	-0.179	-4.62	0.342	Salt Lake City	8.883	-0.128	-4.17	0.298
Denver	9.624	-0.206	-5.37	0.413	San Antonio	9.300	-0.212	-6.44	0.503
Detroit	9.714	-0.075	-3.86	0.281	San Diego	9.141	-0.065	-2.79	0.159
Flint	9.482	-0.386	-6.82	0.532	San Jose	8.990	-0.085	-2.12	0.099
Fort Worth	8.399	-0.059	-2.38	0.121	Seattle	9.220	-0.140	-6.02	0.469
Houston	9.209	-0.153	-5.17	0.395	St. Louis	10.029	-0.170	-7.48	0.577
Jacksonville	9.205	-0.343	-10.34	0.723	Spokane	8.762	-0.256	-5.24	0.404
Louisville	8.619	-0.139	-6.12	0.478	Syracuse	9.938	-0.487	-15.62	0.856
Memphis	9.463	-0.173	-5.79	0.450	Tacoma	9.078	-0.177	-4.20	0.284
Milwaukee	10.013	-0.207	-6.53	0.509	Toledo	9.835	-0.317	-7.12	0.553
Nashville	9.078	-0.269	-8.42	0.634	Tucson	8.459	-0.146	-2.88	0.169
New Haven	9.791	-0.510	-10.75	0.738	Utica	9.421	-0.374	-5.78	0.449
Omaha	8.845	-0.114	-2.41	0.124	Washington, DC	9.980	-0.136	-3.96	0.277
Philadelphia	10.612	-0.195	-6.05	0.471	Wichita	9.000	-0.227	-4.63	0.343
Phoenix	9.089	-0.134	-4.54	0.335					

Note: Estimated coefficients for the pooled city data are $\ln D_o$ = 8.41, r = -0.010, and R^2 = 0.010.

pendent variable. In all cases, a greater proportion of variation could be explained for city-by-city estimates of the density function than for the model that used pooled data. Although the results emphasize the limitations of empirical generalizations that are based on the density function hypothesis with constant coefficients, they are typical of other results obtained by using data from U.S. cities (3, 6). The null hypothesis—that the constant coefficient density function is appropriate for all cities—is rejected at the 1 percent level in both cases. Obviously, more elaborate hypotheses are required to explain population density within and across cities.

Estimates for the pooled data in which the parameters vary according to the scheme given in Equations 6 and 7 are given in Table 2. Recall that the conditioning variables are use of public or private transportation (X_1), income (X_2), age (X_3), and population (X_4). The specification is that the coefficients for the density gradient are quadratic functions of these conditioning variables. Examination of the significance levels of the parameters on the linear and quadratic terms for the specifications given in Table 2 indicates that each of the conditioning variables is important in shifting the density from city to city and between tracts. This general observation is confirmed by comparing the R^2's in Table 2 with those given in Table 1 for the constant coefficient model as applied to pooled data.

On a more specific basis, results obtained by using the public-private transportation variable to condition the coefficients of the density function show that its major effect is on the coefficient of distance (r). For the constant term, the estimated parameter on the linear term is not statistically significant and the parameter estimate for the quadratic is only marginally so. Estimates on the constant, linear, and quadratic terms for the coefficient of distance are -0.0867, 0.456, and -0.0517 respectively, and all are statistically significant. The estimates show that the public-private transportation variable first increases and then density decreases. What the result shows is that, in cities and tracts for which the value of the public-private transportation variable is low, the density gradient is lower than it is in cities for which the transportation variable has a high value. Thus, if other things are equal, cities that have below-average levels of public and private transportation and contemplate policy measures designed to improve it should expect a decrease in the absolute value of density.

Parameter estimates for the density function, specified with coefficients conditioned as hypothesized in Equations 8 and 9, are given in Table 3. The table is similar in construction to Table 2 except that estimates in the constant columns are repeated for reference. The table gives all parameters as statistically significant, and the R^2 for the pooled data is improved to 0.49. The parameter estimates are generally interpreted as were those given in Table 2.

For the constant coefficient $\ln D_o$, the estimated linear parameters show that densities in the CBD increase with increased public and private transportation, income, and age and decrease with population. The significant estimates of the linear and quadratic parame-

Table 2. Estimation of exponential density function with coefficients jointly conditioned on selected variables (variation in parameters according to Equations 6 and 7).

Conditioning Variable	Parameter	$\ln D_o$ Coefficient	t	r Coefficient	t	R^2
X_1	Constant	8.545	86.08	-0.0867	13.92	0.32
	Linear $(X_k)^a$	-0.179	0.87	0.456	12.76	
	Quadratic $(X_k^2)^a$	0.222	1.91	-0.0517	2.14	
X_2	Constant	8.895	87.68	6.59 E-3	2.81	0.26
	Linear $(X_k)^a$	5.91 E-5	2.72	-2.17 E-5	12.54	
	Quadratic $(X_k^2)^a$	-4.714 E-9	4.36	8.75 E-10	7.33	
X_3	Constant	8.689	85.88	-0.120	1.42	0.21
	Linear $(X_k)^a$	0.015	4.81	-1.19 E-3	2.50	
	Quadratic $(X_k^2)^a$	-9.96 E-5	5.86	1.23 E-5	5.03	
X_4	Constant	9.367	119.59	-2.90	22.18	0.28
	Linear $(X_k)^a$	-1.33 E-6	8.55	4.20 E-7	20.92	
	Quadratic $(X_k^2)^a$	5.10 E-13	8.51	-1.14 E-13	16.05	

Note: E term indicates decimal movement.
[a] The index k takes on values 1, 2, 3, and 4 to indicate each of the four conditioning variables.

Table 3. Estimation of exponential density function with coefficients jointly conditioned on selected variables (variation in parameters according to Equations 8 and 9).

Conditioning Variable	Parameter	$\ln D_o$ Coefficient	t	r Coefficient	t	R^2
X_1	Constant	8.8746	91.88	-2.0146 E-1	11.53	0.49
	Linear	2.3102 E-1	1.71	2.4260 E-1	6.42	
	Quadratic	—	—	-3.7874 E-3	-11.21	
X_2	Constant	8.8746	91.81	-2.0146 E-1	-11.53	0.49
	Linear	1.2194 E-5	1.42	-9.6841 E-6	-7.78	
	Quadratic	—	—	1.2931 E-10	3.30	
X_3	Constant	8.8746	91.88	-2.0146 E-1	-11.53	0.49
	Linear $(X_k)^a$	5.8489 E-4	-0.80	9.3994 E-4	3.56	
	Quadratic $(X_k^2)^a$	—	—	-6.3914 E-6	-4.67	
X_4	Constant	8.8746	91.88	-2.0146 E-1	-11.53	0.49
	Linear $(X_k)^a$	-3.2657 E-8	-0.41	2.5331 E-7	15.20	
	Quadratic $(X_k^2)^a$	—	—	-6.6665 E-14	-14.54	

Note: E term indicates decimal movement.
[a] The index k takes on values 1, 2, 3, and 4 to indicate each of the four conditioning variables.

ters for the coefficient of distance show that r increases at higher levels of public and private transportation use and higher income levels and decreases with increasing city age and population. The first effect would indicate a flatter density gradient in cities with higher average income and greater use of public transportation.

Perhaps the best way to assess the implications of this final version of the VCM is to evaluate the density function for each of the cities included in the sample. This has been done for the city-specific conditioning variables at within-city sample means (Table 4). Such information makes it possible to do specialized analyses for particular cities by using the estimates given in Table 3. More generally, it is apparent from a comparison of Tables 1 and 4 that the VCM produces reasonable estimates for the density function. The advantage of the VCM is thus the improved fit and increased reliability of parameter estimates and, most importantly, the increased possibility of functional analysis of population density based on commonly advanced arguments of socioeconomic conditioning.

USE OF EMPIRICAL RESULTS

Two examples demonstrate how the empirical results can be used in the context of policy making and forecasting. One example involves a representative city obtained by setting the conditioning variables of the density function coefficients at mean sample values. The second example used is that of Washington, D.C.

The analysis of the impacts of changes in public transportation, income, age, and population is made on a partial basis; that is, the value for one of the conditioning variables is changed while others are held at current levels for the two example cities. First, three levels are considered for each of the variables that are assumed to condition the coefficients of the density function: the current level and 50 and 100 percent increases in it. The results obtained by using these assumptions are given in Table 5. These results show, for example, that in the typical city setting public and private transportation at the current level increases $\ln D_o$ by 0.0494 and r by 0.0517. By contrast, increasing the public and private transportation variable by 100 percent raises the value of the constant by 0.0989 and the gradient by 0.103 04. Similar interpretations of the results apply for the Washington, D.C., example and for the other conditioning variables.

What the results in Table 5 show is that the major impact of the conditioning variables is on the density gradient. This is not surprising since the specification of the structure for the varying coefficients featured possible changes in the gradient. What is encouraging is that the results are reasonable for the changes considered even though some of the results are for values of the conditioning variables far from the sample means. This indicates that the surface being approximated by the polynomial is sufficiently stable so that projections or forecasts based on assumed values of the conditioning variables can be viewed with some confidence.

Impacts of changes in the transportation variable on the density gradient (r) and representative structural shifts in the density function are plotted in Figure 1. The interpretation for the shifted density functions is that they are cross sectional and thus refer to levels of equilibrium. Thus, shifts that result from changes in the conditioning variables represent density relations to which the cities would gravitate as a result of policy changes or other possible exogenous effects. Finally, the similarity in the shifting density gradients shown in Figure 2 indicates that the VCM can be consistent with cities and tracts that have different characteristics

Table 4. Estimates of density function coefficients based on varying coefficient model.

City	$\ln D_o$	r	City	$\ln D_o$	r
Akron	9.0223	-0.175 4	Pittsburgh	9.1589	0.030 81
Baltimore	9.1219	-0.086 5	Portland	9.0365	-0.131 39
Birmingham	9.0055	-0.141 01	Providence	9.0587	-0.191 57
Chicago	9.1495	0.078 5	Richmond	9.0846	-0.129 26
Cincinnati	9.0504	-0.083 39	Rochester	9.0772	-0.151 85
Dayton	9.0676	-0.168 36	Salt Lake City	9.0096	-0.215 1
Denver	9.0399	-0.119 55	San Antonio	9.0016	-0.101 21
Detroit	9.0373	-0.018 7	San Diego	8.9008	-0.113 02
Flint	9.4459	-0.297 51	San Jose	9.0112	-0.191 52
Fort Worth	9.0097	-0.165 0	Seattle	9.0423	-0.127 74
Houston	8.9848	-0.044 85	St. Louis	9.0911	0.080 84
Jacksonville	9.0128	-0.107 18	Spokane	8.9996	-0.206 7
Louisville	9.081	-0.125 008	Syracuse	9.0781	-0.164 27
Memphis	9.0308	-0.044 47	Tacoma	9.0094	-0.209 05
Milwaukee	9.0907	-0.056 99	Toledo	9.0388	-0.156 14
Nashville	9.024	-0.109 8	Tucson	8.9777	-0.207 1
New Haven	9.1092	-0.199 26	Utica	9.0841	-0.234 5
Omaha	9.0436	-0.131 25	Washington, DC	9.1478	-0.000 955
Philadelphia	9.1784	0.075 24	Wichita	9.000	-0.203 38
Phoenix	8.9984	-0.151 33			

Table 5. Impact of current values and 50 and 100 percent increases in levels of conditioning variables on central densities ($\log D_o$) and density gradient (r) for the typical city and Washington, D.C.

Level	Conditioning Variable			
	X_1	X_2	X_3	X_4
Typical City				
Current				
D_o	0.049 4	0.1187	0.3269	0.0185
r	0.051 7	-0.0823	0.0326	0.1223
50 percent increase				
D_o	0.074 2	0.1781	0.4907	0.0278
r	0.077 5	-0.1138	0.0343	0.1673
100 percent increase				
D_o	0.098 9	0.2374	0.6539	0.0371
r	0.103 14	-0.1395	0.0253	0.2016
Washington, DC				
Current				
D_o	0.100 3	0.1965	0.4094	-0.0247
r	0.104 6	-0.1030	0.0345	0.1535
50 percent increase				
D_o	0.150 4	0.2347	0.6141	-0.0371
r	0.156 3	-0.1385	0.0283	0.2016
100 percent increase				
D_o	0.200 5	0.3130	0.8189	-0.0494
r	0.207 7	-0.1634	0.0063	0.2306

Figure 1. Impact of public transportation on density gradient (r).

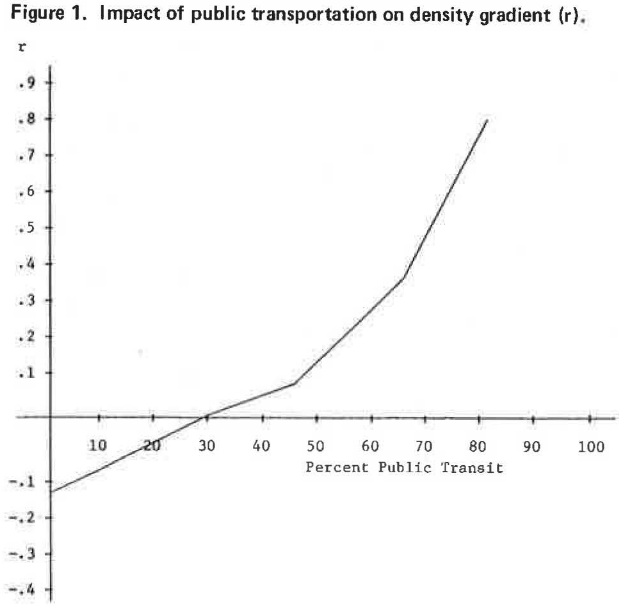


Figure 2. Impact of public transportation on density function for 50, 10, and 0 percent use of public transit by commuters (assuming same percentage of riders at all distances).

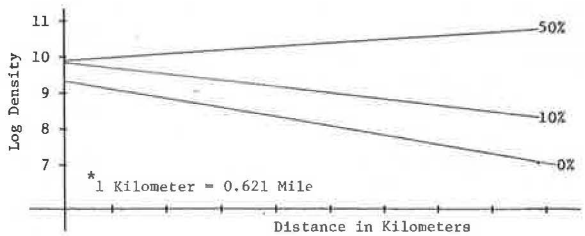
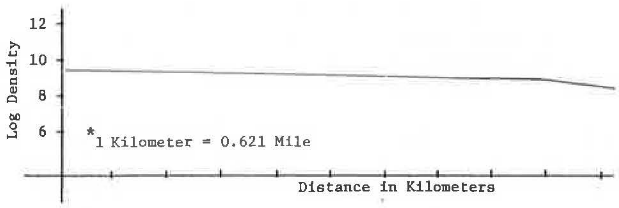


Figure 3. Impact of public transit for a special case [30 percent transit riders the first 5 km (3 miles) from city center and decreasing patronage beyond 5 km].



and can thus explain much of what in a simpler hypothesis would be attributed to spurious variation.

Mills (4), Mohring (5), Muth (6), Pendleton (7), and others have found empirical evidence that improvements in transportation tend to reduce the density gradient. The evidence provided by the VCM indicates that, as the percentage of public transit users increases, r decreases; in fact, as shown in Figure 1, r becomes positive when the number of public transit riders exceeds 30 percent. This occurs in four cities: Chicago, Philadelphia, Pittsburgh, and Washington, D.C. The estimates of r based on city-specific values for the conditioning variables (Table 4) indicate that r was positive in all cases except that of Washington, D.C., in which case it was essentially zero. Thus, the city-specific results based on the VCM (and also the ordinary least squares estimates given in Table 1) corroborate the findings of the more general analysis of the impact of transportation on the density gradient.

Additional information for policy analysis is contained in Figure 3, which assumes that a relatively substantial number of riders consistently use public transit to travel some predetermined distance from the CBD and that eventually, at greater distances, the number of riders decreases. Because the marginal cost of public transportation is mostly time related, this result would apply if identical income groups had a tendency to locate approximately equal distances from the CBD. In general, then, subsidies designed to increase the number of public transit riders would result in decentralization. Because the percentage of public transit use is a tract-specific variable, the VCM approach can measure, within a particular area of a city, changes in density patterns that are caused by a shift in the number of transit riders. For example, the impact of the new mass transit system in Washington, D.C., could be approximated for each specific city tract. This allows for the development of spatial—or, more generally, three-dimensional—density functions.

SUMMARY AND CONCLUSIONS

The varying coefficient model has been proposed as a method for introducing city- and tract-specific variables into the exponential density functions used to study urban structure. A major advantage of the VCM is that it permits the introduction of such variables while retaining an interpretation that can be reconciled with the body of theory that justifies the use of the exponential functional form. As a result, results obtained by applying the VCM can be compared with the massive empirical literature on urban density functions. Most estimated density functions are only special cases of the general VCM with a polynomial structure that relates the coefficients of the density function to socioeconomic conditioning variables.

Application of the VCM to data from 43 randomly selected 1970 census tracts for each of 39 U.S. cities provided a number of interesting results that may help to resolve a problem raised by recent studies in the application of the density function. It has been shown that questions about the appropriateness of the exponential functional form and specification errors associated with the omission of city- and tract-specific variables can be handled in the context of applied density function studies by using the VCM framework. In this study, the explanatory power of the density function and the significance levels of the structural parameters were greatly enhanced by the application of the VCM in studying the 1970 data.

The results also show that the conditioning variables that reflect transportation mode, city age, household income, and population could be used to provide reasonable explanations of apparent structural differences between cities and tracts. Of these results, perhaps the most interesting relates transportation mode to density. Analysis of the polynomial structure relating these tract-specific variables to the density gradient gave results that have a natural interpretation based on the opportunity cost of travel time as income increases. Other results, although perhaps less novel, are consistent with hypotheses that have emerged from more elaborate theories that support the exponential density function.

The most important results of the application of the VCM are those that relate to the use of the urban density function as a tool for policy analysis and projection. Until now, empirical work on urban density functions (including tests of the form of the density function and exploratory analyses of possible additional variables for explaining density patterns) has been largely descriptive. By introducing a method for including possible policy control variables and additional uncontrollable variables directly related to time, this study offers an expanded area of application for the density function hypothesis. The analysis of a typical city and of Washington, D.C., shows that effects of policies designed to influence transportation mode can be directly examined in the context of an estimated density function. When density is a target in urban planning, estimated VCMs of the type presented in this study can assume an important role in the structure of planning models. The relation between city age, population, and time illustrates how the model can be used in forecasting. Because these uncontrollable variables can be accurately projected on the basis of simple expressions in time, the cross sectionally estimated density function can be used for forecasting changes in urban structure. Although such forecasts can yield little information about the adjustment to new levels of equilibrium, they should provide urban economists with a valuable tool. The lack of information on rates of adjustment indicates that this is an area that requires further research.

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