TRANSPORTATION RESEARCH
RECORD

No. 1466

Planning and Administration

Issues in Land Use and Transportation Planning, Models, and Applications

A peer-reviewed publication of the Transportation Research Board

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
WASHINGTON, D.C. 1994

Transportation Research Record 1466
ISSN 0361-1981
ISBN 0-309-06072-9
Price: $30.00

Subscriber Category
IA planning and administration

Printed in the United States of America

Transportation Research Record 1466

Contents

Foreword

This volume contains papers focusing on various aspects of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), design issues in land use and transportation, land use models, and traffic generation (regional, shopping, traffic volume and classification, and multimodal trip distribution).

Six papers discuss various aspects of ISTEA: a conceptual model for transportation planning that is set forth by redefining the set of central problems and acceptable solutions that transportation planners must address by giving the reshaped planning process a system of information feedback loops; the passage of ISTEA and under what conditions legislation that points in significantly different directions is enacted; implementation issues associated with ISTEA; evaluation of how metropolitan planning organizations and their planning partners are responding to the act on the basis of comprehensive reviews of transportation planning in nine metropolitan areas; and presentation of the application frameworks from a U.S. Department of Defense logistics management program and its relevance to the six information management systems specified in ISTEA.

Six papers on land use and transportation cover an empirical analysis to test the impacts of land use mix, population density, and employment density on the use of single-occupant vehicle transit, and walking for both work trips and shopping trips; the relation of location and land use to travel patterns in Florida; the effect of neotraditional neighborhood design on travel characteristics; the use of land use transportation models for policy analysis; a stated preference experiment concerning residential location choice; and the impacts of commuter rail services as reflected in single-family residential property values.

Three papers survey various aspects of travel characteristics: changes in regional travel characteristics and travel time expenditures in the San Francisco Bay Area from 1960 to 1990, the results of 4,000 shopper interviews at two shopping centers in Florida looking at impulse shopping and impacts of accessibility, multimodal trip distribution structure and application.

The remaining paper discusses the development of a traffic volume classification monitoring system based on adaptive and neural network computational techniques.

Intermodal Surface Transportation Efficiency Act and Interactive Transportation Planning and Decision Support: A New Conceptual Model

LINDA K. HOWE AND RICHARD K. BRAIL

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) changes the conceptual model for transportation planning and decision making by redefining the set of central problems and acceptable solutions that transportation planners must address and by giving the reshaped planning process a system of information feedback loops. This new conceptual model is called Interactive Transportation Planning and Decision Support (ITPDS). It is characteristically flattened, cross-functional, data-rich, messy, and customer oriented. The implementation of ITPDS would be significantly enhanced by placing stakeholders in a collaborative meeting environment supported by an interactive and accessible geographic information system relationally linked with a variety of data bases, models, and multimedia representations. Although a computer-based ITPDS system is not now in use, it is thoroughly feasible. Such a system would support ISTEA's new data and analysis requirements and improve organizational cooperation and productivity through data sharing, visualization, and consensus building. A computer-based ITPDS would also provide a tool that could graphically link long-range plans with transportation improvement programs.

Thirty years ago, in a seminal essay entitled *The Structure of Scientific Revolutions,* Thomas Kuhn described the history of science as a series of paradigm changes (*1*). According to Kuhn, a paradigm is the universal, generally accepted set of central problems and solutions used by a community of practitioners to define what they do. Redefinition of a paradigm occurs after a period of what Kuhn called "abnormal science," during which time practitioners become increasingly uncomfortable about the lack of fit between their expectations (which are generated by the normal model) and their observations (which result from practice and experiment). The crisis builds until a new paradigm emerges, reestablishing fit not so much by negating the previous set of problems and solutions as by incorporating them into a more comprehensive model that deals better with current interests and reflects better current observations of the environment.

Such a change is occurring right now in transportation planning, and a number of important features of this emergent model are reflected in provisions of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and its implementing rules, particularly 23 CFR 450 Subparts A–C concerning statewide and metropolitan planning. Over the course of the last 2 years it has become clear to many across the country that ISTEA really does establish a redefinition of the central problems for transportation professionals by placing new emphasis on connectivity, choice, air quality, and cost efficiency. ISTEA also confirms a new set of acceptable solutions for the set of transportation problems by giving priority, for example, to system management over construction of new capacity and by shifting attention to manipulating travel demand rather than increasing travel supply. To implement these changes in focus, the language of both the act and its implementing regulations aims at promoting changes in the planning and programming process, changes that will, it is assumed, produce a more integrated and fiscally efficient transportation system.

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There is much in this post-ISTEA planning process that will look very familiar to planners; however, planners should not be fooled by familiarity. They need to pay attention to the effects of the new mandates on the traditional model. Thus, for example, it is important to consider the implications of moving planning elements and activities to different areas of the process, of creating new planning and system performance linkages, and of infusing new information and analysis requirements into the planning process. It is also important to think about the implications of requiring more public participation and of vigorously shuffling the roles and responsibilities of traditional players—metropolitan planning organizations (MPOs), state departments of transportation (DOTs), and transit agencies—while adding new ones—for example, air pollution control boards and private freight shippers. The result of the changes, we argue, is a new conceptual model for what transportation planning is and how it happens.

Although the outlines of this new model are not as explicit in the regulation as many would like them to be, a careful reading of the planning rule and its preamble discussion reveal five major themes, from which we have constructed the principal features of the model that we call Interactive Transportation Planning and Decision Support (ITPDS). Briefly, after ISTEA the planning process will be flatter, cross-functional, data-rich, messy, and more customer oriented. As we hope to make clear in this paper, ITPDS represents a practical vision of how the new planning requirements can be made to work in the real world. For the purposes of this paper, we focus on metropolitan-level planning; however, the principles of ITPDS can be applied as well to both statewide and corridor-level plans.

We also suggest that, although not absolutely necessary, ITPDS virtually begs for implementation in a collaborative, computer-supported environment. Shiffer (*2*), for example, describes a prototype of such an environment for urban design that combines a simple geographic information system (GIS) with multimedia representations. An environment designed to support development of an MPO's long-range plan and transportation improvement program (TIP) would require considerable resources, including a collection of both spatial and nonspatial information and an assemblage of technical tools, particularly in view of the 15 planning elements listed in 450.316 and the air emissions analysis needed for compliance with the Clean Air Act Amendments of 1990. The vision, however, of stakeholders sitting together in a meeting room interacting collectively with a GIS that is relationally linked to a variety of robust data bases, what-if models, and multimedia representations creates the exciting possibility of transforming the transportation decision-making activity through data sharing, visualization, cooperative planning and design, and consensus building.

The technology is certainly within our grasp. And our experience during TRB panels and National Transit Institute curriculum development committees, in which we have participated in fairly simple collaborative word processing in a physical meeting room, as well as descriptions of computer-supported meeting environments such as those at Xerox's Palo Alto Research Center Colab (*3*) or the University of Arizona's College of Business and Public Administration (*4*), suggest the capability of the computer to enhance the kind of collaborative decision-making process now mandated by ISTEA.

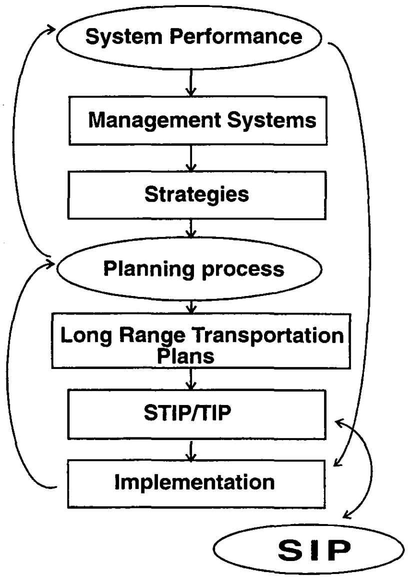

FIGURE 1 Pre-ISTEA project planning model.

BACKGROUND

As many have pointed out, ISTEA redefines familiar transportation concepts and requirements such as the comprehensive, continuing, and cooperative process, the federal-aid highway classification system, TIPs, public participation, and transportation system management. It also abandons others, for example, separate areawide highway location studies and transit project alternatives analysis as well as the distinction between federal-aid primary and secondary highways. ISTEA also establishes some new requirements such as congestion management systems, conformity, state long-range transportation plans, the national highway system, and 15 metropolitan and 23 statewide planning factors for consideration. It even changes the name of one of the U.S. Department of Transportation's (U.S. DOT's) modal administrations from the Urban Mass Transportation Administration (UMTA) to FTA. ISTEA is not, however, just a tinkering with names and definitions. Taken as a whole this legislation and its implementing rules embody a fundamental conceptual shift regarding the nature of the transportation problem and thus the kinds of solution that are acceptable and the manner in which the planning and programming of these solutions should occur.

In research presented at the 1977 Annual Meeting of TRB Manheim described the emergence of a model for urban transportation planning that had been institutionalized through a series of planning guidelines from FHWA and UMTA in the mid-1970s (*5*, p.324–353) (Figure 1). Programming, he argued, had replaced long-range planning as the primary concern of transportation planners. He defined programming as the mid- to short-range project selection process whose goal is development of a realistic list of resource-constrained construction activities. And, indeed, programming—which involves project proposal, analysis and evaluation of design alternatives, selection, preliminary engineering, and construction—has been the central occupation of transportation planners for more or less the last 25 years. Moreover, few would dispute that the normal solutions implemented during this period have been building, expanding, or otherwise improving highways to increase roadway capacity for cars and trucks, the dominant form of transportation in the United States. Meanwhile, transit's primary problem has been viewed, with few exceptions, as providing mobility for the transportation disadvantaged (that is, the poor, the old, and the carless) and maintaining traditional fixed-route systems to carry those on work trips into the old urban core (*6*). Pedestrian and bicycle movements have generally been considered neither a transportation problem nor a transportation solution; rather, they have been almost universally relegated to the domains of recreation and urban design.

In a sense, however, even as Manheim described his programmatic model, he set the stage for the swing back toward planning that is reflected in ISTEA. As Manheim warned almost a quarter century ago, programming is not planning. The regulations, he wrote, did "not [make] clear to what extent the TIP must be consistent with the Long Range Plan. . . . Nothing . . . in the new FHWA-UMTA regulations requires consideration of a range of alternatives, identification of social, economic, and environmental effects, or timely public involvement, in developing the TIP and its annual element or the TSME [transportation systems management element]." Moreover, since only major transit projects using federal funds had to undergo alternatives analysis, Manheim suspected that, over time, programming would produce "assemblages of projects proposed by lower-level jurisdictions . . . transit agencies and state highway agencies" unrelated to larger goals (*5*, p.344–346).

When in the early 1980s Meyer and Miller described the decision-making process commonly used for programming transportation projects, they too noted the abandonment of normative social goals and the dominance of individual or regional political goals as motivators for what got built (*7*, p.77–92). We have found this observation well supported by our own conversations with various federal staff, transportation planners, and transit managers. According to the general wisdom, until ISTEA state DOTs made most of the important decisions about highways, whereas transit operators selected at least three-quarters of the transit projects in the United States. Rarely was there much coordination across modes. Generally the process would begin when a DOT or operator sought funding in Washington, D.C. If the response was positive a highway location study or a transit alternatives analysis was performed along with a draft environmental impact statement (EIS); if all went well the desired final version of the project was selected, funded, engineered, and built, all following guidelines from one of the modal administration's grants management staff. Congressional earmarking could speed the process along; citizen participation or legal action under the National Environmental Policy Act (NEPA) could slow or stop it. The legal requirement that the project be included on a metropolitan TIP was hardly noticed. Since TIPs were easily amended and not financially constrained, they functioned more like wish lists than serious capital programs (*8*). Throughout the process the essential relation was that between the grant recipient, who both planned and executed the project, and the federal government (U.S. DOT or Congress), which controlled the funding.

The programmatic model got things done and yielded many projects that were beneficial to local regions, including the extraordinary Interstate highway system. It is fair to say, however, that the programming model tended to be quite conservative, giving highest priority to proven solutions such as highways and fixed-route transit even as awareness of the economic costs and other negative impacts of these solutions grew. Suffice it to say, the failure of the programmatic model to respond to a changing social and political environment became increasingly evident to a range of observers, particularly as various transportation-related concerns emerged as matters of significant public debate. Among these concerns were the continued failure of most metropolitan regions to meet Clean Air Act goals for ozone and carbon monoxide along with an accumulation of research showing vehicles to be a major cause of the problem (*9*); increasingly congested roads despite road building (*10*); the growth of the NIMBY (not in my backyard) syndrome, which made it difficult to site both large- and small-scale transportation projects (*11,12,* p.171–256); the realization that transit had generally failed to follow the move of population and activity to Edge City (*13,14*); the development of an argument that the lack of infrastructure investment had contributed to America's loss of competitiveness in a global marketplace (*15*); and the decline in real dollars of spending on transportation (*16,17*). The passage of ISTEA should be viewed as an effort to fit a new set of solutions to this new set of transportation problems.

To some extent ISTEA accomplishes this by returning to the broad planning concerns of the 1960s and 1970s. Certainly the intent of this act goes well beyond the relatively narrow programmatic problems of increasing system capacity or improving mobility for disadvantaged groups. The transportation problem now explicitly includes energy efficiency, air pollution, economic development, and global competitiveness as well as connectivity and choice (*18*).

ISTEA, however, also reflects much that is new since the 1960s. Indeed, one can argue, for example, that underlying a large part of ISTEA's approach to transportation problem solving are the principles of quality management, as set forth by Demming, Juran, Crosby, and others. These principles have brought a major paradigm change to business management and are threatening to do the same to public administration. For example, this way of thinking reverses the traditional process of " produce it, price it, promote it." Instead, customers' needs, desires, and expectations are elicited first and are then used to shape the design of products and services that meet customer criteria. Such products promote themselves. Second, when a service or product regularly deviates from some level of acceptable customer-defined quality, attention is given to the process of production rather than to worker performance; indeed, workers, those who use and understand the system, are viewed as the source of the solution rather than the source of the problem and are asked to help fix the process.

ISTEA begins with the premise that the transportation product is not performing acceptably—too little connectivity, too much congestion, too much air pollution. Then, to a large extent, ISTEA seeks process solutions and draws on the expertise of system users to help find them. For example, the concept of flexible funding, the delegation of power over real money to MPOs, fiscal constraints on TIPs, and conformity can all be viewed as process changes. In addition, to continue the analogy with the quality management model, under ISTEA, customers—both internal customers (that is, the workers or public employees) and external customers (that is, the system users, whether they are freight shippers or commuters)—are asked to help shape both the public involvement process and, through this process, transportation products that meet their needs and expectations.

These are just some of the ways ISTEA expands and redefines the business of transportation planning and programming. But process change alone does not completely explain the new model. The glue that ties the whole thing together, integrating the technical and planning activities, is information. The 15 factors for metropolitan planning and the 23 factors for statewide planning represent data that must be collected, analyzed, and fed into process and products. The monitoring and management systems are actually information systems related to asset management and system performance. They function as both inputs and outputs of the overall planning and programming process. Moreover, this information must be shared among all of the cooperating partners, including the public, in the reengineered transportation system.

FEATURES OF ITPDS

The key to understanding the ITPDS model is to see it as a cooperative and inclusive planning process combined with linked planning products [the long-range plans, major investment studies, the state transportation improvement program (STIP) and TIP, not to mention the state implementation plan (SIP)] and embedded in an information system (Figure 2). The outlines of this model are visible throughout both the new planning regulation and its preamble discussion. For example, the framers distinctly tie together process, products, and information in their clarification of how the management systems relate to planning.

> The planning process provides a mechanism for linking the existing human, natural and built environment with future development patterns. . . . While the most recognized products of the process are the transportation plan and TIP . . . the continuing generation and analysis of information [for the management systems] through the planning process is also a vital product. The planning process as envisioned in ISTEA is a dynamic activity which effectively integrates current operational and preservation considerations with longer term mobility, environmental and development concerns. (*19*, p.58041)

Another example is found in the discussion of programming: "Programming is no longer just assembling a list of projects that may be able to proceed; it is now a process for comprehensively managing project advancement in relation to other transportation and transportation related activities that impact transportation system performance" (*19*, p.58048).

In other words the new conceptual model begins with the linear clarity of programming's traditional problem-seeking/problem-solving process and then enhances it by creating information loops that link system performance back to goals and strategies, tying to-

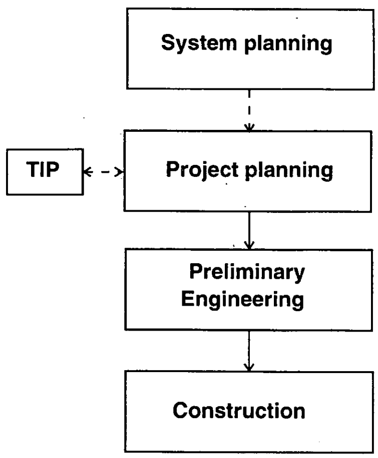

FIGURE 2 Simplified version of post-ISTEA project planning model.

gether not only the various modes of transportation but also the process and its typical outputs—plans, programs, and management systems—at different scales and on different levels. Compared with what has gone before, ITPDS is decidedly flattened, cross-functional, data-rich, messy, and customer oriented. Application of the model provides a tool for addressing the legislative mandate to create a more inclusive, better coordinated, more responsible process that will produce a more efficient, better coordinated, more responsible transportation system.

Flattened

A major aspect of the new model is the flattening of power relationships among major players. Although 450.312(c) gives MPOs the lead in coordinating the various planning and programming activities, 450.312(a) explicitly states that the MPO, the state, and public transit agencies will "cooperatively determine their mutual responsibilities" with regard to who performs major investment studies and how the transportation plan, the TIP, and the work plan are developed. Thus, other than placing the MPO at the center of what can be viewed as a kind of project team, the regulation remains open with regard to who should do what. A similar disbursal of responsibility occurs with regard to the development of the management systems. Although generally states are given the lead here, 450.320 flattens a strictly top-down approach by mandating cooperation:

> As required by the provisions of the management system regulations 23 CFR part 500, within all metropolitan planning areas, the congestion management, public transportation, and intermodal management systems, to the extent appropriate, shall be part of the metropolitan transportation planning process.

Indeed, in responding to an objection about the vagueness of role definition in the notice of proposed rule-making (NPRM), the federal policy staff refused to set firm criteria, explaining that planning responsibilities must be shared, that cooperation means "working together," and that the sorting of roles and duties "should be driven by local decisions regarding best mechanisms for achieving coordination" (*19,* p.58052).

In addition, it is important to note that the cooperative approach, when it is applied to planning major transportation investments, tends to flatten even the relationship between the implementing agency and the federal funding agency. According to 450.318(b),

> when any of the implementing agencies or the MPO wishes to initiate a major investment study, a meeting will be convened to determine the extent of the analyses and agency roles in a cooperative process which involves the MPO, the State department of transportation, public transit operators, environmental resource and permit agencies, local officials, the FHWA and the FTA, and where appropriate community development agencies, major governmental housing bodies, and such other related agencies as may be impacted by the proposed scope of analysis.

The rhetoric of the regulatory language suggests an equality among participants that supports the regulation's explicit assignment of responsibility to the group as a whole for the decision regarding what agency will perform the corridor/subarea study and which major alternatives should be evaluated. Since the study must be multimodal, even as it fulfills a number of formerly modal-specific requirements, such as FTA's alternatives analysis under Section 3 of the Federal Transit Act, and since it may not be performed by the agency that will ultimately implement the outcome, there is a significant weakening of the relationship that often predetermined the modal outcome of previous major investment studies. What this means is that FHWA and FTA have, albeit tentatively, relinquished some control over the federal purse strings in recognition, as the proposed rule-making states, of "the increased responsibility of States and local decision makers in evaluating alternative investments and their financial responsibility for the Federal resources provided" (*20,* p.12069). Or, in other words, ISTEA has continued a general flattening of the relationship between the federal and local levels.

Certainly there is a good possibility that the new model will fail if the stronger players are allowed to overwhelm the weaker ones. There is also the possibility that the adoption of the flattened project team approach, well known in the private sector, will actually increase rather than decrease accountability for all players since there is no longer a fixed set of organizational rules behind which players can hide (*21,* p.166). Nevertheless, although there may not be specific rules and definitions for how the flattened process will work, the federal policy makers assert that they will be watching to ensure that no agency dominates unreasonably: "Evaluation of the level of cooperation will be a major factor in FHWA/FTA's planning finding made in conjunction with STIP approval and certification of the planning process in TMAs" (*20,* p.58045).

Cross-Functional

The cross-functional feature of the model is related to flattened, but it refers primarily to the composition of the planning team. In a sense it is the model's equivalent to intermodal. Very simply, it means that the new process must bring together a working group having a range of perspectives and interests. Planning teams will no longer be limited to those with a single perspective but must also include "other providers of transportation, e.g., sponsors of regional airports, maritime port operators, rail freight operators, etc." [450.312(a)], as well as planners, operators, permitters, environmental resource staff, federal highway and transit administration staff, local officials, housing experts, private providers, and interested citizens. Even the planning products will be more cross-functional. For example, the corridor/subarea study for major investments serves a varied set of legislative goals—alternatives analysis, input to the environmental statement, financial analysis—even as it considers a "range of alternative modes and technologies (including intelligent vehicle and highway systems), general alignment, number of lanes, the degree of demand management, and operating characteristics" [450.318(b)].

Data-Rich

Transportation planning has always been based on the technical analysis of data. Under ISTEA this basis is substantially broadened and deepened. Section 450.316(a) requires "explicit consideration" of 15 elements, which are to be "analyzed as appropriate, and reflected in the planning process products." Some of these elements are relatively new to transportation planners, for example,

> the likely effect of transportation policy decisions on land use and development and the consistency of transportation plans and programs with the provisions of all applicable short- and long-term land use and development plans (the analysis should include projections of . . . economic, demographic, environmental protection, growth management, and land use activities . . . and projections of potential transportation demands based on the interrelated level of activity in these areas) [450.316(a)(4)]; the effects of all transportation projects [as determined through an analysis of] the effectiveness, cost effectiveness, and financing of alternative investments in meeting transportation demand and supporting the overall efficiency and effectiveness of transportation system performance and related impacts on community/central city goals regarding social and economic development, housing, and employment [450.316(a)(6)]; [and] an analysis of goods and services movement problem areas, as determined in cooperation with appropriate private sector involvement . . . addressing interconnected transportation access and service needs of intermodal facilities). [450.316(a)(7)]

In addition, to meet the mandate, plans shall "consider" (a word that implies collect and analyze data) energy use; roadway connections; abandoned rights-of-way; life-cycle costs for bridges, tunnels, and transit operations; and transportation-related air emissions. This general list of planning elements is further elaborated in the discussion of the transportation plan at 450.322, which adds requirements for information on congestion management strategies from ride-sharing to pedestrian facilities and pricing; bicycle facilities; rehabilitation and maintenance of the existing system; multimodal corridors; the extent to which the metropolitan plan meets national and state goals for housing, economic development, and environmental protection; financial capacity; and public participation. In a comparison of ISTEA and the previous metropolitan planning provisions prepared by FTA planning staff, this list represents a sizeable increase in requirements for data and analysis; previous rules had simply required consideration of "appropriate" information without specifying areas (*22*).

Finally, just to enforce the mandate, the discussion at 450.322 states that the plan must be more than a mere list of policy statements and that it must be updated every 3 to 5 years "to confirm its validity and its consistency with current and forecasted transportation and land use conditions and trends." The plan must be a strategic plan including "both long-range and short-range strategies/actions that lead to the development of an integrated . . . intermodal system" and shall "include design concept and scope descriptions . . . in sufficient detail . . . to permit conformity determinations." Thus, it is clear that to carry out the new mandate a great deal of current data as well as valid analytical tools will need to be made available to the planning team in forms that allow comprehensive and concrete integration and cross-analysis of information. Or, in other words, transportation planning needs a more data-rich environment.

Messy

Balancing the collection, evaluation, and integration of information is the feature that we call "messy." It is a recognition that the new planning process is never quite finished because it is dynamic, nonlinear, evolving, iterative, flexible to the point of being slightly chaotic, complex, ad hoc, open to all, and generally hard to grasp. In the preamble discussion for the proposed rule-making, the new planning model was called a "systemic process," with the "plan . . . [being] dynamic, subject to more frequent revision and intended to serve as a 'current' framework for transportation decision-making. . . . It [is] . . . contemporaneous, comprehensive, and strategically driven." Indeed, planners have always known that planning is continuous; now the regulation institutionalizes this truth by finding that a partial plan not only is acceptable but also is expected as the natural outcome of the working document [(450.322(b)(8)]. Messiness is an almost inescapable feature of a more inclusive and cooperative process in which various planning activities need to be carried out simultaneously, allowing for a dynamic flow of information that differs according to local situations. A simple example of such messiness can be seen in the discussion of how NEPA requirements should be folded into the corridor/subarea studies. These studies will provide documentation for the EIS, but they cannot be the EIS since they are actually alternatives analyses that may result in substantial modification of the original investment concept [see 450.318(f)].

Customer Oriented

Finally, customer oriented in the ITPDS model means not only that customers' expectations and demands shape the transportation system but also that customers are involved in the planning process. The development of the transportation plan, according to 450.322(b), begins with identification of the "projected transportation demand of persons and goods in the metropolitan planning area." Planners may not find this mandate particularly noteworthy until they consider that the definition of "demand" comes not simply from the outputs of various technical projections and models but also from the involvement of the customers themselves, and that these customers are being asked to become involved early in "an interactive and integrated public sector decision-making process designed to respond to [their] needs" (*23*).

Actually the public participation section of the final rule represents one of the more substantial rewritings of the proposed rule. The NPRM pointed in the direction of enhanced public involvement but left the nature of the new public participation mandate rather open. The final rule adds significant detail. Section 450.316(b) explicitly encourages participation by a wide range of customers, including private providers, freight shippers, ride-sharing agencies, and public officials, as well as those "traditionally under-served by the transportation system, including but not limited to low-income and minority households." According to the rule, the effort should be to create a "proactive public involvement process that provides complete information, timely public notice, full public access to key decisions, and supports early and continuing involvement of the public in developing plans and TIPs" [450.316(b)(1)]. The preamble discussion makes clear that certification of both statewide and metropolitan planning processes will include an assurance that performance criteria for public involvement are met *(19,* p.58055).

COMPUTER-SUPPORTED ITPDS

A number of practical problems are likely to arise during the attempt to plan and make decisions within the kind of flattened, cross-functional, data-rich, messy, and customer-oriented process that we have described. Not the least of these is the need to provide information on a great diversity of topics for a group with widely varying levels and areas of expertise. We suggest that use of computer-supported planning techniques rooted in a GIS could help to overcome a good portion of this problem while actually improving the quality of the group product.

A GIS displays information in spatially defined thematic layers that can be assembled one on top of another to produce useful composites, which can then be manipulated and analyzed. For example, wetlands, steep slopes, and public parklands in a community can be digitally mapped in different layers; these could be overlaid on other layers showing roadways, fixed-rail commuter and freight services, bus routes, paratransit service areas, bike lanes, sidewalks, and commercial land uses. The composite might then be used to envision potential environmental issues arising from construction of intermodal linkages, or it might be used to illustrate where new intermodal connections would address multiple objectives.

A GIS can also be linked with nonspatial data bases, models, and multimedia representations through relational and object-oriented structures, thereby significantly enlarging the scope of the information system available for query and analysis. Visual representations of specific physical factors attached to locations on the GIS and viewed as either slides or videos would allow stakeholders to visit a site without leaving the room. This could be particularly useful when the focus is regional transportation planning. At any rate, a good review of what is currently available in the way of multimedia is provided by Kindleberger (*24*), whereas Schiffer (*2*) and Shiffer and Wiggins (*25*) have discussed generally the usefulness of visualization as a way to translate quantitative information into qualitative understanding for planning with nontechnicians. Langendorf (*26*) has experimented with a GIS-supported *charrette* model (*27*) to redesign parts of Dade County, Fl., after Hurricane Andrew, and Hartgen et al. (*28*), for example, have described use of a GIS in conjunction with simple models for long-range regional transportation planning in North Carolina. These all suggest to us that the linkage of multimedia with the GIS can create a planning tool that is both powerful and legible. There are still a number of issues that need to be resolved for handling transportation networks in an all-purpose GIS, but these are being worked on. For example, Transcad by Caliper Corporation is a transportation-focused GIS that allows users to ask questions of the spatial data and display layers, and the development of linkages between TRANPLAN and ARC/INFO is currently under way.

Although many current GISs are designed to be run only by highly proficient technical staff and are not designed to be used in group environments, ITPDS in a collaborative planning setting needs an information system that is broadly accessible to a wide variety of users through well-designed graphic interfaces. Ideally, it should be a potent decision support system having quite robust interactive capacities, permitting users to query the data base in various ways as well as do what-if analyses. For ITPDS the computer support system would also need to contain impact, trend, and financial models; some of these models are reasonably good right now, whereas others require serious work. The addition of hypermedia capacity to the GIS would allow users to display the impacts of various decisions both textually and graphically. Finally, an on-the-fly annotation system would allow local stakeholders to actively participate in the creation over time of a truly comprehensive regional information system.

One need not, however, wait for such an ideal system to be developed. As Shiffer and Langendorf have demonstrated, GIS-based applications for supporting group planning and site design efforts in collaborative and *charrette*-like situations are beginning to occur now. Although currently available information systems may be imperfect and incomplete, their use could still provide significant aid to stakeholders who are attempting to carry out ISTEA mandates in a flattened, cross-functional, data-rich, messy, and customer-oriented environment. To understand something of how this computer-supported ITPDS model would function, one needs to imagine a group of stakeholders and cross-agency staff sitting together in a room viewing the same computer-generated images on a wall-sized screen. A staff technician operates the hardware, keying in commands and making annotations in response to comments and questions from the group. Assuming that all participants have some basic understanding of how the system works as well its informational capacities, any individual can call for display of the maps, overlays, information, model results, and visualizations that are in the GIS-based decision support system. Thus, all members of the collaborative planning group have access to the full range of information and analysis in formats that allow them to integrate concerns in multiple ways and to visualize the results of suggestions.

We think that this tool would significantly enhance both the functioning of the new conceptual model for transportation planning and the quality of the plans and programs that are its products. Few will argue the computer's ability to store, manipulate, analyze, and display large quantities of information. According to Peters (*21,* p.108) equal access to information is essential for the success of flattened work processes in which everyone is responsible and accountable. Access to information is also an explicit criterion for the new public involvement process under 450.316. The ability of this system to display and manipulate information in graphic, tabular, and textual modes can facilitate communication among people across functions and areas of expertise. The system's capacity to zoom in and zoom out, displaying information at different scales, as well as its capacity to accept comments or annotations would help to organize the messy complexity of the new model. It would also help to maintain focus and thus the productivity of a collaborative group. Finally we suggest that this system would enable clearer linkages between planning and programming. For example, if TIP projects were placed in the GIS and overlaid on the long-range plan, decision makers and stakeholders could see immediately both program balance and intermodal connections that might otherwise be missed. And in the end this is the purpose of both ISTEA and ITPDS—facilitating better linkage between planning and programming by developing a process firmly based on a comprehensive understanding of the needs of all the users of the total transportation system.

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Publication of this paper sponsored by Committee on Passenger Travel Demand Forecasting.

Dynamics of Policy Change: Reflections on 1991 Federal Transportation Legislation

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The legislative history of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) is examined from the standpoint of four theoretical models of the policy process. The models, drawn from the policy literature, focus on (*a*) interest groups and iron triangles, (*b*) policy networks and entrepreneurs, (*c*) enlightenment, and (*d*) advocacy coalitions. The logic of each model is outlined, and the manner in which it applies to the process surrounding the passage and implementation of ISTEA is suggested. The relative merits of the models are compared, and their usefulness in providing an understanding of the dynamics of the policy process is discussed.

In October 1991 the U.S. Congress passed a transportation bill, the Intermodal Surface Transportation Efficiency Act (ISTEA), that reauthorized the national highway and transit programs for the next 6 years. Observers describe ISTEA in a number of different ways, ranging from those who see it as a distinct departure from past policies to those who view it as a natural extension of ongoing debates within the transportation policy community. The purpose of this paper is to describe and compare several of these perspectives in order to understand more fully the dynamics behind this important legislation.

MODELING THE POLICY PROCESS

The study of public policy can be approached from two different sets of questions or concerns. The first emphasizes rational analysis and recommendations for adopting one policy rather than another. This broad umbrella encompasses technocratic and economic studies prescribing the most efficient policy and engineering studies that draw on professional criteria to analyze and evaluate specific policies. Much of the transportation policy literature falls into this category, at least ostensibly.

An alternative set of concerns focuses on the policy process, on how decisions are made. It questions, among other things, how different issues are placed on the policy agenda, the roles of interest groups and administrative agencies, who has the most influence on decisions, and how change comes about. Many who focus on transportation policy view this process as essentially a black box that is either unfathomable and anarchic or less interesting than the first set of concerns—namely what policies are rationally preferable.

Others, however, attempt to think more systematically about this process and lay out, if you will, the internal dynamics of the black box. One way to do this is to develop a model of the process. By identifying the major variables and the relationships among them, models provide theories or explanations that help us understand the policy process. They are essentially propositions that the policy process is not an entirely random affair, that we can trace patterns and relationships and improve our understanding of the process. Models by definition simplify reality much as a road map does. As a result there is always a tension between a model and the reality that it purports to describe. Does it overlook some key variables? Does it lure us into manipulating reality to fit the model?

In describing and comparing models, we would like especially to emphasize the distinction between rational analysis and studies of the policy process. It is common to deal with one or the other of these concerns with either analysis or process. However, some of the most interesting questions about the policy process ask whether there is a connection between analysis and process. Does politics override rational analysis? Or does analysis simply follow the election returns, as Thomas Dooley disparagingly remarked about the Supreme Court? Conversely does analysis help to shape political debate and policy choices? To what extent do technocrats, economists, policy professionals, and engineers fit into the policy process? And by extension, by understanding the process can we increase the effectiveness of rational analysis?

In explaining the development of ISTEA, some have suggested that a particular model of the policy process seemed to explain events as they unfolded. They stress the dramatic changes introduced by ISTEA, a view widely portrayed in the media and by some of the participants in the legislative process itself. These sources stress that ISTEA marked a major departure from traditional highway policy by increasing the funding potential for transit, by opening dedicated highway funding to a broad spectrum of uses ranging from historic preservation to bicycle trails, and by elevating metropolitan planning organizations from an advisory capacity to full partners in programming transportation funds.

Others challenge this emphasis on change and on winners and losers as greatly overdrawn, however. Instead of traditional highway interests losing out to a new coalition, they argue that ISTEA was broadly influenced by the best thinking on the subject, that there were no big winners and losers on the important issues, and that in any case the results are too murky to fully anticipate the results of the legislation (personal interviews, Steve Lockwood, November 23, 1993; Ron Kussey, April 9, 1993).

This paper draws from the wider policy literature to present several models, asking what they tell us about the policy process surrounding ISTEA and the role that analysis plays. It outlines the logic of each model and then suggests how it applies to the process surrounding the passage and implementation of ISTEA. In the conclusion we compare their relative merits and try to determine if one is more useful than another. Does a particular model help us understand some part of the process that we may have overlooked? Does it resonate with our understanding of what happened better than another one does? Does it help us anticipate the prospects for the ISTEA legislation? Note that we are not asking which model is true

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in any objective sense, but which one is most useful and robust in helping us understand the dynamics surrounding the policy. Does one model point to a question or aspect of the policy that we would otherwise have overlooked? Does one help us anticipate the eventual outcome of the policy or the difficulties that may arise in implementation?

INTEREST GROUPS AND IRON TRIANGLES

The traditional view of the policy process holds that policy is driven solely by bargaining among narrow and relatively fixed political interests. One popular version of this common view holds that policy is made by an iron triangle—special interests, related congressional committees, and agencies. In this model each of these parties is driven by its own interests and mandates to collude with the other parties to put forth a policy that serves their mutual and immediate interests. These parties establish close working relations and reinforce each others' interests, making it hard for others to enter the process. Policy analysis in this model works within this constellation of actors—it is funded by their agenda and promotes their interests. There is little or no room for independent analysis or studies that do not serve the interests of this cartel.

This model predicts that the highway lobby and its congressional allies were the major players in developing ISTEA and that these interests mobilized to shape new highway legislation as the existing authority approached expiration in 1991. As events unfolded, however, it became increasingly clear that the highway lobby was not simply a set of colluding interests with strong congressional allies. It was composed of several different groups, and although they all shared a basic and strong belief that highways should be the centerpiece of any federal program, there were important differences among them. Major players included, first, the Congress, which was deeply interested in congressional control over the disposition of funds and projects or, in more colloquial terms, "pork." A second major group of players was professionals in the highway planning community at both the federal and the state levels. Consistent with their identity as nonpolitical technical experts, their main goal was to apply professional or technical criteria to the program (*1,2*). They tended to see a basic difference between their own interest in applying technical, professional standards and the political orientation of Congress toward separate constituencies. A third group included suppliers and interest groups—for example, road builders and materials suppliers—who were primarily interested in keeping the funds flowing. This third group tended to support the goals of the others but was not wedded to them immutably.

As 1991 approached the Interstate highway program, which had provided the framework for distributing funds since the mid-1950s, was nearing completion. It became increasingly clear that pork would be a very salient issue and that it could undermine the entire highway program. In 1987 President Reagan had vetoed a highway bill, and although Congress overrode his veto by a single vote, it was the first veto in the history of the federal highway program. His reasons for vetoing the bill—that it contained too many pork barrel demonstration projects—signified the eroding credibility of the program. Although the override secured highway and mass transit funding for another 6 years, professionals recognized that federal surface transportation policy was in serious trouble. The increase in congressional earmarking of funds for specific projects was viewed as a natural outgrowth of the diminishing rationale for expanding the highway system on a federal basis. Indeed the 1987 bill had 152 earmarks. Members of the highway lobby, successful for so many years in dominating policy decisions, feared that unless action was taken to develop a new rationale for a national program, congressional earmarking would escalate and further damage prospects for a continued federal program.

These fissures suggest that the iron triangle model may be too simple and one dimensional. The three models described in the following sections challenge its relevance, claiming that it ignores much of the fluidity and unpredictability in the policy process and that it greatly underestimates the roles that ideas and analysis can play. We will describe each model briefly and consider whether it tells us anything useful about the development of ISTEA.

POLICY NETWORKS AND ENTREPRENEURS

According to the model that focuses on policy networks and entrepreneurs, policy is not made by a narrow and fixed set of actors. Rather the policy arena is made up of loose collections of parties who share a concern or knowledge about a specific policy issue (*3*). This arena contains a number of elements or policy streams—problems, ideas, and interested actors. By and large these elements go their separate ways with little or no relationship among them (*4,5*). Likening this arena to a "policy soup," Kingdon (*6*) observes that "[p]roposals are generated whether or not they are solving a problem, problems are recognized whether or not there is a solution and political events move along according to their own dynamics."

For example, transportation analysts may be working on some new technology that may or may not address a problem that is salient in the political system and that may or may not be of interest to political leaders. Changes in oil prices or new evidence of pollution may trigger a transportation problem unrelated to existing policy proposals. In the meantime research on new energy sources or automobile technology tends to follow its own dynamics and may or may not address these problems. Political elites respond to a host of competing issues, and the salience of transportation issues may have more to do with what else they have to address than with the immediacy of particular problems or the logic of suggested policies. Political actors become involved around particular aspects of transportation that fit with their own agendas and then may move on as another issue—health care or crime, for example—grabs their attention. Policy analysts for their part typically pursue the logic of their chosen methodologies and prescribe policies that may or may not address the realities described earlier.

According to this model scores of issues are ignored or sidetracked and are never dealt with. But sometimes policy is made, and the interesting question is how these elements connect to each other. The model predicts that at various times, often serendipitously, opportunities arise for connecting problems, policy ideas, and elite interests and that entrepreneurs may perceive that it is in their interest to take advantage of these occasions and mobilize the various parties to craft a policy response. According to Kingdon and others (*5,7*) entrepreneurs are individuals who are "willing to invest their resources in return for future policies they favor.

What questions does this model pose for the development of the ISTEA legislation? It is sensitive to the numerous actors who became involved in the development of the legislation and the fact that transportation policy was formulated by a larger set of actors than those traditionally associated with the highway lobby. Thus it can account for the important roles of those with environmental and urban interests who came to transportation via these other policy arenas. It also predicts that the issues and participants will shift and that subsidiary issues will become attached to transportation, such as local participation in planning and clean air. And finally it suggests that there can be important differences among the various participants as they move from issue to issue. It helps us trace out the various problems and solutions that were being posed by the different parties and the fact that they did not always connect with each other.

As noted the policy professionals were pursuing their own definition of highway policy that challenged the widespread use of pork. The Interstate had been turning into a pork barrel project for some time, and the technical criteria that had ostensibly defined the program had been eroding slowly with small provisions that ensured that each state got its fair share. Whereas funds were originally allocated according to cost to complete, for example, political agendas led to changes in the mid-1960s to give every state a minimum 0.5 percent of the funding. In the face of these adjustments, the highway lobby emphasized technical criteria and highways of national significance to refocus the program around a more defensible rationale. They believed that there were several lessons to be learned from the 1987 legislative experience and that a replacement for the Interstate system was needed to distribute highway funds in a manner that relied on technical criteria rather than political criteria. They hoped that their technical analyses would give them the muscle they needed to counter congressional efforts to divert funds to special demonstration projects.

In the meantime the administration initiated an independent parallel set of activities under the rubric of Secretary Samuel Skinner's strategic plan. Early in 1991 the administration, partially concerned with not increasing the federal budget deficit, unveiled its post-Interstate proposal after the President introduced it in the State of the Union address. Like the proposal from the highway lobby the administration position focused first on the need for a nationwide system of highways to replace the Interstate and second on the need for greater flexibility in the use of funds. The term *national significance* was never defined clearly, however. The selection criterion for nationally significant highways was primarily its level of traffic. Flexibility in funding was to be accomplished through block grants to states (*8*).

Other players, as predicted by the model, were pursuing their own agendas and interests. The main impetus for transportation policy had always been in the House Environment and Public Works Committee, chaired by Representative Roe (D-N.J.), who had campaigned in the House for his chairmanship by promising new projects. To support such projects Roe was preoccupied with raising funding levels and focused his energies on a campaign to give a "Nickel for America" in the form of an additional 5-cent gas tax. To win support for this proposal, he tied the success of his promised $6.8 billion in "congressional projects of national significance" (i.e., pork barrel demonstration projects) directly to support for the tax.

The Nickel for America proposal, although supported by the House leadership, created major strategic problems for the traditional highway community. First, as presented by Chairman Roe, it was explicitly linked to demonstration projects and thus it was directly at odds with the intention of the crafters of post-Interstate policy. Second, by raising the possibility of tax increases, the House leadership caused a significant splintering of support among members and within the transportation community. (For example, the trucking industry was opposed to the tax increase.) In the meantime the President was determined not to raise taxes, and Roe eventually had to drop his tax plans. Because of these conflicting agendas and the lack of any strong leadership, Roe was never able to put together a supporting coalition behind the House bill.

There was also some division within the highway community over the technical merits of various approaches to the bill. California at one point threatened to break away from the AASHTO-led bill and support a more reform-oriented bill.

The model also predicts that policy would very likely never be passed without strong leadership from someone who saw a chance to take advantage of a new opportunity. The party who played the kind of entrepreneurial role predicted by the model most clearly was Senator Daniel Patrick Moynihan (D-N.Y.). Moynihan had a longstanding interest in public works and a particular interest in urban highways dating from the 1950s (*9*). He had been instrumental in the development in the 1960s of Washington, D.C.'s, Pennsylvania Avenue Development Corporation, which eventually revitalized this major urban artery, and had actively pursued his interest in public works during his tenure in the Senate. Moynihan had an unusually free hand as chair of the subcommittee because the aging chair of the full committee, Quentin Burdick (D-N.D.), who died in office a year later, had been a fairly weak chair since his reelection in 1988. He also succeeded in forging an unlikely alliance for reform with the ranking minority member of the subcommittee, Senator Steve Symms (R-Idaho), who supported devolution of authority to states and localities, as well as Senator Frank R. Lautenberg (D-N.J) and longtime environmental advocate Senator John H. Chafee (R-R.I.).

This model thus highlights several important aspects of ISTEA's development that would be overlooked by the traditional iron triangle model.

ENLIGHTENMENT MODEL

A second alternative to the iron triangle model is the enlightenment model. This model also stresses that policy is made in a loosely constructed arena of interested parties—advocacy groups, professionals, actors associated with other policy arenas, and so forth. The various parties are all pursuing their interests, but their interests are not fixed and inviolable. They can change and shift as events unfold and as new information and analyses are presented. The emphasis here is on the ideas that float around in this arena rather than on the disconnect among the various streams.

> Picture a community of specialists. . . . Ideas float around in such communities. Specialists have their notions of future directions and their specific proposals. They try out and revise their ideas by going to lunch, attending conferences, circulating papers, holding hearings, presenting testimony, publishing articles, and drafting legislative proposals. Many, many ideas are considered at some point along the way. (*10*)

Thus ideas can play an independent role and introduce new information and proposals into the process. Individuals are not only pursuing reasonably well defined interests but also get caught up in thinking about and trying to solve policy problems. Over time a consensus gradually coalesces around a policy response to an emerging problem. Because this consensus usually evolves over time and because it involves a genuine change in perspective, it is referred to as an *enlightenment model,* pointing to the gradual acceptance of new ideas (*11*).

This model tells us to look for efforts to wrestle directly with the policy issues involved and to develop a consensus among the different parties. And, in fact, beginning as early as 1967 the highway community initiated a series of efforts to build a consensus for a post-Interstate policy. By the mid-1980s they increased their efforts and organized a broad-based series of meetings to orchestrate and coordinate the various interests in new legislation. Hearings were held in each state, technical advisory groups were organized to solicit and synthesize the views of all interested parties, a history of the Interstate program was commissioned to glean the lessons learned from the program (*12*), and a series of strategic plans was prepared and published both within the U.S. Department of Transportation and in the industry in general. Led by AASHTO and the Highway Users Federation for Safety and Mobility, these groups organized a series of actions, known as Transportation 2020, which involved a series of public meetings around the country and the creation of a technical advisory committee with representatives from a wide range of groups. The aim of the Transportation 2020 approach was to present a united front to the Congress for the 1991 bill.

Depending on one's perspective it was possible to find evidence of consensus and agreement as well as strong differences. One participant noted that professionals came to agree on several major issues. One was the value of flexibility and the value of allowing states some leeway in developing their own plans. Another was the value of simplicity and reducing complex federal guidelines and oversight criteria. Political officials, however, never agreed on the value of simplicity and in the end were responsible for an increase in the number of federal regulations. Differences also remained over the amount of money to be contained in the legislation, because the administration continued to resist any increase in taxes and the congressional committees favored more funds for demonstration projects.

ADVOCACY COALITIONS

A third alternative to the iron triangle model agrees that relatively open networks of shared interests dominate the policy arena and that policy is made as members of the network come to agree on an idea. According to this model, however, there are severe limitations on the extent to which policy actors will change their core beliefs and it is very unlikely that change will come about by searching for a consensus. Rather, change occurs when there is a coalition of action-oriented individuals who are capable of transforming an idea into policy and displacing those who adhere to the existing policy (*13*). "Once an advocacy coalition is formed, the idea evolution process essentially ends. The central purpose of the coalition is not to second-guess its belief-ideas system, but rather to displace the status quo policy, its support structure, and to establish the dominance of its own policy ideas" (*14*). Thus the model emphasizes the difficulty of changing basic ideas and policy commitments and the unlikelihood that change will come from learning or the exchange of ideas. Whereas the enlightenment model stresses the evolution of ideas through increased knowledge and understanding, the advocacy coalition stresses strong allegiance to a core ideology. Policy change is unlikely unless one organized coalition displaces the dominant one.

The model predicts several important facets of the process surrounding ISTEA. Legislative change was unlikely as long as the highway lobby continued to dominate the process. Change depended on a new, opposing coalition that challenged the positions of the highway lobby. The two coalitions would pursue fairly defined initial commitments and core beliefs that would change little once the coalitions were formed and that would remain very powerful and determinative. Finally, it predicted that a change in policy would reflect the view of one coalition over another rather than a compromise between them.

There is some evidence to support these predictions. Interviews with members of the highway lobby suggest that they were completely preoccupied with the technical aspects of highway legislation and the dissension in their own ranks and overlooked other policy debates related to the environment and urban sprawl. Their initial policy framework distracted them from defining the issue in broader terms or learning from parallel events or interests outside their traditional coalition. They were partially supported by the House, whose members were preoccupied with congressional earmarking and developing a more positively conceived system of national significance.

In the meantime a completely different coalition was developing outside of the purview of the first coalition. Specifically, several environmental and urban planning groups were becoming increasingly active in the transportation arena. Their activity stemmed from a prior interest in the environment and specifically in clean air legislation. A cluster of environmentally oriented and urban planning groups had come together around the reauthorization of the clean air legislation, which passed in 1990 [Clean Air Act Amendments of 1990 (CAAA)]. Several members realized that the prospects for clean air were profoundly affected by transportation legislation. Indeed, some of their proposals for effecting cleaner air through transportation measures had failed to survive in the development of CAAA. This coalition reassembled as the Surface Transportation Policy Project (STPP). Unlike the traditional transportation community's belief in the need for a national highway system, the underlying belief of the STPP coalition was quite the opposite—existing incentives for using single-occupancy vehicles and for building new highways for those single-occupancy vehicles had to be ended.

Although STPP was a new player in the transportation policy network, members of the coalition seized on the opportunity presented by the renewal of transportation legislation as a natural extension of their work on CAAA. They saw the 1991 surface transportation act as an opportunity to overcome some of the weaknesses in CAAA and to devise some positive means to encourage clean air rather than to rely solely on a regulatory approach. Furthermore, they realized that in drafting the CAAA they had underestimated the dominant role of state departments of transportation in affecting air quality. Several saw the transportation issue as an occasion to rectify this oversight and counter the role of the state highway departments. The following quotation underscores that this interest in transportation was a natural extension of their prior work on the environment:

> We knew early on that clear air was going to be driving a lot of where the committee was going. . . . The transportation debate has been so overwhelmingly dominated by the highway community for so many years. The nature of what the committee did on clean air should have been a signal to the highway community. (*15*)

This common belief system was reinforced by the close ties of the group to the Senate Committee on Environment and Public Works, which had jurisdiction over CAAA. The environmental groups organized under STPP and the chair of the Senate subcommittee, Daniel Patrick Moynihan (D-N.Y.), shared a strong commitment to a non-highway-oriented bill. Moynihan, as noted, had a long and active interest in urban planning issues dating back to the 1950s and appreciated that 1991 might provide a long-awaited opportunity to rethink the highway program. Moynihan needed the support and expertise of the environmental groups, and over the course of the next few months they hammered out a bill that looked very different from that passed by the House.

A number of observers and media reports reinforce the picture of competing coalitions, of intentional gamesmanship, and of clear winners and losers. For example, according to some observers, those drafting the Senate bill took pains to keep their activity very low profile, particularly vis à vis members of the highway lobby and those working on the House bill. As a result the traditional planning community was quite surprised when the Senate introduced a surface transportation bill before the House did. This perspective is reflected in the reporting on the bill's introduction:

> In a significant victory for a coalition of environmentalists and urban planners, the Senate Environment and Public Works Committee on May 22 approved a five-year surface transportation bill that would radically alter federal highway policy. . . . Most remarkable about the Senate bill is that it was crafted with the interest of environmentalists and urban planners in mind, rather than those of the traditional highway lobbyists who have typically left their imprint in such reauthorizations. The so-called road gang of highway lobbyists was focused on the House Public Works Committee, which traditionally has taken the lead in introducing such bills, when the Senate bill was unveiled. The group includes the American Trucking Associations, state transportation officials, motor vehicle manufacturers and the Highway Users Federation. (*16*)

Finally, the model raises an interesting question about the relationship between legislation and implementation. It suggests that if legislation promotes significant policy change it usually favors the beliefs and agenda of one group over another. It is well known, however, that in our decentralized political system, interests that do not prevail at one level are very likely to pursue their interests during other stages in the process, such as the implementation stage. As Stone (*17*) warns, even when a policy is crafted in an open and broadly representative process, political adjustments during the implementation process "often are narrowly based, typically are achieved covertly, and therefore encourage self-serving behavior." Thus it is predictable that when legislation is passed because one coalition displaces rather than accommodates another, the legislation is less likely to be implemented in its original form and is more likely to respond to narrow special interests during implementation.

COMPARING MODELS

ISTEA was finally passed on November 27, 1991, and was signed into law on December 18. The Senate had moved quickly in the previous summer to pass its bill on June 19. The House bill had a much more troubled course. The Nickel for America proposal foundered and was pulled from the floor on August 1 and was formally abandoned on September 18. A revised House bill was introduced on October 10, passed by the committee on October 15, and passed by the full House on October 23. A 20-day conference ensued as the differences were worked out.

The final bill contains important aspects of both the House and Senate bills (Table 1). One apparent victory for the Senate was the inclusion of $6 billion for congestion mitigation and air quality, the only new money in the act. The Senate provisions for special treatment of large metropolitan areas did survive the conference, as did a strong urban orientation for funding. House provisions prevailed on overall funding levels ($38 billion) and congressional approval of the national highway system map.

In assessing which positions prevailed, however, because the Senate bill was a matter of record during the development of the final House bill, the House provisions were almost certainly crafted with the conference in mind. Thus it is extremely difficult to assess winners and losers without a careful and thorough analysis of which parties held which positions at a particular time, which is beyond the scope of this paper. Furthermore, even stated positions at a point in time cannot be accepted as completely objective measures of a party's true position, since all parties engage to some extent in grandstanding, manipulation, and gamesmanship.

How useful are the models in anticipating the dynamics of the process and its results? And more particularly, what do they tell us about the role of analysis in the process and indeed whether it played a significant role? A growing number of observers argue that there is no single, unambiguous answer to these questions, that the answers depend on the perspective one has on policy making. Each of the models outlined here leads to different questions and evidence and conclusions. These observers go on to argue that it is helpful to apply several perspectives to a given policy issue because each will direct us to certain events and activities that we may have otherwise overlooked (*18*). If we applied only the traditional iron triangle model we would overlook significant differences within the highway coalition and the important cleavage between professional analysts and congressional and administration interests. The policy arena model points to a much more fluid and interactive arena of activity and suggests why it was initially very difficult to formulate a coherent policy. The enlightenment model leads us to look at the ideas circulating within the broad community and to ask whether various parties changed their views and what efforts were made to formulate a consensus. And, finally, the advocacy coalition model directs us to look for evidence of competing interests and the power and salience of deeply held commitments and beliefs. Taken together the models provide a more robust understanding of the process surrounding ISTEA and the eventual outcome than any single one of them would have.

Some may find it unsatisfying to conclude with multiple models and will try to identify the one that is most useful in providing an understanding of the process and the role of analysis in that process. We would agree with Graham Allison, however, that it is seldom useful to apply only one model to the policy process. Such efforts inevitably leave out some dimensions and opportunities for shaping and influencing the debate and substance of policy. Thus we conclude that the policy process is not simply a black box that defies analysis and explanation, that it is possible to model what goes on within the box. But neither can it be captured in a single model or explanation. The policy arena is much more interesting and ripe with opportunities than either of these options suggests.

ACKNOWLEDGMENTS

This work on ISTEA is part of an ongoing study of ISTEA and its implementation in the Transportation Policy Program at the Institute of Public Policy, George Mason University, which includes Jonathan L. Gifford, Thomas A. Horan, Ronald Fraser, William Mallett, and Scott Talkington. The authors would like to acknowledge the helpful suggestions of David Luberoff and Robert Nakamura on this paper. An early version of the paper was presented at the Fourteenth Annual Research Conference, Association for Public Policy Analysis and Management, in Denver in 1992. The authors gratefully acknowledge the support of FTA.

TABLE 1 Surface Transportation Legislative Provisions

Provision	House Bill (as passed)	Senate (as passed)	Final
National highway system (spending)	$37.6 billion for 155,000-mile system.	$22 billion for interim national highway system, including $14.2 for maintenance.	$38 billion for national highway system, including $17 million for maintenance.
National highway system (map)	Congress to approve proposed road map for system within two years.	Anticipates formal system from DOT Secretary within two years.	Requires Congressional approval of map by 9/30/95.
Transfer of highway funds to transit	Up to 35%	Up to 20%	Up to 50%; up to 100% with DOT Secretary approval
Surface transportation program	$36 billion for "flexible mobility" programs	$45 billion.	$23.9 billion
Urban/rural mix of funds	$13 billion for urban areas; states choose whether to spend another $13 on urban or rural areas. Urban ≥ 50,000	75% of surface transportation program to be divided among metropolitan areas of at least 250,000 and other less-populated areas in amounts equal to the proportion of their population. Remaining 25% could be spent anywhere.	≥20% of surface transportation program on safety and transportation enhancement; ≥62.5% of remaining 80% divided among urban areas of at least 200,000 and other less-populated areas in amounts equal to the proportion of their population. Remaining 37.5% could be spent on projects regardless of population.
Metropolitan planning	Urbanized areas must establish metropolitan planning groups to coordinate modes. Each group must work with state DOT to develop a transportation improvement program that encompasses all projects in the area. The program would have to conform to a long-range transportation plan and Clean Air Act programs.	Metropolitan planning group must be designated for each metropolitan area of more than 50,000 by agreement between governor and local governments. Larger metropolitan areas must form planning groups, as well as smaller.	Urban areas of more than 50,000 must establish metropolitan planning groups, which will work with states to develop a transportation improvement program that encompasses all federal transportation projects within the metropolitan area. It must conform with a long-range transportation plan and Clean Air Act programs. Areas with more than 200,000 are deemed transportation management areas and have stricter planning requirements.
Congestion and air quality	Nothing	$5 billion for "congestion mitigation and air-quality improvement" program for urban areas of 50,000 or more that fail to meet federal clean-air standards	$6 billion.

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The authors are responsible for any errors in this paper.

Publication of this paper sponsored by Committee on Intergovernmental Relations and Policy Processes.

Implementing Intermodal Surface Transportation Efficiency Act of 1991: Issues and Early Field Data

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Implementation issues associated with the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) are examined. In particular it is discussed whether ISTEA is more a truly revolutionary change in policy or a continuation of the status quo. These issues are considered in the context of a legislative battle that did not produce clear winners and losers, in which both sides appeared to have achieved what was important to enable a test of their own hypotheses, and in which each side had an interpretation of what the spirit or the intention of ISTEA is and how it should play out. The result is an experiment testing the viabilities of two world views. One view sees a public policy largely at odds with the real public sentiment on transportation, in which the will of the people has been distorted by federal intervention to favor single-occupancy vehicles and urban sprawl. Given an alternative this view predicts that the public will opt for different behavior and lifestyle changes. The other view sees public policy as largely consonant with abiding public preferences, behaviors, and land-use patterns that are unlikely to change quickly as a result of the flexibility and local focus introduced by ISTEA. The complexity is compounded by the new role of metropolitan planning organizations, especially with regard to requirements for public participation and clean air. Finally, since the expression of public preference is related both to the outcome of the policy experiment and to the ongoing legitimacy of the institutions (including metropolitan planning organizations) charged with its implementation, this participatory framework is critical to understanding the future direction of transportation policy.

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) is one of the most widely heralded pieces of transportation legislation since the 1950s. Is it truly a revolutionary change in transportation policy? Does ISTEA, together with recent clean air legislation, remake transportation planning, programming, and financing as well as the intergovernmental system through with they operate? Or is it merely a modest shift from the previous trajectory?

It is not easy to assess such broad-scale questions about the impact of transportation policy systematically. Nobel economics laureate Robert Fogel, in his assessment of the impacts of railroads, for example, underscores the difficulty of assessing even so dramatic a change as that. He concludes that the conventional wisdom that railroads were instrumental to 19th century American growth was simply not well founded (*1*). Uncertainty about an ex post assessment of a technology of that scale gives pause to an assessment of the significance of ISTEA and the Clean Air Act Amendments of 1990 (CAAA). Clearly, we will have to wait and see.

These new laws incorporate air quality as an important priority in transportation policy, place states under deadlines to achieve clean air goals, give states and localities greater flexibility in the use of federal transportation funds, and alter the authority and responsibilities of metropolitan planning organizations (MPOs). The impacts of these changes, realized through implementation, will provide evidence for or against the viabilities of two very different outlooks on the world. One emphasizes mobility and social choice, whereas the other regards environmental quality and sustainability as the overriding consideration in transportation policy. Whether ISTEA effects actual changes in the decision-making process, in investments, and ultimately in the design of the infrastructure system must now be determined through implementation. But implementation may also determine how these two world views are themselves transformed and how this transformation of perception could affect the evaluation process. The consistent message of Fogel's historicism is that objectivity during a profound period of change is uncommon. This makes careful review of the progress of this sociocultural experiment a critical element of the transportation policy debate.

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ISTEA raises implementation issues that range from recasting intergovernmental relations to altering individual travel behavior. The scope of these issues, together with the uncertainty of new and untried legislation, makes a comprehensive review of implementation a formidable undertaking. In addition, full evaluation now of a policy passed in late 1991 would be premature and might sell short those responsible for implementation. The goals of this paper are more modest: to identify some key problems and to suggest how they might be categorized and monitored.

We draw from three sources of information and insight. First, policy implementation has been a topic of significant research and analysis for at least 20 years. The literature provides guidance on what types of issues are likely to give rise to implementation problems. Second, the legislative history of ISTEA helps to identify the key actors, institutions, and issues as well as the strategies and agendas that they characterize. Our third source of insight is the early evidence on implementation from the Washington, D.C., national capital metropolitan region. On the basis of these sources, we identify key issues and discuss what sources can inform an ongoing assessment of ISTEA implementation.

After the introduction this paper is organized in six sections. The first presents a brief overview of the major provisions of ISTEA. The second reviews the literature on implementation to identify classes of issues that may give rise to problems "ISTEA-ing" transportation planning and programming. The third section reviews the legislative history of ISTEA and identifies implementation issues related to advocacy politics. We then review early experience with implementing ISTEA in the Washington, D.C., metropolitan region; this is followed by a synthesis of insights from the implementation literature, legislative history, and field experience to identify key concerns that warrant continued observation through 1996. Concluding remarks follow.

MAJOR PROVISIONS OF ISTEA

ISTEA provides greater flexibility to state, local, and regional planning entities, but it also places them under new obligations requiring openness to public dialogue and input. As a departure from transportation policies of the post–World War II era (which focused on developing the Interstate highway system) ISTEA provides greater flexibility for funding transportation modes that include not only highways but also carpools and vanpools, transit, commuter rail, and municipal bikeways. Yet the bill does not mandate much reallocation of spending. Of the $151 billion authorized for transportation under ISTEA, $110 billion can be spent by state and local governments on any transportation mode. Of the remaining $41 billion, $17 billion is allocated to maintaining (but not expanding) the existing Interstate highway system and $16 billion is allocated to maintaining the nation's bridges. Only $8 billion is earmarked specifically for expansion of Interstate-type highways.

ISTEA also requires states to develop and implement six management systems in cooperation with MPOs: pavement on federal-aid highways, bridges on and off federal-aid highways, highway safety, traffic congestion, public transportation facilities and equipment, and intermodal transportation facilities and systems. To aid in the development of congestion management ISTEA allocates $6 billion to the Congestion Mitigation and Air Quality improvement program.

Although a broader range of choices for local and state planning and decision-making units does not preclude continuation of past spending patterns, the provisions of a complementary piece of legislation make this course more difficult. The CAAA require that transportation and capital investment plans conform to state clean air plans (*2*). These provisions complement and magnify the requirements of CAAA, for example, mandating congestion management for nonattainment areas. One of the strongest arguments of environmentalists in their successful support of CAAA was that automobile emissions are the greatest threat to air quality because vehicle trips are rising at three to four times the rate of population growth. This rate of automobile use is, furthermore, offsetting the benefits of reduced emissions through automobile and fuel modifications. Consequently, CAAA mandates reductions in the number of trips as an important element of protecting air quality.

According to CAAA new highways can only be built as part of a plan to improve air quality. Significantly, these new restrictions come with enforcement authority. In cases of noncompliance federal money can be withheld. Moreover, CAAA allows parties of interest to block funding and construction by suing decision-making units. For example, the Natural Resources Defense Council might sue an MPO or a state department of transportation (DOT) if state and local plans fail to meet new restrictions. Environmental interest groups have expressed their intention to use this new advocacy power (*3*).

ISTEA triples the money earmarked for spending in metropolitan areas. In return the bill requires that local governments participate in more rigorous transportation planning with state transportation agencies, considering air quality and energy use as well as social and economic impacts. ISTEA strengthens the roles of MPOs in conducting planning and programming (*4*). These measures include giving MPOs in major metropolitan areas significant control over federal funds; hence, states must also work with MPOs or risk forfeiting these funds. Such reciprocity provisions may nullify some of the parochial conflicts that originate from the composition of MPOs, which are often made up of officials from local jurisdictions that are recipients of federal funds.

ISTEA contains several provisions aimed at enhancing the role of the private sector in the design and operation of transportation services. This includes a relaxation of restrictions on toll roads as well as a provision for up to five congestion pricing demonstration projects. Additionally, the act provides $660 million for testing intelligent vehicle-highway systems (IVHS). IVHS technologies, ranging from computerized traffic control centers to fully automated freeways, are envisioned as having significant private-sector involvement. One such approach could employ bundling innovative public-private partnerships to provide IVHS information functions that assist in diverting traffic from congested areas (*5*). Indeed, the strategic plan developed by IVHS America suggests that 80 percent of the costs for IVHS will be in the form of private-sector products and services (*6,7*).

The measure also introduces a variety of new participants to the transportation planning process through requirements for public participation as well as enhancement provisions that expand the number of stakeholders and that provide $2.8 billion for scenic and historic preservation and environmental and landscape improvements. As a result a broader range of interest groups (e.g., preservationists and designers) now have a stake in the decision-making process for regional and state transportation projects.

Finally ISTEA is largely silent on some issues that powerfully affect transportation and clean air. Most notably, although it requires MPOs to consider the effect of transportation decisions on land use, ISTEA includes no direct constraints on use and development, which are traditionally the purview of local government. Any changes in land-use regulation will therefore only be developed from the bottom up, that is, by local officials, to comply with the air quality requirements of CAAA.

IMPLEMENTATION LITERATURE

The scope and magnitude of the changes stipulated in ISTEA suggest a broad range of implementation issues. One source for identifying which of these is central to the assessment of success is the literature on policy implementation. Since the seminal work of Pressman and Wildavsky (*8*) implementation has become one of the central foci of policy analysis. A sizeable literature is now available to serve the development of implementation studies (*8*). Generally this documents and explains why policies are typically not carried out as intended and why major changes are usually made (Louise White, personal interview, August 4, 1993).

Academic inquiry into implementation evolved in three phases. The first generation sought to anchor the field of study identifying policy implementation as an important problem and demonstrating specific cases in which execution mattered. The second generation focused on broadening the significance of execution to a range of policy fields through a series of case studies. The current generation is concerned with developing an effective theory of implementation and identifying principles that apply to most policy domains, thus attempting to secure an element of synergetic advantage for the field of implementation studies (*9*).

A brief review of the implementation literature suggests several insights useful in identifying key implementation issues for ISTEA. First, it is essential to recognize the activation of public programs as a complex political process. The actors and institutions that are engaged are not minions of rigidly organized hierarchies. Thus, it is appropriate to ask what provisions have been made to ensure willing cooperation between and within these agencies. To the extent that

ISTEA diminishes the power, prestige, or personal satisfaction of the actors charged with its implementation, those sufficiently disenchanted may seek to resist or subvert it (Gifford et al., this Record).

A second and related insight concerns the practical reliance on the intergovernmental system. Federal officials often lack effective leverage over state and local bureaucracies and, moreover, lack knowledge about the incentives and bureaucratic goals that guide those officials. Some believe that in the case of ISTEA federal agencies simply cannot have much of an impact in terms of policy guidelines (*10*).

A third insight is that implementation problems often arise in just those areas where the policy formulation process has generated the greatest controversy. In a sense "the mishaps of program administration are actually rooted in the policy-making process" (*11*). In the case of ISTEA policy formulation gave rise to several sharp differences, as we shall see in the next section. These controversial areas should clearly be considered possible key implementation subjects.

Finally, effective implementation is sometimes displaced by the desire of Congress and the executive to achieve short-term tangible deliverables that influence the allocation of inputs. Cash flow rather than intelligent planning is often the most important implementation issue for actors at all levels. A desire to get the money flowing may undermine efforts to effect some of the more fundamental changes in comprehensive planning (*6*).

LEGISLATIVE HISTORY OF ISTEA

Many consider ISTEA a revolutionary reorientation of transportation policy from automobiles and highway building to a multimodal, environmentally sensitive strategy. Some of the distinctive provisions of ISTEA were neither designed nor supported by the coalition of highway interests, which has traditionally dominated highway policy. Rather, they originated from a relatively small coalition of environmentalists and urban planners. If highway interests suffered a planned strategic defeat at the hands of the environmentalists and urban planners, as some have already suggested, this may lead to future implementation problems. For a broader discussion of issues related to the legislative conflict see the paper by Gifford et al. in this Record.

ISTEA's legislative history, however, may also be interpreted as an interplay of interests in which two coalitions ultimately obtained much of what they thought essential to establish conditions that would help prove the validity of their particular world view. Each world view, in turn, reflects a strongly held conviction regarding what kind of transportation system the public really wants. In the following historical discussion we refer to these two principal groups as the mainstream coalition and the reform coalition. The terms are used for notational convenience and are intended as neutral modes of reference.

By the mid-1980s the Interstate highway system was largely complete. The 1991 reauthorization offered an opportunity to reassess and redefine federal transportation policy, providing a new focus for the next 20 to 30 years. In recognition of the significance of this opportunity the mainstream coalition began, in the mid-1980s, to develop a new more inclusive rationale for transportation policy through a process of extensive consultations and hearings. These meetings, known as Transportation 2020, formulated a post-Interstate highway policy based on two concepts: a newly identified system of highways of national significance or a national highway system and the devolution of authority to the state and local levels. Meanwhile a parallel effort moved forward under the auspices of a strategic plan commissioned by the U.S. Department of Transportation under Secretary Samuel Skinner. This strategic plan also emphasized the importance of highways of national significance.

Early in the 1990s a coalition of environmental and urban planning groups began to formulate a transportation initiative to complement, and indeed to help implement, the CAAA passed in 1990. The coalition of groups that had recently succeeded with the passage of the CAAA reorganized as the Surface Transportation Policy Project (STPP). The core belief of the STPP, in sharp contrast to that of the mainstream coalition, was that existing incentives for single-occupancy vehicle use and new construction designed to accommodate its growth were not in the public interest. The view that the public's true preference was for more livable and environmentally sustainable communities seemed justified by the success of recycling programs and by a new environmental ethic. These beliefs accorded with the ideas of the Senate Committee on Environmental and Public Works (which had jurisdiction over the CAAA), and especially with those of the subcommittee chair, Senator Daniel Patrick Moynihan (D-N.Y.). Thus began collaboration on a Senate transportation bill that matured as ISTEA.

In assessing implementation prospects it is important to understand the extent to which the final legislation constituted a planned victory by the reform coalition, an accidental victory by the reform coalition, or in fact no victory at all. Although there may be a certain appeal to victory, stealth, and defeat, our interest in these issues is that parties who lose in policy formulation may well be actively engaged in achieving their objectives through subverting or influencing implementation.

Did ISTEA really represent a victory of the reform coalition rather than a compromise? Some accounts maintain that the success of the reform coalition was partly attributable to a stealth strategy that avoided cross-coalition debate by maintaining low visibility in the policy formulation stage. Meanwhile, much of the debate within the mainstream coalition was absorbed with the nature and extent of congressional participation and with oversight of the designation of routes in the national highway system. Thus, the low visibility of the details within the reform dialogue in the Senate served to avert the full mobilization of opposition and allowed a concentrated focus on reform priorities for transportation legislation.

The stealth hypothesis rests on the assumption that the members of the reform coalition consciously concealed their activities. Yet obscurity might have been circumstantial rather than deliberate, since neither coalition had much incentive to engage in the specialized dialogue of the other. Hence, an involuntary lack of communication about differences might have averted an impasse. A main legislative concern of the highway interests was apportionment, or who got the money for major programs. The notion of providing more flexibility to local constituencies, which resonated well with the public involvement concerns of the reform coalition, also supported a desire for the devolution of authority that had long been sought by the mainstream. Flexibility of funding (to include nonhighway projects) was a principle that had no natural enemies, and thus no ready-made opposition. There was little apparent political incentive to distinguish this principle from the related concept of devolving authority to local decision-making units such as MPOs. The result was a law that placed more emphasis on local decision making but that had many prescriptive planning requirements related to participation of environmental groups and the public. Ironically, given the complexity of the program, only those career professionals with an intimate knowledge of how programs are administered are in a position to have any idea who really won or lost (Steve Lockwood, personal interview, November 23, 1993).

Another useful interpretation is the "whole-orange" scenario of conflict resolution whereby two parties contesting for possession of an orange have different purposes in mind. The first wants to consume the flesh and the second wants to use the rind in a recipe. Since the underlying interests are quite different it is possible for both to win full possession of the orange, or at least that whole portion of it that serves each one's interest (*12*). If both sides got primarily what they wanted from the legislative process, in what sense was anyone the loser? A winner may eventually be determined if one of their competing visions ultimately prevails. Hence, the evaluation of implementation is even more important than if the legislative contest had created clear winners and losers.

In terms of the literature on implementation, however, it seems advisable to at least consider the implication of the stealth strategy hypothesis: the conjecture that victory was due, at least in part, to the suppression (through strategic restraint) of open debate and confrontation. The perception that the environmental community won its case primarily by its maneuvers and strategies rather than on the basis of the substantive merits of its position might provoke the opposition to reverse its losses (*10*). So far, however, there is very little evidence to suggest that either side was significantly disgruntled by the outcome.

Finally there may be important divisions within the federal transportation community that could affect its overall performance. Consensus within that community was based on appropriations, and therefore, the inability of appropriations to meet authorization levels without a larger reservoir of money (which is what most expect from ISTEA) could magnify a sense of rivalry between transit and highway interests (Joel Markowitz, personal interview, July 21, 1993). Consequently, no matter which hypothesis one accepts as an explanation for the legislative history—stealth strategy or circumstantial scenario—the need to monitor and evaluate the consequences of ISTEA is imperative.

NATIONAL CAPITAL METROPOLITAN REGION

The authors have collected preliminary evidence on implementation experience in the national capital metropolitan region. The selection of this area was based on the fact that since it is 1 of 13 multistate metropolitan regions, examination of this area is useful for exploring a range of jurisdictional issues likely to emerge under ISTEA. Its proximity also makes it a convenient case study area for the authors. One should bear in mind, however, that the national capital metropolitan region is not a typical metropolitan area precisely because it is multijurisdictional and also because its economy is so closely tied to the federal government. Additional research is necessary to balance the conclusions drawn from what some consider a highly nonrepresentative situation.

Sources of information include public records and interviews with officials who have responsibility for formulating, planning, and implementing transportation policy. This group includes professionals within organizations charged with coordination and integration of the policy process across the 20 counties and municipalities within three state-level jurisdictions (for the purposes of the analysis in this paper the District of Columbia is considered a state). In addition we interviewed principles from most of the environmental and community interest groups who have been actively involved in the implementation process. (See Table 1 for a list of interviewees.)

Overview

Transportation planning, programming, and financing occur through the actions of a complex web of federal, state, and local governments, private actors, and interest groups. This web is especially complex in multistate jurisdictions like the national capital metropolitan region. Each state has its own department of transportation [Virginia (VDOT), Maryland (MDOT), and the District of Columbia (DCDOT)]. The cities and counties of the region vary widely in income distribution, geographic size, and population density. There are also a host of quasigovernmental organizations, some with public affiliations and some with private affiliations.

All three state entities are required to submit two state improvement plans (SIPs) to comply with CAAA. The first, which was due on November 15, 1993, must reduce levels of volatile organic compounds by 15 percent by 1996. The second, which was due in 1994, must reduce levels by 20 percent by 1999. These in turn must be coordinated with transportation improvement plans (TIPs) for the metropolitan regions.

The National Capital Transportation Planning Board (TPB) is the designated MPO for the area, contracting for staffing with the Washington Area Council of Governments. Its meetings are open to the public. TPB is divided into two advisory committees, the Technical Advisory Committee (TAC) and the Citizen's Advisory Committee (CAC), and it is responsible for formulating the area's TIP, the primary document for regional transportation planning. The TAC recommends projects to be funded under the 10 percent set-aside for safety projects, whereas the CAC performs a similar function with respect to the 10 percent enhancement set-aside. Endorsement under these set-asides by VDOT (as well as DCDOT and MDOT) requires prior approval from the TPB as part of its TIP. Be-

TABLE 1 Interviewees from Environmental and Community Interest Groups

Name	Organization	Position
Burfield, Roderick	Office of Government Relations, Washington Metropolitan Area Transit Authority	Director
Hassell, John S., Jr.	Linton, Mields, Reisler & Cottone	Consultant (former Federal Highway Administrator)
Jones, Ellen	Washington Area Bicyclists Association	Director
Keller, Mary	Maryland Department of Transportation	Senior Transportation Planner
Lockwood, Stephen C.	Farradyne Systems, Inc.	Consultant (former Assistant Administrator for Policy, Federal Highway Administration)
Markowitz, Joel	San Francisco Bay Area Metropolitan Transit Commission	Manager of Advanced Systems Applications
McDowell, Bruce	Advisory Commission on Intergovernmental Relations	Director of Governmental Policy Research

cause of this connection between the responsibility for forming the TIP and requirements for public involvement as well as the high priority conferred on TIP by ISTEA, this review focuses primarily on issues raised by TPB.

Besides the state and regional structure the subregion of Northern Virginia has a Transportation Coordinating Council (TCC) that meets quarterly to address subregional issues (Roderick Burfield, personal interview, August 4, 1993). TCC is chaired by the Northern Virginia representative of the Commonwealth Transportation Board and comprises representatives of local governments. TCC advises TPB and VDOT on issues relating to Northern Virginia. In Maryland a similarly designated advisory committee, the Technical Committee, comprises the heads of four state agencies: Transportation, Historical Preservation, State Highway, and Mass Transit (Mary Keller, personal interview, August 4, 1993). The District of Columbia has no similar specialized entity because it is a unitary jurisdiction that does not need to coordinate its efforts with those of a larger state government. Its subregional interests are looked after by the D.C. Department of Public Works.

Responses to ISTEA

One of the earliest responses to ISTEA's requirements for public involvement was the formation of the CAC to TPB. In addition, TPB immediately opened its meetings to all interested parties, allowing them an opportunity to make a 3-min statement during a 20-min period at the beginning of each meeting. However, some feel that this involvement occurred too late in the process to provide meaningful input on complex issues and that public involvement must start well in advance of the meetings during which decisions are made. Merely inviting the public to attend when the agenda has already been set and the plans fully conceptualized is insufficient.

Early evidence and interviews suggest that public-interest groups have begun to participate in meetings of CAC. Active groups include the American Automobile Association, D.C. Roadbuilders, the American Trucking Associations, the Greater Washington Board of Trade, D.C. Wards 3 and 5, the Chesapeake Bay Foundation, the Sierra Club, and the Washington Area Bicyclists Association (WABA). CAC now sees itself as an advisory body with a regional focus and with a mandate to influence both long-range and short-range planning and to inform the public on transportation issues. The committee sponsors a series of citizen forums to help meet these objectives. Meeting times for TPB hearings were recently shifted from the lunch hour to 5:00 p.m. to facilitate a more diverse attendance (*13*).

One area that has been influenced by public involvement has been an increased emphasis on new bicycle projects, placing strategic bicycle paths so that they connect projected Metrorail sites with high-activity areas like the University of Maryland. Prince George's County, Md., has seen most of this activity so far, but Arlington County, Va., also has an active bicycle path program.

Some of the planning for these projects, however, predates ISTEA. A regional bicycle plan was developed by the Bicycle Technical Subcommittee of TPB in 1989 and was published in 1991, the year that ISTEA was passed. Bicycle interests sought $60 million in new projects over a 5-year period. TPB suggested a much more conservative 20-year distribution of funds (Ellen Jones, personal interview, August 11, 1993). To make their priorities known WABA arranges special bike tours for members of the community, pointing out hazardous conditions, repair priorities, and new construction possibilities. At these and other events they distribute literature and explain the intricacies of the ISTEA legislation. Most of the members of local planning commissions attend the bike tours, and many of the interest group's detailed recommendations have been implemented to improve safety and accessibility.

Although these projects are not large or expensive by comparison with highway projects they are significant in the sense that they facilitate the kind of lifestyle changes sought by the STPP coalition. WABA is quick to point out, however, that much of the region remains unaware of the funding potential that exists and that Prince George's and Arlington counties are exceptions to the general condition of knowledge and public participation (Ellen Jones, personal interview, August 8, 1993). The D.C. Department of Public Works has proposed the addition of a Metropolitan Branch Trail, but advocates claim that it is seriously underfunded and that District officials remain unaware of the potential that exists within the new legislation to improve alternative transportation.

The evaluation of projects has emerged as a potential issue of contention. As mentioned previously, in addition to projects funded as technical improvements others may be funded as enhancements. Reconstruction of the 1905 vintage Union Train Station in Alexandria, Va., is an example of a proposal made under the enhancement provision. The submission of that project was made on August 1, 1993, after the deadline for grant applications had been postponed several months. VDOT needed extra time to make preparations for evaluating proposals and establishing a process to make endorsements. As a result Virginia has just begun to solicit new project proposals. Little if any evaluation is conducted on enhancement proposals at this time because of the lack of the technical expertise required to make assessments and because the number of proposals has been so small that there is little need to prioritize the proposals (Mary Keller, personal interview, August 4, 1993). TPB has plans to prioritize projects or project categories in the future (Gerald Miller, personal interview, August 8, 1993).

Some groups are concerned about the inertia of projects once they are included in the TIP. The Chesapeake Bay Foundation submitted formal comments on the content of the TIP, requesting that it include language to the effect that projects may be dropped (*14*). The comments of the Washington Metropolitan Area Transit Authority focused on similar concerns: the delegation of the governor's transportation authority to state DOTs (seen as contributing to business as usual) and the ability of the statewide transportation plan to address longterm issues (Docket Division, Office of the General Counsel, FHWA). Underscoring these issues the Metropolitan Washington Council of Governments (MWCOG) recently released a report prepared by Price Waterhouse that indicates a 20 percent shortfall in funding for the long-range plan (*15*).

In addition to such procedural and technical issues is a political dynamic. Participants at a recent workshop raised the possibility of a new MPO for the Virginia part of the region if cooperation with Maryland and the District of Columbia became troublesome. There were also indications that MDOT would rather work through the counties than through the designated MPO (the TPB). The issue concerned whether or not discretionary money could cross state lines, and since the TPB is a tristate entity Maryland and Virginia were concerned that they might end up subsidizing improvements in the District of Columbia. The issue was resolved by an agreement, formalized as a bylaw, that the flexibility of funding stops at the state line. This, of course, does not resolve all of the economic rivalries between the states that have been intensified by linkage to the CAAA requirements.

The Washington metropolitan region plus three rural counties (Stafford County in Virginia and Charles and Calvert counties in Maryland) make up the Metropolitan Washington Statistical Area (MWSA), which has been designated by the Environmental Protection Agency (EPA) as the jurisdiction of the Metropolitan Washington Air Quality Committee (MWAQC) for the purpose of formulating plans to reduce smog 15 percent by 1996 and 20 percent by 1999 (Figure 1). These plans must be coordinated as part of the SIPs. Fairfax County, Va., recently vetoed the 15 percent reduction plan, which was due November 15, 1993, over the issue of an Employee Commute Option (ECO) that would require businesses with 100 or more employees to reduce single-occupancy vehicle commuter trips by 20 percent, which Virginia jurisdictions considered an excessive burden on business (*16*).

Maryland's interests place it in conflict with Virginia over the ECO. Maryland counties are in a better position to cope with the ECO requirements than Virginia because of greater access to mass transit and higher-density land-use patterns in that state. In addition the adoption of the ECO in Baltimore is mandatory because it has a more serious air quality problem, and that city is concerned about the migration of its larger businesses to the Washington, D.C., area to avoid compliance. Thus if the Washington area as a whole rejects the ECO this creates an internal conflict in Maryland that the state would prefer to avoid by keeping its own playing field level. The ECO requirements highlight both inter- and infrastate competitive conflicts that will be very difficult to resolve. The smog reduction plan for the MWSA was finally passed without the controversial ECO measures (and still awaits doubtful approval by the EPA), but the much tougher 1999 plan is due next year, and the issue will undoubtedly resurface (*17*).

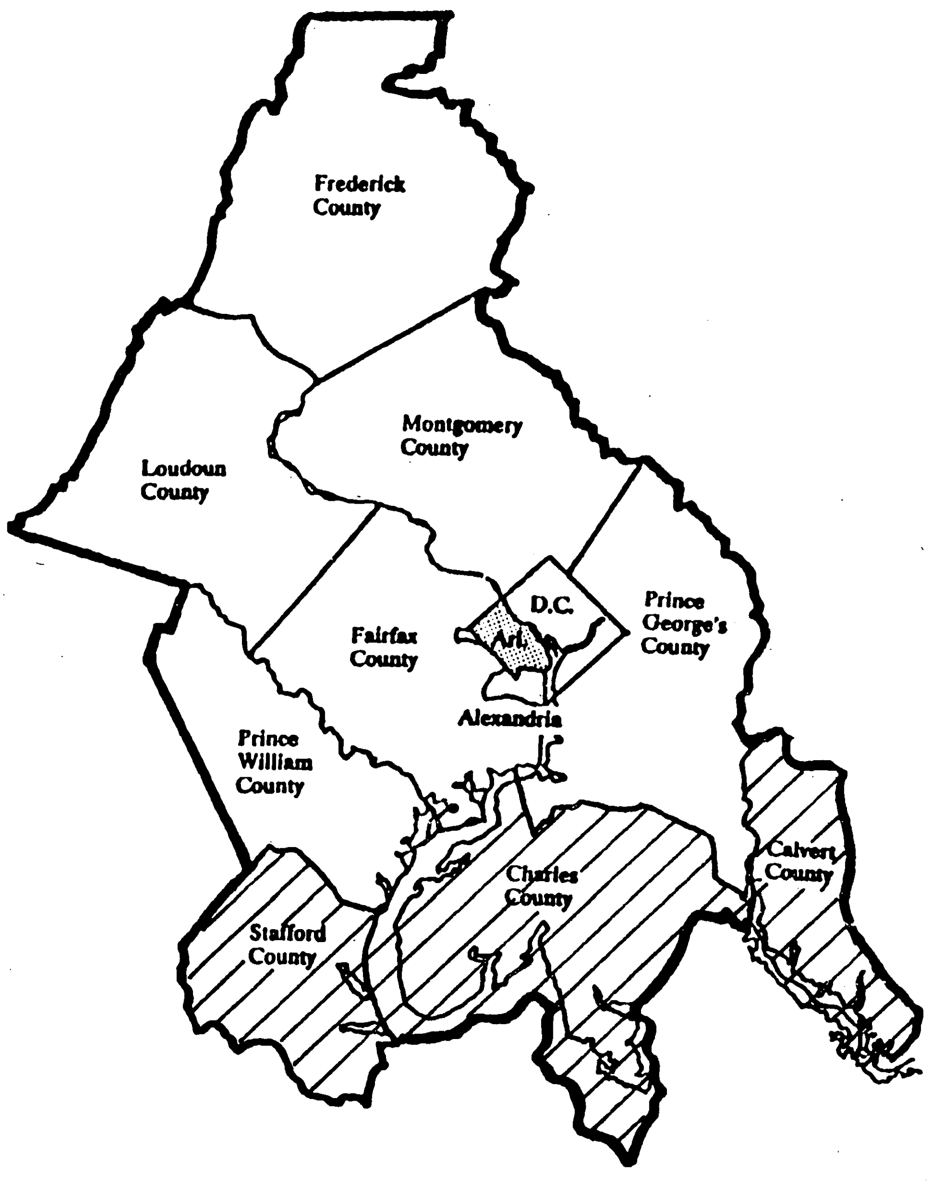

FIGURE 1 Metropolitan Washington Air Quality Committee (MWAQC) jurisdiction (hatched areas not in the MWCOG jurisdiction). (Map courtesy of the Greater Washington Research Center.)

KEY ORGANIZATIONAL ISSUES IN IMPLEMENTING ISTEA

The foregoing analysis suggests that both political and technical aspects of implementation will be critical for ISTEA. This is true for institutions as different elements of the intergovernmental system, particularly states and MPOs, vie for advantage. It is also true for interest groups as different constituencies, either established or emergent, organize their positions on ISTEA. The jurisdictional and interest group issues that are played out in the political arena are related to a set of serious constraints on organizational resources for both the MPOs and the states.

After two decades of declining budgets the now-restricted capacities of the MPOs are being asked to perform at a higher operational level than at any time in their histories. The gap between expectations and the resources required to fulfill them is at a historic maximum, and ISTEA fails to address this capacity problem directly since it funds MPOs as a percentage of the total funding. With the requirements for comprehensive air quality planning, for example, technical planning is now more complex than ever.

The political challenge is less obvious. MPOs have acquired the responsibility for dividing up funds for surface transportation projects under the STPP, administered by FHWA. These are non-mode-specific projects, divided within the 5-year TIP, that are fiscally constrained to available funds (not proposed taxes) and cannot assume increases based on authorizations (which are only upper limits rather than guarantees of funding). Someone must therefore prioritize projects within these constraints, and the challenge becomes political in the sense that the parties to the MPO each must receive enough out of the settlement to support it. The constraint on the political distribution of benefits is similar to that imposed on a legislative body that must make hard funding decisions. But the MPOs have neither the resources nor the legitimacy of real governmental bodies. Partly for this reason, as Maryland has demonstrated, some states would prefer to work directly through chartered local entities like the counties, assuming the responsibility for regional planning themselves. Finally, if one believes that the MPOs are essential to the implementation of ISTEA, both the technical and the political challenges are critical to the future since the MPOs can be emasculated by either (*18*). In addition MPOs now have some authority over programs that used to be under the discretion of the state DOTs, creating possible bureaucratic tension and requiring accommodation between the states and MPOs.

State DOTs likewise have two technical and political challenges. First, some will have to build from scratch. Only five or six states have significant planning capacities. Oregon is probably the leader, having had an integrated long-range transportation plan since the 1970s (*19*).

Second, the need for DOTs to build partnerships with other agencies such as those responsible for air and water quality can magnify the implications of a lack of planning capacity. Many practitioners see the governor as the pivotal actor both as the primary authority for resolving conflicts arising between bureaucratic jurisdictions and as the authority for helping to build the capacity for joint planning. In states with environmental and economic development planning experience, it has been the executive who has provided coordinating authority (Bruce McDowell, personal interview, July 21, 1993).

Perhaps what is occurring is a bureaucratic cultural shift. Because it is difficult to overcome inertia from an institutionalized mission (which has been internalized by individuals through a long process of cultural identification) change may only result from interest group pressure unless the executive becomes more directly involved in managing institutional change (*7*). In some states governors have delegated their authority under ISTEA to their DOTs rather than confront the problems of defining this complex new mission, a step that advocacy groups such as STPP may challenge. The tension between institutional inertia, the mutual dependence of major organizational units (especially the MPOs and the states), and the expectations created by groundbreaking legislation are themes in most of the practitioner comments encountered in the study. One side regards change with apprehension, and the other side regards inertia with frustration. What sort of accommodation will work?

Beyond the direct technical and political challenges for organizations at the state and local levels are problems involving the larger community. ISTEA promotes private-sector involvement in new areas such as demand management and IVHS. In addition to this encouragement of private-sector participation, the act requires early and significant public participation in decision making (*20*). At this stage public participation is primarily important from the perspective of the provisions because failure to adequately address the regulations would render the MPO's product invalid (J. S. Hassell, Jr, personal interview, July 21, 1993). Again, these challenges require a high degree of political expertise that may not be available to MPOs.

MONITORING AND EVALUATION

Continued monitoring of ISTEA in the Washington, D.C., area should focus on three substantive domains: investments, on-street changes, and public involvement.

Investments

The continued tension between various institutions and interest groups over discretionary funds in support of the environmental or highway coalitions will continue to be important. Nearly all of the interviewees identified the allocation of flexible funds as a significant factor to be monitored. They are concerned with whether the funds are being spent on special projects, construction, or system management. Evaluation should be informed by the degree that flexible funds get used, what projects get considered, and how quickly they become obligated. Since there is an obligation limit on highways and transit we also need to measure the share that gets obligated specifically to innovative programs, even though the definition of this category is subjective.

In the short term evaluation must be concerned with whether investments that affect the modal infrastructure have shifted as a result of ISTEA. The conventional argument is that categorical grants skewed investment toward highways, and it will be important during the early years to determine if the supposed shift in priorities has modified the pattern (Joel Markowitz, personal interview, July 21, 1993). Whether the allocations reflect an integration between land use, transportation, and air quality is a question that directly addresses the world view of the reform coalition.

On-Street Changes

Some feel that the starting place for evaluation ought to be the priorities established by Congress, that is, the criteria governing the intermodal and Interstate systems, congestion demand issues, and the physical capacities of facilities. This set of criteria is more closely related to the world view of the mainstream coalition.

Public Involvement

The problem with this set of criteria is that there is no consensus about what it means. Most respondents, however, see education as a critical overall factor, so it would make sense to monitor the accuracy and credibility of the information provided to the public in terms of the other two categories mentioned. In other words how well is the public being informed about project funding and planning and physical changes to the transportation infrastructure?

In addition, not only is the law a little ahead of the average citizen but the uncertainty connected with its regulatory environment also places formidable constraints on implementation. Initially, therefore, it seems a good idea to review comments on the rulemaking process at FHWA in the form of letters, exceptions, and so forth. This should give an indication of who has become disillusioned with the bill and provide hints as to whether resources are being committed to active opposition. The deadline for comments on the first phase of the process, involving the planning regulations, occurred during midsummer 1993, and the deadline on the conformity regulations and compliance with CAAA occurred in October 1993 (*21*).

CONCLUSIONS

According to our findings four major factors affect implementation:

1. The politics of the states and their local subregions, including rural versus urban and interurban and interstate rivalries over funding and economic development;
2. The extent to which interest groups are able to coalesce at the regional level and overcome parochial interests;
3. The politics of intergovernmental relations between MPOs and the states, including issues related to bureaucratic culture and accommodation; and
4. The quality and quantity of expertise (both political and technical) available to the various actors, including interest groups.

The literature on implementation highlights the roles played by the various actors throughout the policy process, from policy formulation and design to implementation, and emphasizes the importance of status, suggesting that parties that feel left out of the design phase may reemphasize their perspective by attempting to move implementation toward their view of balance (see the paper by Gifford et al., this Record). Yet the emphasis on status, although instructive, may be somewhat thin. Why is status important in the first place? The legislative history of ISTEA suggests that, on the whole, neither faction was left out. Hence, status may not be the overriding issue, at least in terms of a concerted effort to right some perceived imbalance.

It may be useful to view ISTEA implementation as a sociocultural experiment of the validity of two competing world views. On the one hand is the reform coalition, which views the current state of travel and land use as the result of bias and manipulations of public policy to favor automobile-centric hypermobility. Public policy, according to this view, has been significantly displaced from public base preferences. A milder rendition of this view is that public preferences have shifted, whereas public policy has not shifted, it has not shifted yet, or it has not shifted enough. According to this view the public need only be provided a real alternative to precipitate a shift in behavior. The legislative provisions essential to this view are MPO authority, public participation, linkages to air quality regulation, and funding of enhancements.

On the other hand is the mainstream coalition, which views the current arrangement as largely consistent with the public's base preferences. They are willing to accept greater authority for the MPO because they feel it will change little. This faith is realistic in the sense that it rests on years of administrative experience and on a tacit understanding of administrative processes. These processes in turn rest on deep-seated convictions about the legitimacy of institutions that even transcend statutory provisions. Such deep-seated convictions are related to established ways of doing things, to electoral accountability, and to a pragmatic assessment of the unwillingness of the public to suffer the high-opportunity costs associated with direct participation in a process of change (*22*).

The analogy of a sociocultural test implies a single objective standard of evaluation, which may be misleading. It is unlikely, for instance, that both groups will use the same criteria to judge the viability of an integrated regional community. The reformers value livability and environmental sustainability. The mainstream values mobility and choice. When these values are inconsistent one should expect conflict, and possibly fragmentation. The expectation that a definitive experimental result or a future fusion of horizons will resolve the significant value differences is probably an acutely idealistic presumption, especially for planners and engineers steeped by education and temperament in pragmatic virtuosity.

Finally, since the expression of public preference is related both to the outcome of this sociocultural experiment and to the legitimacy of the institutions charged with its implementation, it might be well to ask the public what it thinks of the situation (*23*). To what degree do people feel that transportation planning and coordination should be the responsibility of a national, state, local, or interjurisdictional regional authority?

One recent study found that although public confidence has been going down the decline was much more precipitous for federal and state governments than for local government (*24*). What this indicates is that confidence in local authority relative to that in federal and state authorities has been increasing for at least 20 years, providing a partial explanation for the consensus on the devolution of governmental responsibility. A similar study of a cross-jurisdictional level of authority between state and local governments may be instructive. It might provide a new reference point for the development of an effective theory of implementation in a world that increasingly manifests a tendency toward public participation in the policy process within a regional frame of reference.

ACKNOWLEDGMENTS

The authors acknowledge a grant from FTA, U.S. Department of Transportation. In addition, the authors would like to thank Roger Stough for his comments and contributions to the study. All errors of analysis or interpretation are the responsibility of the authors.

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Publication of this paper sponsored by Committee on Intergovernmental Relations and Policy Processes.

FTA-FHWA Metropolitan Planning Organization Reviews: Planning Practice Under Intermodal Surface Transportation Efficiency Act and Clean Air Act Amendments

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The Clean Air Act Amendments of 1990 (CAAA) and the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) have changed how metropolitan planning organizations (MPOs) conduct transportation planning. The manners in which MPOs and their planning partners are responding to the challenges and opportunities of these acts are evaluated on the basis of comprehensive reviews of transportation planning in nine metropolitan areas. The reviews by FTA and FHWA, with assistance from the U.S. Department of Transportation's Volpe Center, evaluate compliance with federal regulations and policies and increasingly focus on responses to ISTEA and the CAAA as guidance evolves. The acts expect MPOs to provide leadership in defining a regional vision, selecting projects, and improving air quality. To succeed MPOs must overcome a period of diminished resources, technical capabilities, and institutional roles. Particularly in areas with severe air pollution, MPOs must work with other agencies to overcome institutional and technical barriers and identify affordable and politically supportable strategies that meet stringent air quality targets while accomplishing traditional transportation goals. Many MPOs approach ISTEA as a lever to overcome fragmentation and lead regions toward systemwide planning. To realize the promise of ISTEA and CAAA, long-range plans must become strategic, framing and evaluating financially realistic alternatives that can be used to guide elected officials and the public through the hard choices required to balance air quality and transportation concerns. Transportation improvement programs, which often consolidate decisions made outside the MPO process, must demonstrate links to the long-range plan and how projects are selected to accomplish regional objectives.

In rapid succession the Clean Air Act Amendments of 1990 (CAAA) and the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) have drastically changed how metropolitan planning organizations (MPOs) conduct urban transportation planning. This paper provides insights into how MPOs are responding to the challenges and opportunities of these landmark acts. These observations are based on a series of comprehensive reviews of the planning process in the largest metropolitan areas being conducted jointly by the Office of Planning, FTA, and the Office of Environment and Planning, FHWA, with the assistance of the U.S. Department of Transportation's Volpe Center (*1–3*).

The reviews evaluate compliance by the MPOs and other transportation planning agencies in metropolitan areas with FTA and FHWA regulations and policies (*4–7*). The reviews began with an evaluation of how successfully metropolitan areas satisfied the pre-ISTEA federal planning requirements. As the CAAA and ISTEA guidance has been finalized, the reviews have increasingly focused on responses by the largest metropolitan areas to the two acts—both on progress and innovative approaches and on the general problems encountered. The reviews are the basis for formal findings identifying necessary improvements to the planning process in each area issued in reports by the regional administrators of FTA and FHWA.

This paper analyzes some of the major trends identified in the reviews completed to date. The paper focuses on five topics related to sound planning under ISTEA and CAAA and analyzes practices observed in the nine reviews completed to date.

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BACKGROUND

The independent planning reviews are being undertaken jointly by FHWA and FTA to determine how successfully the urban transportation planning process in each metropolitan area addresses broadly defined regional transportation needs and whether the planning process meets federal planning requirements. The first three pilot reviews began with site visits, which were conducted just before passage of ISTEA in December 1991.

Under the federal regulations in place before passage of ISTEA, metropolitan areas were required to apply a continuing, cooperative, and comprehensive (3C) transportation planning process. The process had to develop plans and programs that address transportation needs and that are consistent with the overall planned development in the metropolitan area. The planning process also was to be carried out by the MPOs in cooperation with the state and transit operators.

The state and the MPO were required to self-certify that the urban transportation planning process was in conformance with these regulations. Self-certification was intended to grant increased responsibility for transportation planning to states and MPOs and was a prerequisite for receiving federal funds for highway and mass transit projects. According to the joint planning regulations, self-certification did not relieve FHWA and FTA of oversight responsibilities and the obligation to review and evaluate the planning process. The first objective of the independent planning reviews was to allow FHWA and FTA to fulfill these responsibilities to evaluate the planning process and the credibility of the self-certification.

The ISTEA, which amended 23 United States Code (U.S.C.) and the Federal Transit Act, mandated fundamental changes to the metropolitan planning process. As explained in the March 2, 1993, Notice of Proposed Rulemaking (NPRM) for metropolitan planning (*4*), significant changes require that

- The long-range plan include environmental and intermodal considerations and provide a financially constrained 20-year vision of future transportation improvements;
- Transportation improvement programs (TIPs) function as strategic management tools to accomplish the objectives of the plan; TIPs are to be prioritized, financially constrained, and subjected to air quality conformity requirements in nonattainment areas;
- Planning emphasize the efficiency and performance of the overall system; and
- Strategies that consider the broad range of possible modes and their connectivity be developed and that 15 diverse and comprehensive factors, including congestion management strategies, travel demand reduction, land-use effects, and expansion of transit, be developed.

The transition between pre- and post-ISTEA periods was smooth for the independent planning reviews. The reviews began with a broad interpretation of the joint planning regulations, expanding from a foundation of the 3C process to consider good planning practice. From their beginning the reviews focused on three things: (a) the extent to which working relationships between MPOs and their planning partners were clearly defined and cooperative, (b) technical capabilities for transportation and air quality modeling, and (c) the effectiveness of public participation. This focus anticipated many of the planning considerations and requirements in ISTEA.

As the transportation planning requirements of CAAA and ISTEA have evolved, the reviews have increasingly emphasized second and third objectives. Second, the reviews allow FHWA and FTA to assess the ability of the metropolitan planning processes to address the evolving requirements of CAAA and ISTEA. And third, the reviews assist metropolitan areas in preparing for future federal certifications of the planning process, as required by ISTEA for metropolitan areas with more than 200,000 population. Areas that fail to receive certification will be sanctioned by having federal funds withheld under the circumstances discussed in the Final Rule. The planning reviews involve a federal team from FHWA headquarters and regional and division offices, FTA headquarters and regional offices, and the Volpe Center of the U.S. Department of Transportation. During site visits the team meets with representatives of all agencies involved in regionally significant transportation planning in each area, including MPOs, state departments of transportation (DOTs), state and regional air quality agencies, public transit operators, and county or city planning departments.

The reviews are based on an open-ended exchange of information built around a structured and disciplined framework. The comprehensive and multimodal approach fosters an understanding of the local planning context and encourages the systematic view envisioned by ISTEA. For each area federal staff gain appreciation for the unique planning environment and identify the strengths and weaknesses of the planning process and barriers that must be overcome to meet the requirements of ISTEA. The MPO and other planning agencies receive a clearer sense of the changes required to meet ISTEA expectations. Both federal and local participants benefit from the opportunity to take a comprehensive view of the metropolitan transportation system and to discuss concerns, problems, and solutions.

Candor is encouraged because the assessments are not certification reviews. And because each area's planning process is undergoing a period of transition and uncertainty, federal and regional staff approach the reviews with great interest and intensity. By consensus each team has developed extensive and specific findings on necessary improvements, presented in a formal report issued by the regional administrators of FTA and FHWA.

The fourth objective of the planning reviews is to identify and analyze national trends in metropolitan planning under CAAA and ISTEA. This paper represents the initial effort to perform cross-cutting analysis by synthesizing findings from the reviews completed to date:

Site	*Date of Visit*
Kansas City	1991
Chicago	1991
Los Angeles	1991
Pittsburgh	1991
Houston	1992
Twin Cities	1992
Portland	1992
Sacramento	1993
Denver	1993

SUMMARY OF MAJOR FINDINGS

This paper provides insights into current planning practices and the gap between this status quo and important expectations of ISTEA and CAAA. The analysis focuses on five important aspects of metropolitan transportation planning, contrasting what the federal team looked for in good planning practice, as defined by the joint planning requirements and later by the two acts, to what it found in practice.

The status quo and the expected characteristics of the planning process under the ISTEA and CAAA can be considered two ends of a spectrum. Table 1 describes a spectrum of planning practice in the five areas considered in this paper. At one end the status quo is based on generalized problems common to many but not necessarily all of the areas evaluated. At the other end are ISTEA and CAAA goals or expectations for transportation planning.

The difficulty is that because both ends of the spectrum are in great flux, attempts at definition are analogous to shooting at two rapidly moving targets. The planning process is changing in all of the metropolitan areas evaluated, primarily in response to the two acts. Work on some of the reviews began before passage of ISTEA, and some mandated changes will not have to be in place until future years. As a result planning processes were being evaluated against standards that were not completely formalized at the time of the reviews. The intent of the reviews was to provide constructive guidance on how to modify current practices to meet standards not yet finalized. This analysis concentrates on trends rather than on observed practices, many of which have already been modified. The planning practices of individual metropolitan areas should actually be placed somewhere between the two ends of the spectrum. Although practices in most areas are moving toward the right end of the spectrum, the speed of movement will be of major concern.

TABLE 1 Spectrum of Planning Practice

Aspect	Status Quo	ISTEA/CAAA Goals
1. General MPO role	Removed from major decisions	Broker, leader, consensus builder
2. Long range plan	Single scenario Focus on 1 or 2 modes	Alternative scenarios Multi-modal and inter-modal. Focus on system performance. Incorporates 15 factors.
3. Links between Plan and TIP	Not clearly established.	Clearly established. TIP - strategic management tool.
4. Fiscally constrained Plan/TIP	No.	Yes.
5. Public role		
Participation	Limited -- e.g., hearings on draft Plan/TIP.	Actively encouraged. Early and substantive.
Representation	Limited.	Broad - public/private sector, citizens.

MPO Roles and Responsibilities

Expectations

The federal team looked for collaborative and well-coordinated working relationships between the MPO and other agencies involved in regionally significant transportation planning in each metropolitan area. In most cases this includes city or county planning groups, state DOTs, transit operators, or other MPOs serving the same area. In air quality nonattainment areas, state or regional air quality management agencies often play major roles in transportation planning.

Beyond collaborative working relationships, ISTEA and CAAA clearly expect the MPO to play a pivotal role in metropolitan planning, whether as a leader, manager, or builder of consensus among other agencies that can have different perspectives and priorities. The planning process should be a disciplined and structured effort that is the basis for programming of investments and not a paper exercise to meet federal requirements, largely disconnected from important transportation decisions.

CAAA and ISTEA leave many of the details of the working relationships between the MPO and the other agencies to local negotiation. The acts, however, mandate significant responsibilities for MPOs, including air quality conformity determinations for the plan and the TIP; development of a multimodal and financially constrained plan, with a realistic long-range vision; working cooperatively with the state and transit operators to develop a financially constrained and prioritized TIP; and selection of all projects for the TIP (except for the national highway system, bridge, interstate maintenance, and federal land highway programs), in consultation with the state and transit operators in areas with populations of more than 200,000.

Observations

The MPOs in the Twin Cities (Minneapolis and St. Paul, Minn.) and Portland, Oreg., clearly play roles as consensus builders and successfully coordinate planning processes that influence the long-term directions of their areas and guide the programming of transportation investments. Both MPOs appear to be in strong positions to modify their planning processes to meet the requirements of ISTEA and CAAA. It is important to note that both of these MPOs have broad powers under state statutes that predate ISTEA and have a history of regional leadership.

In the Twin Cities, Metro Council is authorized by state statute to prepare and adopt a comprehensive development guide consisting of policy statements, goals, standards, programs, and maps prescribing the orderly economic development of the metropolitan area. The guide includes direction for land use, parks and open space, airports, highways, transit services, and many public buildings. A Transportation Advisory Board (TAB) manages the 3C process and functions as a forum for cooperative decision making by local elected officials, citizens, and major transportation agencies. The TAB assigns funding priorities and adopts programs, which can be approved or disapproved by the council.

The Twin Cities' long-range transportation plan anticipated important emphases of ISTEA. The plan was oriented toward maintenance of the region's existing transportation system and achievement of system efficiencies by making greater use of underused facilities.

The Portland MPO, Metro, conducts its transportation planning process primarily through the Joint Policy Advisory Committee on Transportation (JPACT). JPACT broadly represents the metropolitan area and is charged with coordinating development of plans defining required regional transportation improvements, forming a consensus of governments on prioritization of improvements, and promoting implementation of identified priorities.

The Denver MPO, the Denver Regional Council of Governments, has recently had its role revised in response to ISTEA. It has the sole responsibility for project selection, and all projects must be included in the long-range transportation plan. The MPO is leading a process to revise the long-range plan in response to changing economic conditions and the new requirements of ISTEA.

In some other areas evaluated significant aspects of transportation planning occurred outside the MPO-led process. Important metropolitan planning and investment programming decisions appeared to be determined primarily by states or transit operators, which discouraged consideration of the extent to which these investments accomplished areawide objectives as defined in a long-range plan. Major resource allocation decisions for planning, capital, and operating funds were not based on a top-down long-range planning process led by the MPO. The long-range regional transit planning efforts dealt with many of the agency-level decisions as predetermined rather than as subject to influence through long-range planning.

Although rigorous planning often occurred at subregional levels, the perspective and priorities of these agencies were often different from those of the overall region. For example, transit operators may use long-range planning to make program decisions, but out of necessity their major concerns may be operational and financial—to meet fare box recovery requirements, reduce deficits, or eliminate inefficient service. For transit operators these concerns can take precedence over broader regional priorities, for example, assigning resources to the projects that most cost-effectively reduce air pollution, regardless of whether the projects are transit, highway, or transportation control measures. In one example a transit operator's plans resulted in construction of a reserved busway without substantial consideration of the feasibility of including other high-occupancy vehicles, which might have reduced bus speeds and efficiency but which also could produce systemwide mobility or air pollution benefits. In another case suballocations were based on historical formulas and not on long-range planning, which is specifically discouraged by the ISTEA Final Rule.

In many areas evaluated the MPO received a prioritized and financially constrained list of projects for the TIP from implementing and other participating agencies, including the state, transit operators, and in the case of the California areas, county transportation commissions. For California MPOs this is encouraged by state planning requirements that define responsibilities for county commissions similar to those defined for MPOs by ISTEA. This general approach, in which the MPOs receive inputs for the TIP that are prioritized and financially constrained outside the overall planning process, is inconsistent with ISTEA, which requires the development of prioritized and financially constrained areawide long-range plans and programs. At its worst some MPO processes are reduced to combining rather than integrating program documents to reflect systemwide objectives. This reduces the likelihood that transportation resources will be allocated on the basis of areawide priorities, including improved air quality and systemwide efficiency.

Although early efforts led by MPOs to develop criteria for allocating ISTEA flexible funds were modest, there was some positive movement in this direction. In the Twin Cities, Metro Council has formed an ISTEA work group to identify ISTEA responsibilities and priorities, reach agreement on organizational roles, and determine procedures for distributing the flexible funds in the ISTEA programs. The work group proposed roles and responsibilities for the Minnesota DOT (Mn/DOT) to play in the allocation of flexible funds and a 2-year timetable for making decisions, completing planning tasks, and satisfying mandates related to ISTEA. The work group was developing formal criteria to use in the evaluation and selection of projects in competitions for the flexible funds, including consideration of population, vehicle or lane miles, or gas tax revenue generation as the basis for allocation of Surface Transportation Program (STP) funds by the state to regions. The work group took a strong position against formula-based suballocation of flexible funds within the region to jurisdictions or to modes.

In Sacramento the MPO had developed flexible STP guidelines that will allow for the selection of projects that meet the travel demand needs identified during the planning process. The STP guidelines were developed through a committee structure that included all modes and transportation interests in the region. The guidelines were evaluated by approximately 100 different agencies and jurisdictions. At the time of the review the MPO was developing criteria that would allow direct comparisons between highway and transit projects.

The Sacramento region was well-positioned to realize the potential of the flexible funding feature because of its transit, congestion, and air quality management planning. Flexible funds could be used to fund projects proposed by the county congestion management agencies or by the transit operator to expand the light rail system. The MPO also had a project selection process for the TIP that will ease fund transfers to finance a range of transportation projects on the basis of projections of revenues, need, readiness, and eligibility.

Development of Scenarios in Long-Range Plans

Expectations

The federal team looked for long-range plans that perform a strategic function for the overall planning process. The plan should identify the key issues that will affect the region over the next 20 years, including demographics, the availability of resources, and the condition of the transportation infrastructure. Although the plan can encourage innovative thinking on future directions, it should also move the area toward a realistic single future vision by consensus of decision makers and the broad public. The future will ultimately be defined in terms of a preferred transportation alternative based on a disciplined look at the reality that each area faces—financial limitations, air quality targets, and other local goals. The analysis that supports the selected alternative should be clear. Preferably, the plan will define and evaluate several distinct alternatives in terms of broad costs and benefits and the ability to accomplish clearly stated areawide goals.

Identification and evaluation of alternative scenarios in the long-range plan are important means of demonstrating the complex trade-offs involved when limited resources are applied to air quality, mobility, and other fundamental transportation concerns. A clear picture of the costs and benefits of alternatives is necessary to focus decision makers and the public on the difficult choices facing metropolitan areas, particularly those in severe air quality nonattainment categories.

The plan should not be static, out-of-date, or an advocacy document but should represent current critical thinking on how best to deal with future challenges. The plan should not be a means of justifying a previously selected set of projects in the TIP; instead, the TIP should be a carefully selected and prioritized set of projects that can be used to implement long-term directions from the plan. The plan should be a cohesive and distinct product that will provide a single source of direction for the area; it should not be a mechanical merger or consolidation of subregional or single-mode plans, although these efforts should be consistent and compatible with the long-range plan and will be important resources in its development.

ISTEA requires consideration of multimodal solutions to the area's most pressing future transportation problems and explicit consideration of 15 factors throughout the planning process and in the products of the process, including the long-range plan and the TIP. The 15 factors include congestion management strategies, travel demand reduction, land-use effects, expansion of transit, and improved transit security. The team looked for serious consideration of a broad range of strategies in the plan. If the selected alternative did not reflect broad strategies, the plan should indicate that these strategies were considered and rejected in terms of their ability to accomplish regional objectives. The team looked for breadth of approach to long-range planning that indicated the ability to adapt to ISTEA requirements.

Observations

The plan developed by SCAG, the MPO for the Los Angeles metropolitan area, provided an excellent example of how a set of clear alternatives can be presented in terms of costs and benefits, including reduction of vehicle miles traveled and air pollution. This approach can encourage understanding of the unavoidable trade-offs between strategies to meet air quality, mobility, and other targets. For Los Angeles, the only metropolitan area in the extreme nonattainment class for ozone, evaluation and selection of cost-effective strategies for reaching attainment should dominate the planning process. The scenarios developed by SCAG encouraged decision makers to focus on what results will be required from specific strategies, including significant growth in transit, reduced trips through telecommuting, and an improved jobs-housing balance to meet extremely demanding air quality and other objectives. Rejection or reduction of one strategy can then be analyzed in terms of the additional burdens placed on the other strategies.

The Sacramento plan presented five different mobility options to guide the region through the year 2010. The building block approach used to develop these options consisted of adding or combining transit expansion, development of high-occupancy vehicle (HOV) lanes, roadway improvements (based on 2010 congestion projections), changes in land use, and transportation congestion management strategies. After evaluation of the different options using performance criteria, the MPO staff concluded that the mobility option that combined the different elements performed the best. A basic option was then presented and evaluated, and additional options were created by adding one or more actions. By describing the ramifications of incremental actions, this approach successfully demonstrated the thinking behind the selected alternative.

Both the Portland and Twin Cities plans presented a multimodal strategy for the areas, with complete descriptions of the transportation projects chosen for eventual implementation. However, neither provided a thorough description of the process that created the vision or the range of investment alternatives considered in the planning process. The emphasis was on moving ahead with programming rather than on demonstrating the analysis that led to the selected long-term alternative.

In Chicago the 1989 long-range plan adopted by the MPO identified the choices that must be made between travel modes such as automobiles and transit and between different transit providers competing for limited resources. Rather than presenting and contrasting multiple scenarios, the proposed plan needed major facilities, such as highways and rail lines, and estimated the resulting financial needs through 2010.

The Kansas City plan did not propose alternative land-use and transportation scenarios. Instead, the plan presented a single future scenario (with separate highway and transit components) based on the extrapolation of historical development trends. The plan revision was expected to take a broader look at approaches to land use.

The plan for Houston included different transportation options, but two of the options focused on roadway improvements, with minimal consideration of the transit or other measures the region might consider to comply with CAAA and ISTEA.

Denver is revising its long-range plan in accordance with ISTEA. The revised plan will be fiscally constrained and will be based on changed demographic and economic assumptions. This revision is being done both in response to ISTEA and because of changing economic conditions.

Clear Linkages Between Long-Range Plan and TIP

Expectations

The federal teams looked for clear and substantial connections between the strategic direction set in the plan and the short-term actions in the TIP. A connection between an unconstrained or wish list plan and a TIP that is primarily a list of projects without explicit criteria for selection is inadequate. Transportation projects should be selected on the basis of cost and performance—their ability to accomplish the objectives of the plan.

These general expectations for the reviews anticipated the requirements in the ISTEA Interim Guidance and Rule for consistency between the plan and the TIP and related discussion in the NPRM for metropolitan planning. (*4*). The NPRM proposed that the plan be "the central mechanism for structuring effective investments." Also, "The financial constraint of the plan would be reflected in more detailed fashion in the TIP." The TIP must become a management tool, "establishing an overall program strategy reflecting the transportation plan."

Observations

The Twin Cities and Portland metropolitan areas provided clear demonstration of the links between plans and TIPs. However, as noted above, plans for both areas began with a single selected alternative. By providing a more developed strategic context for the selected alternative, future plans in both areas could provide more substantial justification for the TIPs.

The Twin Cities Metro Council successfully documented the regional planning context for the TIP's development and the issues and policies that affected project selection. The Metro Council initiated the TIP process by requesting that Mn/DOT and the Regional Transit Board (RTB) submit projects for evaluation by the TAB and the MPO. The process ensured that the TIP reflects the region's priorities, as expressed not only in the long-range transportation and air quality control plans but also in long-range plans of the RTB and Mn/DOT and in local comprehensive plans for land use and transportation.

The Portland area TIP began with an explanation of how the capital improvement component of the plan will be implemented, described which projects will be given priority, and balanced local and regional needs. According to the MPO the baseline consistency of the TIP with the regional transportation plan (RTP) was established in updates of the regional transportation model. Proposed elements of the plan are added to the model to simulate expected future transportation system performance. TIP projects were compared with this projection to determine consistency. As the regional system of project selection is modified to ensure compliance with the multimodal and efficiency criteria of ISTEA, the MPO will require that local and special district projects include a statement of consistency with the RTP.

In the Los Angeles area the TIP reflected the separately determined short-range plans of the region's transit providers, the county commissions, and the California Department of Transportation (Caltrans). Limited links to the regional mobility plan and its goals were developed.

In another area the MPO had the authority to approve and disapprove TIP projects proposed by implementing agencies, but this authority appeared to be exercised primarily when projects exceeded funding constraints. Thus, implementors were not forced to view how their projects fit into the overall regional big picture. Project rankings and selection were primarily determined by the implementors.

The documentation of the planning basis for many of the projects in the Kansas City TIP was not strongly developed. Links between TIP projects and the long- and short-range elements of the plan or connection to explicit regional objectives for energy conservation and improved air quality were not clearly documented.

One area did not clearly establish a regional planning process as the guiding mechanism for selecting the projects in its TIP. Long-term regional criteria and objectives identified by the MPO did not necessarily determine the contents of the TIP. Projects were included on the basis of negotiations between elected officials and implementing modes. For example, the state DOT and the toll road authority appeared to make highway fund decisions and transit operators appeared to make transit fund decisions based primarily on their own criteria and objectives. The MPO incorporated these priorities into the TIP.

The MPO in Denver has revised its TIP selection process to fully comply with ISTEA. Proposals are submitted to the MPO for review. Proposals must have been included in the long-range plan to be considered. The MPO uses criteria based on ISTEA in evaluating projects, and all projects in the TIP are fully funded. The TIP covering 1993 to 1995 was developed by this process.

Financial Constraints on Long-Range Plans and TIPs

Expectations

The plan should not be a wish list with unfunded projects. An unconstrained plan avoids controversy by including projects from all constituents, but it lacks the discipline necessary to guide a metropolitan area toward programming scarce resources to solve combinations of air quality, mobility, growth, or other pressing problems. Although the plan must be constrained and should develop realistic alternatives, it can also provide value by developing unconstrained alternatives as a means of advocating imaginative and challenging future visions of transportation systems for the metropolitan area. If alternatives are presented that are beyond the means of currently identifiable resources, projects can be prioritized to clarify what would be funded if different levels of new revenues are available.

The ISTEA requires that plans be financially constrained over a 20-year time horizon, comparing existing and proposed revenues with the costs of constructing and operating the planned system. TIPs and plans must be financially constrained and prioritized; overprogramming is not allowed. For nonattainment areas financial constraint is the key link between CAAA and ISTEA, with requirements for conformity reviews of both the plan and TIP by the MPO, FTA, and FHWA.

Observations

Typically the MPOs evaluated did not reflect financial constraints and prioritization in their plans or TIPs. Most of the MPOs, however, indicated that in response to ISTEA they expected to incorporate these difficult but crucial dimensions in their next plans and TIPs.

At an aggregate level the Los Angeles plan identified shortfalls, although the plan and its long-range projects were not resource constrained. It assumed that the resources required would be provided by the political process to reach specified goals. The 1992 update was intended to develop more stringent funding criteria and to apply them to general initiatives. This will be important to determine conformity with the State Implementation Plan (SIP) and to meet other ISTEA requirements.

The Los Angeles MPO assessed TIPs prepared by Caltrans, counties, and transit agencies, which were prioritized for consistency with the mobility plan, for conformity with transportation control measures in the SIP, and to ensure priority of HOV lanes over mixed-flow lanes. County TIPs must be constrained by the funds available. The transit agencies consistently faced funding shortfalls for TIP implementation.

Chicago's long-range transportation plan proposed maintenance and expansion that will cost $25 billion through 2010, but its optimistic funding availability forecast fell short of providing the required revenues, and its pessimistic forecast fell very short. Shortfalls could be substantial enough to require reconsideration of basic transportation and land-use strategies. The first step in creation of the TIP, which was fiscally constrained, was adoption by the MPO of fiscal marks for the federal portion of the program. These marks guided the development of lists of projects by implementing agencies, as discussed above.

The TIPs for the Pittsburgh and Houston areas were overprogrammed. The Pittsburgh TIP had a substantial funding shortfall, particularly for the transit portion, which was not prioritized. The Houston MPO estimated that the TIP was approximately 50 percent overprogrammed, and in the 1992 fiscal year less than half of the programmed projects were implemented.

Despite an explicit priority for fiscal restraint in the Twin Cities, the proposed level of highway and transit activity in the plan appeared to be highly optimistic. Metro Council estimated a shortfall as high as $2.1 billion by 2010 for metropolitan highway system improvements, reflecting projection of a significant reduction in state transportation expenditures. To support transit operating costs and the construction of three light rail lines, an additional approximately $1.3 billion was required for the planning period.

The Twin Cities plan attempted to preserve the existing level of regional mobility through the year 2010 while minimizing expenditures. Metro Council recognized national and local economic and financial pressures and attempted to balance mobility and maintenance of quality of life with limited long-term funding. The council's *Metropolitan Development and Investment Framework* emphasized careful management of regional resources by placing the highest investment priority on servicing existing development within the urban service area.

Portland's ambitious 10- and 20-year scenarios described in the plan were not prioritized or financially constrained and faced large funding shortfalls. The MPO, however, had developed an aggressive strategy for creating new funding sources.

The Portland TIP was not overprogrammed; funds had been obligated for the projects listed. During its development the proposed program in the current TIP was determined to cost more than the available funding allows. The MPO worked with the Oregon Department of Transportation (ODOT) to equalize costs and funding. Projects dropped from the TIP because of insufficient funds were maintained in the plan for later consideration.

The Sacramento plan was significantly underfunded. Even though different options for financing the shortfall were explored in the plan, the region was struggling to identify new revenue sources that would be publicly and politically acceptable. The lack of a financially constrained plan, as required by the ISTEA, was an issue between the MPO and the U.S. DOT.

Denver's long-range plan included more than $11 billion in transportation investment, although revenue estimates projected that only $4 billion will be available in 2010. The MPO is studying new sources of revenue and planned to develop a financially constrained 2015 long-range plan based on the 2010 plan to meet the ISTEA deadline. The MPO also intended to produce a 2020 plan that will respond to other ISTEA requirements.

Public Participation

Expectations

The teams looked for demonstration of substantial public participation, with "public" broadly defined to include a range of public agencies, citizens and advocacy groups, and the private sector. A public participation process that relies primarily on formal public hearings to assess drafts of plans, TIPs, or other planning products was considered inadequate. The preferred approach—which encourages early involvement in identifying long- and short-range strategies, in the 3C process down to the corridor or project level, and in programming—is an ideal that is difficult to accomplish. Members of the public are likely to react to decisions that seem to directly affect them but to have difficulty investing the time necessary to become involved in the complexities of long-range planning. Ideally, planning staff will assist the public in participating throughout the technical planning process. Broad public involvement is crucial to building the political consensus necessary to support controversial transportation decisions, including those required for severe nonattainment areas to meet air quality goals.

The ISTEA Rule requires "a proactive public involvement process," including access to complete technical and policy information, timely notices, full access to key decisions, and support for early and continuing involvement in plan and TIP development.

Observations

For several of the areas public participation could be more formally expanded to improve representation throughout the planning process of groups such as large employers; labor, employer, and development associations; environmental organizations; and minority groups.

In Los Angeles SCAG had a Regional Advisory Council of 50 members drawn from business, church groups, and universities to make recommendations to the Executive Committee on proposed plans. A deliberate attempt was made to get the private sector, minority groups, women, and the disadvantaged involved on this committee. Also, opinion surveys and public hearings were used to sample citizen opinion. All area studies had a policy advisory committee on which private citizens sat. SCAG did believe that additional efforts were required to evaluate the impact of transportation planning on the citizenry at large. The county transportation commissions and transit operators maintained their own outreach programs.

For the Chicago area the major source of citizen input to the CATS transportation planning process, including development of the long-range plan and TIP, was indirect, through the local elected officials who serve on the Policy Committee. Public concerns, including requests for information and comments on plans, were primarily communicated through the Council of Mayors and regional councils to CATS. The Council of Mayors provided a forum for disseminating information and solicited comments on regional transportation plans and programs. In addition CATS Policy Committee representatives met with individual citizens and groups at the regional councils, and the transit agencies often presented projects and programs to the councils for review.

In Kansas City the MPO primarily relied on public meetings for input in the preparation of the plan. During the controversial investigation of transportation and land-use options within the urban core, the MPO held 12 public meetings.

The Houston MPO provided an effective means, through membership on subcommittees, for citizens, representatives of environmental action groups, and private transit operators to participate in the planning process.

The Twin Cities has a strong tradition of citizen participation, encouraged by controversies over highway construction, the transfer of Interstate highway funds, airport noise, largescale real estate developments, and proposed light rail construction. This tradition was enhanced by the Metro Council, the RTB, and Mn/DOT's commitments to actively recruiting citizens for their advisory committees. To involve the general public in the planning, development, and implementation of regional plans and policies, Metro Council and RTB had an open appointment policy and a program to actively recruit citizens to sit on advisory committees.

Public participation in Portland occurred through citizen advisory committees for all corridor studies, public meetings to update the plan process, and citizen membership on the Transportation Policy Alternatives Committee (TPAC). Metro appointed six citizens as TPAC representatives. According to Metro the general public was not easily attracted to planning activities, and citizen input came late in the process of updating the last plan, despite TPAC's inclusive membership. Metro expected involvement to increase in the next 2 years through the Region 2040 process, during which public forums and publications will encourage participation in developing a vision for the Portland region. The 17 members of the Metro Joint Policy Advisory Committee on Transportation included representatives from the counties, the city of Portland, Metro Council, the Washington-State portion of the region, the regional transit operator, the Port of Portland, ODOT, and the Oregon Department of Environmental Quality.

After passage of ISTEA the Sacramento MPO took steps to enhance citizen participation in the planning process. This consisted of the formation of three different subregional groups to represent local concerns. These groups report to the MPO's Air Quality and Transportation Committee. The MPO also formed a task force to address bikeway and pedestrian issues and an ad hoc environmental group.

The Denver MPO provides a variety of opportunities for citizen participation. Plans, TIPs, and other planning products are presented before public meetings and hearings. Citizens are represented on task forces established to address regional planning issues. The private sector is represented on task forces and is involved in public meetings and public hearings. The MPO makes an effort to include private representatives on the Transportation Planning Committee and to expand public participation opportunities for both citizens and the private sector.

CONCLUSION

MPOs are now expected to exercise leadership in defining a regional vision for the future, in selecting projects, and in improving mobility and air quality. To do this they must overcome a period in which their resources, technical capabilities, and institutional roles were diminished. In the metropolitan areas with severe air pollution MPOs also must overcome institutional and technical barriers and work with other regional agencies to identify affordable and politically supportable mixes of transportation strategies that can include new automotive and fuel technologies, better management of systems, expanded public transit, pricing, or landuse controls that not only meet stringent air quality targets but also improve mobility and accomplish other traditional transportation objectives. In other metropolitan areas with more modest air pollution, some MPOs welcome ISTEA as a lever to use in overcoming fragmentation and leading regions toward multimodal and systemwide planning.

The reviews have identified several general problems in the planning process that must be overcome if the promises of ISTEA and CAAA are to be realized. Most long-range plans must become more strategic through the framing and evaluation of realistic future alternatives. Alternatives must be financially constrained and presented in a way that guides decision makers and the public through the technical and political trade-offs and hard choices that are unavoidable if air quality and transportation concerns are to be balanced. And long-range plans must be clearly linked to annual transportation improvement programs. These programs, which in some regions are consolidations of planning and programming decisions made outside the MPO process, must be broadened to demonstrate how the projects selected accomplish regional objectives and to consider the costs and benefits of a range of projects. Substantial consideration not only of transit and highway projects but also of other initiatives that respond to the 15 ISTEA factors should be demonstrated.

ACKNOWLEDGMENTS

This paper is based on work performed for FTA and FHWA, U.S. Department of Transportation. The author acknowledges the insights and comments of the federal review team members who participated in the nine independent planning reviews conducted to date. In particular, he acknowledges the contributions of Deborah Burns, the FTA program manager; Samuel Zimmerman, and Robert Kirkland of the FTA Office of Planning; Brian Sterman of the FTA Region II Office; Barna Juhasz and Dean Smeins of the FHWA Metropolitan Planning Division; and Michael Jacobs, Paul Shadle, Terrence Smith, Beth Deysher, and Robert Brodesky of the Volpe Center.

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The views expressed in this paper are those of the author alone and do not necessarily represent the policies of FTA, FHWA, or the U.S. Department of Transportation.

Publication of this paper sponsored by Committee on Intergovernmental Relations and Policy Processes.

Application Frameworks, Information Systems, and Intermodal Surface Transportation Efficiency Act

DANIEL S. HALBACH

Numerous problems traditionally exist in translating engineering models into usable software systems. The high-level logic of the model is often compromised or confused by the low-level programming logic. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) has established the need for six information management systems, the requirements for which may serve to magnify these problems. An approach to solving these problems involving application frameworks is presented. This approach promises to empower engineers and decision makers by relieving the constraints imposed by traditional software development practices. Application frameworks appropriately place the emphasis of software system development on engineering modeling rather than on details of programming. A 6-year U.S. Department of Defense logistics management program that provides evidence of the viability of application frameworks is described. General recommendations for ISTEA information systems are provided.

Translating engineering analysis and decision models into information systems and decision support software has traditionally been subject to several common problems:

- The information in the models is often lost or obscured in the resulting code;
- The structure and complexity of the models are sometimes compromised to facilitate simpler code structure and programming logic;
- Low-level control logic and language-specific overhead are intermixed with the higher-level logic of the original model, making it difficult to locate the model in the code; and
- The resulting code is often difficult to understand, maintain, reuse, and tailor.

Although these problems are perhaps tolerable when the system is developed and used by the same engineers or decision makers in a limited setting, problems such as these are magnified when the system has requirements and expectations that exist for the management systems defined by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) (*1*). Specifically, ISTEA establishes six management systems: pavements, bridges, congestion, highway safety, public facilities, and intermodal facilities. The requirements and expectations for these six systems include

- A set of "procedures, within the State's organizations, for coordination of development, establishment, and implementation of the management systems";
- The ability to tailor the systems to "meet State, regional, and local goals, policies, and resources, [while remaining] acceptable to the Federal agencies";
- The "use of data bases with a common or coordinated reference system and methods for data sharing";
- The need for "documentation that describes each management system . . . for the Federal agencies to determine if the systems fulfill the [intended] purpose";
- "Outputs (e.g., policies, programs, and projects) [that can be] integrated into the metropolitan planning process"; and
- A method to handle "interrelationships among systems to address outputs and issues related to the purposes of more than one management system."

Although the nature of many of these factors is organizational as well as technical, the six ISTEA systems are intended to help agencies at all levels deal with each of these factors. To do this the management systems must

- Ease, not increase, the burden of analyzing and sharing data;
- Provide a clear mapping to the decision models on which their designs are based;
- Be expressed in a manner that is independent of any particular hardware, operating system, data base, or graphical user interface (GUI) platform; and
- Provide clear, direct support for system evolution as state and federal policies evolve.

In short ISTEA management systems must enable engineers and decision makers in all agencies at all levels to do their jobs effectively and efficiently. Moreover the cost of developing, implementing, maintaining, and using these systems must not outweigh the benefits to be gained from them.

Note that although various sources define the following terms differently, for the purposes of this paper the terms *information system, management system,* and *decision support system* will be used interchangeably.

SOLUTION APPROACH

Application frameworks (*2*) offer an innovative yet reasonable approach to solving the problems addressed above. Although the concept of application frameworks has only recently emerged as a software engineering discipline, application frameworks have been in existence for some time. In fact GUIs such as those defined by MS-Windows and Apple Macintosh and Relational Data Base Manage-

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ment Systems (RDBMSs) are examples of application frameworks that have been well received and proven in their respective domains. They are now showing to be equally applicable to other domains, including the scheduling, planning, and decision support required by ISTEA management systems.

Although the GUI and RDBMS examples stated in the preceding paragraph are known by the specific programming languages and "tool kit" libraries that support them, an application framework is fundamentally more than just a language or library of routines. An application framework is a specific, tangible architecture designed to support a particular problem domain. Because they are intended to support entire domains, application frameworks are designed with the goals of tailorability and direct mapping to underlying engineering models. The discipline of application frameworks has evolved in part because of advances in object-oriented programming (OOP), but its concepts and approach can be understood independently of OOP. However, readers are encouraged to learn more about object-oriented software development from the references provided (*3–5*).

Perhaps the best method for describing the concept of application frameworks is via the analogy of a computer circuit board. The board itself provides a tangible, specific architecture designed to allow the computer chips that plug into it to interact in a controlled, predictable manner and to serve a useful purpose. Any particular socket on the circuit board can be occupied by chips from different vendors and with differing characteristics, provided that

- The chip's pins will fit into the socket,
- The chip can receive the full set of inputs sent by the circuit board, and
- The chip will respond with outputs comprehensible by the rest of the circuit.

An application framework is like a circuit board in that it provides the fixed, but generic, architecture for solving a given class of problems. The framework's design provides "sockets" into which specialized software components may be inserted. These specialized components provide the mechanism through which an application framework can be easily tailored while still conforming to the general architecture. The application framework defines the general solution approach to the associated domain of problems, whereas the specialized components tailor the framework to a specific purpose or platform. The specialized components provide an added benefit of encapsulating the low-level details of their implementation. Thus, the framework's representation of the domain model remains clear and separate from these implementation details, adding to the comprehensibility and maintainability of the code.

As stated, constructs provided by OOP (and object-oriented languages, such as C++) directly support the definition and specialization of tailorable components that can be plugged into an application framework. However, approaches exist for creating application frameworks that are independent of object-oriented programming languages (*6,7*). Application frameworks can be tailored for a particular platform (i.e., hardware, operating system, GUI, or data base) simply by creating or refining components to meet the requirements and protocols of the target platform. Likewise, the specific focus and details of the underlying engineering model can be tailored through the same process of defining specialized software components and inserting them into the general framework. The pavement management system (PMS) example in the next section will further illustrate the nature and benefits of application frameworks. The following are keys to a successful application framework:

- It is based on sound engineering analysis and a well-defined domain model;
- It should clearly define and portray the overall goals of the management system and the decision makers who will use it;
- It should clearly define which parts of its structure are tailorable and which are immutable (i.e., which parts of the framework's code are analogous to the replaceable chips and which correspond to the fixed circuit board); and
- It should be developed at an appropriate level of abstraction.

This last point requires further explanation. The level of abstraction of a framework is basically its degree of generality. A highly abstract framework can be applied to a broad range of applications but provides less direct support to any specific application. Conversely a less abstract framework provides more direct support to a specific subset of applications, and is thus easier to implement and tailor for that subset. However, that subset covers a narrow range of applications in comparison with a more abstract framework. The proper level of abstraction is important for two reasons. First, an attempt to instantiate an excessively abstract framework often results in frequent hacking (i.e., opportunistic coding in the absence of design) because of the lack of support from the framework. Second, an attempt to instantiate a framework with an inappropriately low level of abstraction also invites hacking to subvert or circumvent the parts of the framework that do not apply to the application. To address this abstraction issue, application frameworks are designed as a hierarchy of abstractions in which each level in the hierarchy contains frameworks that are specializations of those at the next higher level. For example, an ISTEA-applicable framework might be a specialization of a constraint-based scheduling framework, which in turn is a specialization of a generic constraint-based framework.

The concept of application framework tailorability desires special note. The traditional notion of tailoring involves the end user's ability to define specific values of parameters used in a system's algorithm. For example, the tailoring of existing PMSs is typically a matter of setting break points in a decision tree. Although this type of tailoring is no doubt important, application frameworks offer an additional and more powerful means of tailoring a system via the specialization of components. As shown in the following PMS example, these components can be much more than simple break points. Components can be pavement or bridge classifications, traffic categories, environmental characterizations, and decision algorithms, among others. Each component can define its own specialized features and behavior within the general constructs of the component type. Each pavement type, for instance, can define its own performance curve that will automatically be invoked by the framework at the appropriate time. Thus, new pavement types (with their own performance curves) can be added to an existing pavement management framework without the need to restructure or redesign the rest of the framework. This is true only if the original framework has been appropriately designed to isolate pavement type as a tailorable component (i.e., the framework's circuit board provides a socket for pavement type, instead of hardwiring it).

PAVEMENT MANAGEMENT EXAMPLE

Although application frameworks are more than merely a simple flow chart, the algorithm embodied in a flow chart can be an important distinguishing feature of a framework. Thus, the pavement management example of application frameworks provided in this section begins with the following algorithm:

1. For each time period (e.g., year or season) of the analysis or projection period:
    2. For each pavement section in the inventory:
        3. Determine any changes to traffic or environment (i.e., soil, climate, etc.).
        4. Determine pavement performance during that period (i.e., change in condition).
        5. Recommend treatment based on condition, structure, functional class, traffic, and so on.
    6. Prioritize the recommendations based on condition, structure, functional class, and so on.
    7. Apply treatments as the budget allows.
8. Summarize and report.

From this algorithm the need for the following classes of components can be inferred:

- A time line: an overall analysis period divided into discrete steps (Step 1);
- An inventory of items (e.g., pavements) to be maintained (Step 2);
- Factors (e.g., traffic) that affect the condition of inventory item over time (Step 3);
- Performance prediction functions or algorithms (Step 4);
- Treatments for maintaining and rehabilitating inventory items (Step 5);
- Mechanisms for recommending treatments for inventory items (Step 5);
- Mechanisms for prioritizing the importance of recommendations across the entire inventory (Step 6);
- A means of expressing the costs of treatments, presumably in dollars (Step 7);
- Budget constraints that limit the number and types of treatments applied in a given period (Step 7);
- Relationships between treatments, their applicability to each type of inventory item, and the improvement they make to condition (Step 7); and
- A format for defining and expressing the degree to which the projected treatments achieve the desired goal of the system (Step 8).

Each of the component classes should have a well-defined protocol (i.e., set of functions to perform or responsibilities to carry out). These protocols provide the structure within which a framework can be tailored. As with plugging chips into a circuit board, any component that conforms to the protocol of its generic class (i.e., the socket) can be inserted into the framework. Thus, the protocol defines

- The syntax (name, type, and parameters) of the attributes and functions that apply to the component (i.e., how the chip fits into the socket);
- The context and purpose of each of those attributes and functions (i.e., the inputs the chip is expected to receive from the circuit board); and
- The format, content, and range of the attributes and function return values (i.e., chip outputs that will be comprehensible by the rest of the circuit)

It should be noted that the original algorithm given in this example should also be a tailorable part of the overall framework. This is important for two reasons. First, the algorithm addresses the overall goal of the management system, which should also be tailorable. For example, the original goal—achieving the best network condition given the budget constraints—could be inverted into determining the budget required to achieve a desired average network condition. Second, alternative algorithms could be used to address the same goal. For example, in the algorithm given earlier, Steps 1 and 2 could be reversed, making the primary loop address sections instead of years. Thus, instead of making recommendations across the entire network on an annual basis, the algorithm would, at each step, define an entire life cycle of an individual pavement section (in order of section priority and based on remaining budget). Note that even when the algorithm is changed the definition of the other components (and their protocols) remains the same.

RELATED WORK

Evidence of the validity of the claims made in this paper for the benefits of application frameworks technology has been provided by a 6-year program to provide management systems to the U.S. Department of Defense (DOD) logistics management community (*8*). In the description of this DOD program that follows, the reader will note a remarkable similarity between this domain and the transportation management domain addressed by ISTEA.

The DOD logistics management community encompasses a broad range of subdomains, including funds management, contracts management, personnel planning, inventory and supply tracking, maintenance and modification scheduling, and reliability analysis. Users of these subsystems (i.e., the logistics planners) can be characterized as follows:

- Approximately 1,000 users are spread across 20 sites that operate semi-independently.
- Each site must adhere to common policies established by a central command.
- Information systems are tailorable for each site within these general constraints.
- The systems are used to manage scarce or shared resources (especially time and funding).
- Data must be shared between the multiple applications as well as between sites.
- Each site must provide standardized reporting to the centralized command.
- Coordinated decision making is required for resources managed jointly by multiple sites or multiple applications.
- System requirements are constantly evolving to support a changing environment.

The technical characteristics of the management systems themselves include the following:

- "Legacy" systems must be supported and integrated into the overall system environment.
- All systems must have a GUI to facilitate ease of training and use.
- Data bases may reside across multiple, distributed data base servers.
- Both DOS-based and UNIX-based workstations are supported.

Despite these seemingly overwhelming challenges, the application framework approach described herein has consistently provided low-risk, cost-effective solutions for the DOD logistics management community. On average systems originally budgeted to take 1 year or more to develop are now being delivered in 3 months at a significantly reduced cost (*9*). The generalized logistics applications have been ported and tailored for the various sites with only a fraction of the time and funding typically spent on similarly sized DOD software projects. Specific examples of the efficiencies that applications frameworks have provided for DOD logistics management include the following:

- An automated scheduling system that plans all future modifications to the Air Force fleet of C-130 cargo aircraft was delivered in 5 months, including a graphical editor running in X Window on a UNIX workstation.
- An Army inventory and supply management system that also automates all associated DOD forms was developed and delivered in 3 months.
- A funds management system that plans and tracks sources, commitments, and expenditures of six categories of Air Force maintenance, labor, and materials funding was produced and delivered in 5 months.
- An Army aircraft reliability analysis system that analyzes performance and failure data to predict future maintenance and support requirements was produced in 3 months.

The requirements for each of these systems to have distributed data bases, multiple site coordination, and graphical reporting resulted in original development schedules that were as much as five times as long as what was actually achieved via the help of frameworks. The successful implementation of application frameworks in the DOD logistics management domain is evidence of their applicability to transportation information management system development because of the nearly one-to-one mapping between the aspects of the two domains. In fact the only significant conceptual difference between the domains is that one deals with aircraft, military bases, on so forth, whereas the other one deals with pavement sections, bridges, and so forth.

GENERAL RECOMMENDATIONS FOR ISTEA INFORMATION SYSTEMS

Perhaps the most promising characteristic of application frameworks is that they provide a clear representation of the underlying engineering model free from the extraneous implementation details that are encapsulated within the components. This takes the emphasis of system development off programming and puts it back on engineering and decision modeling where it belongs. As a result application frameworks can actually clarify models rather than obscure them. Experiences gained in the creation of information systems for logistics management, enhanced by this clarifying nature of application frameworks, are the basis for the recommendations provided in this section.

Decision support is more than just data base management with the ability to provide summary reports. Decision support systems must also predict future conditions to aid planning and scheduling. For this planning portion of the management system, the system inputs comprise six general categories:

- Resources and supplies. These represent expendable commodities that are used as part of maintenance and rehabilitation activities. They are typically associated with a simple unit price for the purposes of budgeting. Examples include labor and materials. Units of time required to perform activities may also be treated as a resource, depending on the nature of the decision model.
- Fixed assets. These are relatively permanent entities, such as maintenance equipment or facilities, that represent long-term, capital investments. Although depreciation of these assets may be considered, routine maintenance costs for these assets are usually not a direct concern of the decision models.
- Inventories. These are collections of entities, such as bridges or pavement sections, that share properties of both fixed assets and expendable resources. Like assets, they have some fixed properties, such as the geometry and initial capital costs of pavement sections, while also having resourcelike expendable attributes, such as deteriorating serviceability. Thus, unlike fixed assets the maintenance cost of the inventory is precisely the concern of the management system.
- Environmental factors. These factors define external inputs that are not under the direct control of decision makers, including political, economic, climate, and traffic considerations.
- Goal definitions. Multiple goals may be addressed during the planning process. Examples include determining the budget required to bring the inventory to a desired level of serviceability and determining the highest achievable level of condition across the inventory within a given budget constraint.
- Decision models. These are the procedures or algorithms that transform inputs into outputs.

These decision models can take on several forms, but in general they share the following common features:

- A cyclic, iterative simulation engine to support such things as state-transition models, life-cycle models, or Markov chains;
- Optimization criteria (e.g., objective functions, heuristics, or decision trees) that prioritize activities and determine which of two candidate solutions or alternatives is preferable; and
- A set of constraints or boundary conditions that define feasible solutions, including budgetary constraints, sequencing and precedence of activities, and the appropriate pairing of treatments to inventory item structures and conditions.

The planning and scheduling process provides the following three general categories of outputs:

- Activity schedule. This is the calendar of activities or treatments to be performed when, by whom, and at what expected cost.
- Constraint summary. This is a listing of each occurrence of a constraint that either imposes an active limit on the schedule or has been violated in the case in which two or more constraints are in conflict.
- Condition summary. This provides a summary of expected inventory condition by category (e.g., functional class, region, and structure and year.

These general categories of inputs, outputs, and decision models can and should be represented in an application framework as tailorable components to provide the consistent, maintainable, comprehensible, and tailorable systems necessary for cost-effective decision support. Experience has shown that the issues that affect the viability of application frameworks for management systems fall into three categories: suitability, certainty, and quality. Each of these is individually addressed below.

Suitability

Suitability refers to issues concerning both the models and their inputs that involve the notion of granularity and interdependence. Granularity, also referred to as scale or resolution, is primarily concerned with the required frequency, accuracy, precision, and volume of input data. The data required to drive the models must be feasibly collectable; otherwise, the models will lose their utility. This is the "garbage in/garbage out" principle. More than any other single cause, modeling efforts fail because of the lack of adequate data.

Model interdependence becomes a significant issue when models share triggers, or thresholds, or jointly affect the condition of the inventory. For example, a pavement section should not receive a seal coat and an overlay in the same time period. Likewise a model that addresses faulting in a jointed pavement should also affect the pavement's serviceability index in a consistent fashion. These example problems may appear obvious, but they have been observed in existing, fielded PMSs. These types of interdependency problems are often hard to detect when models are run across large data bases and produce only summary outputs.

Interdependency issues have been successfully handled in practice through the use of matrix interpolation and event-driven modeling. For example, pavement performance models that are based on traffic loading, not time, can be synchronized with time-based models by producing a matrix of outputs at regular time intervals for assumed levels of traffic. The matrix is then used instead of the original model in the subsequent time-based simulation. Event-driven systems can be used to allow asynchronous models to run concurrently by maintaining a single calendar of events (or triggers) that is used to coordinate the models. It is also frequently necessary to prioritize constraints across models, since situations often arise in which competing constraints conflict in a given decision and one must win out. It is useful to provide common units of cost and benefit across models to facilitate the arbitration of conflicting constraints. In any case constraints should be defined as explicitly as possible, even when they are inherently embedded in a decision algorithm.

Certainty

Issues of certainty in models are introduced primarily in the form of stochastic processes and accuracy/precision trade-offs. The stochastic, or probabilistic, nature of physical and economic systems is often ignored in practice with potentially disastrous results. When mean time between failure (MTBF) metrics and interest rates are treated as absolutes, significant risk factors are completely overlooked. Accuracy/precision trade-offs become problems when modelers assume that data provided with several digits of precision are actually accurate to the last decimal place. Both types of certainty issues have been successfully handled in practice via Monte Carlo simulation whereby what-if scenarios are run in batches, spanning likely input ranges.

Quality

Issues of quality are usually characterized by a number of trade-offs, including efficiency versus effectiveness, risk versus return, and constraints versus penalties. Efficiency is usually defined in terms of resource utilization, whereas effectiveness is measured in terms of goal attainment. Management systems for which the effectiveness goals have not been clearly defined frequently overemphasize the locally efficient use of a particular resource at the expense of a more globally effective solution. As mentioned previously risk reduction (i.e., uncertainty management) is frequently ignored as an overall system goal. As a result a solution that provides a high expected return may be chosen, even though risks inherent in the solution may diminish its feasibility, whereas a more robust solution with a slightly lower expected value may be preferable. Reductions in data collection costs and system response time are examples of other goals that are often slighted in the model design.

The notion of system quality must also include user considerations, such as ease of use and comprehensibility. In an effort to create academically or theoretically sophisticated models, model developers have shown a tendency to ignore these user considerations. User support includes the use of GUIs, but it goes beyond that. For example, a highly optimized model that produces drastic changes in the output for a relatively minor change to the input data is inadequate as a decision support tool, despite its optimization, because it cannot be easily comprehended.

Similarly models that rigidly enforce constraints, although they are theoretically sound, can be difficult to use in real environments. For example, because of political or other external factors, decision makers are often faced with situations in which a particular maintenance activity or rehabilitation project must be dropped into the final plan or schedule, even though the decision model has not chosen the activity for the particular time slot. If the system does not allow these unexpected drop-ins because they are theoretically infeasible, the system will be of little direct use to the decision maker. The system must model the real environment, not the ideal one, which means that budgets may overrun and schedules may be rearranged. In practice rigid constraints can be replaced by "soft" constraints that include a cost, or penalty, for violating the constraint. In this manner exceptions to constraints can exist, but at a cost. In the simplest case this cost may just be a warning issued to the user that an infeasible situation has occurred. As previously stated a means of prioritizing constraints and common units of cost and benefit are useful in these situations.

General Useful Features

Identifying the problems and designing the solutions presented in this section are examples of an "easier said than done" situation. To aid in problem identification and solution design, the following list describes the features that have been found to be useful in information systems in general:

- An ad hoc querying capability to create specialized reports;
- What-if scenario support (i.e., a baseline plan and variations on the baseline);
- An ability to create a representative subset of the inventory data on which scenarios may be tested;
- Assertions and exception handling to identify anomalies and debug constraints and algorithms;
- Support for drop-in treatments, that is, user-specified activities that override the model's recommendations;
- Graphical reports to aid in visualizing results; and
- Graceful fault handling when one of a pair of conflicting constraints must be violated.

CONCLUSIONS

To readers who have survived the various software fads and "snake oil" salesmen over the past decades, application frameworks may sound like the next in a long line of would-be panaceas. In truth the benefits of frameworks have been proven in the DOD logistics management domain and are based on sound software engineering principles that have held up in practice. No software development approach will ever remove the need for thoughtful planning and design; in fact careful modeling is the foundation of application framework development. Frameworks can, however, make the modeling and decision-making processes more efficient and effective by removing extraneous programming overhead. Application frameworks appropriately place the emphasis of software system development on the engineering and decision modeling rather than on coding, thereby empowering engineers and decision makers by relieving the constraints imposed by traditional software development practices. The benefits of increased portability, tailorability, and maintainability are more readily apparent, but they should not overshadow the less tangible benefits that frameworks have for supporting intuitive domain modeling.

Although any popularity that application frameworks might gain in the transportation industry will no doubt result in a certain amount of marketing hype and snake oil salesmanship, the foundations for deriving real, sustainable benefits are already in place. Numerous commercial vendors already exist for the related object-oriented technology (e.g., C++ compiler vendors), and other government and commercial arenas have already embraced the concepts. The approach is based on academically sound principles and is independent of any commercial product, platform, or programming environment. Thus, frameworks can prove to be a viable and well-received technology for transportation information management system development in the years to come.

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Publication of this paper sponsored by Committee on Computer Technology.

Residential Density and Travel Patterns: Review of the Literature

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With the increasing concern about the environmental side effects of the use of the automobile, a few researchers, real estate developers, and increasingly policy makers in many states argue for the need for infill housing, mixed land uses, and increased density, especially around transit stations. In making these recommendations they make several assumptions about the relationship between high-density residential development and transportation choices and the resultant environmental impacts. They assume that people in high-density developments will make fewer and shorter trips and walk or use transit more frequently than residents of other areas. Furthermore they often assume that these high-density residential areas have a mix of land uses and a variety of destinations for residents. Finally, they assume that people will be willing to move to high-density areas and, when they do, will change their travel patterns. Several sets of the literature are explored to gain a better understanding of the interactions between the household in high-density residential areas, the land-use characteristics of the area, and the transportation choices of households.

In recent years in metropolitan areas throughout the United States there has been increasing concern about the environmental side effects of the use of the automobile. A large number of metropolitan regions have not been able to meet the national air quality standards and as a result are increasingly recognizing the need to decrease emissions from transportation sources. Increasingly, environmentalists, a few researchers, real estate developers, and policy makers in several states and around the world argue for infill housing, mixed land uses, and increased density, especially around existing transit stations (*1–8*). These forms of development are often called "neotraditional development" (NTD) or "the new urbanism," which go under a variety of names: urban villages, pedestrian pockets, compact cities, and compact urban development. These NTDs include a mixed-use core, similar to a traditional town center, with retail and employment sites and residences surrounding the core (*9*).

Environmentalists and researchers who advocate transit-oriented and high-density development have made assumptions about the relationship between high-density residential development and transportation choices and the resultant environmental impacts. They assume that people in high-density developments will make fewer and shorter automobile trips and will walk or use transit more frequently than residents of areas with lower densities. High-density residential areas are often assumed to have a mix of land uses that provide a variety of destinations for residents. Underlying these assertions is an untested assumption that people will be willing to move into high-density areas and, when they do, will change their travel patterns. If all of these assumptions are true the result should be reduced automobile emissions and lower energy usage. If, on the other hand, people in high-density areas take as many trips of the same distance as people with similar socioeconomic and demographic characteristics who live in lower-density residential areas, the emissions and energy usage will be higher because the travel takes place in greater congestion and, therefore, at lower speeds.

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Although this argument can be seen as a part of the long-standing debate about the appropriate level of density and distribution of urban settlements (see, for example, references *10* and *11*), some previous empirical research supports some of these claims. These studies, using grossly aggregate data, suggest that high-density residential development results in less dependence on the automobile and higher rates of commuting to work by walking or by using public transportation when it is available (*12–15*). However, those studies fail to separate out several factors associated with high-density residential areas that also lead to differences in usage of the automobile, including income, household size, life-cycle characteristics of household members, and other land-use characteristics of the residential area. Thus, density could be seen as a proxy for these other unmeasured variables.

This paper presents reviews of several sets of the literature on the interactions between the households in high-density residential areas, the land-use characteristics, and the transportation choices. First, it presents studies of the relationship between residential density and travel patterns or energy use. These studies will be categorized into (a) empirical studies and (b) policy formulation studies. Next, the relationship between the density and spatial distribution of activities (especially with respect to residential uses) and individual and household decision making about residential location is reviewed. Finally, the relationship between the socioeconomic and demographic characteristics of households and their travel patterns is considered.

RELATIONSHIPS BETWEEN TRAVEL PATTERNS AND DENSITY OF RESIDENTIAL AREAS

Empirical Studies

Previous empirical studies analyzing the relationship between travel and residential density have generally concluded that residents of high-density areas use public transportation or walk more frequently than residents of lower-density areas and travel shorter distances overall (*12–14,16–18*). Goodwin (*16*) also found that the total number of stages (i.e., trips) by all modes was about the same, on average, across various densities. Those studies also found that the rate of automobile ownership was higher in low-density areas.

Pushkarev and Zupan (*2*) used data on the New York region and aggregate data from other regions in the United States to conclude that as density increased so did the number of transit trips, especially among the middle-income households. Even though Pushkarev and Zupan suggest that they considered 105 of the largest urbanized areas, they did not use all of these metropolitan areas for each of their statistical analyses and exhibits. This leads one to question whether the relationship holds for all metropolitan areas or just the ones they included in the exhibits. They also assumed that all work trips are to the central business district (CBD). In considering only the larger nonresidential areas, they ignored nonresidential destinations that are located in residential areas. Through their use of only aggregate regional data, they considered neither the dynamics within neighborhoods nor the accessibility to transit and highways in specific residential neighborhoods. They considered the relationships among income, density, and trips per person and concluded that, on average, members of lower-income households travel less than members of other households at all densities. However, they never separated the travel patterns based on income from the travel patterns based on the level of density. Finally, they showed that households with higher incomes are more likely to own an automobile and, once they own it, are likely to use it irrespective of the density of the neighborhood. However, they did not compare the use of the automobile among members of high-income households in high-density areas with the usage of the automobile among members of other higher-income households in less dense areas.

Newman and Kenworthy (*13,14*) compared metropolitan regions in the United Kingdom, Canada, Europe, and Asia. They found that automobile dependence is lower in higher-density cities than in lower-density cities. Although they considered a wide range of transport, land-use, economic, and technological factors in determining gasoline usage, they have been criticized for not considering all variables simultaneously and, in particular, for underestimating the role of income and gasoline prices (*19*) and for using data of questionable reliability and consistency on gasoline usage, trip lengths, and vehicle occupancy (*20*). They have similarly been criticized for not considering the polycentric nature of many regions and the impact of metropolitan structure on travel patterns (*21*). They used a narrow definition of urban form that considered the density of both employment and housing but omitted the type of land uses and their spatial distribution within the region. Although Newman and Kenworthy (*22*) dispute these criticisms, their research has not accurately accounted for these factors. For example, they assume that the income elasticity of the United States can be used for all countries. In addition, they reached conclusions about the behavior of individuals living in high-density areas based on aggregate regional-level data.

P. Goodwin (*16*) used the 1972 British National Travel Survey to identify relationships between density and each of several other variables: (a) number of trips, (b) distance per trip, (c) distance per person, (d) travel speed, (e) time spent traveling, and (f) time per trip. He concluded that households in high-density areas took the same number of trips overall but took fewer trips by automobile and traveled shorter distances at lower speeds. Although that analysis identified interesting trends (e.g., that all households spent the same amount of time traveling), it did not separate out other factors that may lead to these relationships. The analysis could have been improved through the use of multivariate statistics rather than simple correlations and by explicitly considering travel patterns within specific residential neighborhoods.

In contrast to Newman and Kenworthy, Pushkarev and Zupan, and Goodwin, Holtzclaw (*17,18*) used neighborhood-level data to reach similar conclusions about the relationship between density and travel patterns; Holtzclaw's conclusions, however, can also be challenged on methodological grounds. Holtzclaw chose a series of "neighborhoods" in the San Francisco Bay Area and, in a second study, in other cities in California and compared the number of miles traveled per year. He concluded that the level of travel is inversely related to the density of the neighborhood. His major source of data, the number of automobile miles traveled per household per year, is based on odometer readings of cars tested biennially for emissions. However, that study did not measure the effect of the level of income of residents in these neighborhoods, the mix of land uses in the neighborhood, or the number, frequency, and types of trips taken by other forms of transportation.

Overall these studies suggest that residents of high-density areas travel shorter distances and use public transit or walk more frequently than residents of lower-density areas. Although the researchers confirm this relationship in the aggregate, they do not analyze the relationships at the disaggregate, neighborhood level, nor do they systematically consider the spatial relationships between various land uses. In using aggregate data they have made the questionable assumption that the relationships among variables are constant across space and time. Finally, they do not separate out the relationship between the travel patterns of residents based on their socioeconomic and demographic characteristics and their travel patterns based on the density of the neighborhood.

In a related empirical study, Susan Handy (*23,24*) concluded that residents of NTDs were significantly more likely to make walking trips in their neighborhoods. However, Handy could not determine if these trips to neighborhood commercial areas replaced or were in addition to driving trips. Although that study did not control for the level of density, it nonetheless suggests that a mix of land uses, which occurs within many high-density residential areas, may affect the pattern of travel.

Simulations for Policy Purposes

These empirical studies have been used to justify proposals for higher-density areas within a regionally integrated land-use and transportation system. Although the debate has taken slightly different forms in Europe and the United States, the results are largely the same. In the United States these empirical studies and the work of a few architects and planners (Duany and Plater-Zyberk, Calthorpe and Solomon) have been used as a part of larger proposals for regional development in at least three regions (Sacramento, Seattle, and Portland, Oreg.) and in other local development projects such as Seaside, Fla. (*2,25–27*).

In Portland a national demonstration project, Making the Land Use, Transportation, Air Quality Connection (LUTRAQ), is developing methodologies for creating and evaluating alternative land-use patterns and design standards that will reduce automobile dependence; increase mobility for all segments of the population; minimize negative environmental impacts, especially air quality; reduce energy consumption; and foster a strong sense of community. Using a proposed bypass freeway around the Portland metropolitan region as a case study, LUTRAQ identified alternative land-use patterns, including three types of transit-oriented development (TOD), that reduce travel demand and increase the use of alternative travel modes and modeled the travel behavior associated with these land-use patterns. The LUTRAQ models project an average rate of automobile ownership of 1.62 automobiles per household in the TOD areas compared with 1.90 automobiles per household for the no-action and bypass options (*25*, p.81) and a mode split of 12.1 percent walking, 79.3 percent automobile travel, and 8.6 percent transit travel for all trips from TODs compared with values of 3.8, 89.1, and 7.0 percent, respectively, for the no-action alternative (*25*, p.83) in 2010.

The LUTRAQ case study strongly suggests that high-density mixed-use residential areas have the potential to reduce the level of automobile dependence. Although the study uses state-of-the-art modeling techniques, the achievement of a reduction in automobile travel will still depend on public acceptance of infill housing as a part of TODs. Later evaluation will be required to determine if the assumptions of this model are too optimistic. For example, the use of the rate of walking from surveys in the San Francisco Bay Area for the rate of walking in Portland is questionable given the differences in scales and densities of the two regions. Assumptions about increases in the level of transit ridership are speculative given the long-term decline in transit usage in U.S. cities.

Similarly, the regional transportation plan in Seattle includes a transportation systems management (TSM) alternative with mixed-use and high-density development around a new transitway and expanded rail system. Although the alternatives are not as well developed as those in LUTRAQ, the transit share for work trips to selected centers is projected to increase from 11.3 percent under the no-build alternative (the 1990 rate was 11.8 percent) to 13.0 percent under the TSM alternative, 13.1 percent under the transitway/TSM alternative, and 16.4 percent under the rail/TSM alternative (*26*, p.3–101). These conclusions again show optimism about the willingness of people to use transit and did not consider travel for nonwork purposes.

In contrast, in Europe the debate over the compact city has resulted from concerns about energy efficiency, land-use patterns, and more recently, CO_2 emissions from transportation sources and sustainability. Several studies (*5,6,28*) and official documents of the European Commission (*4*) and the Dutch (*29*) and British (*4,30*) governments have advocated compact development as a more environmentally sound form of development. More recent studies have questioned this conclusion. Breheny (*31*) compared Inner London, Outer London, metropolitan districts, new towns, and rural areas and found that if all of the new development had been located in the compact urban areas instead of in lower-density areas energy consumption would have been reduced by only 3 percent. On the basis of this result he questions whether the policy of containment in compact cities is a sound policy. In spite of this conclusion, his data also suggest that the distance that each person travels per week is lower in inner London and other metropolitan areas than in smaller cities, outer London, and rural areas (*31*). However, his study only considers the pattern of travel and energy use in the aggregate and generalizes to specific locations.

SPATIAL DISTRIBUTION OF ACTIVITIES (LAND USES) WITHIN REGIONS

The literature on the spatial distribution of land uses within regions comprises various similar, albeit distinct, views of the relationship. These models can be divided into the following categories: (a) location theory and (b) central-place theories.

Location Theory

Location theory has generally been concerned about the how various land uses compete for space within a region. Largely on the basis of early work in market towns surrounded by agricultural uses (e.g., von Thunen), these models consider the relationship between land rents and transport costs. According to the basic theory various land uses (e.g., office, manufacturing, and residential) will each have separate bid-rent functions based on the trade-off between the cost of land and the cost of travel. The density and the bid-rent will be highest in the center and decrease farther from the center. For example, headquarters office uses will be located at the center because of the need for face-to-face contact with others, and the owners and managers of companies are willing to outbid those wanting the location for other uses for a location that makes such contact easier. Residential uses have the least to gain from proximity to the center and will therefore be less willing to bid higher rent for central locations. Various land uses, according to the basic location theory, will generally be segregated, with the office uses closest to the CBD, manufacturing will be in between, and residences will be the farthest from the center.

This initial theory was elaborated in models of residential location. This basic model made the following assumptions: (a) the total amount of employment is fixed and located at the center of the city, (b) each household has one worker, (c) residential location is based on the work location, (d) all housing has the same characteristics, and (e) unit transportation costs are constant and uniform in all directions (*32*). Under these assumptions, reductions in transportation costs lead to decentralization as households consume more housing at greater distances from the center.

Various studies of residential location theory reached different conclusions about the relationship between household income and residential location. Theoretical work by Wingo (*33*) and Alonso (*32*) suggests that low-income households were more likely to live in high-density neighborhoods because they will trade off the commute trip and accessibility to transit and other activities for less housing. Higher-income households, they assumed, would be the highest bidders for suburban land because their preferences for housing, lot size, and suburban public services increase faster than the household's dislike of commuting. On the other hand, Muth (*34*), on the basis of empirical research in Chicago, concluded that there is a "negligible partial relationship between income and distance" that is mediated by the age of buildings. In other words higher-income households were more likely to live in newer housing located farther from the CBD. Wheaton (*35*) used data from the San Francisco Bay Area to show that when distaste for commuting was considered, "income in fact may not be a strong determinant of long-run location patterns"; rather, each income stratum will have variability in preference for location of housing. Anas (*36*) clarified this relationship by suggesting the conditions under which the higher-income households would locate farther away from the center: "the bid rent function of higher income households may be less steep than that of the poor, but only if the increase in the preference for land consumption (lot size) by income is sufficiently stronger than the increase in the disutility for commuting time by income" (*36*, p.32). Anas found that the average income of households was higher in the first 2 mi from the CBD of Chicago than it was in any of the 2-mi ranges between 2 and 10 mi from the CBD and that income increased with each distance category (after the first 2 mi) before reaching its highest level at 22–24 mi and gradually declined with greater distances (*36*, p.131).

The differing conclusions of these studies can be explained largely by the assumptions about the preferences for housing and commuting of households with higher incomes. Alonso, Wingo, and Muth assume that all households with higher incomes have preference for more and newer housing (i.e., they assume that housing is a superior good). Wheaton and Anas make the more reasonable assumption that households with higher incomes have a variety of preferences (or tastes) in housing and the neighborhoods in which they choose to live. Thus, households with higher incomes may choose to live in a high-, medium-, or low-density neighborhood.

Central-Place Theory

Central-place theory can be seen as an extension of the basic location theory to market-sensitive employment activities. Location theory would suggest that employment location is a function of land rents and commuting costs of employees, and a reduction in transportation costs will result in the concentration of employment at nodes and a separation of land uses. In contrast, central-place theory considers activities that require access to consumers. Central-place theory as developed by Christaller (*37*) and Lösch (*38*) was directed at the relationship between the distribution and consumption of goods and the number of goods sold and the population served by a central place. Lösch connected the transportation system to the central places and extended the central-place theory to a more general description of relationships between central places and complementary regions.

The central-place theory includes some basic features: (a) the basic function of a city is to be a central place providing goods and services for a surrounding area; the central place locates to minimize the aggregate travel of its tributaries and is central to the maximum profit it can command; (b) the greater the centrality of a place, the higher its order; (c) higher-order places offer more goods, have more establishments and business types (i.e., offer more shopping opportunities), serve a wider tributary area, serve a larger population, and are more widely spaced than low-order places; (d) low-order places provide only low-order goods to low-order tributary areas; these low-order goods are generally necessities requiring frequent purchasing with little consumer travel; (e) central places fall into a hierarchy comprising discrete groups of centers; higher-order centers perform all of the functions of lower-order centers plus a group of central functions; and (f) the hierarchy of centers can be ordered on the basis of three characteristics: market area, transportation, and sociopolitical or administrative separation of functions (*37,38*). Initially, this research was used to develop hierarchies of cities within regions and countries.

In later work Berry and Garrison (*39*) suggest that this theory extends beyond Christaller's and Lösch's explanation of hierarchy of central places to hierarchies of retail and service businesses within regions. Berry and Pred (*40*) suggest that the central-place studies of rural places could be extended to a hierarchy of business centers in urban areas. In urban areas there is a CBD, with subsidiary centers located outside of the center. The number and order of those centers will depend on the order of the city as a central place and the order of its CBD. In a metropolitan area the array of types of centers includes street-corner nucleations, neighborhood centers, and regional centers. Central-place theory attempts to explain the location, size, functional characteristics, and spacing and clustering of centers (*41*, p.3).

Central-place theory thus provides a framework for considering the relationship between residential uses and nonresidential uses. Although central-place theory does not explicitly deal with the question of density, it addresses another assumption related to travel in high-density areas—the proximity and mix of nonresidential uses relative to residential uses.

RESIDENTIAL LOCATION THEORIES

Two types of research have attempted to identify how people choose where they will live. The hedonic pricing models focus on factors that give housing value. Residential choice models identify the factors that households consider in deciding where they would like to live. Although this review is about the transportation choices of households that choose to live in high-density neighborhoods and not how households make this location choice, this literature suggests the constraints and opportunities that households face in making their location decision and the multiplicity of factors that are balanced with these decisions.

Hedonic Pricing Models

Hedonic pricing models of residential location provide an indication of the value that households attribute to various characteristics when they look for housing. Economists use hedonic pricing models to understand the relative importance of various attributes to the market price of a commodity (in this case, housing). Early studies of housing value attempted to calculate the costs associated with air pollution. Ridker and Hennings (*42*), in the earliest study of the cost of air pollution, found the following categories of characteristics significant in determining median property values: property or site and housing characteristics, location (i.e., accessibility to shopping, industrial areas, highways, the CBD), neighborhood characteristics (quality of schools, crime rates), and household income. In other studies of the cost associated with air pollution, these same characteristics and a few others were found to be significant (*43*): public services and costs (*44*) and other land uses in the neighborhood (*45–47*). Kain and Quigley (*48*) were the among the first researchers to focus on individual dwellings and the measurement of the quality of residential services. They found a negative relationship with housing value and other nonresidential uses and a negative value associated with higher density.

Much of the focus of the hedonic pricing work has been on the identification and weighting through multiple regression of key attributes of housing and neighborhoods. This research has provided a list of variables associated with neighborhoods and their relative importance with respect to the price of housing.

Williams (*49*) identifies five general assumptions of hedonic models:

1. A single urban housing market,
2. Complete availability of relevant data on alternative attribute bundles,
3. Freedom of locational choice for consumers,
4. Market equilibrium, and
5. Consumers with identical utility functions except for the observable attributes of housing (*49*, p.312).

Although a few of these assumptions are questionable, the last is perhaps the farthest removed from the reality of the marketplace (*50*). This is also key to this research because it can be read to assume that irrespective of household income households will have the same preference for high-density neighborhoods. However, when this last assumption is considered with the second assumption, one can conclude that similar households with similar incomes (i.e., identical utility functions) will choose housing with different attributes. Thus, the characteristic of housing choices, including the choice of housing in high-density areas, by households with similar incomes can be seen as probabilistic.

Residential Choice Models

Residential choice models focus on the trade-offs that households face when deciding where they will live. Lerman (*51,52*) developed a model that connected mobility choices, which are choices that are made in the long term such as employment location, residential location, housing type, automobile ownership, and mode to work, with travel choices (in the short term) for non-work trips. He assumed that the mobility choice, which includes all of the long-term choices except employment location, are made on the basis of the employment location.

Although this model presents a reasonable framework from which to consider how the residential choice is made, it has some limitations. Most notably, the model, like the Lowry model, assumes that residential location is largely based on location of employment. Although this assumption can be justified in one-worker households, it does not address how two-worker households decide where to live. In addition, the model is not estimated for different socioeconomic groups (*51*, p.326). Finally, this model is based on a small number of prototypical cases and not on the decisions of households that had moved.

Weisbrod et al. (*53*) explicitly considered the trade-offs between transportation and other factors in residential location decisions. Using a sample of 6,000 household from a 1970 survey in the Minneapolis-St. Paul metropolitan area, he did a logit analysis of discrete choices to estimate the contribution of various locational attributes and household characteristics in determining each household's decision whether or not to move within an 18-month period. Each household was assumed to select residential mobility choice and (for movers) the alternative location/housing bundle that maximizes its utility. The utility was expressed as a function of attributes of the alternative (e.g., distance to work, prices, transportation services, neighborhood quality, and housing type) and the attributes of the household itself (e.g., age, income, and household size).

The results showed that a 5 percent reduction in automobile commute time was equivalent to a 1.5 percent decrease in monthly rent, a 3.8 percent decrease in home value, and a 28 percent reduction in crime rate. A similar reduction in bus commute time was worth a smaller amount. Household composition considerations overwhelmed all other trade-offs among housing cost, taxes, transportation access, and crime level. No reduction in automobile travel time or bus travel time could compete with the preference of households with children for single-family detached housing. Finally, age and household composition factors were very strong determinants of the propensity to move. Regardless of travel time to work, crime rates, school quality, or housing costs, older persons and families with several children had a lower probability of moving than younger or smaller households.

Although this study reached interesting conclusions about the importance of access to the workplace and differences in preferences of households with different socioeconomic characteristics, it did not address the trade-offs made in two-worker households. Instead, it assumes that one is dominant over the other. It also assumed that those who moved had the same characteristics and preferences as those who did not move and that those preferences were constant through time. Finally, the study did not address the importance of non-work locations (e.g., schools and personal services) in the decision about where to move.

RELATIONSHIPS BETWEEN SOCIOECONOMIC CHARACTERISTICS AND TRAVEL PATTERNS

Although the relationship between socioeconomic characteristics and travel patterns is embedded in the traditional four-step travel demand models, several targeted studies of the travel patterns of households based on socioeconomic characteristics have been completed.

Much of the research on travel patterns based on socioeconomic and demographic characteristics of households has focused on improving the explanatory power of traditional transportation models by challenging the assumptions used in various stages of the models. This research has focused on the relationship between travel patterns and a variety of factors: income, household size, age (i.e., stage in life cycle), sex roles of household members, and presence or absence of children (*54–59*). Two approaches have been taken to life-cycle stages: (a) cross-sectional, which addresses the behavior of groups with different socioeconomic and demographic characteristics at a point in time, and (b) time series, which uses panel surveys to follow the travel patterns of households as they move through stages in their life cycle (*56*). Cross-sectional studies are of greater relevance in this review.

These cross-sectional studies attempted to isolate the factors that can be used to define the various household types. Salomon (*57*) used a joint choice model to analyze the relationship of life cycle to mobility and travel choices. He concluded that the lifestyle shows a decreasing effect in order with the following decisions: residential location, activity pattern (trip chaining), destination for recreation trips, automobile type, automobile ownership, and mode to work. Lifestyles were categorized into clusters based on age of head of household; age of children, if any; household size; number of adults in household; proportion of household income earned by male and female heads; education level; annual household income; time spent at home, leisure, services, and work for male and female heads of household; occupation (white collar or not white collar); and employment status (part-time or full-time) of female and male heads of household. Salomon used three different combinations of socioeconomic and demographic variables to cluster households and reached the following conclusions about their utilities: (a) income is a poor indicator for the cross-sectional variation in taste; (b) a life-cycle-occupation scheme is very powerful as an indicator of lifestyle; and (c) two additional variables, working status of female head of household and household type, should be used in the segmentation. One of the major limitations of this research is the small sample size used in the analysis.

In related research Salomon and Ben-Akiva (*59*) used cluster analysis to separate households into five clusters to determine if they exhibited different travel patterns. Cluster 1 included households with older (35–54-year old) white-collar males with a wife that was not gainfully employed outside of the home. The second cluster is more heterogeneous, younger, and of higher socioeconomic classes with both husband and wife employed outside of the home. Cluster 3 was defined as the young, family-oriented, child-bearing households. The fourth cluster includes households with lower incomes and lower levels of educational attainment. Cluster 5 includes most of the elderly households in the sample and is distinct from other clusters because of its low income and educational level, small household size, and low rate of participation in the labor force. These clusters were then compared by using a model of constrained level of service, using in-vehicle travel time, out-of-vehicle travel time, and out-of-pocket travel costs, and the differences between groups were found to be statistically significant (*59*).

Salomon and Ben-Akiva's research identifies the difficulty of how to cluster households and the appropriate number of clusters to be used. Hanson and Hanson (*55*) and Clarke and Dix (*56*) define six and eight categories, respectively, that related to the "typical" family cycle. Hanson and Hanson set up these categories: single adults with no children, two adults with no children, at least one adult with child less than 7 years of age, at least one adult with at least one child over 7 years of age, and no children under 7 years of age, "empty nesters," and retired persons. Clarke and Dix (*56*) used two additional categories: families with preschool and school-age children and families with older school-age children. Although Hanson and Hanson (*55*) concluded that "socioeconomic status and role-related variables contribute significantly to an explanation, of the dimensions of individuals' complex travel-activity patterns," they did not differentiate between single-parent and two-parent households and two-worker and one-worker households in their model. Clarke and Dix (*56*) were less ambitious in the results that they presented; they simply showed that the income coefficient differed between life-cycle groups when the number of cars is related to the gross household income.

Zimmerman (*54*) defined five major lifestyles (each with subcategories based on the age of the head of household for each): the typical or nuclear-family household, the single-parent household, the childless-couple household, the single person living alone, and the household of unrelated individuals. Zimmerman did a simple correlation between the trip frequency and the life cycle and concluded that the number of trips varies on the basis of the household structure and the age of the persons who comprise the household unit. Although Zimmerman (*54*) makes a contribution by identifying the differences in number of trips, the number of categories is so large that in a more complex model the results are likely to be trivial. In addition, Zimmerman acknowledged that the life cycle should include considerations of household size, family income, and vehicle ownership.

Although the researchers on the relationship between travel patterns and socioeconomic and demographic characteristics suggest that different types of households have different travel patterns, they do not identify the spatial aspects of the travel. They do not consider the density or characteristics of neighborhoods that households live in when considering the travel patterns.

AREAS FOR FURTHER RESEARCH

The advocates of high-density transit-oriented development make several assumptions about the relationship between density and travel patterns when they advance their proposals. There are many reasons why these assumptions could be successfully implemented in practice. Decreased usage of the automobile is possible in higher-density residential areas because of several related factors. First, high density puts destinations close together, making it possible for residents to walk to activities in an acceptable amount of time. If the residential area has a mix of local serving uses, people may also be more likely to walk to them. Second, by virtue of the fact that more people are in the area, people generally perceive it to be safer to walk in the area. The larger number of people makes it easier to serve the area with public transit because there are simply more people to use the transit [i.e., higher-density areas provide the potential for a higher trip density, as Pushkarev and Zupan (*12*) suggest]. Finally, certain types of households may be more likely to live in high-density residential areas; these households may also exhibit travel patterns different from those of other types of households. Higher-income singles and couples and elderly couples may choose to live in high-density areas because of the lifestyle that it provides them. Low-income households may double up in one housing unit because separate units may simply not be affordable.

What is missing from this debate is a consideration of some of the research results presented in this literature review. Although research using aggregate data suggests that people who live in high-density developments make fewer and shorter trips and walk or use transit more frequently than residents of areas with lower densities, these studies have not separated out other factors, such as income, household size, life-cycle characteristics or household members, and other land-use characteristics for which density may be a proxy. Further research is needed to sort out the importance of the pattern of travel based on socioeconomic characteristics, mix of land uses, density, and other location factors. Such research would enable policy makers to understand the situations in which households might be willing to live in high-density, more urban environments and the extent to which changes in land-use patterns will ultimately reduce the level of overall travel, energy consumption, congestion, and air pollution.

ACKNOWLEDGMENT

This research was completed as a part of doctoral dissertation research in the Department of City and Regional Planning at the University of California at Berkeley. Support of this research by the U.S. Department of Transportation, the California State Department of Transportation, the University of California Transportation Center, the University of California Universitywide Energy Research Group, and the Energy Foundation is gratefully acknowledged.

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Publication of this paper sponsored by Committee on Transportation and Land Development.

Impacts of Mixed Use and Density on Utilization of Three Modes of Travel: Single-Occupant Vehicle, Transit, and Walking

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Findings from an empirical analysis to test the impacts of land-use mix, population density, and employment density on the use of the single-occupant vehicle (SOV), transit, and walking for both work trips and shopping trips are presented. The hypothetical relationships tested focused on whether there is a relationship between urban form and modal choice, whether this relationship exists when controlling for non-urban form factors, whether this relationship is linear or nonlinear, and whether a stronger relationship exists between modal choice and urban form when they are measured at both trip ends as opposed to either the origin or the destination. A review of the literature and experiences suggested that a fair amount of information is known about the impacts of density on mode choice. However, considerable debate exists over whether density itself is actually the causal stimulus or a surrogate for other factors. To address this issue a data base was developed with a comprehensive set of variables for which density may be a proxy, for example, demographics and level of service. This analysis employed a correlational research design in which mode choice was compared among census tracts with differing levels of density and mix. Findings from this research indicate that density and mix are both related to mode choice, even when controlling for non-urban form factors for both work trips and shopping trips. Furthermore, the relationship between population and employment density and mode choice for SOV, transit, and walking is nonlinear for both work and shopping trips. Transit usage and walking increase as density and land-use mix increase, whereas SOV usage declines. The findings from this research suggest that measuring urban form at both trip ends provides a greater ability to predict travel choices than looking at trip ends separately. The findings also suggest that increasing the level of land-use mix at the trip origins and destinations is also related to a reduction in SOV travel and an increase in transit and walking.

This project is part of a research agenda developed by the University of Washington for the Washington State Department of Transportation (WSDOT). The goal of the agenda is to discover ways to plan and implement urban forms that promote increased accessibility. At the crux of this agenda are the intentions to decrease the need to travel, reduce dependence on the single-occupant vehicle (SOV), and enhance the competitiveness of other travel modes. More specifically, this paper documents empirical relationships between urban form (land-use mix and density) and trip making by individuals who use SOVs, transit, and walking as modes of travel. This analysis focuses on two trip purposes: working and shopping.

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This research is important because of recent policy initiatives at the federal, state, and local levels that state that it is no longer feasible to maintain access to opportunities in urban areas by increasing the mobilities of SOVs. Among the commonly cited reasons are economics, new environmental legislation (e.g., the Clean Air Act Amendments of 1990), public opposition, changing demographics, and political pressure to reduce fuel consumption. Several urban-form strategies have been recommended to reduce dependence on driving alone. These strategies include increasing residential and employment densities and intermixing a variety of land uses (residential, employment, and commercial). Although these strategies would seem to enhance the viabilities of alternatives to SOVs, relatively little work has been conducted to test these relationships empirically.

STRUCTURE OF ANALYSIS

The findings presented in this paper are based on a three-phase research approach. In Phase I information was gathered from other sources resulting in the identification of hypothetical relationships between urban form and travel behavior on the basis of theory, past research findings, and current policies. In Phase II the project data base was developed to test these hypothetical relationships. Statistical techniques were used to conduct hypothesis testing (e.g., multiple regression or correlation) in Phase III.

POLICY PERSPECTIVE

Over the past 3 years several policies that are intended to reduce the rate of growth in travel demand through the manipulation of urban-form and a variety of other factors have been enacted at the federal, state, and local levels. These policies are based on a variety of hypotheses that characterize the nature of the relationship between travel demand and both urban-form and non-urban-form factors. Although the intent of this research was to provide insight regarding urban form, it also tested and evaluated the relative impacts of non-urban-form factors. Selected policies that target both urban-form and non-urban-form factors and that affect travel demand include

- The Intermodal Surface Transportation Efficiency Act of 1991, which provides new funding opportunities for non-SOV improvements;

- The Clean Air Act Amendments of 1990, which designate vehicle miles traveled as a form of mitigation to meet air quality attainment;
- Washington State Growth Management Act, which encourages densification and concurrency between development and transportation infrastructure;
- Washington State Commute Trip Reduction Law, which requires major employers to implement transportation demand management (TDM); it also requires the review of parking requirements in local zoning ordinances;
- Washington State Transportation Policy Plan, which encourages mobility options for the public, including those individuals without access to automobiles; and
- Central Puget Sound Vision 2020, which promotes the clustering of development into a hierarchy of mixed-use transit-oriented centers.

REVIEW OF LITERATURE AND EXPERIENCES

A literature review was conducted to identify methods that had been used and findings from empirical research efforts. These methods and findings were then used to test the impacts of urban form on travel behavior. Several areas in which research documenting empirical relationships between urban form and travel behavior was limited were found to exist. There areas include the impact of land-use mix on travel behavior, the relationship between non-work-related travel and urban form, and the collective impacts of urban form at both origins and destinations on travel choices.

In relation to land-use mix, Cervero (*1*) concluded that a significant reduction in midday travel and overall automobile dependence could be achieved through the integration of services into office parks. If further research establishes that an increased mixing of uses at both the household and employment trip ends reduces travel demand, the policy implications may be vast. Much of the existing zoning in urban and suburban areas is based on the principle of separation of land uses. In addition limited research has tested the collective impacts of urban form at both trip ends.

Findings from this review suggest the existence of two conflicting camps of believers regarding the effect of urban form on travel behavior and associated energy consumption. In the first camp are individuals who have concluded that the intensity of development and land-use mix seem to have a measurable impact on travel behavior. Their work is summarized as follows:

- Per-capita energy consumption increases as density decreases (*2–4*).
- Population and employment density are the aspects of urban form (studied to date) that have the greatest impacts on travel behavior (*1,5–7*). Previous research suggests that density has a significant impact on mode choice (*1,7–9*).
- As density increases households with one or more vehicles produce fewer trips, whereas zero-car households experience an increase in trip production (*10*).
- Job-housing policies may not provide the relief from congestion and air pollution that is needed (*11,12*).
- Mixing of uses at the employment trip end has been found to reduce travel demand (*1*).

The second group is more skeptical of the strength of this relationship. Researchers in this camp suggest that the intensity of development may appear to affect travel behavior; however, the underlying causes of this relationship are based on costs and demographics. These researchers most commonly cite the example that higher densities are associated with higher levels of transit service, higher parking costs, and lower automobile ownership rates. Findings from work on non-urban-form factors suggest that density may not be a causal factor itself, but rather a proxy for a host of other economic-related factors that do affect travel behavior (*13,14*).

RESEARCH APPROACH

The conceptual model in Figure 1 illustrates the significance that both urban-form factors (i.e., density and land-use mix) and non-urban-form factors (i.e., income, gender, age, and level of service) have on travel behavior. In this research urban-form factors were the focus, and non-urban-form factors were used as control variables in recognition of their significance. For example, when the impacts of density on mode choice were tested, it was critical to account for the socioeconomic characteristics of the trip maker. This enabled comparisons to be made between trip makers with similar socioeconomic characteristics. This process canceled the impacts of these factors on travel choices, allowing the impacts of urban-form factors to emerge.

This project used a correlational research design in which the relationships between urban form as the independent phenomenon and modal choice as the dependent phenomenon were analyzed (*15*). This research design was cross-sectional and did not offer the ability to identify whether variations in the dependent phenomenon (e.g., mode choice) were a direct reaction to variation in the independent phenomenon (e.g., population density). Therefore, there was no ability to truly document causality. The primary constraint preventing the documentation of causality was temporal. In a cross-sectional research design there is no ability to conduct a pretest; therefore, the impact of the stimuli (e.g., urban form) cannot be longitudinally isolated in an experimental design. The relationship between travel behavior and urban form was cross-sectionally isolated through the control of other variables that affect travel behavior (non-urban-form factors).

Development of a Data Base for Hypothesis Testing

The data used for this project were obtained from a variety of sources. Table 1 presents the data sources that supported each of the

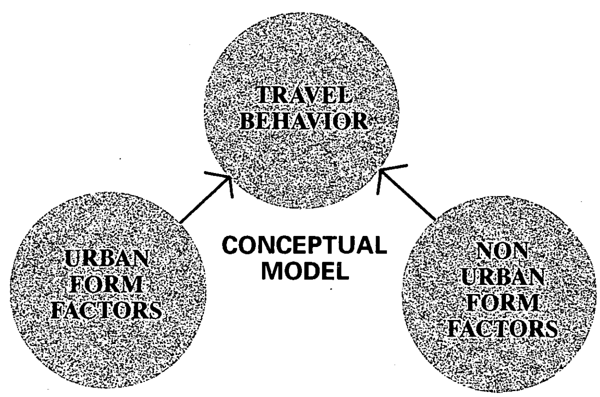

FIGURE 1 Relationship between travel behavior and factors that affect it.

TABLE 1 Data Base Structure

Puget SOURCE	VARIABLE TYPE
Puget Sound Transportation Panel (PSTP)	Travel Behavior, Level of Service for Transit (non-urban form), Demographic Factors (non-urban form)
U.S. Census Bureau	District Population (urban form)
Washington State Department of Economic Security (DES)	District Employment (urban form)
Puget Sound Regional Council (PSRC)	Area of Census Tracts in Acres (Urban Form)
King County BALD file	District Mix (urban form) - using parcel level data

variables in this study. These variables are defined in greater detail below.

This project used data on household travel behavior and demographics (control variables) from the Puget Sound Transportation Panel (PSTP). The PSTP is a 5-year longitudinal cohort study that was conducted between 1989 and 1994. This project was based on the 1989 survey, with approximately 28,955 valid trips made by 1,680 households. The sampling technique that was used for the data collection process in the PSTP is known as "choice based." Transit and carpooling were the infrequent travel choices that were oversampled in the PSTP. To perform meaningful research that would be generalizable to the study population, a weighting system was developed to apply to the 1989 survey of the PSTP (*16*). Another complication associated with coding the trips in the PSTP was associated with trip chaining. The effects of trip chaining on mode choice were not accounted for because each trip was coded independently, making it difficult to identify where a trip chain began or ended.

Data on travel behavior, land-use density, and land-use mix were all coded to the census tract to allow use of a correlational research approach. The percentage of SOV, transit, and walking trips that originated or ended in a census tract were calculated for each census tract. These modal proportions were used as continuous dependent variables in regression analysis. More specifically, the census tract was the unit of analysis. Census tracts with different levels of land-use densities and mix could be compared to test for differences in the proportions of SOV, transit, and walking trips that originated and ended in those tracts.

Variables in Study

The variables used in this project fell into three categories: mode choice, urban form, and non-urban form. Descriptive statistics for and definitions of the variables by trip purpose that were found to be most significant in the statistical analysis are presented later in this paper.

Mode Choice: Dependent Variables

Three alternative travel mode choices are presented in this paper. They are SOV, transit, and walking. Each of these modes was a dependent variable in this study and is defined in Table 2 in association with some basic descriptive statistics.

The mean proportion of work trip origins per census tract was clearly dominated by the SOV (74.76 percent), with a small proportion of transit (5.16 percent) and walking (3.69 percent). Even smaller proportions of work trip destinations were reached by transit (1.68 percent) and walking (3.37 percent). This was due to an increase in the mean proportion of SOV trips at destinations over origins of 5.33 percent.

Urban Form: Independent Variables

The variables representing various measures of population density, employment density, and land-use mix that were found to be most highly related to mode choice for SOV, transit, and walking are presented in Table 3. In some cases there were two variables with the same definition (e.g., popdenA) that differed only in their relationship with trip origin or destination data. If the same variable appears twice (popdenA), it indicates that the variable was significantly related to the proportion of trip origins and destinations for SOV, transit, or walking.

Gross Population Density Gross population density measured the entire population or number of residents within a designated geographic area divided by the size of the designated area, which was the census tract. Variables representing measures of gross population density are presented and defined in association with descriptive statistics for both work trips and shopping trips in Table 3. The average gross population density at trip origins and destinations was found to be the population density variable most significantly related to mode choice. The maximum value for gross population density at the tract level ranged from 40.5 to 47 residents per acre. Between 345 and 443 tracts in which work or shopping trips originated or ended had valid data for population density.

Gross Employment Density Gross employment density measured the number of employees within a designated geographic area divided by the size of the designated area, the census tract. Variables representing measures of gross employment density are presented and defined in association with descriptive statistics for both work trips and shopping trips in Table 3. Employment density was found to be related to both work trips and shopping trips at trip origins, destinations, and an average of the two. The maximum

TABLE 2 Mode Choice Variables

Variable Name	Trip Purpose	Mean	Std Dev	Minimum	Maximum	Valid cases
sovpctO	percent of trips originating in census tracts made by SOV					
	WORK	74.76	26.66	0	100	509
	SHOP	58.61	30.39	0	100	497
sovpctD	percent of trips ending in census tracts made by SOV					
	WORK	80.09	25.94	0	100	446
	SHOP	58.94	33.07	0	100	393
buspctO	percent of trips originating in census tracts made by transit					
	WORK	5.16	13.34	0	100	509
	SHOP	1.23	6.35	0	100	497
buspctD	percent of trips ending in census tracts made by carpool					
	WORK	1.68	5.48	0	51.81	446
	SHOP	1.45	8.45	0	100	393
walkpctO	percent of trips originating in census tracts made by walking					
	WORK	3.69	12.52	0	100	509
	SHOP	3.16	10.03	0	100	497
walkpctD	percent of trips originating in census tracts made by walking					
	WORK	3.37	12.44	0	16.67	446
	SHOP	4.165	14.53	0	100	393

TABLE 3 Urban-Form Variables

Variable Name	Trip Purpose	Mean	Std Dev	Minimum	Maximum	Valid Cases
popdenA	average gross population density per acre at trip origins and destinations (based on trip destination data)					
	WORK	6.158	4.361	0.028	40.503	382
	SHOP	6.44	4.767	0.01	46.97	345
popdenA	average gross population density per acre at trip origins and destinations (based on trip origin data)					
	WORK	6.495	4.888	0.006	44.52	443
empdenO	gross employment density per acre at trip origins (based on trip origin data)					
	WORK	9.93	25.94	0:002	225.16	370
empdenD	gross employment density per acre at trip destinations (based on trip destination data)					
	SHOP	7.9	30.02	0.002	401.43	256
empdenA	average gross employment density per acre at trip origins and destinations (based on trip destination data)					
	WORK	9.465	22.26	0.002	232.58	274
	SHOP	12.46	32.7	0.002	287.49	252
mixentO	mixing of uses at trip origin census tracts (based on trip origin data)					
	WORK	0.443	0.185	0.002	0.794	267
mixentO	mixing of uses at trip origin census tracts (based on trip destination data)					
	WORK	0.471	0.128	0.048	0.794	273
mixentD	mixing of uses at trip destination census tracts (based on trip destination data)					
	WORK	0.471	0.178	0.006	0.794	223
	SHOP	0.478	0.166	0.006	0.794	204

employment density value for a census tract in the study area was 401.43 employees per acre, which was in downtown Seattle. Very few tracts in the study area had an employment density of greater than 200 employees per acre. Between 252 and 274 tracts in which work or shopping trips originated or ended had valid data for employment density.

Land-Use Mix Land-use mix is the composition of uses within a given geographic area. According to Cervero (*1*): "Mixed-use developments are those with a variety of offices, shops, restaurants, banks, and other activities intermingled amongst one another." A descriptive statistic known as an entropy index was developed to describe the evenness of the distribution of built square footage among seven land-use categories. The entropy index was based on the following equation:

$$\begin{aligned}&\text{Level of land use mix (entropy value)}\\ &= -\ [\text{single family} \cdot \log_{10}(\text{single family})]\\ &\quad + [\text{multifamily} \cdot \log_{10}(\text{multifamily})]\\ &\quad + [\text{retail and services} \cdot \log_{10}(\text{retail and services})]\\ &\quad + [\text{office} \cdot \log_{10}(\text{office})]\\ &\quad + [\text{entertainment} \cdot \log_{10}(\text{entertainment})]\\ &\quad + [\text{institutional} \cdot \log_{10}(\text{institutional})]\\ &\quad + [\text{industrial/manufacturing} \cdot \log_{10}(\text{industrial/manufacturing})]\end{aligned}$$

This equation resulted in the development of a normalized value between a minimum of 0 and a maximum of 0.845 (the log of K or the number of categories, which was seven) assigned to each census tract. Definitions and descriptive statistics are presented in Table 3 for the land-use mix variables most highly correlated with mode choice.

Land-use mix at trip origins (mixentO) was found to be significantly related to mode choice for work trips when modal proportions for SOV, carpool, transit, and walking were calculated at both trip origins and destinations. Land-use mix at the trip destination (mixentD) was found to be significantly related to mode choice for work trips and shopping trips when modal proportions were calculated at trip destinations. The maximum value for each of the census tract-level land-use mix variables was 0.794. Between 204 and 273 tracts in which work or shopping trips originated or ended had valid data for land-use mix.

Non-Urban-Form: Control Variables

The non-urban-form factors that were found to be significantly related to mode choice are presented in Table 4. An examination of non-urban-form factors allows the researcher to place urban form in context relative to the myriad of variables that affect travel behavior.

Household-type variables were measures of life-cycle stage. The household types most highly related to mode choice for shopping trips were households with single adults under age 35 (hhtype3) and households with single adults between the ages of 35 and 64 (hhtype4), with mean values of 3.13 and 5.97 percent, respectively. These values indicated that the mean proportion of shopping trips that ended in census tracts and that were made by individuals who lived alone and who were under 35 years of age was 3.13 percent. Hhtype5 (single adults over age 65) was the group most highly related (negatively) with the work trip subset. Overall, households with individuals who lived alone had the strongest relationships to mode choice for work and shopping.

Based on destination data, more than 90 percent of the work trips and shopping trips were made by individuals who had a driver's license. As would be expected, a significantly larger proportion of each census tract's work trip destinations (93.49 percent) than shopping trips destinations (57.86 percent) was reached by individuals who worked outside the home. A small proportion of each census tract's shopping trips was made by individuals who had a bus pass, as indicated by the mean value for all census tracts of 4.3 percent. Roughly 10 percent of all census tract's work trip and shopping trip destinations were reached by individuals who had less than one vehicle available to them. The mean age of the individuals who made shopping trips to all census tracts was 47.28 years.

TESTING OF HYPOTHETICAL RELATIONSHIPS

An analysis of four hypothetical relationships is presented in this analysis. These relationships are global enough to address the published criticisms of similar research efforts. These four hypothetical relationships were as follows:

- Population density, employment density, and land-use mix are related to mode choice.
- Population density, employment density, and land-use mix are related to mode choice when non-urban-form factors are controlled.
- A stronger relationship exists between mode choice and urban-form characteristics at both trip ends than at one trip end.
- The relationship between population density, employment density, land-use mix, and mode choice is nonlinear.

Findings from the analysis of hypothetical relationships between urban form and mode choice are presented below. The statistical methods used to test these hypotheses were selected on the basis of the nature of the hypothetical relationship being tested. Tests of the presence, strength, and nature (+, −) of the linear relationship between various urban-form and mode choice variables were conducted with the Pearson correlation. Multivariate regression was used to test the presence of a relationship between urban-form and mode choice while controlling for non-urban-form factors. Nonlinear relationships between urban-form and mode choice variables were simulated by cross-tabulation. The findings are presented according to the four research questions presented previously.

Hypothesis 1

Hypothesis 1 states: a statistically significant relationship exists between urban form and travel behavior. Empirical relationships between urban form and travel behavior variables for work and shopping trips are presented in Table 5. These findings were the result of simple linear correlation.

The findings in Table 5 indicate that employment density and land-use mix were both significantly related to percent SOV use, percent transit use, and percent walking. Population density was not significantly related to percent SOV use. Percent SOV use had a negative relationship and transit use and walking had a positive relationship with density and mix, which is intuitively correct. Overall, these findings confirm the hypothesis that urban form and mode choice are significantly related. The strongest linear relationships for work trips were between employment density and transit and

TABLE 4 Non-Urban-Form Variables

Variable Name	Trip Purpose	Mean	Std Dev	Minimum	Maximum	Valid Cases
hhtype3	proportion of survey households per census tract with one adult less than 35 years old					
	SHOP	3.13	12.99	0	100	393
hhtype4	proportion of survey households per census tract with one adult between 35 and 64 years old					
	SHOP	5.97	16.4	0	100	393
hhtype5	proportion of survey households per census tract with one adult over 65 years of age or older					
	WORK	0.456	5.113	0	100	446
license1	proportion of survey participants per census tract that have a driver's license					
	WORK	98.07	8.31	0	100	446
	SHOP	90.98	18.58	0	100	393
employ1	proportion of trip ends per census tract made by survey participants that are employed outside the home					
	WORK	93.49	19.11	0	100	446
	SHOP	57.86	31.3	0	100	393
buspass1	proportion of trip ends per census tracts made by survey participants with a buspass (based on trip destination data)					
	SHOP	4.3	19.05	0	100	116
vehavail	proportion of trip ends per census tract made by survey participants that have access to less than one vehicle					
	WORK	9.41	21.64	0	100	446
	SHOP	11.07	20.98	0	100	392
numveh	mean number of vehicles available for survey participants ending trips in each census tract					
	SHOP	2.23	0.725	0	6	393
age	mean age of survey participants ending trips in each census tract					
	SHOP	47.28	12.44	16	82	393

walking; however, significant associations were found between percent walking and population density and land-use mix. These findings suggest that the census tract can be a meaningful geographic unit of analysis for use in measuring the relationship between land-use mix and mode choice for work trips.

The findings in Table 5 indicate that the percentage of walking and transit trips had the highest linear relationship to density for shopping trips. Percent SOV use was negatively associated with density, whereas percent transit and percent walking had a positive association with density. These results were consistent with the findings from the work trip subset. Land-use mix was not found to be significantly correlated with these three mode choice variables for shopping trips. Overall the hypothesis that mode choice for SOV use, transit use, and walking is significantly related to urban form (for shopping trips) was confirmed for population and employment density.

TABLE 5 Correlation Coefficients Between Urban-Form and Mode Choice Variables

WORK TRIPS			
TRAVEL BEHAVIOR VARIABLES	**EMPLOYMENT DENSITY**	**POPULATION DENSITY**	**MIXING OF USES**
% SOV	-0.26	-	-0.13
% TRANSIT	0.59	0.19	0.15
% WALK	0.43	0.34	0.21
SHOPPING TRIPS			
% SOV	-0.15	-	-
% TRANSIT	0.44	0.16	-
% WALK	0.24	0.31	-

Hypothesis 2

Hypothesis 2 states: a statistically significant relationship exists between urban form and modal choice while controlling for non-urban-form factors. Multivariate regression models were developed for each of the mode choice variables (percent SOV, percent transit, and percent walking) to determine whether urban-form variables were significantly related to mode choice when non-urban-form factors were controlled. These models are presented in Table 6 for both work trips and shopping trips. Non-urban-form factors were entered into the regression analysis before the stepwise selection of urban-form variables. Therefore, only those urban-form variables that were still significantly related to the dependent variable (after non-urban-form variables were entered) are presented below. Beta values are presented in association with the variables in each of these models. The slopes (b-values or coefficients) of each urban-form variable were interpreted but are not presented in this paper. More detailed information about these models is available through the Office of Urban Mobility, WSDOT.

The hypothesis that urban form is significantly related to mode choice for SOV use, transit use, and walking when non-urban-form factors are controlled was confirmed by the significance of both urban-form and non-urban-form variables. The findings presented in Table 6 suggest that the percentage of transit and walking (for both work trips and shopping trips) had the highest relationships with the urban-form variables. Urban-form factors were consistently negatively associated with percent SOV use and were positively associated with percent transit use and walking. Percent transit use appeared to be highly related to employment density for both work and shopping. Percent walking (in addition to employment density) was also significantly related to other urban form variables such as population density (for both work and shopping) and land-use mix (work trips). Percent SOV use was also related to employment density. Employment density at trip origins and destinations for work trips and percent transit use was found to be the strongest relationship between an urban-form and mode choice variable. Population density had the greatest effect on walking trips for both work and shopping. Employment density was found to be significantly related to SOV use, transit use, and walking trips for both work and shopping. Mixing of uses had the weakest relationship with mode choice, having the greatest effect on walking for work trips.

Hypothesis 3

Hypothesis 3 states: a stronger relationship exists between mode choice and urban-form characteristics when they are measured at both trip ends than at one trip end. This hypothesis was confirmed only in certain instances. Employment density at trip origins and destinations had the greatest degree of explanatory power over variation in mode choice for transit use for both work trips and shopping trips and for SOV use for work trips. Employment density at trip origins and destinations had the greatest degree of explanatory power over variation in mode choice for walking for both work trips and shopping trips. Land-use mix at trip origins and destinations had the greatest degree of explanatory power over variation in mode choice for walking for work trips. Although they are not universal, the findings from this analysis suggest that average urban-form

TABLE 6 Variables Related to Each Mode by Trip Purpose

	%SOV (regression variables & betas)	%TRANSIT (regression variables & betas)	%WALK (regression variables & betas)
WORK TRIPS	average employment density at trip origins and destinations (-0.29), has a driver's license (0.37)	employment density at trip origins and destinations (0.65)	employment density at trip origins (0.38), population density at trip origins and destinations (0.29), mixing of uses at trip origins and destinations (0.15)
adj. r-sq.	0.2	0.42	0.31
SHOP TRIPS	employment density at trip destinations (-0.18), has a driver's license (0.23), single adult households between 35-64 (0.21), household income (0.16)	employment density at trip origins and destinations (0.32), population density at trip origins and destinations (0.19), distance for carpool trips (0.51)	employment density at trip destinations (0.19), population density at trip origins and destinations (0.26), less than 1 vehicle available (0.15), age (-0.13), has a driver's license (-0.4)
adj. r-sq.	0.14	0.43	0.35

measures rather than measures taken at the origin or destination have the strongest ability to predict variations in mode choice for SOV use, transit use, and walking.

Hypothesis 4

Hypothesis 4 states: the relationship between population density, employment density, and mode choice is non-linear. The purpose of this analysis was to identify the thresholds where shifts from one mode (SOV) to another (transit or walking) occur as a function of population or employment density. (A similar analysis was conducted between land-use mix and the proportion of trips by mode for both work trips and shopping trips. That analysis determined that no detectable nonlinear relationship exists.) The focus of this analysis was to identify the linearity or nonlinearity of the relationship between urban-form variables and SOV use, transit use, and walking. Cross-tabulation was used to separate employment density and population density into intervals to allow changes in the relationship between mode choice for SOV use, transit use, and walking to be detected at different levels of density.

The proportions of trips by SOV, transit, and walking at different levels of density are presented in Figures 2 and 3 for employment density and population density by trip purpose, respectively. The findings from this research indicate that population density has a more significant relationship with mode choice when it is measured at the trip origin, as does employment density when it is measured at the trip destination. Employment density is presented in Figure 2 in association with work trips, whereas population density is presented in Figure 3 in association with shopping trips.

Figure 2 indicates that there is a nonlinear relationship between employment density and mode choice for SOV use, transit use, and walking for work trips. The nature of these nonlinear relationships between employment density and mode choice has significant policy implications. Policies that call for an increase in employment density to encourage transit use and walking and to discourage SOV use for work trips will not be cost-effective unless certain density thresholds are reached. Two thresholds are indicated by Figure 2. Significant modal shifts from SOV use to transit use and walking occur with between 20 and 75 employees per acre and again with more than 125 employees per acre. This analysis suggests that policies that encourage employment densities to increase from 75 to 125 employees per acre will have little effect on mode choice.

Figure 3 indicates that a nonlinear relationship exists between population density and mode choice for SOV use, transit use, and

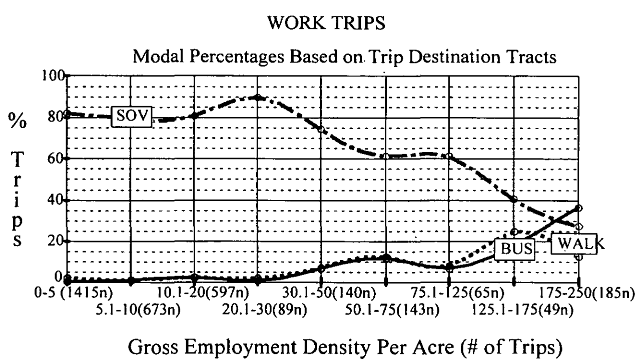

FIGURE 2 Average employment density of trip origins and destinations and mode choice.

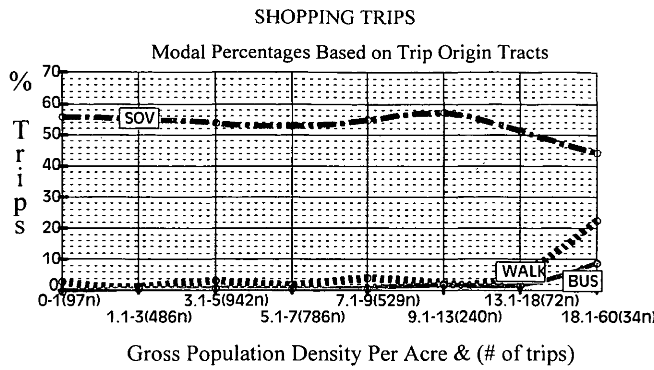

FIGURE 3 Average population density of trip origins and destinations and mode choice.

walking for shopping trips. The authors note that few shopping trips in the panel survey were to or from higher-density census tracts, limiting the ability to separate out intervals at higher densities. This analysis suggests that population densities need to exceed approximately 13 persons or residents per acre before a significant modal shift occurs from SOV use to transit use and walking for shopping trips. This analysis suggests that policies that encourage population densities to increase to levels below 13 persons per acre will have little effect on mode choice. Thirteen persons per acre roughly corresponds to approximately seven to nine dwelling units per gross acre, which is similar to findings from previous research (*8*).

SUMMARY

This paper presents findings from research conducted to test the presence and nature of the relationship between urban form and mode choice at the census tract level. The proportions of trip origins or destinations for SOV use, transit use, and walking were the dependent continuous variables. Relationships between employment density, population density, land-use mix, and SOV usage were found to be consistently negative for both work and shopping trips. The relationships between employment density, population density, land-use mix, and transit and walking were consistently positive for both work trips and shopping trips. General findings identified in the analysis of mode choice were documented through the analysis of descriptive statistics, correlation, regression, and cross-tabulation.

Past research and findings from this analysis suggest that the relationship between mode choice and employment density is nonlinear. The findings presented here indicate that there are two thresholds along a continuum of employment density at which a modal shift occurs from SOV use to transit use and walking. The most compelling of the findings is the dramatic increase in the proportion of transit trips that occur as employment density increases to more than 75 employees per acre. In addition, a significant decrease in SOV travel occurs at relatively low densities (between 20 and 50 employees per acre). This finding could have significant implications for the reduction of SOV travel and the associated vehicle miles traveled required to meet federal Clean Air Act requirements.

The measure of population density that was found to have the strongest relationship with mode choice in correlation and regression analyses was average gross population density at trip origins and destinations for shopping trips. A nonlinear relationship was identified between all three modes analyzed and population density for shopping trips. Walking trips were the most sensitive to increases in population density. Findings suggest that population densities need to exceed 13 residents per acre for changes in mode choice to be detected. The reduction in SOV travel was not as significantly associated with increases in population density as it was with employment density.

The findings presented in this paper indicate that the relationship between mode choice and land-use mix can be measured at the census tract scale; however, the relationships are relatively weak. Only the relationship between average land-use mix at origins and destinations and percent walking for work trips was significant enough to remain in a regression model when non-urban-form factors were controlled. This indicates that further research that focuses on measures of land-use mix at a smaller geographic unit of analysis (e.g., block groups) may be more able to detect relationships with mode choice.

The findings presented in this paper support the use of urban form policies to reduce dependence on the SOV. They also identify a variety of non-urban-form factors that affect mode choice. Furthermore, this research indicates that a comprehensive approach to policy development would be most successful in reducing dependence on SOVs.

ACKNOWLEDGMENT

This project was funded by a grant from WSDOT.

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Publication of this paper sponsored by Committee on Transportation and Land Development.

Getting Around a Traditional City, a Suburban Planned Unit Development, and Everything in Between

REID EWING, PADMA HALIYUR, AND G. WILLIAM PAGE

Beyond some studies relating density to mode choice, vehicle miles of travel, or gasoline consumption, little is known about the relationship of location and land use to household travel patterns. Against this backdrop a 16,000-record travel survey for Palm Beach County, Florida, was analyzed. Six communities were culled from the larger data base, and household travel data were then tested for statistically significant differences in trip frequency, mode choice, trip chaining, trip length, and overall vehicle hours of travel. Households in a sprawling suburb generate almost two-thirds more vehicle hours of travel per person than comparable households in a traditional city. Although travel differences are significant, they are smaller than one might expect given the more than 10-fold difference in accessibility among the communities. Sprawl dwellers compensate for poor accessibility by linking trips of household members in multipurpose tours. Implications for land planning are more complex than simply pedestrianizing or transitizing the suburbs. Communities should internalize as many facilities and services as possible. This is true even where the automobile reigns supreme. Communities should concentrate facilities and services in centers and corridors. This will facilitate efficient automobile trips and tours. The more sprawling the area, the more important this becomes, for through activity centers, linked accessibility to activities can be maintained even as direct accessibility falls off.

As traffic problems have grown and proven resistant to transportation solutions, interest in land planning has also grown. Neotraditional towns, pedestrian pockets, urban villages, and other models of compact, mixed-use development have been advanced as the answer to automobile dependence, excessive vehicle miles of travel (VMT), and intractable traffic congestion.

Beyond some studies relating density to mode choice, VMT, or gasoline consumption, little is known about the relationship of location and land use to household travel patterns (*1–7*). Even the sacrosanct belief in compact development has been challenged by those claiming that decentralization brings activities closer together and that the ubiquitous automobile-highway system has rendered accessibility a minor factor in location and travel decisions (*8–13*).

Against this backdrop, a 16,000-record travel survey for Palm Beach County, Fla., was analyzed. Six communities were culled from the larger data base, and household travel data were then tested for significant differences in trip frequency, mode choice, trip chaining, trip length, and overall vehicle hours of travel. The purpose of the study was to determine whether, after controlling for household income and size, location and land use influence household travel patterns and, if so, in what ways.

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HOUSEHOLD TRAVEL ACTIVITY PATTERNS

Household members have both individual and common needs that are met through activities. Many of the activities are outside the home and so involve travel. Household members have the ability to defer or advance the times of certain discretionary activities and may also have a choice of activity sites. They can reduce overall travel by scheduling activities as part of trip tours or chains instead of making a larger number of single-stop trips that produce a greater volume of travel in toto. The ability to link trips in tours cuts household travel by an estimated 15 to 22 percent relative to separate trips for the same purposes (*14*). The flexibility of the automobile makes it all possible.

DIFFERENT ANGLES ON ACCESSIBILITY

Accessibility influences the ways that household needs are met through travel. Residential accessibility—the distribution of activities around the place of residence—determines the destination, mode, and arguably, even the frequency of home-based trips (*15–19*). It is the primary concern of neotraditionalists, travel demand modelers, central-place theorists, and just about everyone else with an interest in land use and transportation.

Given the large number of linked trips, destination accessibility—the distribution of activities around each other—is another important determinant of household travel patterns (*15–17,20–21*). A "shop which is close to a decision-maker's place of employment may be quite accessible (as indicated by the frequency of use) even though it may be quite distant from the decision-maker's place of residence" (*20*).

STUDY AREA

Palm Beach County, Florida, was chosen as the study area because it is the site of a recent diary-based travel survey, the only general travel survey in Florida to ask about walking and bicycling trips. Other surveys have focused exclusively on vehicular travel (being undertaken for purposes of highway and transit planning).

Palm Beach County has another advantage as a study area. It is a large county that offers some diversity of development within an urban form often characterized as "sprawl." Six communities within Palm Beach County have been singled out. It is for the residents of these communities that travel patterns are compared.

To control for differences in household income, 18 households reporting annual incomes of less than $20,000 had to be dropped

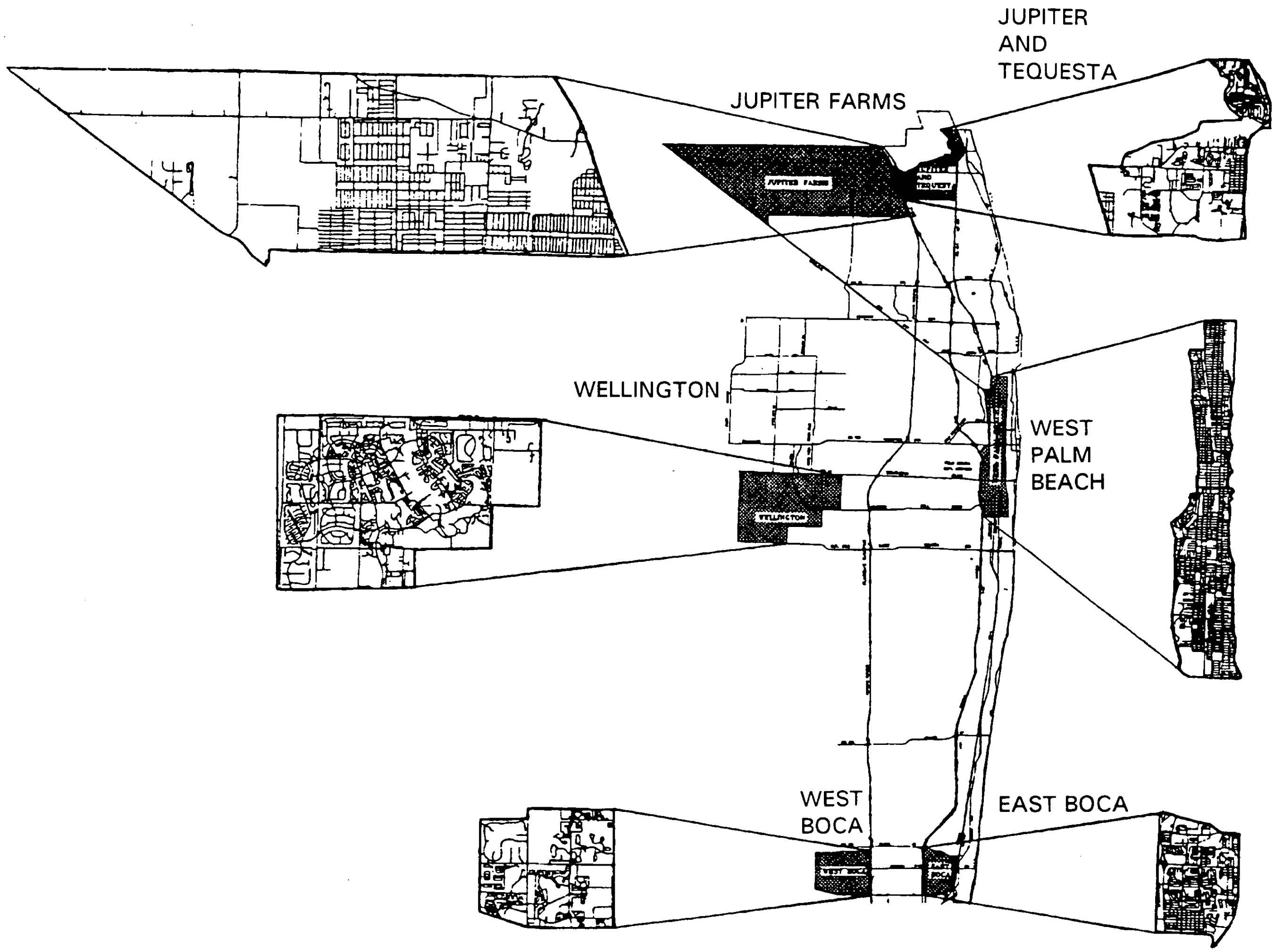

FIGURE 1 Communities of Palm Beach.

from the samples. They are nearly all from West Palm Beach, Jupiter/Tequesta, or West Boca. Three additional households that refused to disclose household income and reported owning no automobile were also dropped. They almost certainly fall into the lowest income categories. With these households out, samples from the six communities show no significant differences in either household income or household size (in chi-square tests). (The chi-square for household income, 24.6 with 25 degrees of freedom, corresponds to the 0.49 significance level. The chi-square for household size, 12.07 with 20 degrees of freedom, corresponds to the 0.91 significance level.)

Figure 1 locates the communities in relation to each other and shows their street networks. All are plotted at the same scale to emphasize how different they are. Table 1 provides a complete set of land-use statistics for the six communities, including accessibility indexes estimated with standard gravity models for work trips and non-home-based trips. (The accessibility index is the denominator of the gravity model used in the standard four-step regional travel modeling process to distribute trips. The index represents the distribution of trip attractions around each zone producing trips. The higher the index, the more accessible the attractions. The index is computed by multiplying the number of trip attractions by the interzonal friction factor, which declines with interzonal travel time, and summing the result over all attraction zones.) Accessibility indexes have been reduced to a common base by dividing values for each community by values for West Palm Beach, the most accessible of the six communities.

Brief descriptions of the communities follow. West Palm Beach is as traditional (not neotraditional, but the real thing) as any place in the county. Its housing stock varies from detached single-family homes to high-rise apartments, all within view of each other. Streets form a dense grid and are narrow by today's standards. The community has corner stores, small building setbacks, rear parking, alleys, accessory apartments, and other hallmarks of traditional development. It is the only community with significant mass transit service and the only one with a real central business district. In terms of densities and accessibilities, it is the most urban of the six communities.

Wellington is a classic 1970s planned unit development (PUD). It has curvilinear streets, loop roads, and cul-de-sacs galore. It has pods of residential development that are walled off and inward facing, with only one way in and out. It has beautifully landscaped

TABLE 1 Characteristics of Palm Beach Communities

	East Boca	West Boca	West Palm Beach	Wellington	Tequesta & Jupiter	Jupiter Farms
Residential Density (dwellings/land acre)	3.15	2.63	3.76	0.76	2.00	0.12
Employment Density (jobs/land acre)	2.58	0.46	6.65	0.24	1.27	0.01
Jobs-Housing Ratio (jobs/ dwelling)	0.82	0.17	1.77	0.32	0.64	0.10
% Multifamily Dwellings	37	49	43	21	33	2
Accessibility Index for Work Trips	0.49	0.22	1.00	0.14	0.31	0.21
Accessibility Index for Nonhome-Based Trips	0.72	0.43	1.00	0.27	0.40	0.08

collector roads with meandering sidewalks. In short it has everything that neotraditionalists love to hate. At the same time Wellington has a good mix of attached and multifamily housing and comes complete with its own shopping centers, schools, recreational facilities, and medical offices, making it self-contained with respect to all daily activities except basic employment. For employment, residents must make the long trek into the urbanized area.

East Boca is one of Florida's early master-planned communities, dating back to Addison Mizner and Florida's land boom of the 1920s. It has a small, walkable downtown, historic neighborhoods on a rectilinear grid, and newer neighborhoods on a modified grid. It is well endowed with public recreational facilities, schools, and small shopping centers. Its streets are tree lined, often with sidewalks, making walking an option for some utilitarian trips (even though distances are longer than ideal for walking). Employment centers are located nearby at Florida Atlantic University, in a large industrial area just west of I-95, and to the south in Broward County. In terms of densities and accessibility, it is the second most urban of the six communities.

West Boca is a suburb of residential PUDs—each well designed and well landscaped but inward oriented and independent of the others. The community has a fair number of schools and parks, four golf courses within a remarkably small area, and several large community shopping centers within the community or nearby. Subdivision and PUD streets are discontinuous to exclude through traffic, but arterials form a grid with good connections to the rest of the region. Although it is farther from employment centers than East Boca, West Boca is accessible to the same employment centers.

Jupiter and Tequesta are twin strip cities; small strip centers line their major thoroughfares, Indiantown Road and Federal Highway. Streets are strictly for automobiles; landscaping, medians, sidewalks, and pedestrian amenities are in short supply. Basic employment opportunities are limited, as are recreational facilities, but the community is well supplied with schools and local service employment, is reasonably dense, and mixes land uses in a fashion (with residential areas running up to the edges of the commercial strips).

Jupiter Farms is the epitome of urban sprawl. It has nothing but large-lot, single-family homes; only one school, one park, and one convenience shopping center; and no employment centers nearby. Almost regardless of their trip purposes, residents must travel to Indiantown Road and then head for the Florida Turnpike or I-95. Jupiter Farms is closer to the ocean and the county's urbanized area boundary than is Wellington but is even less accessible for most purposes since it sits across from the relatively minor urban centers of Jupiter and Tequesta.

TRAVEL PATTERNS

In the discussion that follows, the classification of trips deviates from standard practice. Standard practice, which has its origin in conventional travel modeling, classifies trips as either home-based or non-home based. Trip purposes are defined only for home-based trips. Non-home-based trips are lumped together as a separate, single-trip purpose. Home-based and non-home-based trips are treated as if they were independent, when in fact they are necessarily linked.

In standard practice a trip from home to work without a stop is classified as a home-based work trip. However, if the commuter stops along the way to pick up a newspaper and then proceeds to work, the first leg is classified as a home-based shopping trip and the second leg is classified as a non-home-based trip. The primary purpose of the trip—work—is lost in the classification process.

In the present study trips are classified as parts of tours. By common convention tours begin and end at home. A tour may have only one stop away from home or may have many stops. If at least one stop is for purposes of work, the tour is classified as a work-related tour. Otherwise it is classified as a non-work-related tour. When individual trips (legs of a tour) must be identified by purpose, it will be in terms of the purpose at the destination and the type of tour.

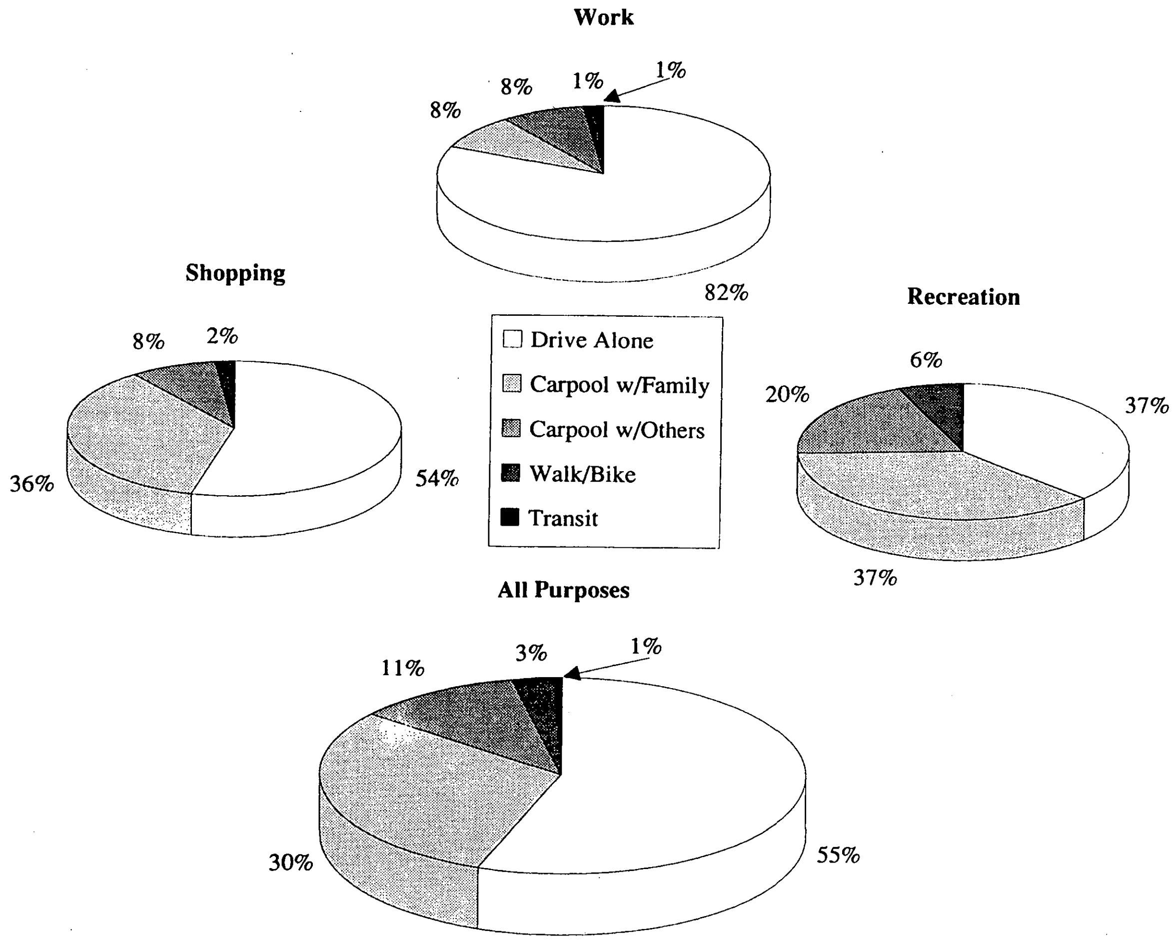

FIGURE 2 Mode splits in Palm Beach County.

Thus, in the previous home-to-shop-to-work example, a shopping trip and a work trip are linked in a work-related tour. This is not a perfect classification scheme, but it makes more sense than the standard classification scheme.

Travel Patterns Countywide

For the entire sample of surveyed households, two travel features stand out. First, Palm Beach County is automobile oriented in the extreme (Figure 2). Only 2.7 percent of the total trips are by walking/biking, whereas a mere 0.5 percent are by transit. Even for recreation only 6 percent of the trips in Palm Beach County are by alternative modes. Mode splits for walking/biking and transit are about one-third the national averages (Figure 3).

Unlike transit and walking/biking, carpooling is a significant mode of travel countywide. Carpooling with members of the same household, which is not even acknowledged as a travel option in most studies, represents 30 percent of all trips. Carpooling with members of other households, generally acknowledged as a travel option only for work trips, represents another 11 percent. Carpooling is much more common for shopping, recreation, and other purposes than it is for work.

Carpooling figures are important because carpooling occurs mostly on multipurpose trips, in which the needs of different travelers are met at different stops. Thus, the accessibility of destinations to one another (what we are calling destination accessibility) becomes an important determinant of tour efficiency and vehicle miles or hours of travel.

The other outstanding fact about countywide travel is the sheer volume of linked trips. The need to overcome poor residential accessibility makes trip chaining a natural in sprawling, automobile-dependent Palm Beach County. Almost half of all work trips are linked to side trips for other purposes (Figure 4). A high percentage of non-work-related trips are also part of multipurpose tours (Figure 5). On balance, 61 percent of the trips made by surveyed households are part of multistop (and usually multipurpose) tours. That is as high a percentage as any reported in the literature (*14,21–29*).

Travel Patterns Across Communities

Travel characteristics for households in the six communities are summarized in Table 2 and Figures 6 through 8. All statistics relate to the 2-day period covered by the travel diaries. Mode splits vary only slightly across communities, less than one might expect given the differences in land-use patterns (Figure 6). Average travel times show more variation, particularly for work trips (Figure 7). Total vehicle hours of travel (VHT) per person also vary considerably, mostly because of differences in average travel times (Figure 8).

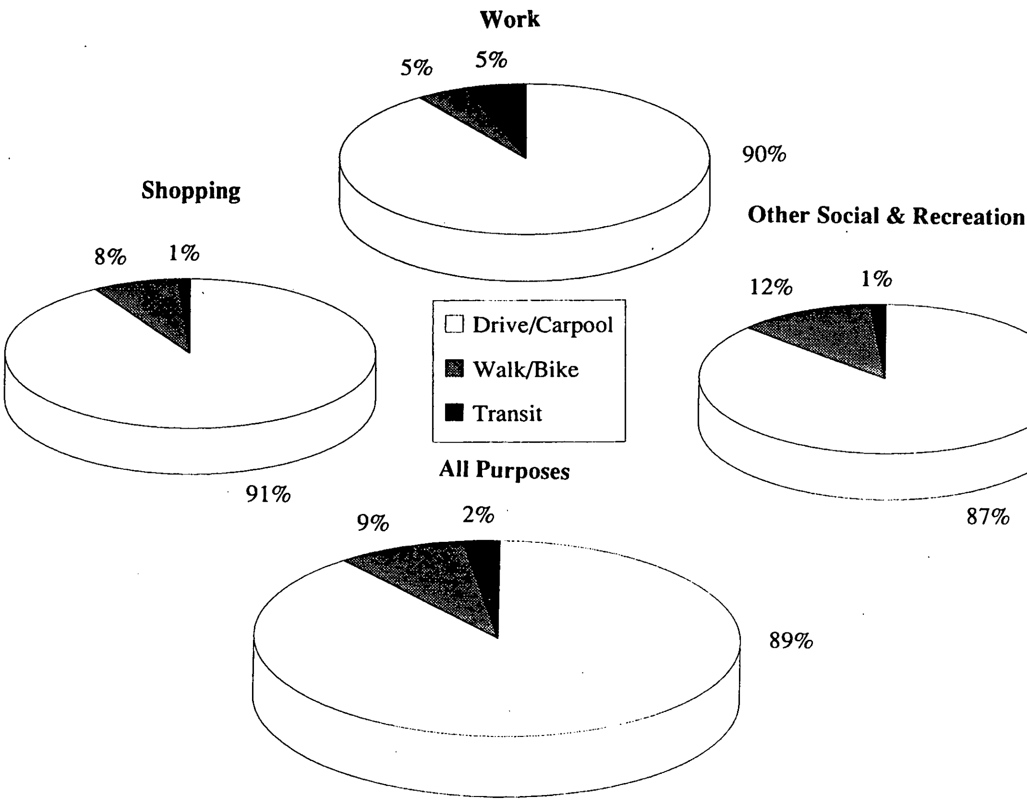

FIGURE 3 Mode splits in the United States (source: unpublished tabulations from 1990 Nationwide Personal Transportation Survey).

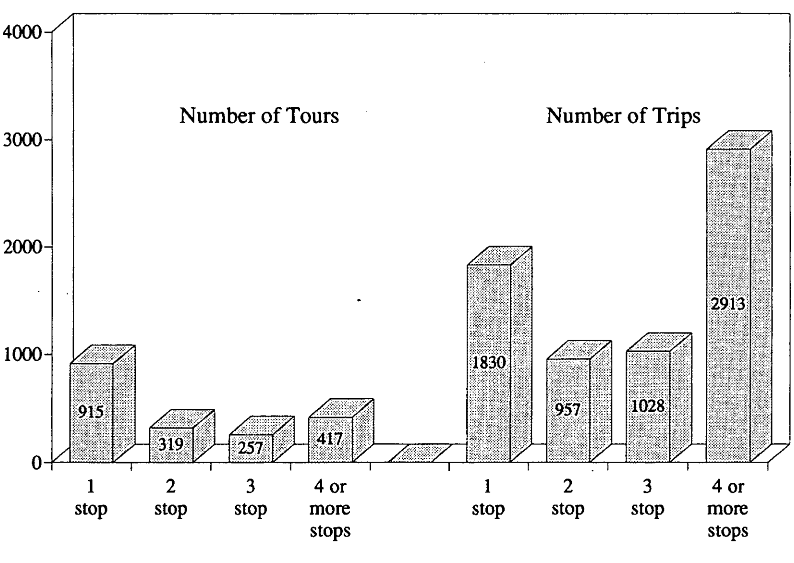

FIGURE 4 Work-related trip chaining in Palm Beach County.

VHT was computed from travel times assuming standard vehicle occupancies of 2.5 persons/vehicle for carpools and 30 persons/vehicle for transit.

VMT could not be easily derived from the travel survey data files since the traffic analysis zones of destinations were not geocoded for one-third of all trips. Differences in VMT are almost certainly even more pronounced than differences in VHT since vehicle travel speeds are highest in areas of high VHT and lowest in areas of low VHT.

The samples in this study are small, and there is considerable variation from household to household within each community. Thus apparent differences among communities could be solely due to chance (sampling variability). To test for significant differences, analysis of variance was performed on the samples. *F*-statistics and

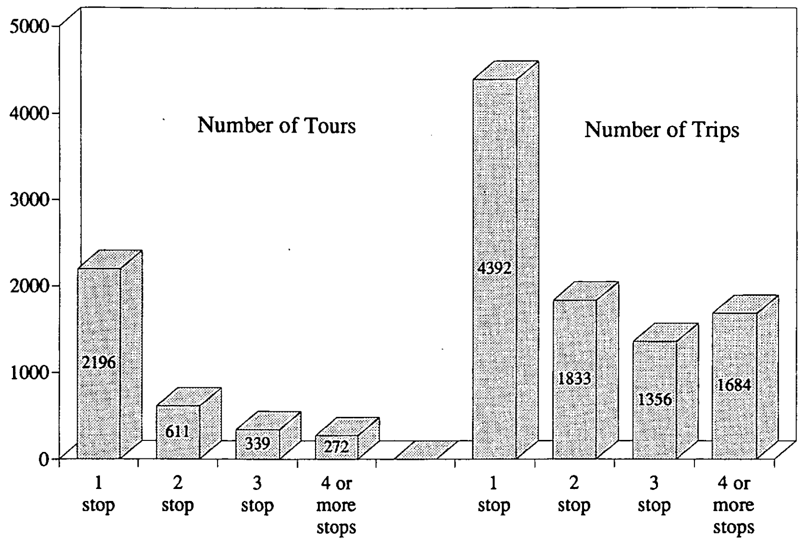

FIGURE 5 Non-work-related trip chaining in Palm Beach County.

TABLE 2 Trips per Person and per Tour in Different Communities

	East Boca	West Boca	West Palm Beach	Wellington	Tequesta & Jupiter	Jupiter Farms
Households in Sample	32	29	29	25	23	25
Trips/Person (Work-Related)	3.70	2.85	3.16	2.48	2.63	3.21
Trips/Person (Nonwork-Related)	2.66	2.85	3.18	3.71	2.73	3.08
Trips/Tour (Work-Related)	2.64	2.51	3.02	2.80	2.47	3.32
Trips/Tour (Nonwork-Related)	1.98	1.76	1.63	1.63	1.90	1.95

significance levels are reported in Table 3. At the 0.05 level, mean values of only three travel characteristics differ significantly across communities:

- travel time for work-related trips,
- travel time for non-work-related trips, and
- total hours of travel per person.

A fourth characteristic, vehicle hours of travel per person, approaches significance at the 0.05 level.

One other important difference is evident among the communities. The time savings realized through trip chaining appear to be much greater for the less accessible communities. For the county as a whole, average travel time per trip declines only modestly as extra stops are added to tours. However, for Jupiter Farms residents on work-related tours, the average time drops from 32.6 min for one-stop tours to 19.3 min for three-or-more-stop tours (Table 4). Declines are also substantial for non-work-related tours made by Jupiter Farms residents and work-related tours made by Wellington residents, workplaces being relatively inaccessible to Wellington.

INTERPRETATION

Stepping back from the statistical tests and eyeballing the community averages, the understanding of travel patterns can be refined even as the conclusions become less confident. West Palm Beach's relative accessibility fails to induce large numbers of automobile users to switch to walking, biking, or transit; apparently, even the best accessibility in Palm Beach County is not good enough for travel by these modes. Yet because of their short automobile trips, West Palm Beach residents still save on VHT.

The community with the worst accessibility, Jupiter Farms, produces the highest average vehicle hours per person. What saves Jupiter Farms from even more VHT is its longer-than-average trip chains and, more importantly, the time savings realized with each additional stop in these chains.

Wellington is an interesting case study. It has the longest work trips by far, yet it still manages to generate fewer vehicle hours per person than West Boca or Jupiter Farms. Internal shopping and recreational facilities produce the shortest shopping and recreational trips of any community, more than offsetting the longer work trips.

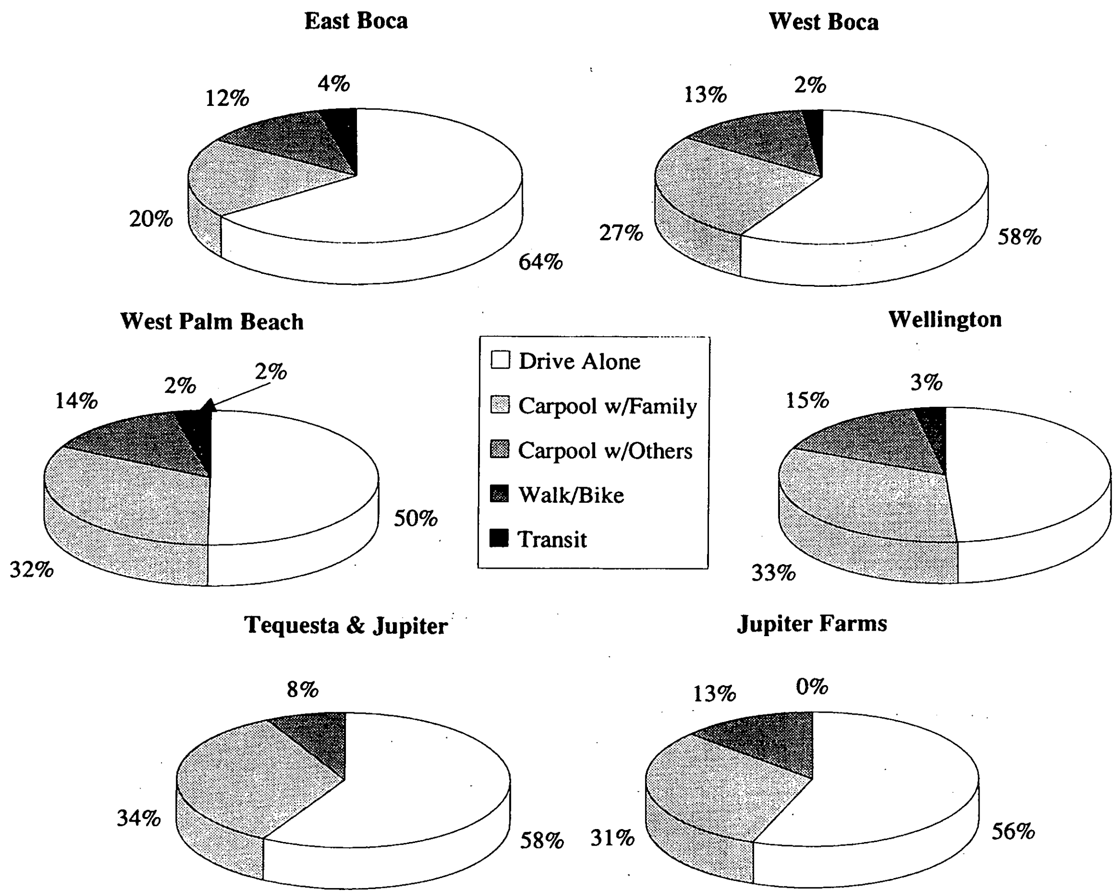

FIGURE 6 Mode splits in different communities.

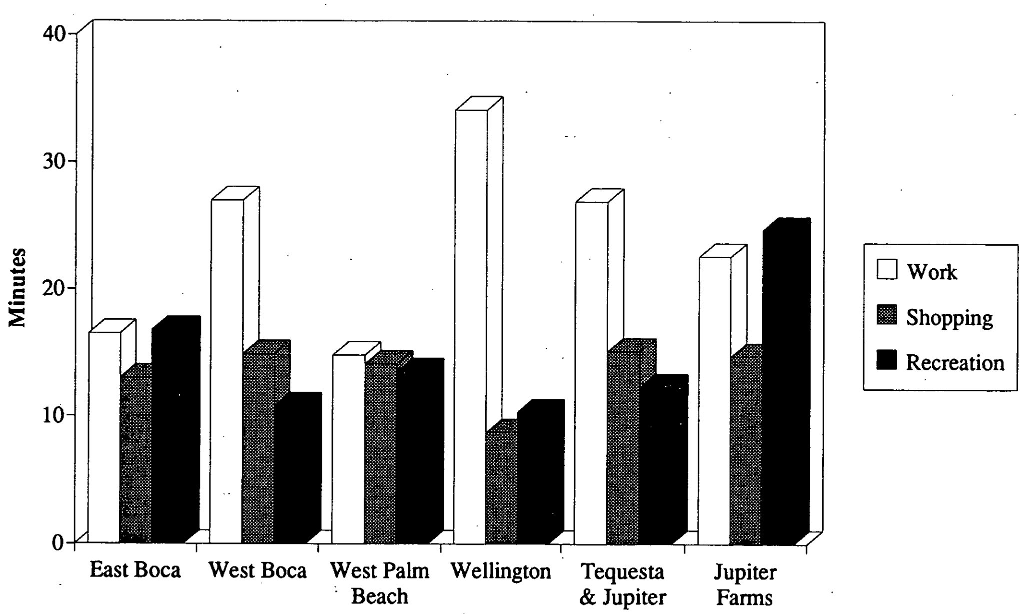

FIGURE 7 Average travel times in different communities.

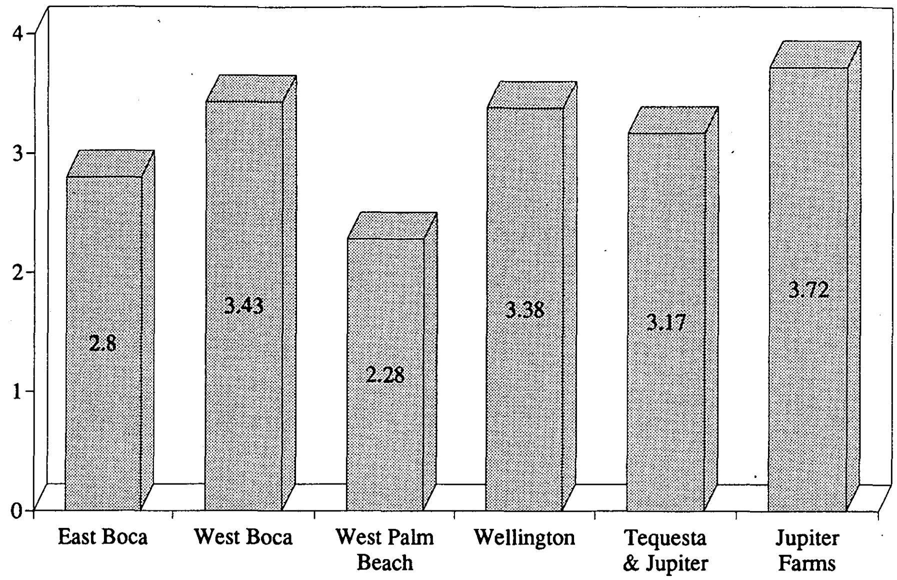

FIGURE 8 Vehicle hours per person in different communities.

TABLE 3 Analysis of Variance for Travel Characteristics Across Communities

Variable Tested	F-Statistic	Significance Level
Trips/Person (Work-Related)	0.76	0.58
Trips/Person (Nonwork-Related)	1.02	0.41
Trips/Tour (Work-Related)	0.65	0.66
Trips/Tour (Nonwork-Related)	0.53	0.75
% Drive Alone	1.26	0.29
% Carpool w/ Others	0.34	0.89
% Walk or Bike	1.51	0.19
Travel Time (Work)	2.79	0.02
Travel Time (Nonwork)	3.12	0.01
Total Hours of Travel/Person	2.72	0.02
Total Vehicle Hours of Travel/Person	2.16	0.06

Jupiter and Tequesta generate some very long non-work-related trips, a result no doubt of their strip development patterns. Even so Jupiter and Tequesta produce fewer vehicle hours per person than the best of the outlying communities. This makes the case for infill development generally, although one might prefer it take the form of East Boca or West Palm Beach.

CONCLUSIONS

In the study area, Palm Beach County, there is an inverse relationship between accessibility and VHT per person (Figure 9). Density, mixed use, and a central location all appear to depress vehicular travel. Even so, VHT does not reflect accessibility to the extent that one might expect. Although Jupiter Farms has 1/10th the accessibility of West Palm Beach, it generates only two-thirds more VHT. Urbanites drive a lot whether they need to or not, and sprawl dwellers can reduce the amount of driving they do through careful trip scheduling.

What saves Wellington from horrendously high VHT is great accessibility to internal shopping, recreation, and school facilities. What keeps Jupiter Farms from being an unmitigated traffic disaster is the accessibility of linked activities once residents make the long trip into town.

Implications for land planning are more complex than simply pedestrianizing or transitizing the suburbs. Communities should internalize as many facilities and services as possible. This is true even where the automobile reigns supreme, as in Wellington.

TABLE 4 Average Travel Time per Trip for Different Chain Lengths and Communities (in minutes)

	East Boca	West Boca	West Palm Beach	Wellington	Tequesta & Jupiter	Jupiter Farms	County-wide
Work-Related Tours							
1-Stop	14.4	23.6	16.1	39.1	27.1	32.7	23.9
2-Stops	17.2	17.4	17.3	19.5	24.5	25.6	21.6
3+-Stops	15.3	24.5	12.8	24.0	24.0	19.3	18.1
Nonwork-Related Tours							
1-Stop	11.3	12.5	15.3	14.0	14.4	15.5	16.8
2-Stop	13.6	17.9	13.5	13.1	14.1	31.5	18.6
3+-Stops	12.8	20.7	10.7	11.8	12.4	16.0	15.3

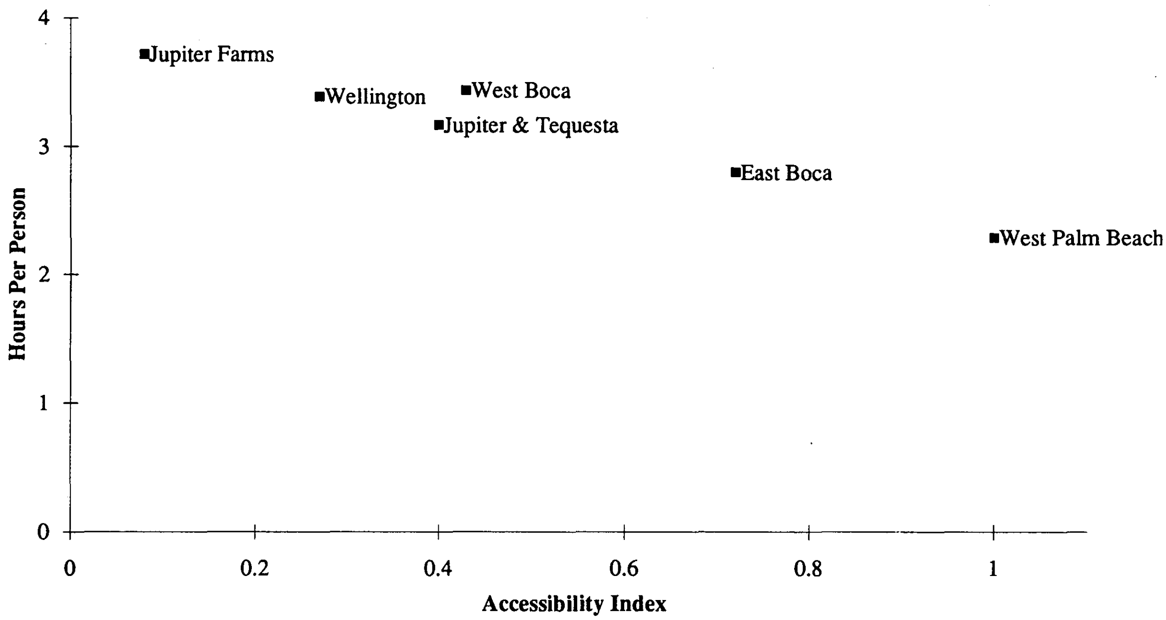

FIGURE 9 VHT per person versus accessibility.

Communities should concentrate facilities and services in activity centers. This will facilitate efficient automobile trips and tours. The more sprawling the area, the more important this becomes, for through activity centers, linked accessibility to activities can be maintained even as direct accessibility falls off.

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Publication of this paper sponsored by Committee on Transportation and Land Development.

Effect of Neotraditional Neighborhood Design on Travel Characteristics

BRUCE FRIEDMAN, STEPHEN P. GORDON, AND JOHN B. PEERS

Neotraditional neighborhood design (NTND) developments receive increasing attention as an alternative community design to standard suburban developments. By altering the spatial relationships through changes in zoning and transportation systems, automobile use is expected to be reduced. NTND requires the close proximity of residential and nonresidential uses connected with a straight, interconnecting street system and a network of bicycle paths and pedestrian walkways. Changes to the geometric design of streets reduce vehicular speeds. NTND has much in common with traditional developments. Because few NTNDs are built the authors researched trip files to see if residents of traditional (e.g., pre–World War II) and suburban (e.g., post–World War II) residential developments exhibit differing travel habits. The effects of traditional and standard suburban community design on household trip rates are evaluated. The analysis uses data from a 1980 regional travel survey of San Francisco Bay Area households. The findings indicate that households in newer suburban tract communities use vehicles more, whereas households in traditional communities rely more on alternative modes of transportation. When considering the results of the study for NTND design, remember that not all mode choice factors that exist in older traditional-design communities would be duplicated in a modern NTND. The findings show that community design and urban form have a significant influence on travel behavior. However, more research is needed to identify the relative influences of household income, automobile ownership, and other socioeconomic factors on trip generation and mode choice.

The 1980s witnessed extraordinary growth in traffic congestion in metropolitan regions throughout the United States. This phenomenon occurred not only in the nation's older metropolitan areas but also in suburban areas developed since World War II. That irony is not lost among city planners and transportation professionals who perceive increasing amounts of travel delay. For it was members of these professions who were largely responsible for the evolution of urban and suburban development patterns that are most common today.

Today's standard suburban development pattern commonly features segregation of land uses served by a strict hierarchy of roadways. Among other reasons this pattern evolved out of efforts to remove through traffic from residential streets to enhance safety and maximize capacity for vehicular traffic to enhance regional mobility. With a few exceptions, one could argue that before the 1980s these broad goals had been largely achieved and in fact will continue to be met in several parts of North America. However, continued growth in the suburban areas of larger urban areas, combined with the inherent difficulties faced by local and state officials responsible for providing sufficient regional transportation system capacity, will result in increasing amounts of congestion and delay.

This has led several urban planning and transportation professionals to revisit the fundamental assumptions that guide typical new development patterns. Many now believe that continued reliance on now-standard models for the development of large areas will have an increasingly negative impact on congestion, environmental quality, and in the long run, economic growth.

Two years ago the state of California enacted congestion management guidelines intended to control urban economic growth, congestion, and air quality by strengthening the connection between regional land-use planning and transportation capacity improvements. (California's Congestion Management Program was established as part of a statewide transportation funding measure approved by voters in 1990.) Administered at the county level, this process includes incentives for local jurisdictions to consider measures that not only facilitate traffic flow (i.e., capacity improvements) but also slow traffic growth attributable to new development (i.e. various transportation demand management measures).

Among those measures being considered in some California counties are alternative design models for new communities. These have been referred to as neotraditional neighborhood design, transit-oriented design, or the pedestrian pocket. A pedestrian pocket community known commercially as Laguna West is now under construction in Sacramento County. Several others of varying size have been proposed or designed. Neotraditional design features are typically reminiscent of pre–World War II small-town development patterns, which featured

- A neighborhood or town center district with considerable pedestrian access and consisting of mixed commercial and office uses;
- Connected grid street patterns that enhanced accessibility along alternate routes between the town center and adjacent residential neighborhoods;
- Close proximity between different land uses, which provided increased pedestrian access to local residents;
- Relatively narrow residential streets with on-street parking and tree canopies; and
- Small home lots with accessible public parks and recreational areas.

Neotraditional design proponents advance it as an alternative to standard suburban design on the basis of the claims that they help address regional congestion and broader goals such as air quality, energy conservation, and the preservation of open spaces. In effect they are seen as a potential way to manage travel demand through community design. To date little documented evidence exists to support claims of their effectiveness in reducing automobile trips and vehicle miles traveled (VMT). This is attributable to the lack of travel survey data available from modern, fully built neotraditional communities.

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NEOTRADITIONAL TRANSPORTATION SYSTEM GOALS AND VMT REDUCTION

In the neotraditional community the automobile should be relied on less than in standard suburban development tracts. The overall transportation objectives are to reduce the number of vehicle trips and (VMT) by

- Limiting automobile use to the most appropriate or necessary purposes by minimizing automobile use for intracommunity travel and commutation;
- Maximizing the opportunities for and attractiveness of alternative modes, including walking, bicycling, and transit use; and
- Addressing public safety concerns through separation of pedestrians and cyclists from vehicular traffic and by slowing vehicular speeds through roadway design.

Ideally, the best way to measure the effectiveness in achieving these goals is to estimate the reduction in vehicle trips and VMT that is mostly attributable to the community and transportation system design. However, no completed neotraditional community exists.

Several recently published articles on neotraditional design recommended new design parameters and guidelines for planners and engineers. One recent paper estimated changes in travel patterns based on the potential reduction in trip generation rates as a function of lower automobile ownership rates among neotraditional community residents (*1*). Although this is a plausible assumption, the estimated reductions are based on conjecture.

This paper reviews statistics from the San Francisco Home Interview Surveys conducted in 1980. It focuses on trip generation reported by residents of pre–World War II and post–World War II residential developments and comments on the comparison of the results from these two subsets. Then criteria for each community type are described.

STUDY METHODOLOGY

By using data extracted from household travel surveys in the San Francisco Bay Area, estimates were made of the relative differences in trip rates among residents of communities designed as standard post–World War II suburbs and residents of older, more traditionally designed communities. The analysis involves a comparison of actual travel data collected from residents of several such communities in the San Francisco Bay Area (*2*).

Differences in trip rates attributable to community design are estimated by comparing the relative differences in actual travel behavior among residents of each type of community. These differences are evaluated by trip type, community design, and other factors.

Trip Types

The Bay Area Transportation Survey (BATS) obtained daily travel characteristics for various trip functions. Survey data were originally sorted into 10 trip categories and were aggregated into the following four categories for the purpose of this analysis.

1. Home-based work trips;
2. Home-based other trips: home/shop–home/change mode–home/person/social–home/education;
3. Work-based trips: work/shop–work/education–work/other–work/change mode; and
4. Non-home-based other trips.

Community Design

BATS coverage extended over the nine-county area shown in Figure 1. This nine-county area lies within MTC's jurisdiction (MTC is the regional transportation planning and project funding agency for the San Francisco Bay Area). This area was divided into the 34 superdistricts shown in Figure 2 and was further divided into 550 subzones (based on 1980 census tracts). The latter, more refined level of demarcation was used to identify survey zones. Communities in these zones were characterized as either standard suburban or traditional. For the purposes of this analysis, standard suburban refers to communities that

- Developed since the early 1950s with segregated land uses (i.e., minimal pedestrian access between residential and nonresidential uses),
- Have a well-defined hierarchy of roads,
- Concentrate site/area access at a few key points via major arterial roadways, and
- Have relatively little transit service.

We drew samples for the standard suburban statistics from various suburban communities located mostly in Contra Costa County (Concord, Pleasant Hill), Santa Clara County (Sunnyvale, Mountain View), and Alameda County (Fremont, Castro Valley).

Survey zones were labeled traditional communities if they

- Were mostly developed before World War II,
- Had a mixed-use downtown commercial district with significant on-street curbside parking, and
- Had an interconnecting street grid and residential neighborhoods in close proximity to nonresidential land uses.

The latter category included some residential neighborhoods within the cities of Oakland and Berkeley and some older, pre–World War II neighborhoods within suburban Bay Area communities. The analysis excluded any residential zones within the city of San Francisco because it contains little suburban-style development, has a high level of transit service and transit utilization, and a high jobs/housing ratio. It is unlikely that these characteristics could be recreated within a new town community to the extent that they exist in San Francisco or a similar large city.

The schematic drawings in Figure 3 illustrate the conceptual differences in community design and circulation patterns between the two land-use models. To simulate likely design conditions and demographics of neotraditional development, the extracted data sample excluded traditional communities in which local conditions were not likely to be replicated in a new development. For example, the analysis excluded residential areas that were adjacent to or within walking distance of urban downtown areas (i.e., downtown Oakland). Similarly, areas with newly developed exsuburban subdivisions that were relatively inaccessible to large employment concentrations at the time of the survey were also excluded.

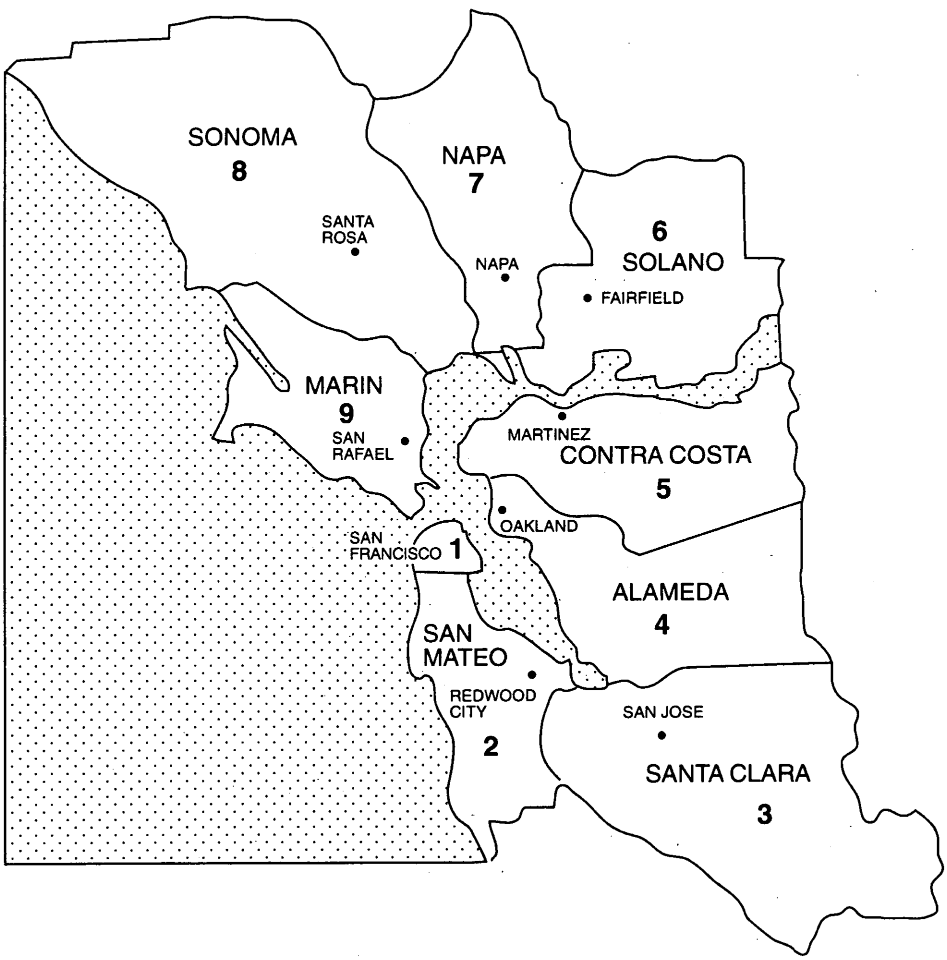

FIGURE 1 San Francisco Bay regional map: county names and codes.

Income Level

To replicate the conditions found in traditional neighborhoods, the Laguna West development in Sacramento County will include a variety of housing stock in price ranges that should attract an equally broad range of household income groups. Likewise, we included a broad range of income groups in the survey data profile. BATS grouped respondents into nine income categories, ranging from $0 to $100,000 in 1980 dollars. To reflect the likely target residential market, we included data on respondents in all but those in the lowest and highest income categories. This effectively eliminated households with incomes at the lowest income level (5 percent of all survey respondents) and the wealthiest 5 to 6 percent of all survey respondents. Thus, the data sample excludes those who would be most transit dependent and those who would be least inclined to consider alternate modes of travel. Approximately 18 percent of all survey respondents from both traditional and suburban areas did not respond to questions on household income. Their responses were also eliminated from the analysis.

Even with the high, low, and no response income categories removed, the mean household incomes in the suburban communities were on average 23 percent higher than the average household incomes in traditional communities. This analysis does not specifically address the potential effect of the income disparity on the study's findings. Recent research investigating the effect of household income on mode choice suggests that household income does positively correlate with automobile ownership and household trip rates. Subsequent research should therefore seek to equalize income levels within both survey populations to obtain more statistically reliable findings. However, the methodology of eliminating the highest and lowest income brackets employed in this study is seen as a reasonable first step to determine (a) if significant differences in travel characteristics between two community types do exist and (b) if there is a basis for performing more extensive, statistically significant analyses.

SURVEY FINDINGS

The comparison of travel characteristics between the standard suburban and traditional communities is summarized in Table 1. This section discusses key observations and findings.

Comparison of Total Trips Per Household

A comparison of total daily trip generation rates shows that the standard suburban rate (11.03 trips/household) was 25 percent higher than the rate for traditional communities (8.83 trips/household). The automobile-driver mode was used for 64 percent of all trips in the

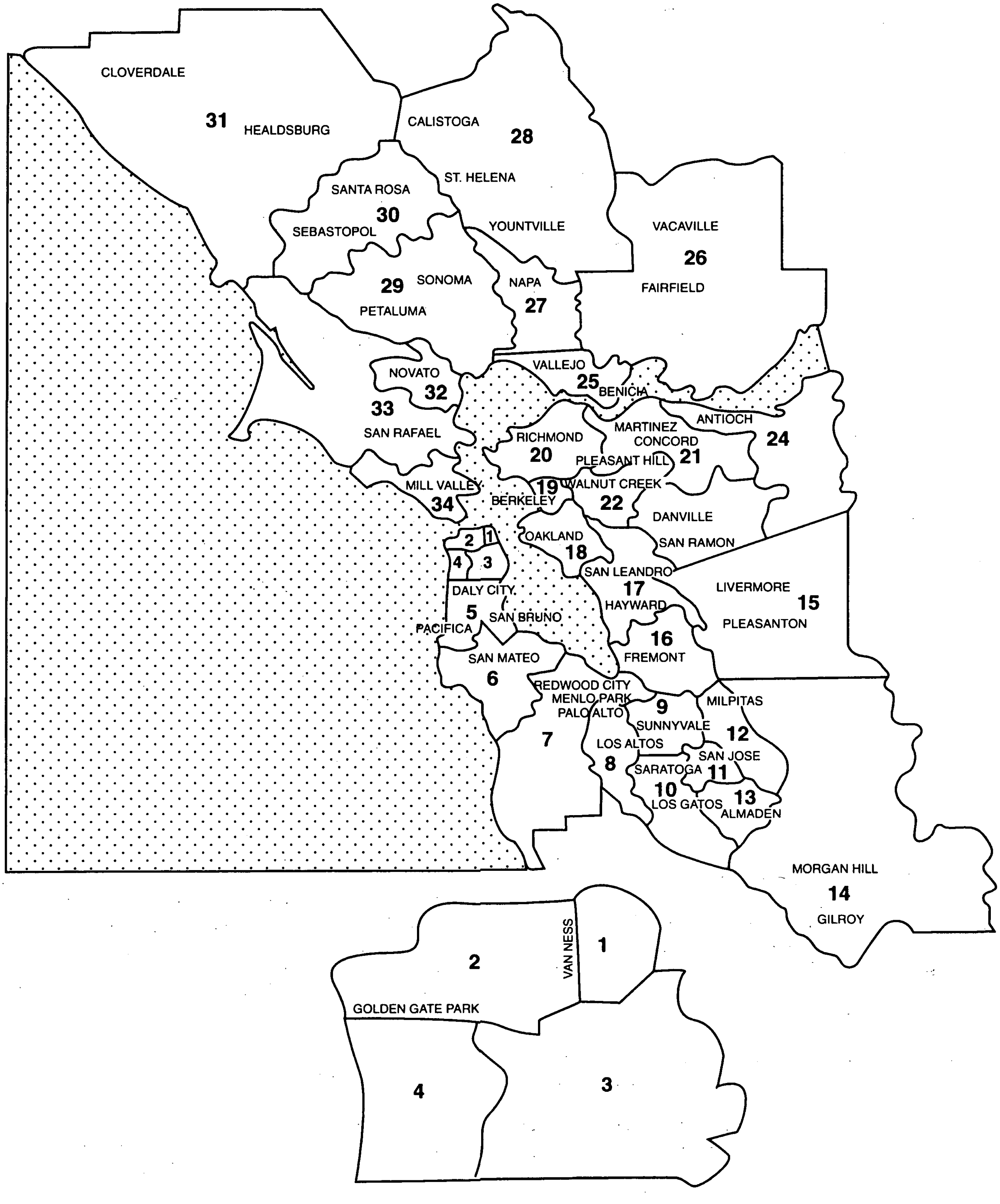

FIGURE 2 Thirty-four-superdistrict system based on 1980 census tracts and 550 travel analysis zones. (Source: MTC, October 1988.)

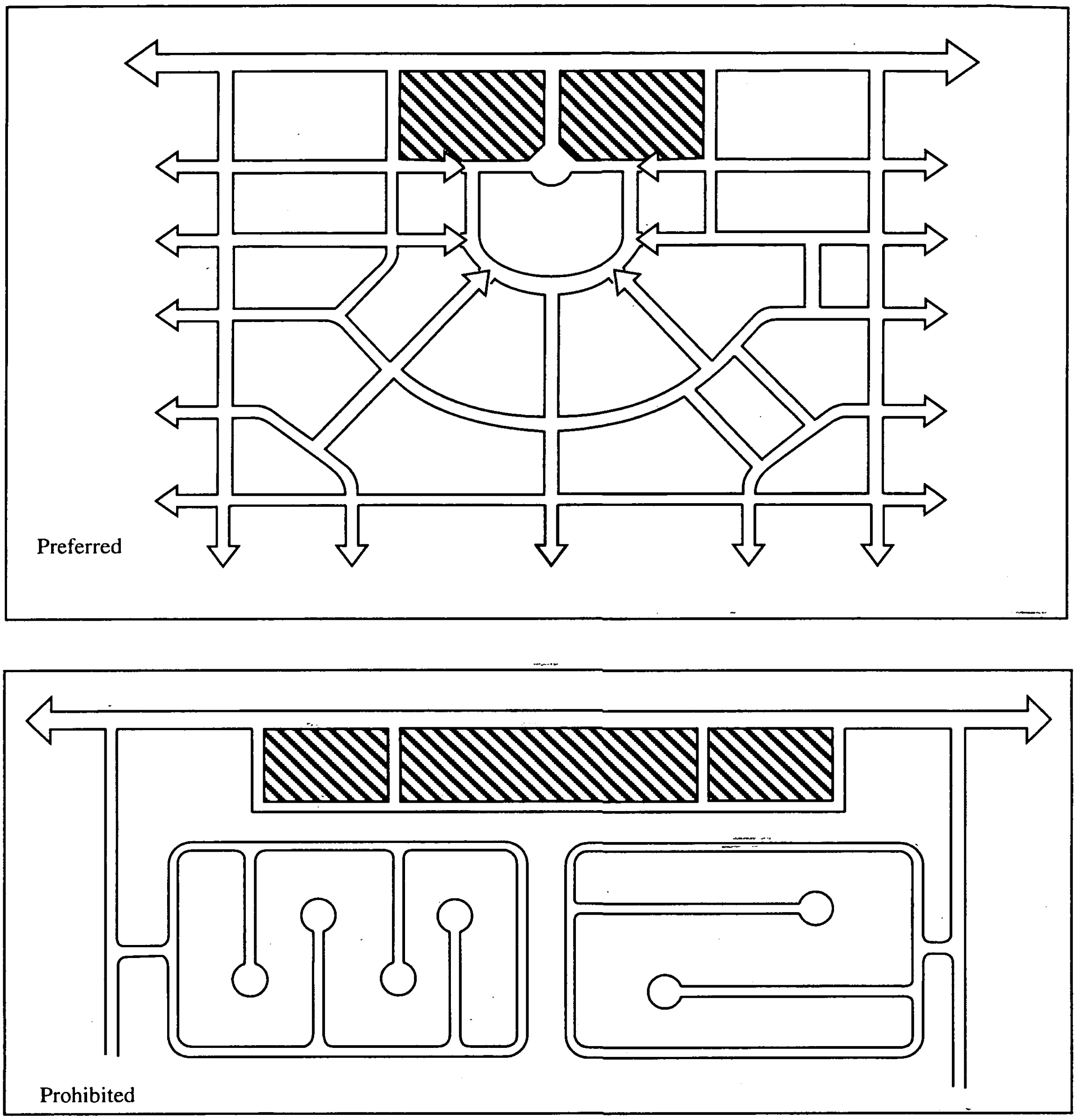

FIGURE 3 Street network comparison: pedestrian pocket versus standard development guide. (Source: Transit-Oriented Development Design Guidelines, Calthorpe & Associates, 1990.)

suburban areas but only 61 percent of all trips in the traditional areas. Automobile use for all trips was about 32 percent higher in the suburban areas (7.1 trips/day) than in the traditional areas (5.35 trips/day). Note that the total number of households surveyed was 7,091. The standard suburban subpopulation was 709 households, and the traditional households numbered 396. Once the high- and low-income groups were removed the final numbers of subpopulation households were 450 and 222, respectively.

Comparison of Trip Percentages

Home-Based Work Trips

The automobile-driver (or drive-alone) rate for standard suburban communities (83 percent) was 14 percent higher than that for traditional communities (73 percent drive-alone rate). Carpooling was slightly higher in traditional communities (9 versus 7 percent), and use of alternative modes (transit, bicycle, pedestrian, other) was almost double—19 versus 10 percent for standard suburban communities. Transit use alone in the traditional community (11 percent) was nearly three times the rate for standard suburban communities (4 percent). The relative shares of pedestrian and walk travel were roughly equivalent—4 percent (traditional) versus 3 percent (standard suburban).

Home-Based Non-Work Trips

Although the differences in mode choice did not contrast as sharply in this trip category, the differences were still significant. The

TABLE 1 Trip Characteristics of Residents of Traditional Communities Versus Standard Suburban Subdivisions and Number of Daily Trips per Household

	Home-Based Work		Home-Based Nonwork		Work-Based Other		Nonhome-Based		All Trips Combined	
	Community									
	Traditional	Suburban	Traditional	Suburban	Traditional	Suburban	Traditional	Suburban	Traditional	Suburban
Mode of Travel										
Auto Driver	73%	83%	51%	60%	70%	77%	58%	66%	61%	68%
Auto Passenger	8%	7%	21%	23%	7%	11%	19%	25%	16%	18%
Transit	11%	4%	7%	3%	5%	2%	4%	1%	7%	3%
Bicycle	2%	2%	6%	3%	2%	1%	2%	1%	4%	2%
Walk	4%	3%	14%	10%	15%	8%	17%	8%	12%	8%
Other	2%	1%	1%	1%	1%	2%	0%	0%	1%	1%
Total	100%	100%	100%	100%	100%	101%	100%	101%	101%	100%

NUMBER OF DAILY TRIPS PER HOUSEHOLD

Mode of Travel	Community Traditional	Community Suburban
Auto Driver	5.3	7.07
Auto Passenger	1.41	1.88
Transit	0.62	0.29
Bicycle	0.35	0.24
Walk	1.06	0.83
Other	0.09	0.72
Total	8.83	11.03

Compiled from data files from the Bay Area Transportation survey (BATS), 1980, Metropolitan Transportation Commission

automobile-driver rate in standard suburban communities was 15 percent higher than that in the traditional communities, and the combined automobile-driver/auto passenger rate was 14 percent higher. Combined use of alternate modes was 65 percent higher in traditional communities (28 percent) than in standard suburban communities (17 percent). Transit use was more than twice as high (7 versus 3 percent). Pedestrian travel was 40 percent higher (14 versus 10 percent). The largest proportion of walk trips in standard suburban communities was for home-school trips. Bicycle travel in traditional communities (6 percent) was twice the rate in suburban communities (3 percent).

Work-Based Other Trips

The mode choice patterns in this category reflect the mode choices for the home-to-work trip described earlier. Mode choice for trips from the workplace generally mirrored the mode used to commute to work. Combined automobile-driver/automobile-passenger rates were about 14 percent higher for the standard suburban areas (88 percent) than for the traditional areas (77 percent). Walk rates for the traditional community residents was 15 percent, versus 8 percent for suburban community residents.

All Trip Purposes Combined

The overall suburban area automobile-driver rate (68 percent) was about 11 percent higher than the rate for traditional areas (61 percent), and the combined automobile-driver/auto passenger rate for suburban areas was 12 percent higher than that for traditional areas. Overall transit use in the traditional areas (7 percent) was about more than double the rate in suburban areas (3 percent). Bicycle use in both areas was relatively low but was higher in traditional areas (4 percent) than in suburban areas (2 percent). Pedestrian activity in traditional communities (12 percent) was 50 percent higher than that in Suburban communities (8 percent).

Figure 4 compares trip percentages and trip rates graphically for all purposes combined.

CONCLUSIONS

The survey findings presented here illustrate significant differences in surveyed travel behavior between the residents of traditional communities and those of suburban communities. Of particular interest are the higher total household trip rates and automobile trip rates found among residents of communities with standard suburban design characteristics. The significant differences in urban design between the two sets of communities from which survey responses were tabulated may affect travel characteristics among respondents. In the traditional communities the relative proximity of housing to nonresidential, commercial land use and the availability and attractiveness of alternative travel modes may make automobile travel less needed and impractical for some trips.

However, these findings are preliminary, should not be considered conclusive, and raise questions that indicate the need for more research. For example, what causes the difference in household trip generation rates between the survey populations? This may be

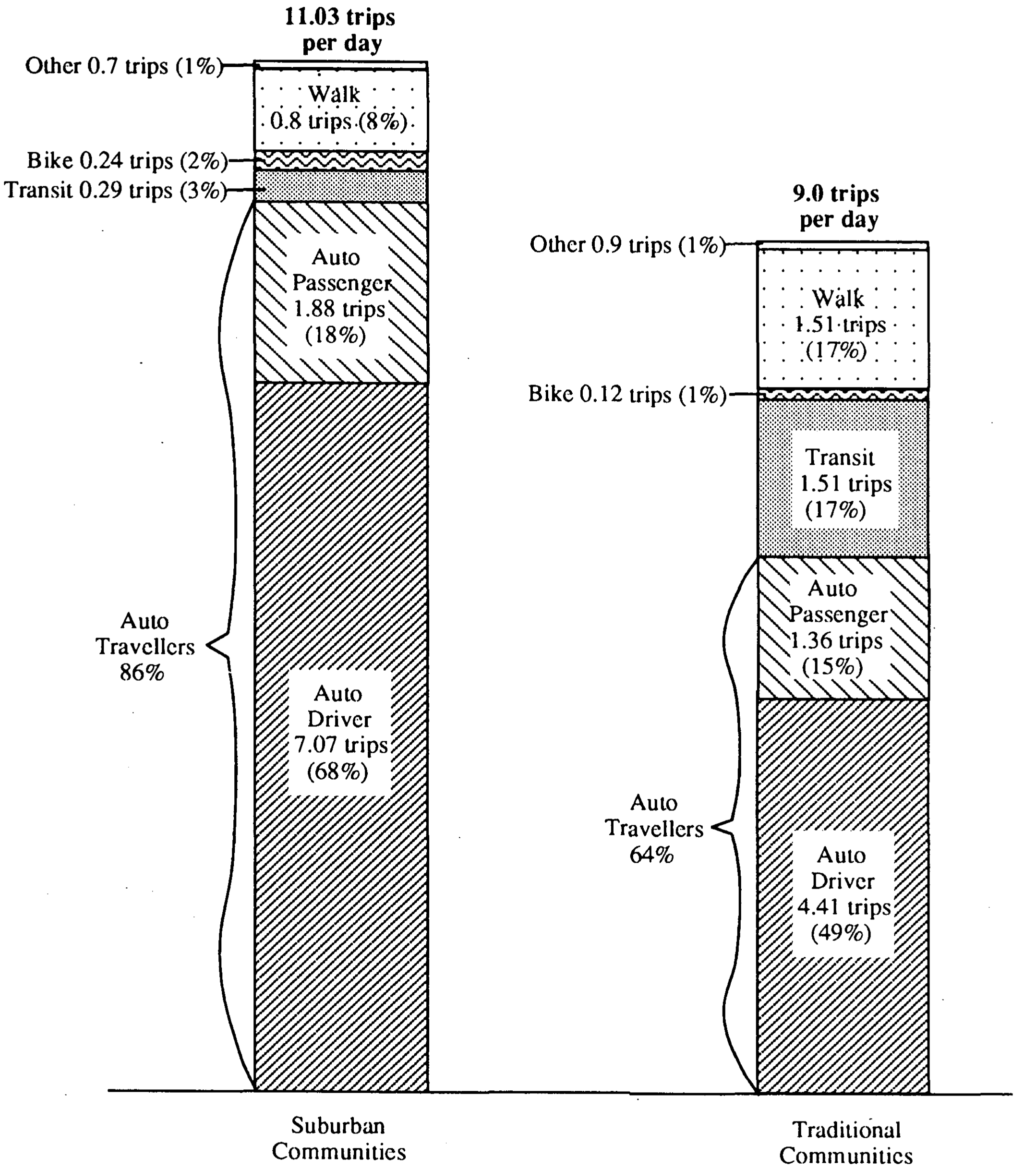

FIGURE 4 Mode choice comparison for all trip types in San Francisco Bay Area: representative samples for suburban communities and traditional communities.

explained by the 23 percent income disparity between the two study groups. Other demographic factors such as household size may also be significant. Follow-on research is needed to isolate and determine the relative impacts of these variables on trip generation and mode choice. Still, the significant degree of variation in travel behavior identified in this comparison indicates that urban form may exert some influence on travel behavior.

Practitioners hoping to use these findings for future applications should not draw direct parallels to expected travel behavior within a neotraditional setting. Several factors prevent such direct comparisons. The traditional communities included in this study have evolved over periods of six or more decades in settings that became increasingly urban over time. Their development was facilitated with the type of infrastructure that is not likely to be duplicated in new nonurban or small urban settings. Specifically, these factors include.

- Access to extensive public transportation networks,
- Close proximity to large employment concentrations that are well served by extensive local and regional transit systems, and
- Lack of secure off-street parking.

It could take years, perhaps decades, for one or more neotraditional communities to evolve to the extent that travel patterns would closely match those of older traditional urban communities. One must also consider the larger geographic context in which a neotraditional community is developed. For example, if a neotraditional community is built as an "island" surrounded by standard suburban subdivisions (as in the case of Laguna West), aggregate changes in overall travel behavior could be limited.

However, these findings do indicate the type of shift or changes in travel behavior that could transpire as neotraditional developments mature. The data contained in Table 1 show that traditional households generate 25 percent fewer daily trips by all modes than suburban households and 32 percent fewer automobile-driver trips. These reductions probably represent an upper limit to what one could expect among neotraditional community residents. Actual results will depend on a number of factors, including

- Proximity and access to large employment concentrations, such as the downtown central business district of a large city;
- Socioeconomic cross section within a neotraditional community;
- Internal jobs-housing balance;
- Individual neotraditional design characteristics, that is, average distances between residential and nonresidential land uses, and the quality and convenience of facilities to accommodate alternate modes of travel such as bicycle paths and walkways;
- Availability of (free) parking near nonresidential land uses; and
- Quality of transit service to internal and external points.

The manner in which these findings should differ from actual future results is in (a) the percentage distribution of travel among the alternative mode choices and (b) the degree of reduction one could expect for automobile trips. These differences are discussed further in the following sections.

Potential Shifts to Alternative Modes

Transit use is higher in the traditional communities, in part because of the availability of bus and rail networks and good levels of service. Given the service-dependent nature of transit patronage, replicating these mode shares within a neotraditional community is not likely to occur in a development's first 10 to 15 years of existence. This would only occur if the development is a large infill project located within a dense urban redevelopment environment with an existing transit infrastructure or if the project is located near a large, diverse employment concentration and is provided with excellent transit service. The proposed Mission Bay development in San Francisco is an example. In lieu of these factors transit use may be only marginally higher than that in a standard suburban environment.

The survey indicated that bicycle use in traditional communities is low, albeit higher than that in standard suburban communities. Some of the planned neotraditional communities such as Laguna West have taken significant steps to encourage bicycle use through bicycle path facility design and the provision of bicycle parking facilities in nonresidential areas. Similarly, plans for other neotraditional communities include extensive pedestrian walkway facilities linking residential and nonresidential areas. Such user-friendly designs and the availability of these facilities could result in higher pedestrian and bicycle mode shares than in standard suburban communities.

Potential Reductions in Automobile Trips

Use of these findings to estimate trip reductions attributable to neotraditional design is complicated by the need for additional research and inherent differences between existing traditional and new, neotraditional communities described previously. This study does not conclusively determine that urban design alone results in lower household trip rates when all socioeconomic variables are held equal, although the degree of difference found indicates that urban design may be a contributing factor. The availability of a mixed-use commercial core accessible to cyclists and pedestrians could theoretically result in some reduction in daily household trip rates. However, more research is needed to confirm this particular hypothesis and to distinguish the relative influence of urban design on travel behavior.

Finally, the extent to which neotraditional communities can replicate traditional communities, thus causing significant modal shifts, will depend on the degree to which the factors discussed in this paper will exist. If elements of these factors can be incorporated, significant mode shifts could occur voluntarily (i.e., without road or parking pricing measures). It seems that well-located neotraditional communities forming the majority of future development within a defined region could have significant benefits in addressing the regional congestion relief and air quality goals.

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Publication of this paper sponsored by Committee on Transportation and Land Development.

Land Use Transportation Models for Policy Analysis

ROGER MACKETT

The objective is to assess the ability of land use transportation models to address some current policy issues. The nature of the relationship between land use and transportation is examined briefly in terms of empirical evidence and the results from modeling exercises. Two studies that use such models and that are being carried out in Britain are examined. Despite these and some convincing arguments by experts, there is little evidence of widespread use of such models. A number of current policy issues are discussed, and then a set of policy instruments that can be used to meet the policy objectives are identified. Evidence on the ability of land use transportation models to represent the impacts of the policy instruments is presented. It is shown how such models can contribute significantly in some areas of policy analysis, for example, reducing congestion and energy use, but can contribute very little to the objective of moving toward a market economy.

The objective of this paper is to assess the ability of land-use transportation models to address some current policy issues. The paper focuses mainly on models that represent the two-way relationship between land use and transportation. This relationship is examined in more detail in the next section. Then the methods used to model it are considered in the following section. In the subsequent section some of the current policy issues in urban transportation are identified and the abilities of the models to address them are discussed. The paper is concluded with an assessment of the way forward.

NATURE OF RELATIONSHIP BETWEEN LAND USE AND TRANSPORTATION

Figure 1 shows the basic relationship between land use and transportation. The diagram shows that land use, that is, the spatial distribution of activities, determines the pattern and scale of trips that use the transportation system. Variations in this affect the level of accessibility, making some places easier to reach, others less so, and so affecting where development occurs. The left side of the diagram is represented by conventional transport models, either aggregate or disaggregate. The right side is represented in a variety of models that have been developed in various countries around the world. Many but not all of these represent the whole two-way relationship. The link from land use to transportation may be regarded as well established and understood, but the converse is much less so, partly because of the long time that it takes for such effects to occur and the consequent lack of empirical data.

There is little doubt that land use does change in response to changes in transportation infrastructure and thereby causes second-round effects on travel demand in addition to the direct effects caused by route and mode switching. This is likely to cause new roads to be used to a greater extent than that forecast by conventional methods. A good example of this is the M25 motorway around London, which was overloaded as soon as it was completed.

However, the nature of the response of land use is complex and causes much confusion. It is important to recognize that the land use response can cause extra traffic without any development occurring. If extra development is stimulated that is a third-round effect. The second-round effect is the result of people choosing a different set of homes and jobs because of the increased accessibility. For example, the opening of a new bridge across an estuary would allow people who work on one side to live on the other. That does not require new homes to be built, and people living on one side can now take jobs on the other side. These effects would lead to new trips above the number changing mode or route. Of course, if developers do build new dwellings, that would attract even more people to live there, causing even more trips. Some employers might choose locations to take advantage of the larger labor market caused by the bridge, producing even more trips.

Similar effects have been noted when railway lines have been electrified, thereby reducing travel times. This means that people can consider a wider range of areas in which to live. This implies that the potential commuters have some notional measure of the time that they are willing to spend traveling to work. If this is so, it implies that building a new major transport infrastructure that links to a major employment center will cause such relocation effects, and hence traffic flows may exceed those predicted by a conventional transportation model.

The three sets of effects may be summed up as

1. First-round effects: change of route and change of mode;
2. Second-round effects: change of residential location, change of employment location, change of shopping location, and change of trip distribution; and
3. Third-round effects: location of new dwellings, location of new jobs, and location of new shops.

If land use effects do occur they will be a form of redistribution rather than genuine generation. However, the redistribution effects may be from a long way away if they involve a change of home or job. Such effects have been modeled by the author for improvement to rail corridors around London using the Leeds Integrated Land-Use Transport (LILT) model (*1*). It was found that many of the extra trips on the improved corridor were due to people making a locational change as well as changing mode. It was found that about one-third of the extra rail trips on the corridor were by people who would have traveled by rail, but along other corridors, particularly the adjacent ones. The other two-thirds were switching mode and, in many cases, location. This effect has important implications for elasticity measurements based on observations on the line being modified, because the elasticity would not include the compensating effects elsewhere, and so would be an overestimate.

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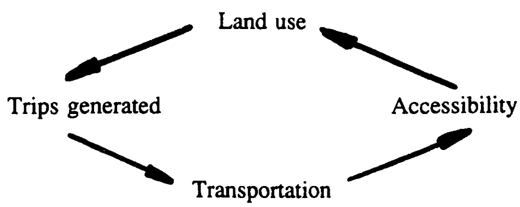

FIGURE 1 Relationship between land use and transportation.

The LILT model (*2*) has demonstrated two other land-use effects. The model was used to show the effects of changes in the price of gasoline and bus fares. The model was run in two ways: first, with spatial distribution of homes and jobs fixed, but allowing people to choose from the sets of homes and jobs, and second, allowing the patterns of homes and jobs to vary as well as the choice of them. Thus, in the former case the second-round effects were represented; in the latter case the third-round effects were added. It was found that when the cost of travel was changed in a way that favored car use, about two-thirds of the overall increase was due to the first- and second-round effects and the rest was due to the third-round effect.

The second phenomenon that the LILT model has demonstrated (*2*) is that when the pattern of homes and jobs is allowed to vary there is always more car use relative to keeping the location patterns fixed for changes in the cost of travel by car or public transportation in either direction. This is because car is the preferred mode. This suggests that as a new highway is built and development occurs there will be extra car use, because some people currently using public transport who are changing location will choose a new location that enables them to use their cars. This can be observed as part of the suburbanization process.

It is relevant to consider the empirical evidence of the land use effects of the building of transportation infrastructure. A major study was carried out on the impact of the Bay Area Rapid Transit (BART) in San Francisco. BART was found to have little impact on the net regional employment and population patterns (*3*), confirming previous evidence (*4*) and suggesting the need for the presence of other favorable factors (*5*). However, they were looking for third-round effects, which could take considerable time to appear. Kreibich (*6*) examined the effects of the building of the Munich, Germany, metro. He found that high-income families tended to move outwards and so exacerbated the separation of homes and jobs.

There have been several studies of the land-use impacts of new highways. The study of the Houston high-occupancy vehicle (HGV) highway (*7*) did not find much evidence of new development, but again, third-round effects were being sought. Moon (*8*) examined the development effects of interstate highway interchanges. He concluded that development does tend to occur there because certain organizations require access to the highway. Another study (*9*) found that land values tended to rise more near interchanges on interstate highways than elsewhere, and this was interpreted as evidence of urban development in response to highway construction.

Thus, the evidence on the land use effects of changes in the supply of transportation is not well defined. There is little doubt that such effects do occur. This lack of clarity means that there is not a single well-specified base on which models can be built. Instead there is a collection of different approaches. For example, Wegener (*10*) has examined 12 urban models and found that they include a wide range of theories. The modeling of these processes is considered in the next section.

MODELING

Transportation modeling started in the 1950s and became widely used as computers became more powerful. However, they were not always used in a sensible and sensitive manner, and there was the well-known backlash (*11*). Wegener (*10*) argues that this was partly due to the fact that such models were linked to the rational planning paradigm that was prevalent in the late 1960s. Boyce (*12*) argues that such models lost favor because of a mismatch between objectives, computer technology, and optimism. Other changes occurred that made them seem irrelevant. For example, during the early 1980s in Britain the government was unsympathetic to planning or anything else that could be labeled "social engineering" because it believed that "the market would provide." The market can provide some aspects of transportation, such as local bus services, but it does not produce large-scale public transportation systems or major highways because of the high cost and high risk. Given a free choice few investors would choose to put their money into transportation projects because they can obtain a better return elsewhere. However, it has become clear even to the British Government that a major investment in transportation is required and that it is useful to have some idea of the likely effects and to be able to compare alternatives in a systematic framework.

Two major transport proposals are being considered in Britain at present: road pricing in London and the rail link to the Channel Tunnel. Both proposals are being evaluated using very complex modeling frameworks.

Road congestion is now seen as a very real problem in London, which is causing London to become less attractive compared with other cities in Europe when it competes to provide a home to various international institutions (*13*). After years of prevarication the Department of Transport has set up a $5 million research program to investigate the merits of road pricing, which it can be argued is a procedure for setting up a market for road space. As part of the exercise a three-tier model is being set up. The middle tier is the London Transportation Studies (LTS) model, which is a conventional four-stage transportation model that is a direct descendent of the 1962 London Traffic Study model. It is still used to evaluate all major road proposals for London. Below this model in the hierarchy is a traffic simulation model that is used for local studies, and above it is a new strategic model that includes the effects on land use; it is being developed by the consultants Marcial Echenique and Partners, who developed the MEPLAN model (*14*).

The evaluation of the proposed Channel Tunnel Rail Link (The Union Railway) is also a very complex modeling structure. The issue is to determine an appropriate route for a new high-speed rail link from the Channel Tunnel into London. For passenger trains that use the Channel Tunnel (which is a railway tunnel with road vehicles carried on railcars), which opened 1994, the through passenger trains from Paris and Brussels, having used new high-speed lines on the eastern side of the Channel Tunnel, must use the existing track to travel the 100 km to London's Waterloo Station. It is predicted that this track will have reached its capacity by the year 2000, hence the proposal to build a new link. There have been debates between the Department of Transport and the Department of the Environment over the route, particularly through London, with the former supporting British Rail's proposal to follow the shortest, and hence cheapest, route, whereas the latter wanted a route more along the River Thames to help to stimulate development along the corridor. The Department of the Environment won the argument, but the station pattern still has to be decided. Since there will be spare capacity on the link, it is proposed that it be used for domestic traffic, that is, to carry commuters. The numbers carried will be influenced by the location of the intermediate stops, the train frequency, and routing. This is all being analyzed by using the complex modeling setup. Because the work is being carried out in a short time period, Union Railways Limited (a subsidiary of British Rail that will be sold to the private sector), which is building the railway, is having to use a variety of models since none of the existing ones could meet all of the requirements. The procedure followed to examine the impact of a particular route, station pattern, or train frequency is to find the revised travel times between pairs of zones through the rail network by using the tree-building elements of a model called the Union Railways General Evaluation Network Tool (URGENT). These are then entered into the generalized cost elements for the LILT model mentioned earlier. This is used to find the trip distribution and modal split pattern, allowing the choice of home and job to vary for subsets of the population. The rail trip pattern is then assigned to the appropriate detailed rail network by using URGENT, and an economic evaluation is carried out (*15*). The LILT model shows that the areas of increased rail accessibility would attract more residents who wish to commute by rail, mainly to central London. They occupy dwellings that would otherwise have been occupied by people commuting elsewhere, usually by car.

There are a number of models of the interaction between land use and transport, as shown in Figure 1. Usually the models contain all of the elements of the conventional four-stage travel demand model, that is, trip generation, trip distribution, modal split, and assignment. In some cases assignment is not included, with the model focusing on strategic issues rather than detailed network effects. Usually, trip distribution comes directly from the locational element of the model. The models include the choice of residence and employment as functions of the accessibility to the opportunities available, that is, homes and jobs, respectively. Some models include the explicit locations of new homes and jobs. The accessibility term contains travel time and cost plus other relevant factors, usually in the form of generalized cost. The models work over time, often incorporating time lags between the variables as the response of land use to changes in the transportation system occurs over a number of years.

The Transport Research Laboratory, which is part of the U.K. Department of Transport, organized a systematic study of land use transportation models by setting up the International Study Group on Land-Use Transport Interaction (ISGLUTI). Part of the original rationale behind the study when it was set up in 1980 was to examine whether the decline in urban public transportation patronage was inevitable or whether land-use policies could be used to reverse the trend. A more general interest was to see whether the long-term effects of transportation policy are simply magnifications of the short-term effects or whether at least some aspects operate in the opposite direction. The work included models from Britain, the United States, Germany, Japan, Australia, Sweden, and The Netherlands. In the first phase of the work (*16*) the models were analyzed in detail, and a series of policy tests was used to examine the impacts of policy. In this phase of the work the policies were examined by using the original data bases on which the models had been applied. This meant that the variations in the responses could have been due to the behaviors of the models or the nature of the cities. To overcome this difficulty, in the second phase of the work a subset of the models was applied to other study areas (LILT to Dortmund and Tokyo and Marcial Echenique and Partners' MEPLAN model to Dortmund and Leeds). This meant that three models were applied to Dortmund in Germany [the original DORTMUND model developed by Wegener (*17,18*), LILT and MEPLAN], two were applied to Leeds (LILT and MEPLAN) (*19*), and two were applied to Tokyo (LILT and the CALUTAS model) (*20*). This work enabled comparative analysis of the ability of the models to predict the impact of policy. The policies examined included the effects of changes in transport costs, changes in travel speeds, such as those caused by the introduction of bus-only lanes, and changes in employment and retailing location policies and measures to improve the vitality of the central areas of cities, measures to reduce urban sprawl, and measures to reduce resource consumption. There did appear to be some discrepancies between the responses of the models, but these can be explained by examination of the structure of the models and their representation of the study area (*21*). For example, it was shown that differences between the models of the effects of changing the cost of car travel on employment location could be explained by the nature of the logit functions used in the models and the relative dominance of other modes.

The ISGLUTI study (*22*) covered nine of the urban models that exist, but as Wegener (*10*) has indicated, there are at least 20 groups of urban modeling centers around the world, with clusters in the eastern United States, western Europe, and Japan, with others in places as far apart as Chile and Australia. Each of the centers has developed one or more models, so many models are available. Both Boyce (*12*) and Wegener (*10*) argue that many of the weaknesses of the complex urban models of 25 years have been overcome. The advances that have been made include better theory, greater computing power, and better algorithms.

Thus, a large number of models are available, many of the weaknesses have been overcome, there has been a systematic study of a number of the models, and there are two examples in Britain of the use of such models in current studies. However, despite all of these factors there does not seem to be widespread application of such models.

Potentially these models have a great deal to offer in analytical terms. The growing awareness of the impact of transportation means that they should be used if they can offer analytical assistance. In the next section the relevance of the urban models to some of these issues will be considered.

POLICY ANALYSIS

In this section some of the current transport policy issues are considered, and the appropriateness of integrated land use transportation models will be examined.

The following are some of the more significant transport policy issues:

1. Congestion. Cities are becoming more congested as car ownership and use grows. Congestion causes travel times to increase and makes journey planning more difficult as variability increases. It can cause the environment to deteriorate as vehicles travel below their optimal speeds. Hence, a policy objective is to reduce congestion.
2. Energy. There are finite energy resources, and transportation uses a significant proportion of them. As the population moves outward from the city, trips become longer, and cars are used more,

energy usage increases. There is a need to reduce energy consumption. This can be done partly by using more efficient car engines, but there is a need for more drastic action.

3. Safety. Although road safety is improving in many countries, particularly when compared with the rate of growth in car use, there is still scope for improvement. Public transport accidents are relatively rare, but they can be the cause of many fatalities.

4. Environment. Cars produce many pollutants, not only emissions but also noise. Technical innovation can reduce these, but it is very unlikely to eliminate them.

5. Quality of life. Transport is the means to reach opportunities distributed in space, and so improving access can improve the quality of life. There may be a conflict here with other policy objectives.

6. Social inequalities. As some people become richer and acquire more material goods, the gap between them and those without grows wider. Many poor people have no car, so appropriate public transportation is necessary to provide opportunities for such people. It is important to monitor the social impact of policy to see whether the gap between the rich and the poor is narrowed.

7. Public expenditure. In many countries, including Britain, there is a move to control public expenditure to try to control the economy. Transportation is a major item of public expenditure, so a policy of reducing public expenditure is likely to affect investment in transportation.

8. Market economy. Many countries in eastern and central Europe are now moving from a planned to a market economy. The changes include the transportation sector, which means selling state-owned enterprises, often breaking them up into smaller organizations and trying to introduce a market culture into the workforce.

There are other areas of concern, but the eight topics identified here cover a wide range. Although one could consider the application of the models directly in these areas, it is more rigorous to consider a set of policy instruments that can be used to address one or more of the policy objectives identified in the previous list, since the models can be used to examine the effectiveness of the policy instruments in terms of achieving the objectives. In fact some policy instruments may have a negative effect on the achievement of some objectives, implying a conflict between the objectives. The models are useful for exploring such conflicts.

The following policy instruments are available to one or more levels of government.

1. Restriction of peripheral development. In many countries, including Britain, local government has control over where development occurs, often by some form of zoning. This means that it is possible to prevent (or at least slow down) development on the periphery of urban areas.

2. Gasoline tax. Government decides the level of taxation on gasoline. If it is increased, the cost of car use will go up, reducing the level of car usage, and possibly of car ownership. Conversely, a gasoline tax reduction will cause an increase.

3. Public transportation subsidy. Government can decide to pay money to public transportation operators in an attempt to achieve various policy objectives, such as reducing car usage or for social equity reasons. Reducing car usage may be part of a package of measures to conserve energy, reduce pollution, and increase safety.

4. Investment in highways. Public (or private) funding can be used to invest in highways. Usually the appraisal system requires the evaluation of various options, and models can be very useful for determining the impacts of the possible alternatives. As discussed earlier such developments are likely to have implications for land use, which in turn affects the demand for highways.

6. Investment in public transportation infrastructure. Arguments similar to those presented earlier apply to the investment in public transportation infrastructure.

7. Transportation system management. Transportation system management is the modification of the operational characteristics of the system to increase efficiency from the existing facilities. It can include traffic management schemes involving linking traffic signals, ramp-metering to influence access to major highways, and introducing bus-only lanes.

8. Transportation demand management. This is the use of measures such as encouraging carpooling, flexible working hours, and employer subsidies to buy public transportation tickets to change the behaviors of motorists.

9. Road pricing. Charging for the use of road space may be introduced to achieve several objectives, including reducing congestion and reducing public expenditure. It will reduce car usage and raise revenue.

10. Privatization. Much transport infrastructure is publicly owned and so uses public money. It can be argued, as the British Government does, that privatizing transport facilities will improve efficiency and ensure that supply is better matched to demand.

11. Deregulation of local transport services. Deregulation encourages competition and, it can be argued, as the British Government does about bus deregulation, which took place in 1986, causes costs to be reduced and also ensures that supply better matches demand.

These policy instruments link to the policy objectives, as shown in Table 1. The relationships are not simple, and the strengths of the linkages are subjective. Nonetheless, it is useful to illustrate the existence of such relationships so that the policy objectives can be linked to the land-use transportation models via the policy instruments. The policy objectives have been specified in terms of the direction in which policy wishes to move. The links are expressed as positive or negative relative to the indicated direction for the policy instrument. The strength of the relationship is indicated by the number of signs. Thus, an increase in a gasoline tax is expected to have a very strong effect on a reduction in congestion but a fairly weak effect on reducing public expenditure. In many cases there are several effects at work, and the symbol in Table 1 indicates the net effect. It is fully recognized that this is a subjective procedure, but it serves several purposes. First, it shows that many policy instruments will help one objective but will hinder progress toward another, and so there are conflicts; second, it shows that there is more than one way to achieve many of the objectives, and so there is a need for analytical tools to help judge the one that is the most appropriate; third, it permits linkages with the land use transportation models, as shown in Table 2. This shows the strengths of the various effects that might be expected. These are shown as the first-, second-, and third-round effects discussed earlier. The first-round effects would be shown by a conventional transport model, but the others only appear in integrated land use transport models.

It is pertinent to examine the evidence for these effects from various models, because if it is valid then it can be related back to the policy objectives listed in Table 1. The evidence for the impacts of policy comes mainly from the ISGLUTI work discussed earlier, particularly from the second phase of the work in which several models were applied to the same city, since this helps to distinguish

TABLE 1 Linkages Between Policy Instruments and Policy Objectives

	Policy objective							
Policy instrument	Reduce Congestion	Reduce energy usage	Increase safety	Improve the environment	Improve the quality of life	Reduce social inequalities	Reduce public expenditure	Move towards a market economy
Restriction of peripheral development	++	++	+	+	?	+	+	?
Increase in gasoline tax	+++	+++	++	++	?	++	+	?
Increase in public transportation subsidy	++	++	++	++	+	++	-	_
Increase in investment in highways	?	--	?	+	?	-	-	?
Increase in investment in public transportation infrastructures	++	++	+	+	+	+	-	?
Increase in transportation system management	++	+	+	+	+	?	-	?
Increase in transportation demand management	++	+	+	+	+	+	+	?
Introduction of road pricing	++	++	+	+	+	+	+	+
Privatisation	-	-	-	?	?	-	+	++
Deregulation	-	-	-	?	?	-	+	++

Note:
+++ very strong positive relationship
++ strong positive relationship
+ weak positive relationship
? relationship not clear
- weak negative relationship
-- strong negative relationship
--- very strong negative relationship

the differences caused by the models from those caused by the cities. In all cases the cities are decentralizing, and so the land use effect is in terms of the speeding up or slowing down of this process. Similarly, car ownership is increasing in all cities, so the effects are also in terms of speeding up or slowing down the growth. In theory it would be possible to reverse the processes, but this would require huge changes in the inputs. The discussion will focus mainly on the first- and second-round effects, because at an urban scale the third-round effects tend to be very difficult to detect. It should be stressed that the analysis here is essentially illustrative, to show that land-use transportation models can demonstrate such effects, rather than a definitive statement of the impacts.

1. Restriction of peripheral development. This was examined in the ISGLUTI work by examining the effects of urban growth with and without restriction on development at the urban periphery. In the application of the LILT and MEPLAN models to Leeds, a city in the north of England (*19*), both models showed that peripheral restrictions would slow down the decentralization of population and employment, reduce the growth in car ownership and car use, and reduce the distance traveled. The models did not agree on which alternative mode would gain from the loss of car trips: LILT said that public transportation would grow more, whereas MEPLAN said a greater number of people would walk. As shown elsewhere (*21*) this difference arises from the base modal split and the nature of the logit model, whereby the alternative mode with the greater initial share gains more of those shifting mode. In theory the ratio of the share on public transportation to that walking remains constant, but the land use change means that this is not strictly the case, since slightly different spatial distributions of population and employment are being used. Similar effects were demonstrated by the LILT and CALUTAS models for Tokyo (*20*). Thus, these models do show the effects of restricting peripheral development in a much more comprehensive way than a conventional travel demand model does.

2. Increase in gasoline tax. This was examined in the ISGLUTI work by looking at the implications of quadrupling of the price of gasoline over a 20-year period. In the application of the models to Leeds, both LILT and MEPLAN produced elasticity values of about −0.3 (*19*). Rather lower values were produced by these two models for the city of Dortmund, at about −0.2, but the DORTMUND model produced values slightly larger in magnitude than −0.3 (*18*). In the case of Leeds, there was a difference between LILT and MEPLAN on the effects on the location of employment, with LILT suggesting a slowing down of the decentralization process and MEPLAN suggesting a speeding up. This difference is associated with the fact that the majority of those ceasing to use a car switch to public transportation in LILT and to walk in MEPLAN for the reasons explained earlier. Because of its radial nature, public transportation serves the city center well and so slows down the job loss, whereas walking requires short trips, and most people live in the suburbs so jobs tend to move outward faster. Both scenarios are feasible. This is an interesting dichotomy and illustrates the strong interrelationships between land use and transportation. The effects for LILT applied to Tokyo were similar (*20*).

3. Increase in public transportation subsidy. This was examined in the ISGLUTI work by considering the impact of making public transportation fares free. Although that would be an extreme example of subsidy, the direction of the effects would be the same for a smaller fare reduction. In the Leeds example (*19*) both LILT and MEPLAN showed that there would be less decentralization of economic activity and more decentralization of population because the housing would be more spread out because of less land being available in the central area. This would exacerbate the direct effect of

TABLE 2 Linkages Between Policy Instruments and Outputs of Land Use Transportation Models

	Land use effects		
Policy instrument	First round effects: travel	Second round effects: locational choice	Third round effects: land-use infrastructure change
Restriction of peripheral development	+	++	+++
Increase in gasoline tax	+++	++	+
Increase in public transportation subsidy	+++	++	+
Increase in investment in highways	+++	++	+
Increase in investment in public transportation infrastructures	+++	++	+
Increase in transportation system management	++	+	+
Increase in transportation demand management	+++	+	+
Introduction of road pricing	+++	++	+
Privatisation	+	?	?
Deregulation	+	?	?

Note: +++ very strong linkage
++ strong linkage
\+ weak linkage
? possible link

the increased public transportation patronage, which would be further encouraged by the slowing down of the growth in car ownership. This shows the reinforcing effect of the land use response in addition to the direct transportation impact. This means that a model that did not include the land use effect would underestimate the response.

4. Increase in investment in highways. This was examined in the ISGLUTI work by considering the impact of inner and outer urban ring roads. For Leeds there was a small overall shift to car use and an increase in the mean distance traveled according to both the LILT and MEPLAN models. However, the land use effects were very small, probably because the analysis was at an urban scale. One would expect a clearer response at a regional level. As discussed earlier much of the excess growth in traffic on the M25 motorway around London is probably due to the land use response. Currently, the Standing Advisory Committee on Trunk Road Assessment, which advises the British Department of Transport on all major highway schemes, is examining the trip-generation effects of such roads, including the land use effects, including considering the potential use of integrated land use transportation models.

5. Increase in investment in public transportation infrastructure. In the ISGLUTI work this was examined by considering the impact of a metro line across the city center. For Leeds (*19*) the LILT and MEPLAN models showed increased public transportation use, greater distance traveled, and more money and less time spent traveling, all of which are reasonable. However, the overall effects were small because of the localized effects of a single line of metro in a fairly small city. The land use effects did not show up. However, as discussed earlier a simplified version of LILT is being used at a regional scale to examine the impacts of the potential new rail link to the Channel Tunnel, having previously been used to identify the strength of the factors that underlie the demand for rail commuting (*1*). The model produces results that are significantly different from those that a conventional transportation model would produce because of the land use effects.

6. Increase in transportation system management. The only example of transport system management considered in the context

of the ISGLUTI work was a bus priority policy whereby bus speeds were increased by 20 percent and car speeds were decreased by 20 percent. For Leeds (*19*) both the LILT and MEPLAN models show the expected shift from car to public transportation use with an increase in the time spent traveling. However, the land use responses are different with LILT, showing less decentralization of economic activity and the population location not being affected, whereas MEPLAN shows slightly more decentralization of both. The extra decentralization of economic activity is associated with the shift from car use to walking. These differences partly explain the different modal shifts in the two models.

7. Increase in transportation demand management. The only form of transportation demand management considered in the ISGLUTI work was a significant increase in the city center car-parking charge. This is a good example of a case in which the land-use effect could be very significant. For Leeds (*19*) both the LILT and MEPLAN models show that economic activity would move out of the city center. There is a shift from car to public transportation use and walking for the journey to work. There would be an increase in car trips to suburban locations, so it could be argued that such a policy would spread congestion rather than reduce it. Similar effects were found for Tokyo with the LILT model (this policy was not examined with the CALUTAS model) (*20*).

8. Introduction of road pricing. This is a form of transportation demand management that would have effects similar to those of the increased parking charge, but it would also increase the cost of making trips across the city center. There would be a reduction in congestion, but this might well lead some people with high values of time to switch to using a car. There would also be some route switching to avoid the charging area. Overall a switch from car use would be expected, but this would be mitigated by the increase in car trips to the suburban location of economic activities outside the charging area.

9. Privatization. It is very difficult to identify the potential land use effects of privatization. In effect it would make the supply side more responsive as operators modified their services to match demand. It would also make it more useable as operators enter and leave the market. This means that people might become less willing to make significant locational changes because of a lack of confidence in the future of the local transportation system. If this is so the land use response might be smaller. On the other hand it might be faster as the supply side changes. It also means that there is a need for a new set of models of transportation supply. When these exist they can be incorporated into the land use transportation framework, so that the suppliers of transportation can identify the best long-term options, allowing for land use changes.

10. Deregulation. The removal of regulation in transportation would also enable the supply side to be more responsive in terms of service and fares, so the comments for privatization apply here. There is a need for more empirical as well as theoretical work on the long-term impacts of both concepts.

Table 2 reflects the relationships discussed here. Returning to Table 1, if the linkages indicated are accepted as reasonable then the type of model being discussed here is useful for helping to achieve certain policy objectives. These are summarized in Table 3. This shows that there is a wide range of policy areas in which this type of model is of value. Such models would be particularly useful for examining policies associated with congestion and energy use and, to a lesser extent, with safety, the environment, and social inequalities.

TABLE 3 Degree of Usefulness of Land Use Transportation Models for Policy Analysis

Policy objective	Degree of usefulness
Reduction of congestion	Very useful
Reduction of energy usage	Very useful
Increase safety	Useful
Improve the environment	Useful
Reduce social inequalities	Useful
Improve the quality of life	Moderately useful
Reduce public expenditure	Moderately useful
Move towards a market economy	Of little use

CONCLUSIONS

It has been shown that land use transportation models have responsive mechanisms that modify the effects that a conventional transportation model would show. The results here are illustrative rather than definitive, but show the complexity of the responses that the models can represent. The fact that different models can produce apparently different results shows the need for clear understanding of the models. It also suggests that different urban systems can respond in different ways to the same policy instrument.

A number of suggestions for further work can be made.

1. A systematic appraisal of the empirical evidence of the land use effects of transportation should be carried out, since the evidence is spread widely in the literature. Gaps for further empirical work can then be identified. Such further work might well include monitoring of the impact of new transport infrastructure, including surveys of the various responses. This work should be used to validate the existing models.
2. The land use transportation relationship should be extended to include the environment. The effects not only of transportation on the environment but also the effects of the environment on locational and travel choices should be included.
3. Economic evaluation of new transportation schemes should include the land use effects. The appraisal framework should be extended to include such effects. It is important that the welfare effects on the various bodies concerned are shown. These include the users, the operators, and the government, so the impacts shown by the models should be disaggregatable to permit this.
4. Methods of incorporating political processes and fuzzy data should be considered since politics has a strong influence on land use and the current models tend to focus on topics that can be easily measured. There may be useful ideas from the field of artificial intelligence that can be adopted.

It is not clear why these models are not more widely used. The arguments put forward by Boyce (*12*) and Wegener (*10*) are persuasive. This paper has shown the policy relevance of the models. There is a need for more research, application, and debate.

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Publication of this paper sponsored by Committee on Transportation and Land Development.

Stated Preference Investigation of Influences on Attractiveness of Residential Locations

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A stated preference experiment concerning residential location choice was conducted in Calgary, Alberta, Canada. Each respondent was asked to indicate an order of preference for a set of hypothetical residential location alternatives. Each alternative was described by specifying a monthly charge, number of bedrooms, travel time to work, travel time to a shopping center, and proximity to light rail transit (LRT). This placed the respondent in a situation in which it was necessary to trade off between better or worse conditions regarding these attributes. Information was also collected on actual home location, actual workplace location (if the respondent was employed), family size, and total household income. The set of observations thus obtained was used to estimate the coefficients for various alternate utility functions in logit models of this choice behavior. All of the attributes were found to have statistically significant effects on the attractiveness of residential locations. Specific findings were that travel time to work is worth approximately 25 Canadian dollars (C$25) per hour, travel time to work is about two times as important as travel time to shop, an additional bedroom is equivalent to approximately C$155 per month, and being within walking distance of an LRT station is worth about C$217 per month. Both household income and family size were found to have significant influences. These results provide empirical evidence that the transport system influences the attractiveness of residential locations. They also contribute to further understanding of this aspect of urban system behavior in Calgary and demonstrate the potential for this process to be used elsewhere. Also included is a table providing an extensive summary of the factors considered in the literature on residential location choice.

It has long been argued that the transportation system, through its effects on accessibilities, has various impacts on the attractiveness of locations as sites for activities. More specifically, it has been asserted that the relative travel times and ease of access provided by the roadway and public transport systems serving an area influence the relative degrees of attractiveness individuals associate with different residential locations in the area.

This paper describes an investigation of the influence of various factors, some of which are transportation related, on housing preferences in Calgary, Alberta, Canada.

REVIEW OF LITERATURE

There is an extensive literature on the study of residential location choice behavior in urban areas. The content of this literature is considered in terms of (*a*) the factors found to have an influence, (*b*) the nature of the observations of preference (revealed versus stated), and (*c*) the analysis procedure used.

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Factors

A wide variety of dwelling unit attributes, location attributes, and household characteristics have been shown to influence housing choice behavior. A list of some of these attributes and characteristics is included as Table 1, together with the relevant source references.

Most studies have found that money cost, dwelling unit size, and proximity to activities have major influences. Similarly, household size, life cycle, and income have often been identified as important characteristics.

Various attributes and characteristics have been found to have significant influences in some studies and insignificant influences in others. For example, Butler et al. (*1*) and Weisbrod et al. (*2*) found that the form of tenure (rent versus own) influences housing location selection, whereas McDonald (*3*) found that form of tenure does not improve the explanatory power of models of residential location choice behavior. These differences in findings appear to arise because studies vary in terms of both context and approach.

Revealed Preference and Stated Preference Data

Indications of the actual choices made by households are called revealed preference observations. These data can be used to estimate the parameters of models of residential preferences, and they have a high degree of validity in that they represent actual behavior. However, they suffer from a variety of shortcomings.

Revealed preference data describe the compromises households make, not their true preferences. The disequilibrium and habit that affect real-world residential location behavior cause households to not necessarily realize their preferences, but rather stay put or accept what the market has to offer (*2,4–7*).

A related problem is the existence of correlations among the attributes in real-world data. For example, a positive correlation is to be expected between house size and travel time to work in many cities because larger houses tend to be located toward the edges of built-up areas. Such correlations make it difficult to separate the influences of different factors using statistical analyses of revealed preference data. In addition, collecting real-world data is usually very expensive and time-consuming (*8,9*).

In contrast stated preference observations can be obtained by running relatively inexpensive stated preference experiments in which the respondents are presented with hypothetical alternatives and asked to indicate which alternative is preferred. The structure of the data can be controlled to avoid correlations, and the individuals taking part in the experiments are not hindered by real-world supply

TABLE 1 Factors Found To Influence Residential Location Choice and Sources

Factor	Source (ref. no.)
Attributes of Dwelling Unit	
Cost—price, rent, taxes	1, 5, 7, 12, 13, 14, 18, 19, 25, 29, 30, 44, 45, 46, 47, 52, 54, 56, 59, 62, 68, 70, 71, 72, 75, 77, 78, 81, 82, 83, 84
Building size—number of rooms or bedrooms	1, 7, 12, 14, 17, 29, 30, 44, 56, 62, 71, 72, 73, 77, 83
Building size—floor area	19, 46
Lot size	3, 13, 17, 19, 44, 46, 64, 65, 67, 71, 77, 78, 83
Building type—bungalow, multifamily	1, 7, 14, 19, 29, 31, 44, 52, 59, 65, 72, 77, 83
Number of floors	13
Building design and layout of rooms	17
Quality of construction	1, 17, 29, 46, 60, 63, 65, 71, 72
Age	7, 14, 19, 29, 30, 44, 46, 47, 52, 56, 62, 65, 71, 78
State of repair	19
Form of tenure—rent or own	1, 2, 58, 59, 71, 77, 80
Lot layout	17, 52
Availability of enclosed parking	13, 29
Proximity to traffic	17, 52
Attributes of Location	
Accessibility to workplace	1, 3, 5, 7, 14, 17, 18, 28, 29, 30, 31, 41, 44, 46, 48, 49, 52, 54, 59, 62, 71, 72, 73, 75, 77, 78, 80
Accessibility to shopping and other nonwork activities	1, 5, 14, 17, 19, 28, 29, 30, 44, 46, 48, 52, 80, 83, 86
Accessibility to other activity locations	19, 46, 54, 61, 70
Accessibility to schools	19, 29, 46, 52
Accessibility to CBD	47, 51, 63
Public transport quality	2, 7, 12, 17, 28, 29, 46, 52, 54, 59, 85
Availability and quality of public services—water, power, fire, police, etc.	1, 12, 30, 52, 56, 61, 71, 75
Relationship to previous home location	1, 3, 4, 7, 66, 69, 83
Availability of parking	5, 29, 65
Attributes of Neighborhood	
Prestige or quality	1, 14, 30, 45, 46, 55, 56
Average income for households in area	28, 44, 45, 59, 65, 71, 72
Crime rate	3, 44, 46, 54, 71, 72, 75, 79
Demographic mix—race and age	3, 17, 19, 25, 28, 29, 59, 65, 72, 80, 85
Proportion rental properties	25, 84
Housing turnover rate	19
Proportion of single-family dwellings	56
Density and openness of built form	12, 13, 17, 19, 47, 52, 61, 62, 65, 71
Traffic, noise, and air pollution	3, 5, 44, 46, 54, 65, 68, 50
Presence of "antiresidential" land uses	17, 52
Topography	14, 17, 54, 71
Character and maturity of landscaping	17, 19, 52, 71
Pleasantness and degree of interest	65
Quality of view from dwelling unit	13, 52
Pedestrian safety	5
Quality of schools in neighborhood	28
Good area for children	52
Characteristics of Household	
Income	1, 3, 7, 14, 17, 27, 28, 29, 30, 44, 51, 53, 56, 62, 63, 71, 73, 80, 83
Occupation	51, 59, 61, 72
Level of education	27, 29, 44, 71, 72, 75
Number of people in household	1, 7, 14, 28, 29, 30, 31, 55, 56, 57, 59, 63, 71, 74, 77
Number of employed people in household	7, 29
Number of children in household	7, 18, 27, 28, 63, 74, 83
Lifecycle status and related indicators	1, 7, 14, 27, 30, 31, 55, 56, 71, 72, 77, 80, 83
Race	1, 17, 27, 28, 29, 60, 76
Car ownership	29, 57, 59
Mode use	29, 59
Work schedule and its flexibility	7
Familiarity with neighborhood	17

limitations. Attention can be focused on the attributes of interest—with the influences of other attributes held constant. Of course, the question remains: do those playing a hypothetical choice game behave in the same way that they would in reality? There is also the possibility that respondents playing games can be led in their responses and the possibility that the choice behavior exhibited is unrealistic if the respondents find the hypothetical situations too unbelievable. Nevertheless various researchers claim that accurate and realistic results are obtained when the experiments are properly designed to account for these problems (*9–11*).

Various forms of ranking exercise and stated preference technique have been used in a number of studies of housing preferences, and these have successfully provided insight into the influences of different attributes and aspects of the choice processes involved (*5,7,12–24*). However, in most cases respondents were asked to give direct indications of the importance of different attributes rather than make choices that involved trade-offs among attributes—thereby limiting the analysis of choice behavior that was possible.

Analysis Procedure

A number of statistical analysis procedures have been used with observations of choice behavior to investigate how preferences are influenced by various factors. One technique that has been used extensively with success in residential location choice analysis is the estimate of logit models, in which the resulting coefficient estimates and associated statistics are used to make inferences about the strength and statistical significance of the influences of specific factors (*25–31*).

METHOD

The logit model estimation process was employed in this research: disaggregate stated preference observations of housing choice behavior were collected and used to estimate coefficients for various housing attributes in logit models of location choice behavior. The details of this procedure are described in the following paragraphs.

Modeling Framework and Statistics

The logit model is a mathematical model that represents the behaviors of individuals trading off among the attributes of alternatives when selecting one alternative out of a set of available alternatives (*32*). It has the following simple and convenient form for the choice situation considered in this research:

$$P_i^* = \frac{\exp(U_i^*)}{\Sigma_i \exp(U_i)} \qquad (1)$$

where

i = index representing housing alternatives,
i^* = a particular housing alternative,
P_i^* = probability that housing alternative i^* is selected, and
U_i = utility value associated with alternative i.

The utility function that ascribes utility values to the housing alternatives has the following general, linear form:

$$U_i = \phi_1 \cdot X_{1i} + \phi_2 \cdot X_{2i} + \ldots + \phi_n \cdot X_{ni} + \ldots \qquad (2)$$

where

n = index representing attributes,
X_{ni} = value of attribute n for alternative i, and
ϕ_n = utility function coefficient associated with attribute n.

The statistical properties of the linear utility function coefficient estimates are well behaved (*32*). Consequently, this formulation is a very attractive one for modeling choice behavior, and it enjoys widespread use (*33*).

When the values for the utility function coefficients have been estimated, the relative influences of factors can be determined by taking ratios among the resulting coefficient values. The significance of differences among the estimates can be considered using standard t-statistics and t-ratios, with the t-ratio for a given parameter estimate being the t-statistic for the estimate's difference from 0. A t-statistic or t-ratio is significant when it has an absolute value greater than 1.96, indicating that there is a less than 5 percent chance that the associated difference is due to random effects only (*34*). The overall model goodness-of-fit can be considered by using a goodness-of-fit index as follows (*35*):

$$\rho^2(0) = 1 - \frac{L(*) - N}{L(0)} \qquad (3)$$

where

N = number of coefficients in estimated model,
$L(0)$ = log-likelihood for model with zeros for all coefficients, and
$L(*)$ = log-likelihood for model with estimated coefficients.

This $\rho^2(0)$ index is analogous to the R^2 statistic for linear regression in that it ranges from 0 to 1, with larger values indicating a better fit. It also takes into account the number of parameters used in the model, favoring more parsimonious model specifications (*35*).

Housing Attributes Considered

It has been found that only a relatively small number of attributes should be presented in stated preference experiments (*10*). The influences of the transportation system on housing preferences were of primary interest in this research. Accordingly consideration was limited to a subset of what appeared from the literature review to be some of the most important attributes influencing housing preferences, including some related to transportation. These are as follows:

- Money cost per month, representing a rent or a mortgage payment, with three values considered: 500, 800, and 1,000 Canadian dollars (C$);
- Number of bedrooms, representing the size of a dwelling unit, with two values considered: two and four;
- Minutes of in-vehicle travel time to work, with two values considered: 15 and 30 min;
- Minutes of in-vehicle travel time to a shopping center, with two values considered: 5 and 15 min; and
- Proximity to a light rail transit (LRT) station, with two values considered: within walking distance and not within walking distance.

Descriptions of the hypothetical alternatives considered in the stated preference experiments performed for this research were developed by selecting one out of a set of possible values for each of these attributes and combining these selected values into a bundle representing a complete alternative. To keep the total number of possible alternatives at a manageable level, only a few realistic values were specified for each attribute. The money values were staggered to allow for a wider range of trade-off rates (*36*). The result was a set of 48 separate hypothetical alternatives. A separate 7.5- × 12.5-cm card was prepared showing the bundle of values for the attributes for each of these alternatives.

Clearly many important attributes were left out. In the interviews the respondents were told that all other attributes were constant among the hypothetical alternatives, with the intention that these attributes should not influence the relative attractiveness of the alternatives. This made it possible to focus in on what was of interest in this case.

Data Collection

Calgary is the principal metropolitan center in southern Alberta, with a 1991 population of 710,000. It has an extensive public transport system, including 85 LRT vehicles running on 29.3 km of track radiating from the central business district (CBD).

In November 1992 more than 390 choice experiments were conducted with individuals selected randomly at various shopping areas in Calgary. Each experiment was a voluntary interview in which the respondent was approached and asked to rank four hypothetical housing alternatives in order of preference from best to worst, taking into account the needs and wants of the respondent's present household. In each case these four alternatives were selected randomly from the full set of 48 alternatives in the "deck" of cards to maintain the orthogonality of the variables (*9*). Each respondent was also asked a variety of questions regarding socioeconomic status and household characteristics, including

- home location,
- workplace location, if the respondent was working,
- number of people in household,
- combined annual before-tax income of household,
- number of licensed drivers in household, and
- number of cars available for use by people in household.

After removing incomplete interviews, the result was a data set with 377 disaggregate stated preference observations. This data set was used to estimate the coefficients in a variety of logit models with different utility functions as described in the results section.

The logit model estimations were performed by using the exploded logit technique (*37*). This technique attempts to predict the full ranking of the alternatives in an observation—in contrast to the more limited prediction of the single, most-preferred alternative in standard logit analysis.

RESULTS

Various alternate utility functions were considered by using different combinations of variables. The estimation results for a selection of some of these utility functions are discussed below.

Function 1

The estimation results for the initial utility function considered are (the numbers in parentheses below each parameter estimate are *t*-ratios for the estimates)

$$\begin{aligned} U_i = & \underset{(13.9)}{-0.003163} \cdot COST_i + \underset{(10.8)}{0.4905} \cdot BEDS_i + \underset{(9.5)}{-0.05384} \cdot WORK_i \\ & + \underset{(3.0)}{-0.02474} \cdot SHOP_i + \underset{(8.3)}{0.6866} \cdot LRTP_i \end{aligned} \quad (4)$$

where

$L(0) = -1198.13$; $L(*) = -967.56$; and $\rho^2(0) = 0.188$,

$COST_i$ = money cost per month for alternative i (C$),

$BEDS_i$ = number of bedrooms for alternative i,

$WORK_i$ = in-vehicle travel time for trip from alternative i to workplace (min),

$SHOP_i$ = in-vehicle travel time for trip from alternative i to shopping center (min), and

$LRTP_i$ = 1 when an LRT station is within walking distance of alternative i and 0 otherwise.

All of the coefficient estimates are statistically significant and have signs (positive or negative) consistent with what would be expected. For example, the coefficient for $COST_i$ is negative, consistent with the expectation that an increase in price would make an alternative less attractive. The value for $\rho^2(0)$ is reasonable, indicating a reasonable model fit.

The *t*-statistic for the difference between the coefficient estimates for $WORK_i$ and $SHOP_i$ is 2.83, making these two estimates significantly different. This indicates that these two types of in-vehicle times have significantly different impacts and should be considered separately. The ratio between these two estimates is 2.18, indicating that in-vehicle travel time for home-based work trips is 2.18 times as important as the equivalent time for home-based shopping trips when selecting housing locations.

The coefficient estimates for $COST_i$ and $BEDS_i$ together imply a trade-off money value for a bedroom of C$155.07 per month, which seems reasonable. That is, it seems reasonable to expect a household to be willing to pay an additional C$155.07 per month in rent for an additional bedroom.

Some of the other trade-off money values implied by the coefficient estimates are

- A value of in-vehicle time for home-based work trips of C$17.02/min/month (which converts to a value of C$25.53/hr, assuming 20 round-trips to work per month) and
- A value of C$217.07/month for being within walking distance of the LRT.

The value for in-vehicle time is within the range for such values and appears reasonable (*38*). The value for being within walking distance of the LRT may be slightly high, but it may be picking up some respondents' anticipation of the potential money savings associated with reduced dependency on an automobile.

Function 2

The total household income can be expected to influence the perception of money costs. An attempt was made to include representation of this influence within the model by dividing the money cost for each alternative by the income for the household. The results for a utility function that includes this indication are as follows:

$$\begin{aligned} U_i = & \underset{(12.5)}{-118.8} \cdot COST_i/INC + \underset{(10.4)}{0.4761} \cdot BEDS_i + \underset{(9.2)}{-0.05185} \cdot WORK_i \\ & + \underset{(3.2)}{-0.02649} \cdot SHOP_i + \underset{(8.0)}{0.6697} \cdot LRTP_i \end{aligned} \quad (5)$$

with $L(0)$ equal to $-1{,}198.13$, $L(*)$ equal to -944.38, and $\rho^2(0)$ equal to 0.208 and where INC is the total annual income for the respondent's household (C$/year).

All of the coefficient estimates are again statistically significant and have signs consistent with what would be expected. The value for $\rho^2(0)$ is higher than that for $\rho^2(0)$ in Function 1, indicating a better model fit. It is therefore appropriate to represent the effect of income in the utility function in this way.

The units of the implied trade-off values with this utility function change from what they were in Function 1: with this function an additional bedroom is worth 4.8 percent of the respondent's income; being within walking distance of LRT is worth 6.8 percent of the respondent's income; and in-vehicle time for home-based work trips has a value of 0.0004364 of the respondent's annual income per minute per month, which converts to a value of 126 percent of the respondent's wage rate. The calculation of this conversion is as follows: With 20 round-trips per month, a 1-min trip duration adds up to 40 min over a month. The implied value of a minute of travel time is therefore $0.0004364/40 = 0.00001091$ of annual income. With 240 working days of 8 hr each, the wage rate per minute is $1/(240 \cdot 8 \cdot 60) = 0.000008681$ of annual income. Thus, a minute of travel time is worth $0.00001091/0.000008681 = 1.257$ of a minute of wage.

Function 3

The number of people in a household can be expected to influence the perception of the number of bedrooms. To investigate this the variable for the number of bedrooms was split into a series of separate variables according to the number of people in the household. Initially, this series included a separate variable for one, two, three, four and five or more people. The results indicated that it was most appropriate to use two separate variables, one for two or less and the other for three or more people. The results for this utility function are as follows:

$$\begin{aligned} U_i = &-124.8 \cdot \text{COST}_i/\text{INC} + 0.1230 \cdot \text{BEDS}_i^{2-} + 0.8703 \cdot \text{BEDS}_i^{3+} \\ &\quad (12.6) \qquad\qquad (2.0) \qquad\qquad (12.1) \\ &+ -0.05575 \cdot \text{WORK}_i + -0.03013 \cdot \text{SHOP}_i + 0.6421 \cdot \text{LRTP}_i \\ &\quad (9.6) \qquad\qquad (3.5) \qquad\qquad (7.6) \end{aligned} \tag{6}$$

where

$L(0) = -1{,}198.13$, $L(*) = -911.28$, and $\rho^2(0) = 0.234$;

BEDS_i^{2-} = number of bedrooms for alternative i when number of persons in household is 2 or less and 0 when number of persons in household is more than 2; and

BEDS_i^{3+} = number of bedrooms for alternative i when number of persons in household is 3 or more and 0 when number of persons in household is less than 3.

All of the coefficient estimates are still statistically significant and have retained signs consistent with what would be expected. The value for $\rho^2(0)$ is higher than that for $\rho^2(0)$ in Function 2, indicating that it is appropriate to use this representation of the effect of household size.

The *t*-statistic for the difference between the coefficient estimates for BEDS_i^{2-} and BEDS_i^{3+} is 7.92, which means that these two variables should be kept separate. The ratio between these two estimates indicates that the number of bedrooms is 7.08 times as important to households with more than two people when selecting housing locations. This ratio may be somewhat exaggerated in this instance: the hypothetical alternatives had either two or four bedrooms only, which meant that this research did not obtain any indications of preferences for two bedrooms rather than one bedroom. Such preferences would likely be most prevalent in households with two people, and missing indications of them in particular likely reduced the apparent importance of bedrooms for these households more than for other households.

In fact it is rather encouraging that smaller households tended not to place as high a value on larger dwellings. This tendency suggests that respondents were making choices on the basis of their actual situations rather than merely reacting to what was presented to them out of context, which lends validity to the indications of behavior provided by the results.

A wider range of numbers of bedrooms in the hypothetical alternatives and a more complete description of the life-cycle status of households would have allowed a more complete analysis of preferences regarding numbers of rooms. However, wide ranges of attribute levels lead to sets of alternatives that are so large that the use of a deck of cards becomes infeasible.

Function 4

The total household income can be expected to influence the perception of travel times as well as money costs. An attempt was made to indicate this by multiplying the travel times by the logarithm of the income for the household. The results for a utility function that includes this indication are as follows:

$$\begin{aligned} U_i = &-124.3 \cdot \text{COST}_i/\text{INC} + 0.1239 \cdot \text{BEDS}_i^{2-} + 0.8725 \cdot \text{BEDS}_i^{3+} \\ &\quad (12.6) \qquad\qquad (2.0) \qquad\qquad (12.1) \\ &+ -0.05134 \cdot \text{WORK}_i \cdot \text{LN(INC)} \\ &\quad (9.7) \\ &+ -0.002719 \cdot \text{SHOP}_i \cdot \text{LN(INC)} + 0.6409 \cdot \text{LRTP}_i \\ &\quad (3.5) \qquad\qquad (7.6) \end{aligned} \tag{7}$$

with $L(0)$ equal to $-1{,}198.13$, $L(*)$ equal to -911.57, and $\rho^2(0)$ equal to 0.234.

All of the coefficient estimates continue to be significantly different from 0 and have signs consistent with expectations. The value for $\rho^2(0)$ is the same as that for $\rho^2(0)$ in Function 3, indicating that the two utility functions have the same goodness of fit. This means that combining INC with WORK and with SHOP does not improve the fit of the model, even though it adds further complexity. On this basis it is judged appropriate to not include INC in this way.

Function 5

It is not unreasonable to expect that those people living within walking distance of LRT and those people not living within walking distance of LRT differ in terms of their perceptions of the benefits of proximity to LRT. This is because there will be some self-selection in that households most concerned about being close to LRT will be more inclined to move to locations close to LRT. As time progresses this will lead to a relatively larger proportion of LRT-proximity-sensitive households in areas close to the LRT. There may also be some ex post rationalization in which respondents who live within walking distance of LRT add support to their home location selection by exaggerating (either consciously or subconsciously) the importance of proximity to LRT—which is a form of what has been called *postpurchase* or *reporting bias* (*39,40*). In addition members of those households who actually live close to

LRT will have had relatively more opportunity to use LRT to its full advantage and may thereby develop a more accurate appreciation of the actual value of being within walking distance of the service.

The evidence of such a difference was investigated with the data obtained in this research. The results for a utility function that distinguishes between the perceptions of those who do and those who do not live within walking distance of LRT are as follows:

$$U_i = \underset{(12.7)}{-125.2} \cdot COST_i/INC + \underset{(2.1)}{0.1279} \cdot BEDS_i^{2-} + \underset{(12.0)}{0.8658} \cdot BEDS_i^{3+}$$
$$+ \underset{(9.6)}{0.05571} \cdot WORK_i + \underset{(3.5)}{-0.02981} \cdot SHOP_i + \underset{(3.9)}{1.369} \cdot LRTP_i^C$$
$$+ \underset{(6.8)}{0.5952} \cdot LRTP_i^F \quad (8)$$

where

$L(0) = -1{,}198.13$, $L(*) = -908.86$, and $\rho^2(0) = 0.236$;
$LRTP_i^C$ = 1 when an LRT station is within walking distance of alternative i and the respondent's actual home location is within 400 m walking distance of an LRT station (designated C for close) and 0 otherwise; and
$LRTP_i^F$ = 1 when an LRT station is within walking distance of alternative i and the respondent's actual home location is not within 400 m walking distance of an LRT station (designated F for far) and 0 otherwise.

Again, all of the coefficient estimates are statistically significant and have signs consistent with what would be expected. The value for $\rho^2(0)$ is higher than that for $\rho^2(0)$ in any other function, indicating that this utility function provides the best model fit out of those considered.

The *t*-statistic for the difference between the coefficient estimates for $LRTP_i^C$ and $LRTP_i^F$ is 2.13, which means that these two variables should be kept separate. The ratio between these two estimates indicates that being within walking distance of LRT is 2.30 times as important to households located within walking distance of LRT in reality.

It should be noted that only 10 percent of those interviewed were from households located within walking distance of LRT. This will have increased the sampling error for the information concerning these households' evaluations of proximity to LRT in particular. The amount of confidence placed in the coefficient estimate for $LRTP_i^C$ must be reduced accordingly. Nevertheless, the results indicate that there is a statistically significant difference in these two groups' perceptions of the importance of being within walking distance of LRT.

Several studies (*7,17*) have found that transit service quality and availability have only marginal effects on housing location preference overall. The findings here suggest a much more dramatic effect, in particular among those living within walking distance of LRT. Others (*41*) have found that those households selecting suburban residential locations with poor or non-existent public transport service did so in part because they tended not to use public transport. These various findings suggest that there tends to be at least two groups of households: one group that tends to use public transport and for whom public transport service is an important factor influencing the quality of residential locations and another group that tends not to use public transport and for whom public transport service is almost irrelevant to the quality of housing locations.

CONCLUSIONS

Various housing attributes and household characteristics have been shown to have a statistically significant influence on housing preferences in Calgary. This includes several transportation-related attributes—thus indicating that the transport system has an effect on the attractiveness and hence on the value of residential locations in Calgary. The LRT in particular has been shown to have an impact on housing values. Various trade-off rates among the housing attributes have been identified, and these seem plausible and consistent with indications from other sources. There is some suspicion that the money values are a bit high, for proximity to LRT in particular. Several factors could have acted to make these values somewhat less than completely reliable. Some respondents may have correlated cost with quality and therefore selected more expensive alternatives more readily—even though respondents were told to assume that all unmentioned attributes were the same across all alternatives. Also people may have some tendency to spend hypothetical money more readily than, for example, forgo hypothetical bedrooms. It would be good if the respondents in a survey could be made to feel the impacts of the money costs more directly. This has been done for some forms of choice experiments related to transportation behavior (*42*), but it may be very difficult to do for housing choice behavior given the large amounts of money involved.

The models of housing choice behavior resulting from this work can be used to assess the impacts of changes to the transportation system in Calgary. Function 1 and its implied trade-off values can be used in cases in which the distribution of household characteristics is not known. Function 5 and its implied trade-off values can be used to achieve a greater accuracy when the required information on household characteristics is available.

The stated preference techniques that were used were found to be very successful in many ways. A useful data set with good statistical properties was obtained easily and quickly with very little cost. There is still some concern that all the attributes presented to the respondents proved to have a significant influence simply because values for these factors were specified and the respondents felt compelled to consider them. It would be an interesting experiment to include a factor thought to have little or no influence, such as style of doorknob, to see if such a factor turns out to have little or no influence in the data.

The work reported here has provided necessary tools for planning analysis and has contributed to the further understanding of the behavior of the urban system in Calgary. Of course it has left many questions unanswered, and further work should be done. The existing data set should be used to investigate the potential impacts of automobile availability and workplace location (including its service by LRT) on housing preferences. The results here could be combined with the results from further hypothetical choice experiments investigating other factors. The reliability of these stated preference results could be investigated further by comparing them with revealed preference data (i.e., a sample of the actual housing selections made in Calgary).

ACKNOWLEDGMENTS

Malcolm Logan, Richard Louie, Pele Ma, Partha Parajuli, Godfred Quain, and Robert Talarico provided valuable assistance in the collection and preparation of the data and offered helpful suggestions on how to improve the work, all done as part of a graduate course in civil engineering at the University of Calgary. The Natural Science and Engineering Research Council of Canada provided important financial support.

An earlier version of this paper was presented at the ITE District 7 Annual Conference in Edmonton, Canada, in 1993 (*43*).

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Publication of this paper sponsored by Committee on Transportation and Land Development.

Impacts of Commuter Rail Service as Reflected in Single-Family Residential Property Values

ROBERT J. ARMSTRONG, JR.

Limited empirical evidence currently exists concerning the capitalization effects of commuter rail facilities. Both positive and negative influences may be present. Transportation agencies and property owners often differ in their views over both the existence and the extent of such impacts from commuter rail facilities, and resulting public participation can have a significant impact on the planning and design process of commuter rail facilities. Single-family residential properties in metropolitan Boston, Mass., are examined. Results indicate that there is an increase in single-family residential property values of approximately 6.7 percent by virtue of being located within a community having a commuter rail station. At the regional level there appears to be a significant impact on single-family residential property values resulting from the accessibility provided by commuter rail service. Findings related to commuter rail-generated right-of-way proximity effects are inconclusive. The potential policy implications of these findings are discussed in the context of property value impacts associated with the construction and operation of new commuter rail facilities.

Property value impacts, and the consequent public reaction and citizen participation resulting from such impacts, can have a significant effect on the planning and design process for new transportation facilities. Such has been the case in the Boston metropolitan area with the Massachusetts Bay Transportation Authority's Old Colony Railroad Rehabilitation Project. This project, first proposed in 1983, aims to rehabilitate three rail lines south of Boston to carry commuter rail service. In some areas significant pockets of opposition have arisen concerning the potential impacts, with station and right-of-way proximity impacts often cited as primary concerns (*1*). Public reaction has led to continued reevaluation of various aspects of the project and has led to a second impact review process on one of the three lines as construction on the other two lines begins. Throughout the project strong differences of opinion have been expressed concerning its impact on residential areas; however, there is limited empirical evidence directly related to commuter rail service with which to support the various positions that have been taken.

Proximity to commuter rail stations may have positive or negative impacts on residential property values. In the case of heavy rail rapid transit, station-related traffic and noise have been observed to have a depreciative effect on residential property values (*2,3*). The same is expected in the case of commuter rail, although this impact may be less in locations where commuter rail stations have smaller parking capacities than those typically found at suburban heavy rail rapid transit stations. In addition stations may in many cases be located in higher-activity areas, making nearby residences susceptible to additional traffic and noise that may not be directly related to the station itself. Proximity to rail stations may also confer certain benefits, such as improved accessibility to commercial centers. In the case of heavy rail rapid transit, this has been observed to result in increased residential property values (*4–9*). Again, similar impacts are expected to exist in the case of commuter rail stations. Both positive and negative property value impacts from stations may be present (*10–12*).

One study in Philadelphia of Southeastern Pennsylvania Transportation Authority and Port Authority of Pennsylvania and New Jersey commuter rail service found strong evidence that accessibility from commuter rail stations is indeed capitalized into house values, with an increase of 6.4 percent of the average house value being observed (*13*). However, this study's use of census tract median values does not allow for more disaggregate analysis, nor does it examine possible impacts related to commuter rail rights-of-way.

Proximity to commuter rail rights-of-way should result in negative impacts on residential property values. Environmental externalities including noise, ground-borne vibration, airborne pollution, and visual intrusion can be generated by rail operations along rights-of-way and can result in significant public concern and involvement, particularly in the case of new facilities that use completely new or long-abandoned rights-of-way. Empirical evidence concerning the property value impacts of proximity to rail rights-of-way is extremely limited, with most studies focusing solely on stations. In San Francisco there was no evidence that proximity to either the elevated or at-grade Bay Area Rapid Transit right-of-way resulted in a decline in property values (*3*). Analysis of highway facilities has indicated property value losses resulting from proximity to highway rights-of-way. A study of highway alignments in New Jersey, Maryland, and Virginia revealed that the average loss in value in four study areas was about 6.6 percent of the property value, with most value losses occurring within 305 m (1,000 ft) of the highway right-of-way (*14*). A study in Troy, Mich., showed that the values of homes away from the highway were about 5 percent higher than the values of homes whose property lines abutted the highway right-of-way (*15*).

The study presented herein attempts to examine both station and right-of-way property value impacts resulting from commuter rail service. Although a new commuter rail facility will probably have varied property value impacts over time during the planning, construction, and operation of the facility, this study will focus on the spatial, rather than the temporal, element of these property value impacts. This is due in large part to the fact that commuter rail service in the Boston area, as in many other areas around the United States, has operated over existing rights-of-way for a significant number of years, limiting the availability of appropriate study areas with newly

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implemented services and facilities, which would be required for a more involved time series analysis using pooled or longitudinal data sets. Identification of the existence and magnitude of property value impacts from a well-established commuter rail facility at a given point in time will therefore be used to satisfy the purpose of the study.

STUDY AREA

Potential study areas within the metropolitan Boston area were considered. An extensive commuter rail system operated by Amtrak under contract to the Massachusetts Bay Transportation Authority (MBTA) provides a variety of potential study areas. To further limit the study area to a more manageable extent, only 1 of the 11 commuter rail routes was chosen for analysis.

Several criteria were considered in the selection process. First, to provide the ability to identify property value changes resulting from varying regional and local accessibility, the rail line should extend a significant distance from Boston proper. Second, there should be a sufficient sample of bona fide arms-length transactions of detached single-family residential properties, available in as limited a time period as possible to reduce the introduction of any unwanted time series variation in the data set. The third criterion is that the line be representative of the type and quality of service available throughout the entire commuter rail system. A fourth criterion was that there be minimal impact from freight train operations on the same line used by the commuter rail operations. This will serve to prevent freight rail-generated right-of-way proximity effects from complicating the measurement and interpretation of commuter rail-generated right-of-way proximity effects occurring on shared rights-of-way. One final criterion was that there be minimal influence from other commuter rail lines upon the study area. Such an influence would be potentially difficult to differentiate from the impact of the line under study and could complicate the interpretation of the empirical findings.

The commuter rail line that met most of the required criteria was the Fitchburg/Gardner Line, running northwest from North Station in Boston, with a terminus located approximately 72 km (45 mi) away, in Gardner, Mass. (Figure 1). This line, however, operates on a right-of-way that is shared with freight service. Based on analysis of freight rail lines operating in New England in 1990, the only commuter rail lines operating exclusively commuter rail service included the Needham Line and a limited portion of the Rockport Line. These lines, however, did not meet the other criteria. Specifically, the Needham Line had undergone significant rehabilitation during the mid-1980s, perhaps resulting in some perceived service impacts, and also extends only 14.5 km (9 mi) from its terminus in Boston. The portion of the Rockport Line operating only commuter rail service does not provide a large enough study area to obtain an adequate sample size without introducing unwanted time series variation. Therefore, the Fitchburg/Gardner Line was chosen as best meeting the remaining criteria for selection. Service from Fitchburg to Boston only was analyzed, since the Gardner terminal received only limited service during the 1990 study period. Therefore, the line will henceforth be referred to as the Fitchburg Line.

Because both the sales transaction data for the single-family residences and much of the public services information were available by municipal jurisdictions only, it was necessary to determine which municipalities surrounding the Fitchburg Line could be reasonably considered to be within the service area for the line. No

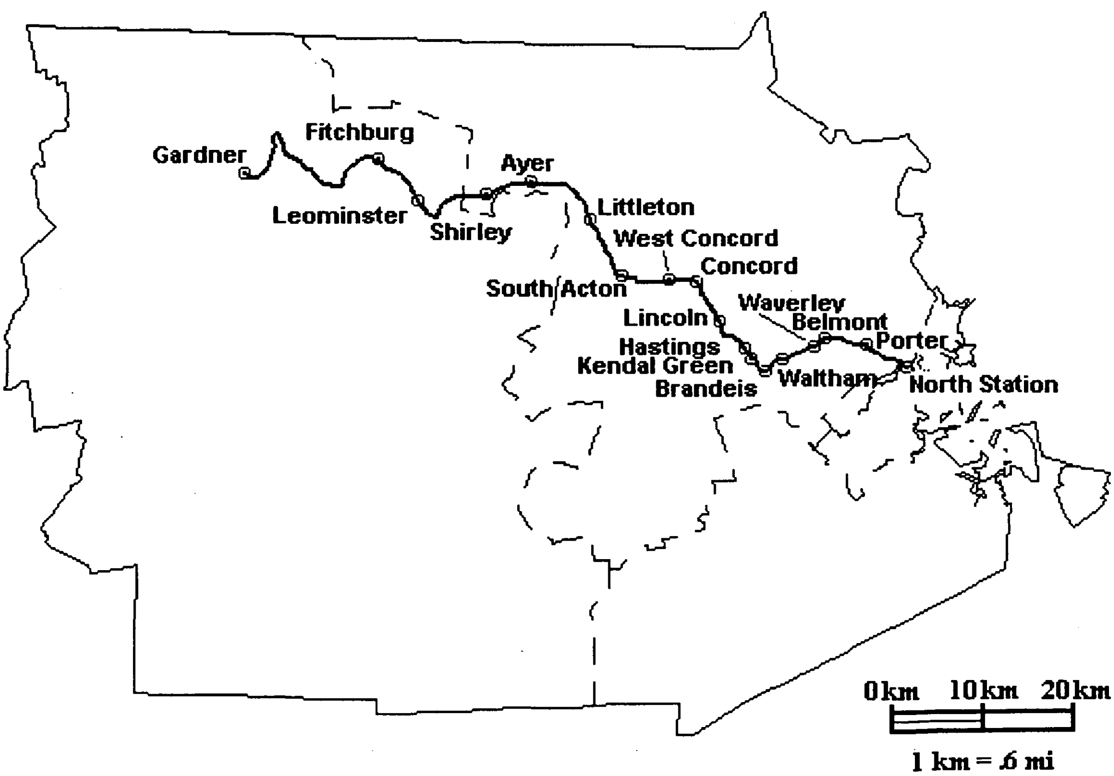

FIGURE 1 Fitchburg/Gardner commuter rail line.

data, such as parking lot license plate survey information, were available for use in delineating a service area. Therefore, assuming that the service areas of individual commuter rail lines do not overlap to any significant extent, delineation of the extent of the line's service area involved including those municipalities that fell more than 50 percent within a region roughly 16 km (10 mi) from the line. To be conservative this distance was chosen as the maximum extent of the service area in regions that were beyond the influence of other commuter rail lines.

The study area that resulted from this process is shown in Figure 2 and encompasses 1920 km^2 (741.8 mi^2) and 38 municipalities with a total 1990 population of 630,478 persons. Analysis of the dates when these municipalities were established indicates that there is no correlation between the age of these communities and whether they are served by commuter rail. Table 1 presents the 1990 populations and the housing characteristics of these communities.

MODEL AND VARIABLE SPECIFICATION

The methodology followed involved the collection of 1990 sales prices from bona fide arms-length transactions of detached single-family residential properties (land and improvements) from the 38 municipalities in the study area. A universe of 451 properties transacted between June and August of 1990 is used. The general form of the model used is

$$P_h = \alpha + \sum_{i=1}^{I} \beta_i B_i + \sum_{j=1}^{J} \beta_j S_j + \sum_{k=1}^{K} \beta_k T_k + \sum_{l=1}^{L} \beta_l A_l + \sum_{m=1}^{M} \beta_m E_m + u_h \tag{1}$$

where

- P_h = hth observation of housing prices,
- α = intercept term,
- β = estimated coefficients or implicit marginal prices on each individual variable or characteristic,
- B_i = structural attribute variables,
- S_j = site attribute variables,
- T_k = the local service provision and costs variables,
- A_l = locational and accessibility variables,
- E_m = local environmental impact variables, and
- u_h = stochastic disturbance.

Transaction data from a real estate trade journal covering all residential property transactions in Massachusetts by county registry and municipality were used to obtain bona fide arms-length transactions of detached single-family residential properties only (*16*). For each observation a detailed and extensive set of data was collected representing five major categories of independent variables.

Structural Attribute Variables

Structural attribute variables include

- Usable living area,
- Number of bedrooms,
- Number of bathrooms,
- Heating system attributes (type and fuel),
- Architectural style,
- Number of stories,

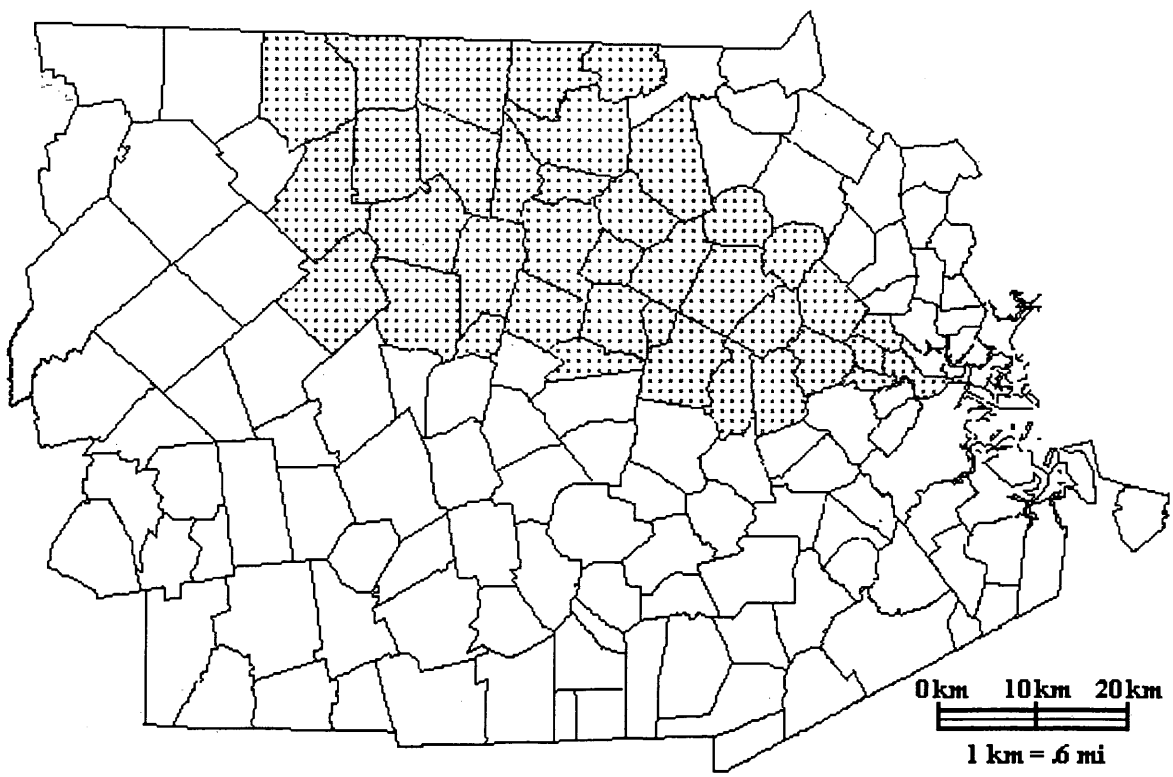

FIGURE 2 Study area.

TABLE 1 Population and Housing Characteristics of Study Area Communities

	1990 Population					Single-Family Housing Units (b)
	Total	Pop. Density per sq km (a)	1980-90 Growth	% 18-64 Years	Median Age	
Massachusetts Total	6,016,425	282	4.9%	63.89%	33.57	1,237,786
Middlesex County						
Acton	17,872	344	1.9%	68.26%	34.78	4,263
Arlington	44,630	3,328	-7.4%	65.54%	37.02	7,946
Ashby	2,717	44	17.6%	60.88%	33.11	867
Ayer	6,871	301	-1.7%	65.65%	29.54	1,066
Bedford	12,996	366	-0.5%	66.44%	36.87	3,048
Belmont	24,720	2,080	-5.3%	63.18%	38.01	4,568
Boxborough	3,343	124	6.9%	72.66%	31.90	657
Cambridge	95,802	5,921	0.5%	75.28%	31.11	3,295
Carlisle	4,333	109	31.1%	66.42%	38.37	1,433
Concord	17,076	264	4.8%	66.43%	38.38	4,465
Dunstable	2,236	52	33.8%	66.99%	33.01	701
Groton	7,511	89	22.1%	64.77%	33.95	2,276
Hudson	17,233	571	5.0%	66.33%	33.47	3,885
Lexington	28,974	679	-1.7%	61.95%	41.08	8,774
Lincoln	7,666	203	8.0%	60.70%	32.59	1,405
Littleton	7,051	165	1.2%	65.01%	35.44	2,158
Maynard	10,325	761	7.7%	65.39%	33.81	2,467
Pepperell	10,098	173	25.0%	62.15%	31.23	2,351
Shirley	6,118	149	19.4%	66.92%	32.18	1,119
Stow	5,328	115	3.6%	66.35%	35.84	1,690
Sudbury	14,358	228	2.4%	66.19%	37.07	4,616
Townsend	8,496	100	18.0%	60.69%	31.15	2,395
Waltham	57,878	1,801	-0.6%	71.50%	31.63	8,257
Watertown	33,284	3,166	-3.2%	68.77%	34.72	3,098
Wayland	11,874	300	-2.4%	64.17%	39.38	3,856
Westford	16,392	209	22.0%	64.68%	33.72	4,760
Weston	10,200	229	-8.7%	64.61%	40.97	3,198
Worcester County						
Ashburnham	5,433	54	33.3%	61.61%	32.71	2,037
Bolton	3,134	61	23.9%	65.60%	36.76	1,005
Clinton	13,222	953	3.5%	62.52%	32.85	1,999
Fitchburg	41,194	579	4.1%	60.34%	31.27	5,813
Harvard	12,329	181	1.3%	69.28%	25.05	1,683
Lancaster	6,661	93	5.2%	66.58%	31.31	1,643
Leominster	38,145	511	10.5%	63.69%	32.82	6,903
Lunenburg	9,117	132	8.5%	62.95%	35.73	2,968
Princeton	3,189	35	31.5%	63.94%	35.11	1,015
Sterling	6,481	82	19.1%	63.18%	33.96	1,861
Westminster	6,191	67	20.5%	62.61%	35.13	2,061
Study Area Total	630,478	328	4.3%	66.86%	34.29	117,602

1 sq km = .386 sq mi

Source: 1990 U.S. Bureau of the Census Data

(a) Population density per sq km of land area only (water not included), except for Massachusetts, which is total area

(b) Not directly comparable to "single family residential properties" utilized in this study

- Number of garage spaces, and
- Age.

These data were collected from property record cards obtained from local assessor offices throughout the study area.

Site Attribute Variables

Site attribute variables include

- Land area,
- Number of pools,
- Zoning, and
- Neighborhood type.

Land area and the existence of a pool were determined from the property record cards. The determination of whether the property was zoned residential or commercial was based on both property record card data and local zoning maps. Neighborhood type acts as a control variable for variations in community income levels, development patterns, population density, economic activity levels, cultural diversity, and other factors not explicitly included in the model that may affect the value of the property within the community. Rather than develop neighborhood type indicators from census data and other primary sources, an existing formal classification system developed in the mid-1980s by the Massachusetts Department of Education was used (*17*). This classification system consists of seven community types, including

- Urbanized centers, which are manufacturing and commercial centers, densely populated, and culturally diverse;
- Economically developed suburbs, which are suburbs with high levels of economic activity, social complexity, and relatively high income levels;
- Growth communities, which are rapidly expanding communities in transition;
- Residential suburbs, which are affluent communities with low levels of economic activity;
- Rural economic centers, which are historic manufacturing and commercial communities with moderate levels of economic activity;
- Small rural communities, which are small towns, sparsely populated, and economically undeveloped; and
- Resort/retirement and artisan, which are communities with high property values, relatively low income levels, and enclaves of retirees, artists, vacationers, and academicians.

Local Service Provision and Cost Variables

Local service provision and cost variables include

- Actual school quality (standardized test score index),
- Perceived school quality (per pupil expenditure),
- Violent and nonviolent crime, and
- Tax rate ($ per $1,000 assessed valuation).

Actual school quality is measured by a weighted index developed from state standardized test scores in various grade levels and subject areas (*18*). Perceived school quality is measured by per pupil expenditure in each community (*19*). Violent and nonviolent crime data are used as proxies for the quality of local police services, with crime data reported by the Massachusetts Department of Safety. When considering the quality of local services, one must also consider the costs involved with the provision of such services. The local property tax rate serves as an indicator of the cost for local services.

Locational and Accessibility Variables

Many of the locational and accessibility variables were developed by means of an extensive analysis with geographic information systems (GISs). These accessibility variables include.

- Travel time to the nearest local commuter rail station;
- Mainline commuter rail travel time from the nearest local station to the central business district (CBD);
- Travel time to the nearest local highway interchange;
- Mainline highway travel time from the nearest local highway interchange to the CBD;
- If the residence is within a 1.6-km (1-mi) walk shed of a commuter rail station, the walking distance to the nearest commuter rail station is estimated, using a walking speed of 82 m (270 ft)/min and the straight-line distance; and
- The existence of an MBTA rail rapid transit station within the same community as the residence.

The 451 residential properties were geocoded and assigned explicit latitude/longitude coordinates such that relative distances to various transportation facilities could be accurately measured. U.S. Bureau of the Census TIGER/Line files provided the spatial framework for this analysis (*20*) and were supplemented with 1:25,000-scale and 1:100,000-scale U.S. Geological Survey quadrangle maps and rail system maps from MBTA and freight rail operators.

Accessibility to the Boston CBD was measured for both commuter rail and automobile/highway modes. Accessibility measures for both modes were disaggregated into local accessibility to the rail station or highway interchange and regional accessibility, represented by mainline travel times on either the rail line or highway network. Regional accessibility on mainline portions of both commuter rail and the highway network represents actual observed travel times in minutes. Actual travel times on the Fitchburg Line were taken directly from the operating schedule in effect during the sample period. Since MBTA commuter rail operations typically keep to their scheduled departure and arrival times, the scheduled times should be a highly accurate measure of the actual mainline travel times. Actual travel times on all segments of the study area limited-access freeway network were sampled by the author between April 1992 and September 1992 from interchange to interchange, at peak periods and in peak directions, using the average-speed technique. Existing freeway travel time estimates that were available from public sources were not believed to be detailed enough for the purposes of this analysis. Sample days were chosen so as not to coincide with holidays and any other days that would have resulted in abnormal travel patterns.

Local accessibility to either rail station or highway interchange is estimated on the basis of the latitude/longitude coordinate-derived straight-line distances, in combination with an average local access speed weighted by local population density. Local access times were estimated in this way rather than by shortest path routines using GIS because limited resources would not permit the vast numbers of individual shortest-path routines that would have been necessary.

Additionally, the necessary data describing the characteristics of each individual link in the local road network file were not immediately available. Therefore, a number of actual travel times for these local accessibility variables were measured to calibrate a weighting system in which average speeds on local road networks increased somewhat with decreasing local population density. This allowed for reasonably accurate estimates of local access times in different communities based on a limited number of actual observations.

Local Environmental Impact Variables

Local environmental impact variables include

- Distance to nearest railroad right-of-way, used as a proxy for noise, vibration, and other proximity effects from the railroad right-of-way, and
- Distance to nearest highway right-of-way, used as a proxy for noise, vibration, and other proximity effects from the highway right-of-way.

In addition care was taken to note any homes that were within measurable sound contours of local airports or military bases; however, none of the study properties were affected by these types of facilities. Because both commuter rail and freight rail operations share the right-of-way, an attempt was made to differentiate the two impacts by using various sets of dummy variables representing different threshold distances corresponding to various threshold impact levels and the maximum impact level for both freight rail and commuter rail operations and their predominant proximity impact, noise.

It should be noted briefly that although the data set is cross sectional in nature, this does not rule out the possibility of the existence of autocorrelation. In studies that use cross-sectional data on observations ordered in space, these observations may be correlated because of their relative locations in space. One would expect the correlative effect to be much stronger at shorter relative distances.

A study of assessed values in Ann Arbor, Mich. revealed that by using an autoregressive model with higher-order autoregressive terms representing relative distance lags between the dependent variables, approximately 79 percent of the explanatory power of the equation was found to be originating from the autoregressive terms (*21*). Independent variables that had been significant before the inclusion of the lag terms, such as distance to the city center, became insignificant. Much of the effect was thought to be related to local street patterns and local neighborhood characteristics.

This finding sheds doubt on the reliability of estimated coefficients in multiple linear regression models that use dependent variables exhibiting close relative distances. In particular studies that use observations from homogeneous neighborhoods to control for variation in neighborhood attributes may unintentionally introduce spatial autocorrelation into the data set. An analysis of the relative distances of the 451 observations used in this analysis reveal that the vast majority of these relative distances are well over 3048 m (10,000 ft), making the potential for significant spatial correlation in this analysis minimal.

RESULTS AND INTERPRETATION

Ordinary least-squares regression was used along with a log-log model specification, with the natural logarithm of sales price used as the dependent variable. Early model specifications revealed that the number of pools, actual school quality as represented by the weighted index of standardized test results, heating system type (forced air, forced hot water, etc.), and zoning designation (residential, commercial) were consistently insignificant even at the .10 level by a one-tailed test. In the case of zoning designation, only 4 of the 451 properties were located in commercially zoned areas, such that insufficient variation in this variable existed to make any determination as to its impact upon property values. Therefore, the first model specification presented in Table 3 includes only those variables defined in Table 2.

It is anticipated that the bed, bath, and story variables will all exhibit positive coefficients. Age is anticipated to exhibit a negative coefficient; however, the AGE100 dummy variable is expected to have a positive coefficient, since this indicates that the home is of antique status, typically resulting in a significant property tax reduction. The three style categories are all expected to exhibit positive coefficients, since these styles are those that were generally more in demand at the time of the study. The variable representing no garage is expected to exhibit a negative coefficient, whereas the cardinal measurement of the number of garages used for those homes with garage space is expected to exhibit a positive coefficient.

Lot size is expected to exhibit a positive coefficient. It is unclear how the three community type variables will affect property values, yet it is believed that all three will exhibit positive coefficients. However, the variable GROWTH may exhibit a negative coefficient, resulting from the potentially negative aspects of rapid growth and transition within a community.

School quality indicators are expected to exhibit positive coefficients, and both the crime rate and tax rate variables are expected to exhibit negative coefficients.

Accessibility-related variables are anticipated to exhibit negative coefficients, indicating a decrease in property value with increasing distance from either regional or local activity centers. Both of the dummy variables STATN and MBTA, indicating a location in a community with a commuter rail station or a rapid transit station, respectively, are expected to exhibit positive coefficients.

Finally, the proximity effects variables FT700 and FT400 are both expected to exhibit negative coefficients since they are dummy variables representing proximity to the Fitchburg Line right-of-way. The two remaining variables, RAIL30 and HWY25, are expected to exhibit positive coefficients, indicating increasing property values as distance from freight rail and highway rights-of-way increases.

Output for this first specification is presented in Table 3. This specification does not perform exceptionally well, with half of the independent variables insignificant at even the .10 level by a one-tailed test. Nine of the coefficients, including HTWATR, CAPE, GAR0, GROWTH, lnTXRATE, lnAUTO1, lnWLKTIM, MBTA, and FT750, react in directions opposite to that which is hypothesized. Of these, only lnTXRATE and lnWLKTIM are significant. The variable MBTA, indicating that the residence was located within a community that had an MBTA rail rapid transit station (sometimes offering connections with commuter rail service), is both insignificant and reacts in the direction opposite to that which is hypothesized, suggesting that the ability to transfer between commuter rail service and rail rapid transit service at any given station has an insignificant impact on residential property values in the community in which the station is located.

lnTXRATE does not conform to that which would be anticipated, for example, a negative sign indicating increasing tax rates result-

TABLE 2 Model 1 Variable Definitions

Dependent Variable	
lnSLPRIC	- the natural log of the sales price (fair market property value) in thousands of dollars
Structural Attribute Variables	
lnBEDS	- the natural log of the number of bedrooms in the residence
lnBATHS	- the natural log of the number of bathrooms in the residence
OIL	- heating fuel type is oil (0/1 dummy variable)
HTWATR	- heating system type is forced hot air (0/1 dummy variable)
lnAGE1	- the natural log of the age of the home as of 1990. If age=0, it was changed to 1 before taking the natural log.
AGE100	- a dummy variable indicating that the home is 100 years of age or older, and therefore classified as antique by the local assessor (0/1 dummy variable)
COLONL	- structural style is colonial (0/1 dummy variable)
CAPE	- structural style is cape cod (0/1 dummy variable)
MODERN	- structural style is modern/contemporary (0/1 dummy variable)
lnSTRYS	- the natural log of the number of stories the residence has
GAR0	- if the home has no garage capacity, then this variables takes the value 1, otherwise this variable takes the value 0 (0/1 dummy variable)
lnGARG0	- if the home has garage capacity for one or more vehicles, then this variable takes the value of the natural log of that value.
Site Attribute Variables	
lnLTSQFT	- the natural log of the lot size, as measured in square feet
DVLSUB	- the residence is located within a municipality characterized as an economically developed suburb (0/1 dummy variable)
GROWTH	- the residence is located within a municipality characterized as a growth community (0/1 dummy variable)
RESSUB	- the residence is located within a municipality characterized as a residential suburb (0/1 dummy variable)
Local Service Provision and Cost Variables	
lnPUPIL	- the natural log of expenditure per pupil, measured as an integrated student cost (1989)
lnVCRIME	- the natural log of the number of violent crimes per 1,000 population (1989)
lnTXRATE	- the natural log of the residential property tax rate per $1,000 of assessed valuation (FISCAL year ending June 30, 1990)
Locational and Accessibility Variables	
lnAUTO1	- the natural log of the estimated travel time in minutes from the residence to the nearest limited access highway interchange
lnAUTO2	- the natural log of the actual travel time in minutes from the preferred highway interchange to North Station
lnRAIL1	- the natural log of the estimated travel time in minutes from the residence to the nearest Fitchburg/Gardner line commuter rail station (includes a 5 minute transfer time at station)
lnRAIL2	- the natural log of the actual travel time in minutes from the preferred Fitchburg/Gardner line commuter rail station to North Station
lnINT1	- the natural log of an interaction term defined as [(AUTO1 + AUTO2)/RAIL1]
lnWLKTIM	- the natural log of the walking time from homes within one mile of a commuter rail station to the station (at a rate of 82 meters [1] per minute)
STATN	- the municipality in which the residence is located has an MBTA commuter rail station within its corporate border (0/1 dummy variable)
MBTA	- the municipality in which the residence is located has an MBTA rail rapid transit station within its corporate border (0/1 dummy variable)
Local Environmental Impact Variables	
lnRAIL30	- if the residence is within 915 meters of an active freight rail right-of-way, then this variable is the natural log of the distance in feet to that right-of-way. Otherwise this variable takes the value 0.
FT400	- the residence is within 122 meters (corresponds to the 55 Ldn commuter rail noise contour) of the Fitchburg/Gardner commuter rail line (0/1 dummy variable).
FT750	- the residence is within 229 meters (corresponds to maximum extent of potential commuter rail noise impact area) of the Fitchburg/Gardner commuter rail line (0/1 dummy variable)
lnHWY25	- if the residence is within 762 meters of a limited access highway right-of-way, then this variable is the natural log of the distance measured in feet to that right-of-way. Otherwise this variable takes the value 0.

[1] 1 meter = 3.28 feet

ing in lower property values. One possible rationalization for this outcome is that higher tax rates are correlated with higher overall quality of public services, and that this effect of increasing quality of public services affects the tax rate variables. However, this seems unlikely given that indicators of public service quality such as public safety and school quality are included in the model to control for these attributes. lnWLKTIM indicates that a depreciative effect on residential property values predominates in close proximity to station locations. This may be the result of station-generated pedestrian and automobile traffic and noise, as well as the generally higher-activity areas in which stations appear to be located, resulting in relatively more traffic and other activity that is not directly the result of the stations. This negative impact may be less than that experienced in proximity to a rail rapid transit station, however, since data obtained from MBTA reveals that parking facility capacities at Fitchburg Line stations are significantly less than typical parking facilities at many MBTA heavy rail rapid transit stations.

Because of the relatively poor performance of this specification, the following specification was analyzed by using the variables defined in Table 4. A more simplified model than Model 1 is used in hopes that variable significance and indicated direction of influence will improve. Model 2 still uses 19 independent variables representing a broad range of attributes; therefore, no significant specification bias should be introduced by the removal of some of the

TABLE 3 Model 1 OLS Regression Results

Dependent Variable	= LNSLPRIC
Observations	= 451
R-squared	= 0.742
Adjusted R-squared	= 0.723
Standard Error of the Estimate	= 0.2554582
F-Ratio	= 38.93817

Variable	Coefficient	Std. Error	t-ratio
lnBEDS	0.17252	0.05041	3.422†††
lnBATHS	0.24206	0.04426	5.469†††
OIL	0.04555	0.02782	1.637†
HTWATR	-0.01813	0.02646	-0.685
lnAGE1	-0.04902	0.01305	-3.758†††
AGE100	0.11140	0.06171	1.805††
COLONL	0.03875	0.04071	0.952
CAPE	-0.00369	0.03756	-0.098
MODERN	0.22595	0.06525	3.463†††
lnSTRYS	0.06443	0.05365	1.201
GAR0	0.00023	0.03511	0.007
lnGARG0	0.23656	0.05209	4.541†††
lnLTSQFT	0.09272	0.02121	4.372†††
DVLSUB	0.07605	0.05004	1.520
GROWTH	-0.02036	0.07919	-0.257
RESSUB	0.07380	0.05717	1.291
lnPUPIL	0.63497	0.13360	4.753†††
lnVCRIME	-0.04504	0.01403	-3.209†††
lnTXRATE	0.44299	0.14220	3.115***
lnAUTO1	0.00660	0.04962	0.133
lnAUTO2	-0.04550	0.02039	-2.231††
lnRAIL1	-0.13991	0.09870	-1.418†
lnRAIL2	-0.10929	0.04967	-2.201††
lnINT1	-0.06026	0.11080	-0.544
lnWLKTIM	0.10139	0.05889	1.722*
STATN	0.04774	0.04788	0.997
MBTA	-0.07615	0.07322	-1.040
lnRAIL30	0.01515	0.03478	0.436
FT400	-0.28809	0.14430	-1.997††
FT750	0.12965	0.11200	1.158
lnHWY25	0.00906	0.03109	0.291
Constant	-1.91220	1.33400	-1.433

***,**,* denote coefficient significantly different from zero at the 1%, 5%, and 10% level of significance (two-tailed test)

†††,††,† denote coefficient significantly different from zero at the 1%, 5%, and 10% level of significance (one-tailed test)

variables used in Model 1. Anticipated results are similar to those anticipated for Model 1. Output for this second specification is presented in Table 5.

The performance of Model 2 appears much improved over that of the previous model, Model 1. As anticipated the overall explanatory power of the model has not been reduced by the removal of the insignificant variables. Only 4 of the 19 independent variables are now insignificant. Analysis of the variance-covariance matrix for Model 2 reveals relatively low zero-order correlations among the independent variables. Also the consistently significant *t*-ratios for most of the independent variables would suggest the absence of any notable multicollinearity.

One of the variables of primary interest to this analysis, lnRAIL1, is insignificant in Model 2, although it is statistically significant from zero at the .10 level using a one-tailed test in Model 1. However, at the same time the estimated parameter on this variable also consistently exhibits the anticipated sign (negative), which is interpreted as a reduction in property value as one moves away from the station site and the RAIL1 travel time, as measured in minutes, increases. Additionally, in Model 2, the (0/1) dummy variable STATN, indicating that the residence was located within a community that had a commuter rail station within its borders, is statistically significant at the .10 level using a two-tailed test of significance.

In this model specification as well as the previous specification used in Model 1, the coefficients on the (0/1) dummy variables, when multiplied by 100, can be approximately interpreted as the percent change in the dependent variable P_h for an absolute change in the independent dummy variable, since the model essentially acts as a semilogarithmic model of the log-lin type for these (0/1) dummy variables. In this case with STATN representing a (0/1) dummy variable rather than the natural log of a cardinal measurement, the coefficient of .067 indicates that for single-family residential properties located in communities that have a commuter rail station there is an increase in value of approximately 6.7 percent. It is believed that this impact results primarily from the perceived effect of having a station in the same community as the residence, regardless of the actual travel time involved in accessing the station from particular individual locations within the community.

This finding is consistent with the way in which residential properties are marketed by real estate firms. Often, the fact that the home is located within a community with commuter rail access to Boston may be extolled, and whether the property is 3 min from the station or 8 min from the station is not focused on. This is reasonable, however, considering that for a home located within a community with a commuter rail station, variations in driving times to the station would in all probability be minimal since several kilometers of driving distance may translate into only several minutes of driving time. The greater part of the total trip time occurs on the mainline portion of the trip from the station to the CBD. Therefore, total origin-destination travel time for all properties in the community would essentially be approximately the same, resulting in an approximately equivalent increase in property values across the entire community. This 6.7 percent increase is also consistent with earlier findings by Voith (*13*) in an analysis of commuter rail-service in the Philadelphia region that found premiums associated with accessibility to commuter train service of 6.4 percent of average census tract median house value (*13*).

Regional accessibility, as represented by the RAIL2 variable, provided by commuter rail service does have a consistently statistically significant appreciative effect on single-family residential property values. The coefficient of −.137 on lnRAIL2 can be interpreted to imply that for every 1 percent increase in travel time from the CBD by rail, single-family residential property values depreciate, on average, by 0.137 percent, or a little over 1/10th of 1 percent.

Another variable of primary interest to this analysis is the (0/1) dummy variable FT400, indicating a location within the average estimated commuter rail generated 55Ldn contour of the Fitchburg Line commuter rail line. This variable consistently exhibits a coefficient that is significantly different from 0 at the .05 level using a one-tailed test of significance. In Model 2 the estimated parameter indicates a depreciation in the value of single-family residential properties of approximately 20 percent as a result of being located within 122 m (400 ft) of the Fitchburg Line right-of-way. However,

TABLE 4 Model 2 Variable Definitions

Dependent Variable	
lnSLPRIC	- the natural log of the sales price (fair market property value) in thousands of dollars
Structural Attribute Variables	
lnBEDS	- the natural log of the number of bedrooms in the residence
lnBATHS	- the natural log of the number of bathrooms in the residence
lnAGE1	- the natural log of the age of the home as of 1990. If age=0, it was changed to 1 before taking the natural log.
AGE100	- a dummy variable indicating that the home is 100 years of age or older, and therefore classified as antique by the local assessor
MODERN	- structural style is modern/contemporary (0/1 dummy variable)
lnSTRYS	- the natural log of the number of stories the residence has
GAR0	- if the home has no garage capacity, then this variables takes the value 1, otherwise this variable takes the value 0 (0/1 dummy variable)
lnGARG0	- if the home has garage capacity for one or more vehicles, then this variable takes the value of the natural log of that value.
Site Attribute Variables	
lnLTSQFT	- the natural log of the lot size, as measured in square feet
Local Service Provision and Cost Variables	
lnPUPIL	- the natural log of expenditure per pupil, measured as an integrated student cost (1989)
lnVCRIME	- the natural log of the number of violent crimes per 1,000 population (1989)
lnTXRATE	- the natural log of the residential property tax rate per $1,000 of assessed valuation (FISCAL year ending June 30, 1990)
Locational and Accessibility Variables	
lnAUTO1	- the natural log of the estimated travel time in minutes from the residence to the nearest limited access highway interchange
lnAUTO2	- the natural log of the actual travel time in minutes from the preferred highway interchange to North Station
lnRAIL1	- the natural log of the estimated travel time in minutes from the residence to the nearest Fitchburg/Gardner line commuter rail station (includes a 5 minute transfer time at station)
lnRAIL2	- the natural log of the actual travel time in minutes from the preferred Fitchburg/Gardner line commuter rail station to North Station
lnWLKTIM	- the natural log of the walking time from homes within one mile of a commuter rail station to the station (at a rate of 82 meters [1] per minute)
STATN	- the municipality in which the residence is located has an MBTA commuter rail station within its corporate border (0/1 dummy variable)
Local Environmental Impact Variables	
FT400	- the residence is within 122 meters (corresponds to the 55 Ldn commuter rail noise contour) of the Fitchburg/Gardner commuter rail line (0/1 dummy variable).

[1] 1 meter = 3.28 feet

it is surmised that since the Fitchburg Line operates freight service as well as commuter rail service, this variable represents the impact of proximity impacts generated by freight service as well as commuter rail service. The fact that both freight rail service and commuter rail service operate on the Fitchburg Line makes it difficult if not impossible to accurately differentiate between the two separate sources of proximity impacts. Therefore, the findings concerning the effects of commuter rail-generated proximity impacts, independent of freight rail-generated proximity impacts, are inconclusive.

CONCLUSIONS AND POLICY IMPLICATIONS

It appears that there are indeed property value impacts on single-family residential properties resulting from commuter rail service. At the regional level access to the CBD provided by commuter rail service has an appreciative impact on property values. Even more notable is the finding that single-family residences located in communities that have a commuter rail station have a market value that is approximately 6.7 percent greater than that of residences in other communities.

From the perspective of property value losses sustained as a result of proximity to the commuter rail right-of-way, the findings are inconclusive. Although a statistically significant property value loss of about 20 percent was identified for properties within 122 m (400 ft) of the right-of-way, it is impossible to differentiate between the loss attributable to commuter rail service proximity impacts and that attributable to freight rail service proximity impacts.

These findings suggest that some type of compensatory policy for property owners affected by negative right-of-way proximity effects could be appropriate in the case of new commuter rail facilities operated along new or long-abandoned rights-of-way if any of the negative proximity effects identified in this study could be attributed to commuter rail service. Such a policy would be in

TABLE 5 Model 2 OLS Regression Results

Dependent Variable	= LNSLPRIC
Observations	= 451
R-squared	= 0.736
Adjusted R-squared	= 0.724
Standard Error to the Estimate	= 0.2550790
F-Ratio	= 63.15376

Variable	Coefficient	Std. Error	t-ratio
lnBEDS	0.18664	0.04948	3.772†††
lnBATHS	0.24227	0.04286	5.653†††
lnAGE1	-0.05173	0.01247	-4.149†††
AGE100	0.11864	0.05985	1.982††
MODERN	0.21267	0.05904	3.602†††
lnSTRYS	0.09769	0.04385	2.228††
GAR0	-0.01700	0.03378	-0.503
lnGARG0	0.22586	0.05060	4.464†††
lnLTSQFT	0.10008	0.01967	5.088†††
lnPUPIL	0.75894	0.11310	6.711†††
lnVCRIME	-0.04741	0.01224	-3.873†††
lnTXRATE	0.56672	0.11090	5.109***
lnAUTO1	-0.03085	0.03683	-0.838
lnAUTO2	-0.02926	0.01434	-2.040††
lnRAIL1	-0.04565	0.04794	-0.952
lnRAIL2	-0.13734	0.03233	-4.248†††
lnWLKTIM	0.07157	0.05235	1.367
STATN	0.06778	0.03780	1.793††
FT400	-0.20398	0.10490	-1.944††
Constant	-3.18970	1.09000	-2.928***

†††,††,† denote coefficient significantly different from zero at the 1%, 5%,and 10% level of significance (one-tailed test).

***,**,* denote coefficient significantly different from zero at the 1%, 5%,and 10% level of significance (two-tailed test)

addition to current practice regarding the partial mitigation of proximity impacts by means of application of noise treatments and construction of noise barriers, and could possibly be financed with a limited value capture policy by using special assessments to capture a portion of the communitywide increase in property values indicated in this study. Alternatively, possible reductions in public opposition as well as potential reductions in project cost and increases in project benefits resulting from the timely implementation of proposed commuter rail facilities may justify such a compensatory policy independent of any value capture policy.

A compensatory policy such as the one described above could have the potential for fairly compensating those residential property owners located within close proximity of the new commuter rail facility, but not within the right-of-way. Properties within the right-of-way are, of course, already compensated through negotiated purchase or eminent domain acquisition. An extension of these existing compensatory policies to include residential properties within close proximity of the right-of-way, but not within the right-of-way, could serve to reduce public opposition to needed transportation improvements and would also result in a more equitable outcome for all involved. From a social benefit-cost perspective, compensatory payments made to the affected property owners can be viewed as a transfer rather than a net loss or cost to society, since the actual cost to society is the cost imposed on negatively affected property owners in proximity to the right-of-way. A methodology similar to the one used in the present study could be employed in an attempt to quantify impacts on individual property owners, with the prospect of even more accurate estimates of potential impacts, considering the large amount of machine-readable assessors' data compiled by and accessible to each community.

The potential for the practical application of such a policy, however, is somewhat doubtful, given the legal impediments that have been met in the use of similar computer-aided techniques, such as the estimation of assessed property values, and the potential for various institutional impediments as well. The use of computer-aided valuation techniques by local assessors' offices to update property valuations has in the past been met with some opposition by various aggrieved parties attempting to appeal valuations. Many of these techniques are based on the use of multiple regression models in some ways similar to the one used in this analysis. However, even though the legal validity of these techniques appears to be undecided, the general trend appears to be toward acceptance of these techniques as admissible evidence in a court of law. In addition the cooperation of the various local communities served by the commuter rail line would be required, leading to the potential problem of institutional impediments to the application of such a policy.

Given the inconclusive findings of the present study concerning the proximity effects of commuter rail service, future considerations for related analyses should include further attempts to differentiate and quantify property value impacts resulting from commuter rail service on both shared and dedicated rights-of-way. In addition the possible time series effects of the planning, construction, and operation of new commuter rail facilities is another area of possible future study. Such analyses may yield further insights into the effects of commuter rail facilities on residential areas, such that the relationship between transportation planners and the public will continue to become one that is less adversarial, resulting in a more effective and less costly transportation planning process as well as improved transportation services.

ACKNOWLEDGMENTS

The author wishes to acknowledge with gratitude Robert D. Ballou, John R. Mullin, Paul W. Shuldiner, and George I. Treyz of the University of Massachusetts at Amherst for their guidance, technical support, and patience throughout the development and completion of the manuscript that served as the basis for this paper. The Volpe National Transportation Systems Center, U.S. Department of Transportation, is also gratefully acknowledged for allowing the author to use their computer facilities. Persons from various local, state, federal, and private agencies and organizations with whom the author has had countless conversations and meetings, too numerous to mention separately, are also gratefully acknowledged.

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The views expressed in this study are those of the author and are not necessarily shared by the individuals and agencies who have contributed to this report. The author assumes sole responsibility for the contents and use of the material presented and for any errors or omissions herein.

Publication of this paper sponsored by Committee on Transportation and Land Development.

Changes in Regional Travel Characteristics and Travel Time Expenditures in San Francisco Bay Area: 1960–1990

CHARLES L. PURVIS

An update of a 1984 study by Kollo and Purvis is presented. Results from the 1990 household travel survey conducted in the San Francisco Bay Area are compared with results from surveys conducted in 1965 and 1981 and decennial census data. The study shows a decline in trip frequency per household and per person between 1981 and 1990, which is offset by an increase in average trip duration, yielding an apparent constant travel time expenditure per person and per household. Regularities in average travel time expended per household vehicle are also analyzed. Changes in Bay Area demographic characteristics from 1960 to 1990 are described to provide context to the changes in aggregate travel characteristics. Changes in household trip rates by trip purpose and travel mode are also summarized. Findings show a decline in home-based non-work-related and non-home-based trip rates per household and increases in home-based work-related trips per household.

This research project is an update to the 1984 study by Kollo and Purvis (*1*). The authors' 1984 study compared results from the 1965 and the 1981 household travel surveys conducted in the nine-county San Francisco Bay Area. Comparison was also made with journey to work characteristics from the 1960, 1970, and 1980 U.S. decennial censuses. The present study updates the information provided in the 1984 paper to provide results from the 1990 Bay Area household travel survey and includes new information related to changes and regularities in travel time expenditures of Bay Area households based on analysis of the 1965, 1981, and 1990 household travel surveys.

There is a basic need for a careful and comparative review of results from metropolitan area household travel surveys to detect survey strengths and weaknesses, devise strategies and methods for correcting problems and biases, and planning strategies for estimation of new sets of regional travel demand forecasting models. A thoroughly structured travel survey analysis project related to cleaning, editing, weighting, expanding, linking trips, and flushing out survey idiosyncrasies and data outliers is a critical precursor to travel demand model development activities. The study described here is but one element of the 1990 household travel survey analysis project.

This research also adds to a growing genre of literature related to comparative aggregate analyses of metropolitan travel characteristics. Most of this research is related to the temporal stability or regularities of travel characteristics, typically focusing on the basic presumption of constancy of trip generation, trip distribution, and mode choice model coefficients. Selected studies of this genre include Kannel and Heathington's (*2*) study of Indianapolis travel characteristics based on household surveys conducted in 1964 and 1971, Yunker's (*3*) 1963 and 1972 survey analysis of Milwaukee, Smith and Cleveland's (*4*) analysis of the 1953 and 1965 Detroit surveys, Cohen and Kocis's (*5*) study of Buffalo and Rochester, the aforementioned study by Kollo and Purvis (*1*) for the San Francisco Bay Area, Norris and Shunk's (*6*) analysis of 1964 and 1984 travel characteristics in the Dallas region, and Walker and Peng's (*7*) study of changes in the Philadelphia region between 1960 and 1988. Other collections of results related to metropolitan area household travel surveys include an ITE committee report (*8*) from 1979 and the *Characteristics of Urban Transportation Demand* (*9*) manual published by the Urban Mass Transportation Administration.

Findings from this aggregate analysis of Bay Area household travel surveys generally supports theories related to travel time budget research conducted between 1961 and 1985. On the other hand, analyses of travel time expenditures by market segment (e.g., household size and vehicle availability) show notable instability and irregularities in travel time expenditures. The vast research heritage related to travel time budgets includes early works by Tanner (*10*) and numerous efforts by Yacov Zahavi (*11–14*), Zahavi and Ryan (*15*), Zahavi and Talvitie (*16*), and Zahavi and coworkers (*17*).

Interest in travel time budget research apparently peaked in the late 1970s and early 1980s, culminating in a 1-day conference on personal travel budgets held at the University of Leeds in the United Kingdom in May 1979 (see the special issue of *Transportation Research* A, Vol. 15A, No. 1, published in January 1981). Precious little research related to transportation travel time or money budgets has appeared in the professional literature after 1985, perhaps because of the passing of a principal proponent of travel budget models, Yacov Zahavi, in the early 1980s or perhaps because of the lack of research material (or research budgets) for the continuing analysis of travel time budgets. The information included in this paper may help to rekindle interest in travel budget and travel time expenditure research.

The Bay Area household travel surveys for 1981 and 1990 are apparently showing a real decline in trip frequency per household and per person. This is offset by a real increase in average trip duration (average trip time), yielding, on an aggregate basis, an apparent constant travel time expenditure of approximately 2.7 person-hr of travel per household per weekday and 1.0 person-hr of travel per person per weekday. This finding of an inverse relationship between trip frequency and trip duration is consistent with much of Zahavi's analyses conducted in the 1970s.

The remainder of this paper discusses comparability issues related to the 1965, 1981, and 1990 household travel surveys, changes in Bay Area demographic and economic characteristics between 1960 and 1990, changes in travel time expenditures and related characteristics between 1965 and 1990, and changes in regional household trip rates from 1965 to 1990.

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COMPARABILITY ISSUES RELATED TO 1965, 1981, AND 1990 HOUSEHOLD TRAVEL SURVEYS

In any comparative analysis of household travel surveys it is advisable to provide the reader with information to help in the understanding of similarities and dissimilarities related to survey design, sample design, and survey analysis methods. Fortunately, the Bay Area household travel surveys of 1965, 1981, and 1990 are quite similar in design and analysis, and excellent documentation of all three surveys has been developed. This analysis required revisiting the 1965 and 1981 survey files, especially in terms of calculating mobile persons, mobile households, and travelers versus nontravelers.

The study area for the three Bay Area travel surveys has remained constant, including the same nine counties and the entire region of 6,900 mi^2 (17 900 km^2). Other regions, such as Atlanta, Buffalo, Rochester, and Philadelphia (*5,7*), have increased their study area sizes between survey years and require careful analysis to ensure appropriate comparisons between comparable areas.

The 1965 household travel survey, conducted by the Bay Area Transportation Study Commission (BATSC), was a home interview (face-to-face, in-person) survey of 20,486 households as to their weekday travel behaviors. An additional 10,200 households were queried as to their average weekend daily travel behaviors.

The 1981 household travel survey, conducted by the Metropolitan Transportation Commission (MTC), was a telephone survey of 6,209 households for weekday travel and an additional 882 households for weekend travel. Detailed survey methodology is included in the report by Crain and Associates (*18*) and in a report by Reynolds et al. (*19*).

The 1990 household travel survey, conducted by the MTC during the spring and fall of 1990, was also a telephone survey of more than 10,800 households for weekday travel behavior. Of the 10,838 usable household samples collected by MTC, 9,438 households provided single weekday daily travel diaries, and 1,486 sample households provided either 3-day or 5-day (weekday) travel diaries. The survey results reported here represent the single-day sample only, not the multiple-weekday sample. The detailed survey methodology for the 1990 MTC travel survey is included in a previous report (*20*).

All three surveys were administered to all persons in households ages 5 years and older. All three surveys collected basic household information (household income, vehicle availability, length of residence, structure type, owner/renter tenure), data on each person (age, sex, race/ethnicity, relationship to head of household, employment status), and trip data (detailed means of transportation, origin and destination location and trip purposes, trip start time, trip finish time, vehicle occupancy). Certain "households" in all three surveys were actually group quarters units (boarding houses, fraternities, convents, prisons, etc.) and were excluded from all three sets of analyses. The analysis for all three surveys is of weekday, intraregional personal travel made by residents (age 5 years and older) of Bay Area households. Therefore, the analysis excludes the following travel submarkets: interregional travel made by Bay Area residents, travel made by nonresidents (visitors and commuters), travel made by persons living in group quarters, and commercial travel.

Trip Linking

The trips reported in this analysis are based on linked trip records. Trip linking procedures for the 1965 home interview survey (*21*), the 1981 telephone survey (*22*), and the 1990 telephone survey (*23*) are quite comparable. Trip linking is a technical necessity to remove incidental stops such as changing travel modes (e.g., walk to bus and drive to rail) and serving passengers (e.g., dropping off kids or spouse on the way to work and picking up carpool passengers). Mode-of-access and mode-of-egress trip leg information is retained in special extended versions of the linked trip files for future work in estimating mode of access to transit submode choice models. It is critical in a comparative survey analysis to identify whether unlinked or linked trips are used. The Philadelphia and Dallas studies clearly indicated the use of linked trips in their analysis and also provided a general description of trip linking procedures.

Sample Weighting and Expansion

Weighting and expansion procedures were different for the three surveys. The 1965 survey was expanded to backcast estimates of households by single-family/multiple-family breakdown by 290 regional travel analysis zones of residence (*24*). The 1981 survey was expanded to the 1980 census count of households by household size by 45 districts of residence (*25*). The 1981 survey weighting method reflected the fact that one-half of the 6,200 household samples were from the city of San Francisco. The 1990 survey was expanded to the 1990 census count of households by household size, owner/renter tenure, auto-mobile ownership level, and 34 districts of residence (*26*). All of the results reported in this analysis reflect weighted survey results.

Adjustments for Trip Underreporting

A report (*24*) on the 1965 travel survey discusses screenline adjustment factors to account for trip underreporting in the travel diaries. These adjustment factors were calculated by county and three general trip purposes (home-based work, home-based non-work, and non-home-based) and were applied only to the in-vehicle trips (not the transit trips). Screenline adjustment factors ranged from 3 to 10 percent for home-based work in-vehicle trips and from 5 to 25 percent for non-work in-vehicle trips. No screenline adjustment factors were required for the 1981 survey analysis, and the issue of screenline adjustment factors for the 1990 survey will be addressed in future MTC analyses. The results reported here are for reported travel characteristics before any screenline adjustment factors were applied.

Adjustment of household travel surveys to account for underreporting is discussed by Clarke et al. (*27*) and Barnard (*28*). Clarke and colleagues' summaries of U.S. and U.K. household travel surveys shows expanded survey data at 79 to 99 percent of screenline counts. Barnard's analysis of Australian household travel surveys shows expanded survey data at 55 to 95 percent of screenline counts. Both Clarke et al. and Barnard note the differential underreporting by trip purpose and travel mode, with non-work vehicle trips the most likely trip market to be underreported and with transit trips the least likely to be underreported. The basic conclusion of Clarke et al. and Barnard is that the standard household travel survey tends to underreport household travel on the order of 10 to 15 percent.

CHANGES IN REGIONAL DEMOGRAPHIC AND ECONOMIC CHARACTERISTICS

A summary of key regional, aggregate demographic and economic indicators is provided in Table 1. These characteristics provide a

TABLE 1 Regional Demographic and Economic Characteristics, 1960–1990

Variable	1960 Census	1965 (ABAG)	1965 BATSC Survey	1970 Census	1980 Census	1981 MTC Survey	1990 Census	1990 MTC Survey
Total Population (000s)	3,639	4,216	--	4,628	5,180	--	6,024	--
Population in Households (000s)	3,515	4,106	4,331	4,501	5,059	5,051	5,870	5,870
Households (000s)	1,174	1,387	1,387	1,553	1,971	1,970	2,246	2,246
Total Vehicles (000s)	1,315	--	1,942	2,078	3,317	3,350	3,950	4,020
Employed Residents (000s)	1,433	1,664	1,697	1,882	2,555	2,639	3,152	3,072
School Enrollment (000s)								
Total	904	--	--	1,380	1,464	--	1,504	--
Kindergarten - High School	811	--	--	1,108	975	--	913	--
College	93	--	--	232	419	--	591	--
Mean Household Income (curr. $)	--	$9,400	$9,600	$11,300	$24,400	$26,500	$52,100	$48,700
Mean Household Income (1989 $)	--	$38,600	$39,400	$39,800	$44,200	$48,000	$52,100	$48,700
Household Size	2.99	2.96	3.12	2.90	2.57	2.56	2.61	2.61
Employed per Household	1.22	1.20	1.22	1.21	1.30	1.34	1.40	1.37
Drivers per Household	--	--	1.67	--	--	1.75	--	1.76
Vehicles per Household	1.12	--	1.40	1.33	1.68	1.70	1.76	1.79
Vehicles per Licensed Driver	--	--	0.84	--	--	0.97	--	1.02
Vehicle Ownership (%)								
Households with no vehicle	20%	--	14%	16%	12%	11%	10%	10%
Households with one vehicle	53%	--	44%	44%	36%	35%	33%	32%
Households with two vehicles	24%	--	34%	33%	33%	36%	36%	37%
Households with three-plus vehs.	3%	--	8%	7%	19%	18%	21%	21%

context for later discussions on changes in travel time expenditures, trip frequency, and aggregate travel characteristics. As appropriate, weighted and expanded household travel surveys are compared with data from the respective census or, as in the case of the 1965 survey, with independent demographic backcasts prepared by the Association of Bay Area Governments, the council of governments for the region.

The nine-county San Francisco Bay Area is a large metropolitan region in Northern California with more than 6 million persons residing in an area of more than 6,900 mi^2 (17 900 km^2). The total population of the Bay Area increased by 16.3 percent between 1980 and 1990. The number of households increased by 14.0 percent between 1980 and 1990, and the total number of workers residing in the Bay Area increased by 23.4 percent in the 1980s. The recent upswing in regional average household size between 1980 and 1990 (2.56 to 2.61 persons per household) was the first census since 1960 in which Bay Area household size has shown an increase, not a decrease, with respect to the previous census year.

Growth in personal vehicle availability (+19.1 percent from 1980 to 1990) has outpaced growth in total population. The share of households owning zero vehicles has declined from 20 percent of all households in 1960 to 10 percent of all households by the year 1990. Communities with the highest shares of zero-vehicle households are San Francisco (30.7 percent of households with zero vehicles in 1990), Oakland (23.3 percent), and Berkeley (19.0 percent). The number of vehicles per licensed driver is apparently approaching one vehicle available per driver, although state Department of Motor Vehicle records indicate that the actual number of drivers per Bay Area 1990 household is on the order of 1.87 drivers per household (contrasting to 1.76 vehicles per household).

Census data indicate a gradual decline in total school enrollment in kindergarten through grade 12 in the Bay Area between 1970 and 1990. On the other hand, college enrollments increased steadily between 1960 and 1990.

Regional mean household income increased 11 percent in 1989 constant dollar terms between 1970 and 1980 and increased 17.9 percent between 1980 and 1990. Mean household income for households in the 1981 survey is lower than the mean income from the 1980 census. In contrast the 1990 survey reported that incomes are slightly higher than those from the 1990 census.

CHANGES IN TRAVEL TIME EXPENDITURES AND RELATED CHARACTERISTICS

Key summary statistics that are reviewed as results are obtained from weighted, linked trip files and are the total count of expanded trips and trip rates per household and per person. Sample expansion and trip linking for the 1990 MTC household survey were completed in spring 1993. Soon thereafter the unpleasant reality of a major (−13.3 percent) decline in total trips per household and per person revealed potentially embarrassing results, that is, an absolute decline between 1980 and 1990 in the total number of trips made by Bay Area residents.

Bay Area Comparison with Other Metropolitan Areas

As shown in Table 2, total the number of trips per household (all purposes and means of transportation) gradually declined from 8.78 trips per household in 1965 to 8.71 trips per household by 1981 and then dropped to 7.55 trips per household in 1990. Trips per capita (total persons in household) increased from 2.81 trips per person in 1965 to 3.39 by the year 1981 and then dropped back to 2.93 trips per capita by 1990. All trip rates are expressed in trips per weekday.

One of the first reactions was the following: how does the Bay Area compare with other areas that conducted travel surveys in the early 1990s? Results were compared with those of the Nationwide Personal Transportation Survey (*29*), Los Angeles (*30*), Sacramento (*31*), California (*32*), Dallas (*6*), Philadelphia (*7*), and other U.S. metropolitan areas (*9*). Other metropolitan areas, namely, Los Angeles, Dallas, and Denver, showed modest declines in the numbers of trips per household when their 1960s and 1970s travel surveys were compared with their 1980s and 1990s travel surveys. Only the San Francisco and Los Angeles regions appear to be showing declines in trip rates per person. If they are taken alone and not compared with the earlier 1965 or 1981 travel surveys, results from the 1990 Bay Area travel survey appear generally in line with those for other metropolitan areas.

Although the evidence from Los Angeles and other metropolitan areas suggests that the Bay Area is not unique in terms of declining trip rates, this predicament of dropping trip rates has discomforting implications for the stability of trip generation model parameters. Survey-based, expanded "person" trips (mechanized modes only: vehicle driver, vehicle passenger, transit passenger) were compared with a recently completed year 1990 model simulation, using the 1981 survey-based travel demand models. The number of survey home-based-work person trips, shown in Table 3, was within 1 percent of the number of model-simulated home-based-work person trips. This was encouraging. On the other hand, the number of survey-based home-based-shop (other) person trips was 20 percent less than the number of model-simulated trips, and the number of survey-based home-based social/recreation trips was 39 percent less than the number of model-simulated trips, and the number of non-home-based (NHB) person trips was 20 percent less than the number of model-simulated person trips. This was discouraging. The non-work trip generation models basically responded to increasing household sizes, increasing automobile ownership levels, and increasing real household income levels. Standard non-work trip generation models would only show an ever-increasing trip frequency based on these situations and could not respond to the shifts in travel behavior that apparently occurred in the Bay Area between 1980 and 1990. Norris and Shunk's (*6*) comparative analysis also noted declines in home-based non-work household trip rates in San Francisco, Dallas, Denver, and Atlanta.

The survey and model results for San Francisco and elsewhere indicate structural problems with non-work trip generation models. The results suggest the need for a better linkage between non-work

TABLE 2 Comparative U.S. Metropolitan Area Person Trips per Capita, Person Trips per Household, and Average Household Size

Region	Year	Trips per Capita	Trips per Household	Average Household Size
San Francisco Bay Area	**1965**	**2.81**	**8.78**	**3.12**
San Francisco Bay Area	**1981**	**3.39**	**8.71**	**2.57**
San Francisco Bay Area	**1990**	**2.93**	**7.55**	**2.61**
NPTS	1969	2.02	6.36	3.16
NPTS	1977	2.33	6.59	2.83
NPTS	1983	2.46	6.60	2.69
NPTS	1990	2.63	6.74	2.56
Philadelphia (PJTS)	1960	1.50	5.03	3.36
Philadelphia (PJTS)	1987/88	2.34	6.25	2.67
Los Angeles	1976	2.90	8.10	2.80
Los Angeles	1991	2.40	7.60	3.11
Dallas	1964	2.83	9.12	3.22
Dallas	1984	3.40	8.68	2.60
Denver	1971	2.81	8.69	3.09
Denver	1985	2.87	7.33	2.54
Chicago	1979	2.40	7.20	3.00
Detroit	1980	2.59	7.47	2.90
Sacramento	1991	3.71	9.72	2.62
California	1991	3.90	10.60	2.70
Atlanta	1972	2.49	7.20	2.90
Baltimore	1977	2.90	8.30	2.80
Buffalo	1973	2.50	7.50	3.00
Seattle	1987	4.04	9.89	2.45

Notes:

NPTS and Los Angeles data exclude bicycle and walk trips.

TABLE 3 Comparison of Person Trips in 1990 Survey with Those in 1990 Model Simulation (person mode trips, in thousands)

Trip Purpose	1990 Model Simulated Person Trips	1990 Survey Person Trips	Percent Difference
Home-based work	4,335	4,271	-1%
Home-based shop/other	4,825	3,864	-20%
Home-based social/recreation	2,598	1,594	-39%
Nonhome based	5,025	4,011	-20%
Total	16,783	13,740	-18%

Note: Person mode trips are by mechanized modes: vehicle driver, vehicle passenger, or transit passenger.

trip generation models and work trip distribution models (i.e., total work trip duration). One hypothesis to be advanced and tested is that increases in work trip duration in a household are linked to lower non-work trip generation rates.

Mobile Versus Immobile Survey Respondents

Another initial concern that warranted further analysis was the potential problem of survey respondents falsely claiming that they did not travel during the assigned travel day, basically to avoid the hassle of filling out trip diaries. The term *mobile* is used to denote persons or households who reported travel—by any means of transportation, including walking or bicycling—during their assigned travel day. The mobile share of population, by age of respondent, is reported for the 1981 and 1990 San Francisco Bay Area surveys and is compared with Wigan's (*33*) analysis of the 1981 Sydney, 1978 Melbourne, and 1977 Adelaide, Australia, surveys (Table 4). The mobile share patterns of the Bay Area travel surveys are quite similar to those for the Australian metropolitan areas, averaging 82 percent mobile (18 percent immobile) for the two Bay Area surveys and 78 percent mobile (Sydney), 85 percent mobile (Melbourne), and 87 percent mobile (Adelaide) in Australia. Children ages 5 to 11 years show the highest mobility share, ranging from 86 to 89 percent mobile in San Francisco and from 86 percent in Sydney to 96 percent in Adelaide. Elderly persons, ages 65 years and over, show the lowest mobility share, ranging from 60 to 65 percent in the Bay Area and from 56 percent in Melbourne to 63 percent in Adelaide. These results are encouraging and suggest that the 1990 Bay Area travel survey is not biased because of excessive numbers of respondents falsely claiming no travel.

Changes in Average Trip Duration

The analysis then turned to a review of average trip duration. It was believed that a real drop in household trip rates could make logical sense if the drop in trip frequency was offset by an increase in average reported trip duration. The 1990 survey indicated a modest (10.4 percent) increase in average trip duration between 1981 and 1990 (19.3 to 21.3 min, all trip purposes and modes) that offset a 13.3 percent decline in the total number of trips per household (Table 5). The 1984 study by Kollo and Purvis (*1*) did not dwell too long on the changes in trip frequency or trip duration, basically because of an insignificant decline in the total number of trips per household between 1965 and 1981 (8.77 to 8.71) and a subtle increase in the total average trip duration between 1965 and 1981 (18.6 to 19.3 min). Given the lumpy or spiky distributions of reported travel times, differences of less than 1 min in reported trip duration are probably not significant from a planning or statistical perspective.

The average reported trip duration for home-based work trips in the 1981 survey (26.6 min) is about 9 percent higher than the mean travel time for commuters as reported in the 1980 census (24.3 min). The average reported trip duration for 1990 survey home-based work trips (29.2 min) is 14 percent higher than the mean travel time for commuters according to the 1990 census (25.6 min). These increasing discrepancies between commute travel times reported in

TABLE 4 Share of Population Reporting Travel by Age Group in Household Travel Surveys in Four Cities

		Age Group (Percent Share of Population Reporting Travel)							(Total)
Region	Year	5-11	12-16	17-25	26-34	35-59	60-64	65-99	5-99
San Francisco	**1981**	**89%**	**87%**	**82%**	**86%**	**84%**	**76%**	**60%**	**82%**
San Francisco	**1990**	**86%**	**85%**	**81%**	**85%**	**86%**	**73%**	**65%**	**82%**
Sydney	1981	86%	84%	77%	81%	78%	71%	61%	78%
Melbourne	1978	95%	95%	89%	89%	84%	70%	56%	85%
Adelaide	1977	96%	96%	91%	91%	86%	75%	63%	87%

TABLE 5 Changes in Trip Duration (in minutes) by Trip Purpose in San Francisco Bay Area in 1965, 1981, and 1990 Household Travel Surveys

Trip Purpose	1965 Survey	1981 Survey	1990 Survey	Percent Change 1981 - 1990
Home-based work	25.8	26.6	29.2	9.8%
Home-based shop/other	15.2	15.4	17.1	11.0%
Home-based social/recreation	19.7	19.2	20.7	7.8%
Home-based school	18.5	20.5	20	-2.4%
Nonhome based	15.6	16.7	18.3	9.6%
Total	18.6	19.3	21.3	10.4%

the survey and the census bear further detailed analysis at a more precise geographic level to discern biases in either or both data sets.

Travel Time Expenditures—Households and Persons

Much of the confusion in the travel time budget literature is with respect to the definition of terms. Goodwin (*34*) makes a good case that travel time budgets should be based on all households, on all persons in the households, and for all travel, including nonmotorized travel. Much of Zahavi's research focused either on vehicle travel or travel by motorized means (vehicle driver, vehicle passenger, or transit passenger). The present study analyzes total travel time expenditures per total household and for total population, as well as the more restrictive definitions related to travel time per traveler or travel time per mobile person.

For reporting purposes here, the term *mobile* is used to denote persons or households who reported travel—by any means of transportation, including walking or bicycling—during their assigned travel day. The term *traveler* is used to denote persons or households who reported motorized travel (vehicle driver, vehicle passenger, or transit passenger) during the assigned travel day. The term *total trip* refers to trips made by persons, ages 5 years and older and residing in households, by any and all means of transportation. The term *person trip* is a more restricted definition (similar to the person trips used in travel demand forecasting models) and refers to trips made only by motorized means of transportation.

The basic input data and resulting travel time expenditures and trip frequency rates are presented in Table 6. The share of the population traveling (i.e., making motorized trips) increased from 67 percent of the population in 1965 to 76 percent of the population in 1990. The share of households traveling (i.e., one or more persons in the household making motorized trips) is rather stable at 88 to 90 percent of all households. The mobile household share (i.e., one or more persons in the household making trips by any means of transportation) is also stable at around 91 to 94 percent of all households.

All trip rates per person (total, mobile, and traveling) and per household (total, mobile, and traveling) increased between 1965 and 1981 and decreased between 1981 and 1990.

Total travel time expenditure per mobile person increased 19 percent between 1965 and 1981, from 72 min per mobile person per day (1.2 hr) to 86 min per mobile person per day (1.44 hr). Total travel time per mobile person decreased slightly between 1981 and 1990, from 86.3 to 82.5 min. The total travel time expenditure per traveler is quite similar to the average travel time per mobile person. The average travel time per traveler increased 15.8 percent between 1965 and 1981 and decreased by 5.5 percent between 1981 and 1990, dropping from 84.9 to 80.2 min.

Average travel time expenditure per mobile household increased by 8 percent between 1965 and 1981, from 173 min (2.88 hr) per mobile household in 1965 to 187 min (3.12 hr) per mobile household in 1981. Average travel time expenditure per traveling household showed a 10.7 percent increase between 1965 and 1981 and a 5.5 percent decrease between 1981 and 1990.

Average travel time expenditures per total household and per total household population are shown in Table 7. Travel time expenditure per total household was 2.7 hr per household in 1965 and 1990 and 2.8 hr per household in 1981. Travel time expenditure per total persons in households increased from 0.86 hr per person in 1965 to 1.07 hr per person by the year 1981. Travel time expenditure per total persons in households apparently declined to 1.03 hr per person in 1990. This represents a 2.1 percent decrease in average travel time expended per household from 1965 to 1990, and a 19.8 percent increase in average travel time expended per person in the household from 1965 to 1990.

The three sets of travel surveys were further stratified by automobile ownership level and by household size to detect any other regularities in travel time expenditures by market segment. Average travel time expenditure per person by automobile ownership level increased between 1965 and 1981 and generally remained constant between 1981 and 1990. The most significant changes, from 1981 to 1990, is an 11 percent drop in travel time per person in zero-vehicle households (1.10 to 0.98 hr/person).

Average travel time per person by household size is also shown in Table 7. Average travel time per person decreases with increasing household size. This is because single-person households must perform all household travel chores, whereas multiperson households can share household travel chores between household members. A single-person household in 1990 spent 1.30 hr per day traveling (any means of transportation). A five-or-more-person household in 1990 spent 5.06 hr per day per household, or 0.86 hr per person in the household. The travel time expenditures per person show moderate increases between 1965 and 1981 and a general stability between 1981 and 1990. The travel time expenditure for two-person and three-person households increased between 1981 and 1990; travel time expenditures decreased for one-person, four-person, and five-or-more-person households over this same period of time.

TABLE 6 Mobile Population, Travelers, and Travel Time Expenditures in San Francisco Bay Area in 1965, 1981, and 1990 Household Travel Surveys

Variable	1965	1981	1990	Percent Change 1965 - 1990
Household Population (age 5+)	3,920,000	4,727,400	5,330,400	36%
Mobile Population (age 5+)	3,124,500	3,871,700	4,378,900	40%
Mobile Population Share (%)	80%	82%	82%	
"Travellers" (age 5+)	2,610,200	3,503,300	4,071,400	56%
"Traveller" Population Share (%)	67%	74%	76%	
Total Households	1,386,800	1,970,400	2,246,300	62%
Mobile Households	1,302,700	1,786,000	2,072,500	59%
Mobile Household Share (%)	94%	91%	92%	
"Travelling" Households	1,231,500	1,730,400	2,011,300	63%
"Travelling" Household Share (%)	89%	88%	90%	
Total Trips, All Modes	12,172,400	17,168,100	16,966,700	39%
Person Hours of Travel, All Modes	3,763,500	5,569,300	6,021,200	60%
Average Trip Duration, All Modes	18.6	19.5	21.3	15%
Person Trips (Mechanized Modes)	9,737,200	14,527,400	14,811,400	52%
Person Hours of Travel, Person Trips	3,188,200	4,957,000	5,444,600	71%
Average Trip Duration, Person Trips	19.6	20.5	22.1	12%
Trip Rates (Average Weekday)				
Total Trips per Mobile Pop.	3.90	4.43	3.87	-1%
Person Trips per "Traveller"	3.73	4.15	3.64	-2%
Total Trips per Mobile HH	9.34	9.61	8.19	-12%
Person Trips per "Travelling" HH	7.91	8.40	7.36	-7%
Total Trips per Total Household	8.78	8.71	7.55	-14%
Person Trips per Total Household	7.02	7.37	6.59	-6%
Travel Time Expenditures (Average Weekday, in Minutes)				
Total Travel Time per Mobile Person	72.3	86.3	82.5	14%
Total Travel Time per "Traveller"	73.3	84.9	80.2	9%
Total Travel Time per Mobile HH	173.3	187.1	174.3	1%
Total Travel Time per "Travelling" HH	155.3	171.9	162.4	5%

Careful examination of the coefficients of variation by market segment is required to understand the statistical significance of these minor to moderate changes in mean travel time expenditures per household and per person. Errors in the reporting (and coding) of trip start and trip finish times are prone to occur in household travel surveys and can significantly affect average travel times in the aggregate and by market segment.

Travel Time Expenditures—Vehicles

Changes in aggregate regional vehicles available, vehicle trips, and vehicle hours of travel per household are summarized in Table 8. The surveys show a more than doubling in the number of vehicles available and the vehicle hours of travel in the Bay Area between 1965 and 1990. Average vehicle trip duration decreased slightly between 1965 and 1981, from 18.4 min per average vehicle trip in 1965 to 18.0 min by the year 1981. Average vehicle trip duration increased 14 percent between 1981 and 1990, from 18.0 to 20.5 min.

Vehicle trips per vehicle has shown a steady decrease over the three survey time periods, declining from 3.24 trips per vehicle according to the 1965 survey, to 3.08 trips per vehicle in the 1981 survey, to 2.71 trips per vehicle in the 1990 household travel survey. Vehicle hours of travel per vehicle available is rather stable at around 0.92 to 0.99 hr expended by each vehicle each day. The 1990 travel survey indicated that the average vehicle was on the road approximately 0.93 hr (56 min) per day.

Further analysis of vehicle travel time expenditures in the Bay Area should investigate changes in average trip length, in miles, per vehicle for the three household travel surveys. A network-based evaluation of vehicle miles of travel and average trip speeds using travel survey records is needed for a careful outlier analysis to edit and correct or to delete trip records and as a precursor step for trip distribution model development.

TABLE 7 Total Travel Time Expenditures per Household and per Person by Automobile Ownership Level and Household Size in San Francisco Bay Area in 1965, 1981, and 1990 Household Surveys

Auto Ownership Level

Auto Ownership Level	Avg. Total Travel Time/Household/Weekday (Hours) 1965	1981	1990	Pct. Change 1965-1990	Avg. Total Travel Time/Person/Weekday (Hours) 1965	1981	1990	Pct. Change 1965-1990
0	1.71	1.95	1.79	4.7%	0.86	1.10	0.98	14.0%
1	2.32	2.04	1.96	-15.5%	0.80	1.05	1.02	27.5%
2	3.21	3.15	2.90	-9.7%	0.88	1.06	1.01	14.8%
3+	3.93	4.13	3.81	-3.1%	0.95	1.09	1.07	12.6%
Total	2.71	2.83	2.68	-1.1%	0.86	1.07	1.03	19.8%
1+	2.84	2.93	2.78	-2.1%	0.86	1.07	1.03	19.8%

Household Size

Household Size	Avg. Total Travel Time/Household/Weekday (Hours) 1965	1981	1990	Pct. Change 1965-1990	Avg. Total Travel Time/Person/Weekday (Hours) 1965	1981	1990	Pct. Change 1965-1990
1	1.25	1.34	1.30	4.0%	1.25	1.34	1.30	4.0%
2	2.13	2.33	2.30	8.0%	1.06	1.13	1.15	8.0%
3	2.63	3.09	3.06	16.3%	0.88	1.00	1.02	16.3%
4	3.23	4.24	3.79	17.3%	0.81	1.03	0.95	17.3%
5+	4.17	5.76	5.06	21.3%	0.72	0.99	0.86	19.4%
Total	2.71	2.83	2.68	-1.1%	0.86	1.07	1.03	19.8%

CHANGES IN REGIONAL HOUSEHOLD TRIP RATES, 1965–1990

Changes in regional household trip rates, comparing the 1965, 1981, and 1990 Bay Area household travel surveys, are summarized in Table 9. Changes in household trip rates by trip purpose and travel mode are shown in Table 9.

The only trip purpose showing an increasing number of trips per household between the 1981 and 1990 surveys is home-based work trips. The 5.3 percent increase in home-based work trips per household between 1981 and 1990 represents a 20.1 percent increase in regional, aggregate home-based work trips. This compares with a 20.0 percent increase in regional, aggregate employed residents. This simply means that the number of work trips per worker did not change between 1981 and 1990.

Home-based non-work trips are broken down into three trip purposes: home-based shop (other), home-based social/recreation, and home-based school. Home-based shop (other) is a catchall trip purpose and includes shopping, personal business, medical/dental, unlinkable serve passenger and change travel mode purposes, and so forth. Home-based social/recreation trips include indoor and outdoor recreation trips, visiting, and eating meals. Home-based school includes student trips from home to school and school to home, regardless of grade level.

TABLE 8 Characteristics of Vehicle Travel in San Francisco Bay Area in 1965, 1980, and 1990 Household Travel Surveys

Characteristic	1965 Survey	1981 Survey	1990 Survey	Percent Change 1965 - 1990
Vehicles Available	1,941,600	3,349,700	4,020,100	107%
Vehicle Trips	6,288,000	10,307,000	10,914,300	74%
Vehicle Hours of Travel	1,928,300	3,093,200	3,738,000	94%
Average Trip Duration (min.)	18.4	18.0	20.5	12%
Vehicle Hours of Travel / Vehicle	0.99	0.92	0.93	-6%
Vehicle Trips / Vehicle	3.24	3.08	2.71	-16%

TABLE 9 Weekday Regional Trips per Household by Purpose and Mode in San Francisco Bay Area in 1965, 1981, and 1990 Household Travel Surveys

	Home-Based					
Mode	Work	Shop/ Other	Social/ Recreation	School	Nonhome Based	Total
In-vehicle person						
1965	1.518	2.307	0.915	0.295	1.499	6.535
1981	1.558	1.964	1.011	0.387	1.894	6.814
1990	1.701	1.643	0.682	0.393	1.695	6.115
% Diff. 65-90	12%	-29%	-25%	33%	13%	-6%
Transit						
1965	0.220	0.085	0.035	0.086	0.060	0.486
1981	0.206	0.085	0.044	0.126	0.097	0.558
1990	0.200	0.077	0.028	0.084	0.091	0.479
% Diff. 65-90	-9%	-9%	-20%	-2%	52%	-1%
School Bus						
1965	--	--	--	0.146	--	0.146
1981	--	--	--	0.089	--	0.089
1990	--	--	--	0.075	--	0.075
% Diff. 65-90	--	--	--	-49%	--	-49%
Walk						
1965	0.090	0.286	0.177	0.514	0.281	1.348
1981	0.076	0.188	0.143	0.285	0.303	0.995
1990	0.061	0.151	0.089	0.160	0.287	0.748
% Diff. 65-90	-32%	-47%	-50%	-69%	2%	-45%
Other						
1965	0.031	0.053	0.057	0.057	0.065	0.263
1981	0.050	0.037	0.063	0.065	0.042	0.257
1990	0.029	0.020	0.029	0.032	0.027	0.137
% Diff. 65-90	-6%	-62%	-49%	-44%	-58%	-48%
Total						
1965	1.858	2.732	1.184	1.097	1.906	8.777
1981	1.890	2.274	1.262	0.952	2.335	8.713
1990	1.991	1.891	0.827	0.744	2.100	7.553
% Diff. 65-90	7%	-31%	-30%	-32%	10%	-14%

All three home-based non-work trip purposes show steady declines in the number of trips per household over the three Bay Area household travel surveys. The number of home-based social/recreation trips per household increased slightly between 1965 and 1981, only to show a precipitous drop of 34.5 percent (1.26 to 0.83 trips per household) between 1981 and 1990. This might mean that Bay Area residents are not having fun any more or that household members are trading off out-of-home social/recreation activities for in-home (or weekend) social/recreation activities. The Bay Area travel surveys do not indicate what people are doing at home—whether they are asleep, working or telecommuting, playing, eating, socializing, or watching television. Thus, it is impossible with current survey data to understand the true nature of the trade-off between in-home activities and out-of-home activities.

The number of non-home-based trips per household increased substantially between 1965 and 1981 (1.91 to 2.34 trips per household) only to fall back to a level moderately higher than the 1965 trip rate (2.10 trips per household).

The total number of transit trips per household decreased slightly between 1981 and 1990, from 0.56 to 0.48 trips per household. The number of school bus trips per household also showed a slight decrease between 1981 and 1990. In-vehicle person trips showed the most significant absolute decline between 1981 and 1990, dropping from 6.81 to 6.12 trips per household. The total number of vehicle trips per household (not shown in Table 9) decreased from 5.23 trips per household in 1981 to 4.86 vehicle trips per household by 1990. A steady decline in the number of walk trips per household can be shown between the three household travel surveys, dropping from 1.35 walk trips per household in 1965 to 1.00 trips per household by 1981 and then leveling off at 0.75 walk trips per household by 1990.

CONCLUSIONS

Results from the 1990 San Francisco Bay Area household travel survey provides major challenges to Bay Area transportation planners. An apparent decline in trip frequency per household and per person is offset by an increase in average trip duration, yielding an apparent stability in the average travel time expended per household and per person. Findings from this study are generally consistent with the travel time budget studies of the 1970s and early 1980s. Findings may also rekindle interest in travel time budget analyses and alternative travel demand forecasting models based on activity analysis, time use studies, and travel time budgets.

Comparison of model-simulated trips with 1990 survey trips shows an excellent match for home-based work trips, yet a moderate overprediction of non-work trips with respect to 1990 survey person trips. The non-work trip generation and trip distribution models in use in the Bay Area are not structured to account for this inverse relationship between trip frequency and trip duration. Trip generation models are typically built to provide ever-increasing non-work trips per household on the basis of assumptions of real income growth and growth in automobile ownership per household. New and improved non-work trip generation models may need to incorporate some direct linkage with work trip distribution models (e.g., total work trip duration).

There is a significant potential for underreported trips in the 1990 survey, especially for non-work trips, and for vehicle driver, vehicle passenger, walking and bicycling trips. There is probably a minor (5 percent) underreporting of transit trips in the 1990 household travel survey. As a part of a cross-validation project, MTC will assign the raw, expanded survey trip records to regional highway and transit networks for analysis of screenline loadings and for analysis of vehicle miles and person miles of travel. This project would also allow for the editing and correction of survey outliers (e.g., trips with absurdly low or absurdly high travel speeds).

There is a relatively stable share of mobile persons and households for the three Bay Area household travel surveys. This means that the share of persons falsely claiming no travel is not a major problem with the three household surveys.

The 1990 survey was conducted in less than ideal situations. Survey response rates declined between 1981 and 1990. In 1981 69 percent of eligible households contacted completed the survey; in 1990 49 percent completed the survey. The survey consultant reported problems owing to interviewer fatigue as well as interviewee fatigue and a reported a higher degree of interviewer turnover than expected. It is also unclear what impact that the October 1989 Loma Prieta earthquake had on moderating travel patterns, the impact of the economic recession in the United States on moderating out-of-home travel, the nature and extent of the in-home substitution for out-of-home activities, and the nature and extent of weekend travel substitution for weekday travel.

The most challenging aspect of this future research could be the integration of travel time expenditure concepts into a disaggregate travel demand model system for use by regional transportation planners. The findings of this aggregate analysis should be used to inform a more detailed and rigorous disaggregate travel behavior analysis.

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DISCUSSION

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This interesting and provocative paper uses data from a 1990 travel survey to update the well-known previous comparison of results from the 1965 and 1981 surveys in the San Francisco Bay Area (*1*). In particular Purvis is to be congratulated for extending the analysis to include daily travel time.

Understanding how people use their time, both in activity participation and in traveling to and from those activities, is critical to the understanding and modeling of travel behavior, and one can identify considerable recent interest in time use research among travel demand researchers (*2–4*). The traditional approach to travel forecasting does not incorporate activity participation and the related concept of time use; however, the past 15 years has seen the development of the activity-based approach to travel analysis [for a recent review, see the paper by Axhausen and Garling (*5*)]. This approach has yielded considerable insight regarding travel behavior, and it serves as the basis for emerging travel modeling frameworks (*6,7*).

Although I am reluctant to enter the constant travel time budget debate (*8–11*), I do feel compelled to make some general observations about interpreting data and inferring relationships from the data and to make some observations that pertain specifically to the results reported in this paper. In making these observations, I cannot avoid expressing concern about the constant travel time budget theory. Each of us has only 24 hr each day in which to accomplish our wants and needs, and we therefore all do have a time budget. Thus, if we spend more time in one activity on a given day we have no alternative but to spend less time in another activity on that day, and vice versa. But this does not mean, for example, that if we make fewer trips (for whatever reason) we will necessarily choose to make them longer in duration to maintain a constant daily travel time budget, and vice versa. Certainly, the data presented in this paper do not provide evidence to support a constant travel time budget theory.

Perhaps the most important general point to be made is that it is dangerous to infer behavioral regularities from very aggregate data, because the apparent regularities could arise for multiple reasons. It seems clear that in the case reported in this paper changes over time at the disaggregate level interact with changes in the population distribution to provide apparent temporal stability at the aggregate level. The results reported in Table 7 show that there was substantial change over the period from 1965 to 1990 when one looks at the data segmented by household size, whereas the aggregate data show a great deal of stability over time in the case of daily travel time per household. Specifically, the results reported in Table 7 show that over the period from 1965 to 1990 daily travel time per household increased for each household size segment, with the increases ranging from 4 to 21 percent, whereas the average daily travel time per household remained essentially the same over this period.

The stability of the average daily travel time per household, in the face of substantial changes in travel time per household in the different household size segments, can be very readily explained by the fact that the average household size in the San Francisco Bay Area declined from 3.12 to 2.61 in this period. The increase in the relative proportion of households in the smaller household size categories, which have lower daily travel time expenditures, acted as a counterbalance to the increase in travel time per household per day in each household size category, and the overall average daily travel time per household remained essentially constant. Clearly, had there not been a decline in average household size, Purvis would have found a substantial increase in daily travel time per household over the period of the analysis.

Although the decline in average household size caused daily travel time per household to appear to be stable, the same result did not occur in the case of daily travel time per person because daily travel time per person is greater in those household size segments that increased in proportion in the time period under consideration. On the other hand, even if the daily travel time per household in each household size segment had not changed at all over the period from 1965 to 1990, Purvis would have found a decline in the average daily travel time per household solely due to the decline in average household size over the analysis period.

To determine whether there is any behavioral regularity in travel time expenditure, I would want to examine this question using panel data—that is, to see whether persons or households maintain a constant travel time budget in the face of transportation system and other changes. My hypothesis is that one would not find stability in daily travel time (either per person or per household) from such an analysis, certainly over an extended period of time in which transportation and land-use system changes and/or sociodemographic changes take place. Analyses based on panel data generally show considerable changes over time in time use for various activities (*3*).

In summary the results reported in this paper do not justify the conclusion that we should consider using the travel time budget concept as the basis of a new system of disaggregate travel demand models. In particular I am very uncomfortable with the suggestion that we should use observed stability in aggregate daily travel time as the basis of a new disaggregate model system. Although studying time use and activity participation is vital to the understanding and modeling of travel, I do not think that the concept of a constant travel time budget is a meaningful one, and this paper does not provide evidence that makes me change my mind. However, I do hope that this paper will draw attention to the need to examine time use and activity participation in trying to understand and model travel behavior.

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Publication of this paper sponsored by Committee on Traveler Behavior and Values.

Impulse Trips to Shopping Centers

PAUL C. BOX

The results of about 4,000 shopper interviews taken at two shopping centers—a community type and a regional type—in western Florida are reported. The questions identified separately the proportion of customers of impulse type who decided that they would enter a shopping center only when they were actually driving by the shopping center. For the community shopping center this proportion was 6.1 percent, and for the regional shopping center it was 3.1 percent. However, the changes in access affected only one of the two routes adjacent to the community center and one of the three routes adjacent to the regional center. Since no significant change in access or loss of impulse customers would be involved with the nonrevised routes, the actual proportions of impulse trips potentially lost were 2.6 percent of the total for the community center and 2.3 percent of the total for the regional center. Bypass shoppers (those passing by already but planning a stop) were similar for both centers—30 to 36 percent of the total. Therefore, the growth in volume passing by the sites (made possible only by additional traffic capacity produced by the improvements) would expose the centers to added bypass traffic and would thus more than offset the slight initial drop in the number of impulse customers. Such findings are of potential value to government agencies addressing the question of business loss as a result of eminent domain proceedings for major route improvements. They also may be of value to business owners affected by such improvements who desire to assess their actual likely potential losses.

The purpose of this paper is to assist public agencies in disputing claims of business damage loss for changes in access as a result of adjacent route improvements. Evidently, the findings will also give credence to assessment of the small amount of business damage that actually could occur initially. The amounts of loss are highly site specific and are most strongly related to the type of route improvement and change of access that has actually been constructed. Additionally, it should be noted that the route changes usually provide improved capacity and access for regular shoppers and therefore actually increase the future business activity level—thus more than offsetting the losses due to decreased impulse trips.

Unless an extreme circuity of access is constructed, the improvements to the adjacent route should benefit abutting businesses (once the agonies of construction are over!). In looking at added circuity of travel for basic customers, the area is obviously a factor. For example, people will drive farther to reach a motel or restaurant in a rural area than would be the case in an urban area—particularly if other, competing businesses are more readily accessible.

Data on proportions of impulse trips among the total number of shopping trips were secured at two locations in Florida. One location involved a community-type shopping center at the intersection of two routes where a single-point diamond-type interchange has been proposed. The second location was a regional shopping center abutted by three routes where parallel service roads would be constructed and where grade separations would be constructed so that one access route would overpass the two intersecting routes. Data were secured by interviews with shoppers, and the proportion of impulse shoppers was determined on the basis of answers to certain questions. Information on proportions of trips of other types (generated, diverted, or conventional bypass; see next section) was also obtained. Also, data on whether purchases were made, travel distances, routes of entry and exit, and so forth were secured.

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TYPES OF TRIPS

There are three principal trip types identified in the traffic profession. These are defined in the ITE report *Trip Generation* (*1*) as follows:

1. Primary (generated)—trips made for the specific purpose of visiting the generator. The stop is the primary reason for the trip; for example, a home-to-shopping-to-home combination is a primary trip set. (In the interview studies in Florida generated trips were defined slightly differently as "trips involving a planned visit directly from a given location—such as home—to the shopping center, with direct return to the point of origin.")
2. Passby (bypass)—trips made as intermediate stops on the way from an origin to a primary trip destination. Bypass trips are attracted from traffic passing the site on an adjacent street that contains direct access to the generator. These trips do not require a diversion from another roadway. (In the studies in Florida the definition of bypass trips used was "persons already on one of the adjacent roadways, en route to or from other destinations, who stop in the shopping center.")
3. Diverted linked—trips attracted from other roadways within the vicinity of the generator but in which a diversion from that roadway to another roadway is required to gain access to the site. These roadways could include streets or freeways adjacent to the generator, but without direct access. (The definition of diverted link trips in the Florida study was "trips oriented at some point and destined to another point, with a stop at the subject shopping center being intermediate; however, a change from a normal routing and being a planned visit are required.")

Figure 1 illustrates the three types of trips. Early studies of bypass trips at urban service stations were reported in 1969 by Box (*2*). These were performed by visually tracing movements at eight sites during peak hours. Drivers leaving the station to return toward the direction of their origin were considered to be making generated trips, and these trips were found to range from 12 to 73 percent of the total trips of the entering volume of traffic. The average of such directly generated traffic was 46 percent during the morning rush hour and 42 percent during the evening rush hour. In a study of rural service stations, Billion and Scheinbart (*3*) found 10 to 25 percent of service station traffic to be generated.

In other unpublished studies in 1971, Box recorded the license plate numbers of entering and leaving vehicles, by direction, to determine the proportion of generated traffic. At a 6500-m^2

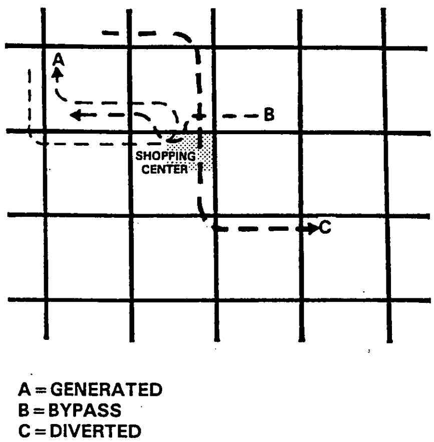

FIGURE 1 Types of trips.

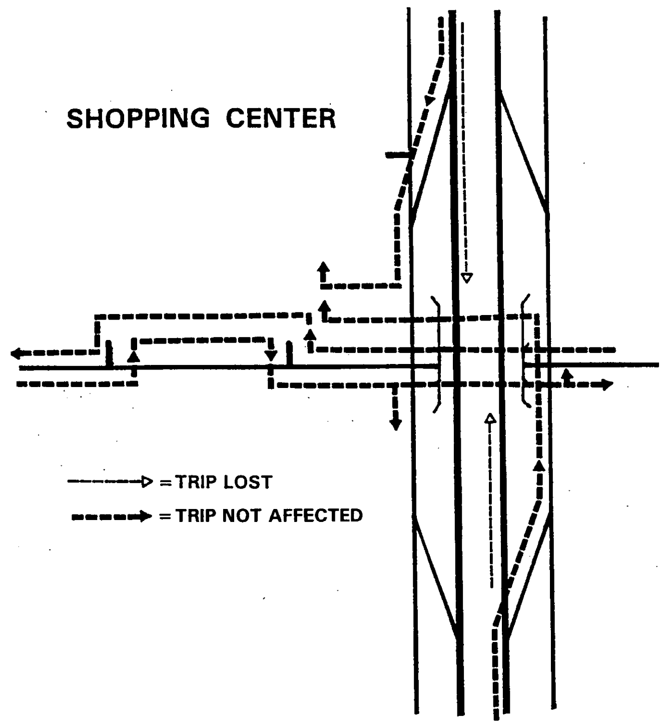

FIGURE 2 Impulse trips at a diamond interchange.

(72,000-ft^2) neighborhood-type center, the weekday p.m. proportion of generated trips was found to be 48 percent, and on Saturday it was found to be 64 percent. A similar study of a 9500-m^2 (106,000-ft^2) community shopping center containing a K-Mart found on a weekday that the proportion of generated trips was 47 percent. There was thus an excellent correlation with the weekday figures among the two shopping centers and the service stations. It was clear that of the driveway volumes counted for such uses, only about one-half could be considered generated (or diverted) trips and therefore could be added to the volumes of the adjacent intersections.

Beginning in the late 1970s a number of interview studies were done and reported to ITE. These are given in Tables VII-1, VII-2, and VII-3 of *Trip Generation,* 5th ed. (*1*). Weekday data for 67 shopping centers, Saturday data for 14 shopping centers, and 37 studies for other land uses are listed.

For any land use it should be obvious that there are two types of bypass trips—the planned and the impulse trip. In the latter a driver enters the site only because it is convenient and because it is seen relatively at the last moment (the actual decision to stop is made on the basis of the observation of the facility rather than on the basis of any type of forethought—other than a need to eat, purchase gas, etc.). Evidently, the impulse trip is subject to possible reduction or loss because of modifications or restrictions of access. Figure 2 illustrates how the impulse type of bypass trip would be affected by construction of a diamond-type interchange.

IMPULSE TRIP STUDIES

There is no way that impulse trips can be detected by passive means such as observing traffic movements or tracing license plates. An interview basically involving a shopper intercept on the premises is required. It therefore requires rights of entry for the purposes of conducting the interviews to be granted by the shopping center owners or management. The interviews at the Florida shopping centers were conducted by using a properly quantified sampling technique. The community shopping center, Tarpon Square, had 16 000 m^2 (177,000 ft^2) of gross floor area and about 1,100 parking spaces. A K-Mart is the major tenant. The interviews were conducted on a variety of different days of the week and hours of the day, with a total of 835 valid samples secured.

The second site was the Countryside Mall, located in Clearwater, Fla. It has an area of about 100 000 m^2 (1,100,000 ft^2) of gross leasable area and contains 5,800 parking spaces. It has four department stores as the major tenants. Again, the interviews were conducted on a variety of days of the week and hours of the day, with a total of 3,160 valid samples secured.

Impulse trips were determined by comparing answers to two key questions. One, under the general heading of "what was the main reason you decided to come to this shopping center on this particular shopping trip," has "just driving by" as the answer indicating an impulse trip. The second question was under the subject of "how did you know where this mall was located?," again with an answer of "just driving by" identifying an impulse trip. When the answers to both of these questions were the same, the trip was defined as of the impulse type, a subset of the general bypass category.

FINDINGS

Figure 3 shows the conditions at the Tarpon Square community shopping center, where full access was generally available by making both right and left turns from the two intersecting major streets. The proposed improvement was to consist of a single-point diamond interchange with US-19 overpassing Tarpon Avenue. Right-turn access would continue to be available from a one-way southbound service road on the west side of US-19 and, using off-ramps and Tarpon Avenue, via this street. Continued full access would be available for at least the main driveway on Tarpon Avenue, which also would be signalized.

From the interview studies the proportions of generated, diverted, and bypass trips were identified (C. F. Wasala, unpublished interview study at Tarpon Square Shopping Center for Florida Depart-

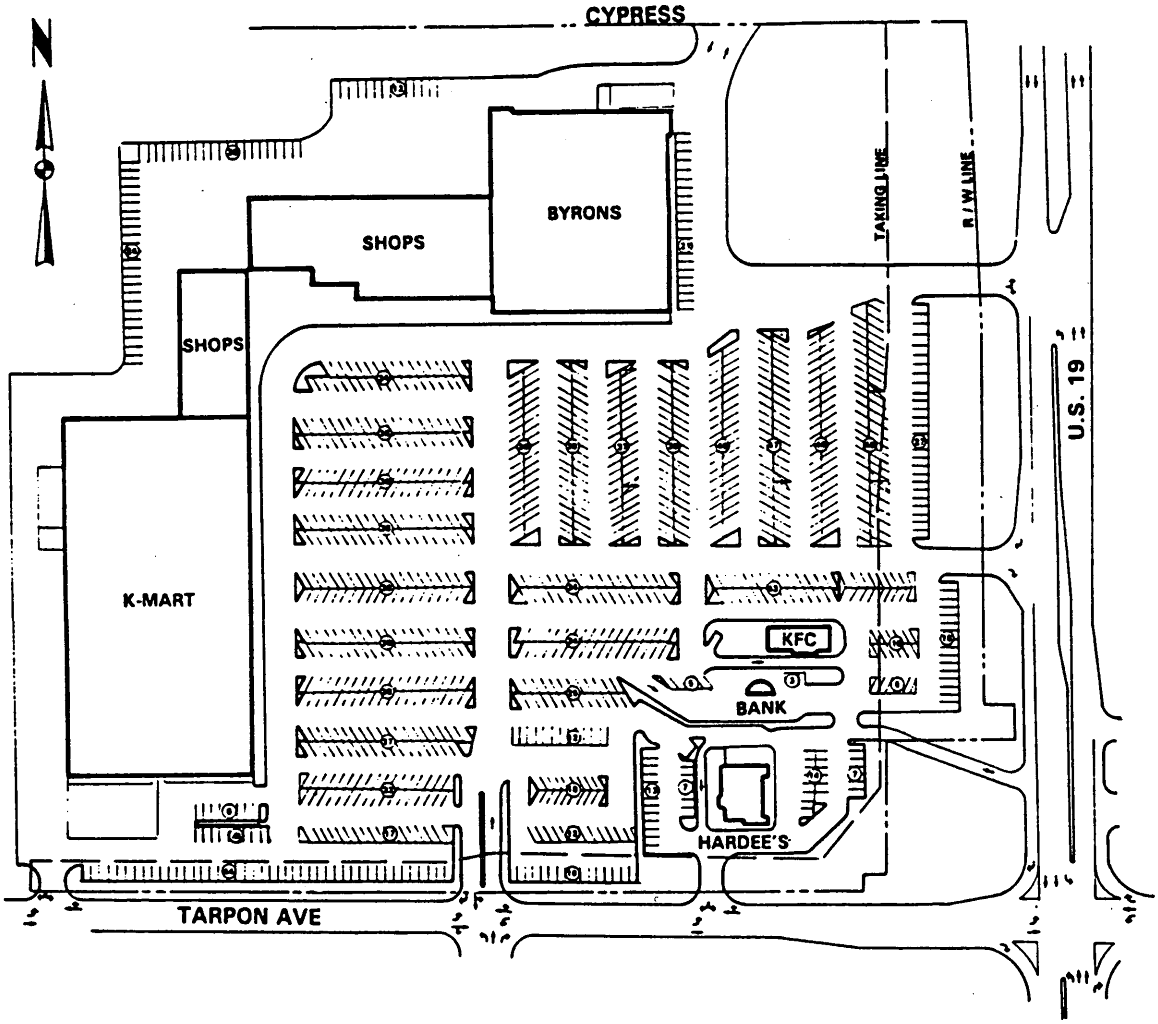

FIGURE 3 Conditions at Tarpon Square before improvements.

ment of Transportation, October 1991). These are summarized in Table 1, including the subdivisions of planned versus impulse bypass trips.

Although the proportion of impulse trips is low, the actual number that would potentially be lost as a result of the improvement is even less. Impulse trips along Tarpon Avenue would not be affected. The final proportion of impulse trips, using only those trips along US-19, was only 2.6 percent of total shopping trips.

TABLE 1 Tarpon Square Trip Characteristics

	Proportion (%)
Generated	12.9
Diverted	50.8
Bypass	
Planned	30.2
Impulse	6.1
Total	100.0

The intersection of US-19 and Tarpon Avenue was heavily congested. The volume on US-19 was approaching saturation, with little room for further growth. Construction of the improvement would do two things: reduce existing congestion and allow for continued further growth of through traffic on US-19. Reduction in congestion would increase the comfort and convenience of access to the shopping center. Future traffic growth along US-19 would increase the exposure and therefore the number of planned bypass trips. The combination of these factors would, without question, provide a positive benefit—more than offsetting the small loss of US-19 impulse trip customers.

The Countryside regional shopping center in Clearwater, Fla., is also located on US-19, south of Tarpon Springs. Figure 4 shows the existing access, which involves some restrictions of left turns, but overall there is full accessibility from all three of the abutting routes (P. C. Box, Unpublished Traffic Access and Parking Study at Countryside Mall for Florida Department of Transportation, July 1992).

The improvement consists of construction of single-point interchanges at Highway 580 and at Countryside Boulevard. The ramp system is shown in Figure 5 and in effect provides a full diamond for the Highway 580 intersection and a half-diamond for the Coun-

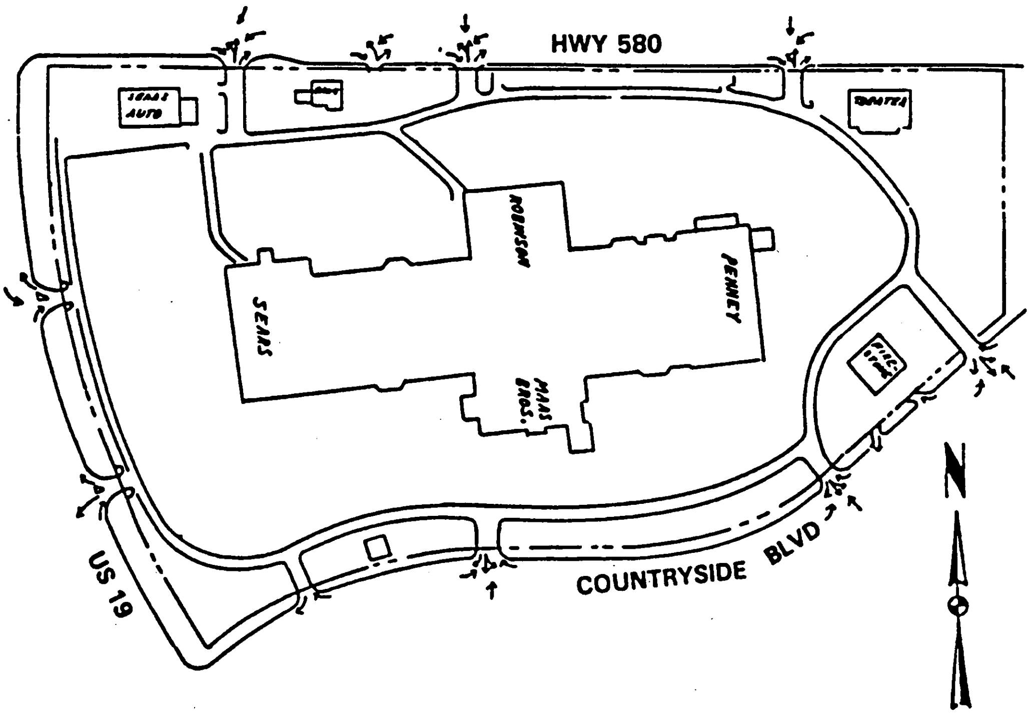

FIGURE 4 Existing access to Countryside Mall.

tryside Boulevard intersection. A right in-and-out driveway was added immediately north of Countryside Boulevard but south of the off-ramp. Remaining access points along US-19 were closed; however, those along Highway 580 and Countryside Boulevard were retained, with generally full access.

Interview studies for the Countryside Mall were conducted in a fashion similar to those conducted for Tarpon Square (C. F. Wasala, unpublished interview study at Countryside Mall for Florida Department of Transportation, November 1990). Similar questions were asked, and the findings relative to trip characteristics are given in Table 2. Again, the proportion of impulse trips to total trips is further reduced by considering just those involving US-19. These amounted to only 2.3 percent of the total.

Traffic conditions were very congested at the US-19 intersections with Highway 580 and with Countryside Boulevard. By improving ease and facility of access through these intersections, the overall accessibility of the shopping center is being improved. Also, the capacity to allow for future through traffic growth on US-19 is being developed, thus increasing the potential volume of planned bypass trips drawn from the through traffic flow. Again, this should result

TABLE 2 Countryside Mall Trip Characteristics

	Proportion (%)
Generated	48.4
Diverted	12.6
Bypass	
Planned	35.9
Impulse	3.1
Total	100.0

in reclaiming the small loss of impulse trips shortly after the completion of construction.

Comparison of the data in Tables 1 and 2 shows the great difference in the proportion of traffic generated (as expected, the regional mall is a greater generator). However, the bypass trip proportions drawn from the existing traffic adjacent to the sites are similar for both centers. The bypass trip average from the reported ITE studies is 41 percent for smaller centers of less than 18 000 m^2 (200,000 ft^2) and 26 percent for larger centers of more than 63 000 m^2 (700,000 ft^2) (*1*). Although there is some correlation, it should be noted that sample sizes for the ITE studies, when reported, were much smaller than those in the studies in Florida, and samples were often taken only during the p.m. peak hour periods.

CONCLUSIONS

The studies show that the proportion of impulse trips in relation to the total number of trips decreases as the center size increases. This is to be expected because few people driving by a large shopping center make a sudden decision to pull in compared with the number who make a sudden decision to pull in to fast-food establishments, for example. In any case the proportion, and therefore the total number, of impulse trips to shopping centers of the sizes studied is very small. When the twin effects of reduction in congestion and added capacity for additional through traffic growth on the boundary roadways are considered, the probability that increased shopping center business will more than offset that lost from the few impulse trips is evident.

Additional interview studies of the type used in the two projects described here would be desirable. Similar data for other types and sizes of land use would be helpful both to public agencies involved

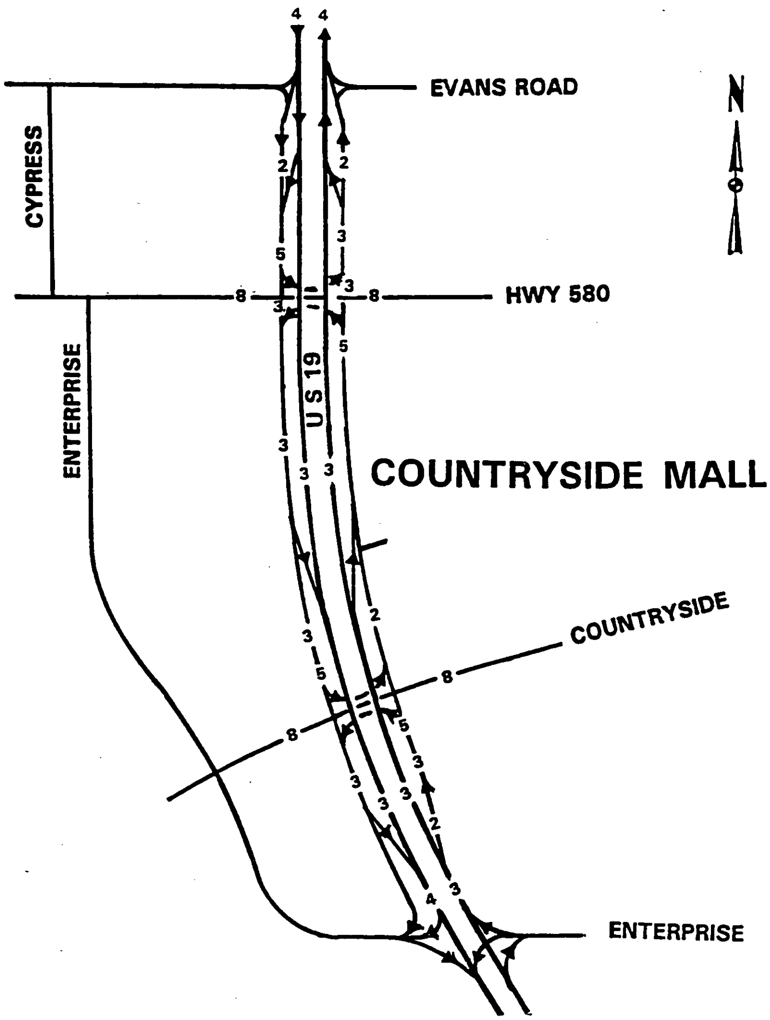

FIGURE 5 Improvement lanes.

in eminent domain proceedings and to owners of those businesses affected by the proposed improvements.

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Publication of this paper sponsored by Committee on Transportation Planning Applications.

Application of Adaptive and Neural Network Computational Techniques to Traffic Volume and Classification Monitoring

W. C. MEAD, H. N. FISHER, R. D. JONES, K. R. BISSET, AND L. A. LEE

A traffic volume and classification monitoring (TVCM) system based on adaptive and neural network computational techniques is being developed. The value of neural networks in this application lies in their ability to learn from data and to form a mapping of arbitrary topology. The piezoelectric strip and magnetic loop sensors typically used for TVCM provide signals that are complicated and variable and that correspond in indirect ways with the desired FHWA 13-class classification system. Furthermore, the wide variety of vehicle configurations adds to the complexity of the classification task. The goal is to provide a TVCM system featuring high accuracy, adaptability to wide sensor and environmental variations, and continuous fault detection. The authors have instrumented an experimental TVCM site, developed personal computer-based on-line data acquisition software, collected a large data base of vehicles' signals together with accurate ground truth determination, and analyzed the data off-line with a neural net classification system that can distinguish between class 2 (automobiles) and class 3 (utility vehicles) vehicles with better than 90 percent accuracy. The neural network used, called the connectionist hyperprism classification network, features simple basis functions; rapid, linear training algorithms for basis function amplitudes and widths; and basis function elimination that enhances network speed and accuracy. Work is in progress to extend the system to other classes, to quantify the system's adaptability, and to develop automatic fault detection techniques.

The FHWA 13-class classification scheme (*1*) divides vehicles largely according to application or axle configuration. Standard traffic volume and classification monitoring (TVCM) practice typically combines one or more piezoelectric strip sensors with one or more magnetic loop sensors in a road-embedded sensor group that provides signals to a commercial electronics package. Although these systems appear to be quite simple, they are in reality quite complicated and possess performance characteristics that can significantly degrade the reliability of the vehicle-monitoring information provided. For example, piezoelectric strip sensors vary greatly in output pulse characteristics from one sensor to another and also from one event to another, even for interactions with similar vehicles, making the process of "simply" counting axles an error-prone task. Furthermore, the sensor installations and electronics typically drift with changes in environmental conditions and with installation aging. These characteristics can lead to unacceptable classification inaccuracies.

Nonlinear adaptive network computing has progressed greatly in the past decade and has demonstrated capabilities and opened new applications to high-speed digital computers. Many traditional computer applications are preprogrammed; that is, algorithms are specifically designed to implement a known numerical solution for an application. Adaptive algorithms, however, offer somewhat greater generality: the adaptive algorithm "learns" by adjusting modeling coefficients to optimize a fit to the available data or to maximize some performance criteria. Artificial neural networks combine many simple, individual processing units interconnected to perform prediction, control, and classification tasks via machine learning. The "neurons" or "nodes" are usually simple nonlinear transfer functions. The training consists of adjusting weights (basis function parameters or interconnection strengths) to best match a training set or to minimize an energy function. Artificial neural networks and adaptive cellular automata show interesting and useful behaviors. Capabilities already demonstrated by existing adaptive computing systems include machine learning (*2–4*), self-organization (*2–4*) bidirectional associative memories (*3,4*), feature detection and pattern recognition and classification (*2–4*), signal processing and noise reduction (*3,4*), processing of speech, handwriting, and natural language (*2–4*), modeling of multidimensional nonlinear and chaotic functions (*5–9*), prediction of physical dynamical processes (*7–9*), and providing new solutions to control (*7–11*) and classification (*12*) problems.

Our goal in the project described here is to harness the capabilities of adaptive and neural network computational techniques to the TVCM application to obtain high classification accuracy, adaptability to a fairly wide range of sensor and environmental conditions, and automatic detection of faults when the adaptive range is exceeded. In addition to these beneficial performance objectives, neural networks have certain other advantages for various applications, including TVCM. They learn inductively from data and can be quite versatile and robust. Using on-line learning, neural networks can predict, control, or classify in drifting systems. Their implementation in software permits low-cost development, whereas implementation in special-purpose large-scale integration (LSI) hardware provides low-cost replication with high-speed performance.

CLASSIFICATION SCHEME

A slight extension of the FHWA 13-class system (Table 1) is used here. The major class boundaries agree with the FHWA scheme; subclasses have been added that are expected to be distinguishable, for example, to separate vehicles that are towing trailers from those

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TABLE 1 FHWA 13-Class Vehicle Classification Scheme Extended To Specify Distinguishable Subclasses

Class #	Subclass	Configuration	Sub-Configuration
1		motorcycle	
	a		w/o trailer
	e		w/ trailer
2		passenger car	
	a		subcompact
	b		compact
	c		full-sized
	d		jumbo
	e		w/ trailer
3		2 axle, 4 tire single unit,utility	
	a		small
	b		medium
	c		large
	d		jumbo
	e		w/ trailer
4		bus	
	a		2 axle,short wheelbase
	b		2 axle,long wheelbase
	c		3+axle
	e		w/ trailer
5		2 axle, 4-6 tire large single unit	
	a	4-tire	w/o trailer
	b	6-tire	w/o trailer
	e	4- or 6-tire	w/ trailer
6		3 axle single unit	
	a		w/o trailer
	e		w/ trailer
7		4-5+ axle single unit	
	a		4 axle
	b		5+ axle
8		3-4 axle single trailer	
	a		3 axle
	b		4 axle
9		5 axle single trailer	
	a		long-tongue trailer
	b		standard semi
10		6-7+ axle single trailer	
	a		6 axle
	b		7+ axle
11		5 axle multiple trailer	
12		6 axle multiple trailer	
13		7+ axle multiple trailer	
14		other	

that are not. In some cases the class is subdivided according to vehicle size. Work to date and the present paper deal exclusively with classes 2a to 2d and 3a to 3d (cars without trailers and utility vehicles without trailers) but neglect subclass information. These classes were initially focused on for two reasons: (a) they cover about 98 percent of the vehicles at our first sensor test site (STS1), and (b) this is a fairly subtle class boundary, which serves well to test the adaptive/neural network approach.

EXPERIMENTAL SENSOR TEST SITE

STS1 was designed to provide a conveniently accessible experimental site with good traffic flow. It is located on the State Route 4 Truck Route about 15 min from Los Alamos National Laboratory. The sensor layout, shown in Figure 1, was designed to offer redundant measurements to permit internal cross-validation and multiple sensor subgroupings that can simulate several different monitoring

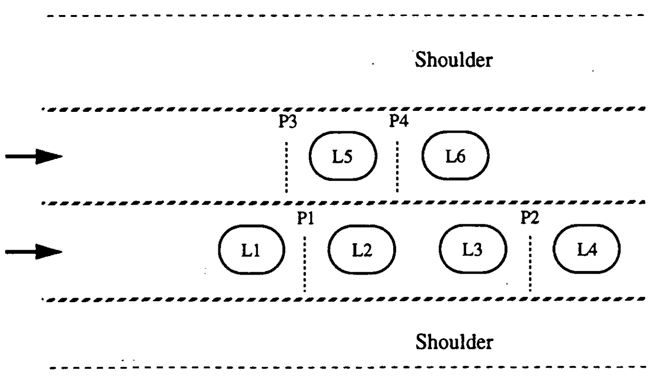

FIGURE 1 Schematic layout of STS1.

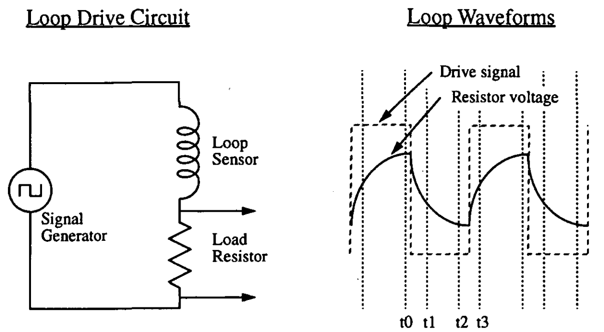

FIGURE 2 Loop readout scheme that is simple, direct, and fast and that uses versatile hardware.

configurations. Both lanes of traffic are monitored with on-track sensors only. The data presented here were obtained at STS1 over the period from November 1992 through June 1993.

DATA ACQUISITION SYSTEM

A key design criterion for the data acquisition system was hardware flexibility combined with off-the-shelf availability. Thus, a personal computer (PC)-based acquisition system was chosen and a 16-channel analog-to-digital conversion (ADC) board for input and a 20-channel counter-timer-board for output were used. This hardware is expected to be readily adaptable to any current TVCM or weigh-in-motion (WIM) sensors and to most future sensor types.

A loop readout scheme was chosen that, although unconventional, is simple, direct, and fast. The scheme is illustrated in Figure 2. A square-wave drive signal is applied to a resistive-inductive (R-L) circuit containing the loop. The voltage across the load resistor is read at four times per square-wave cycle: twice near the maximum current and twice when the current is in the exponential decay following the square wave's voltage transitions. The difference between the peak and decaying readings is related simply to the inductance of the loop, which in turn varies according to the characteristics of a proximate vehicle.

A schematic of the loop data acquisition system is shown in Figure 3. The 5 to 10-kHz square waves for driving up to six loop sensors (about 1 ohm of impedance) are generated by the counter-timer board with sequentially delayed phases. The timer outputs are individually cleaned up and amplified and are then applied to the R-L circuits containing the six respective loop sensors. Most data have been acquired using high-quality audio amplifiers as loop drivers, although a custom-designed seven-channel instrumentation amplifier has been used as well. The loop circuits were typically driven with a 0.4-V *p-p* square wave and the loop current signal amplified by a gain-of-10 amplifier on the ADC board.

The data acquisition system for the piezoelectric strips is illustrated in Figure 4. Since the piezoelectric strips are active sensors, no drive signal is needed, and the acquisition system is simpler. A

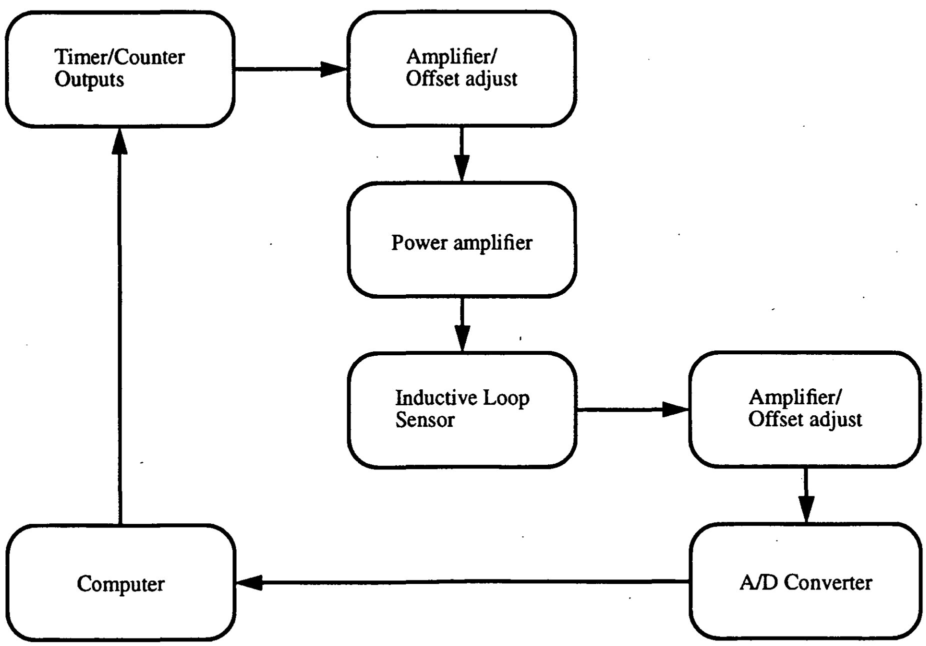

FIGURE 3 Schematic of inductive loop sensor data acquisition system.

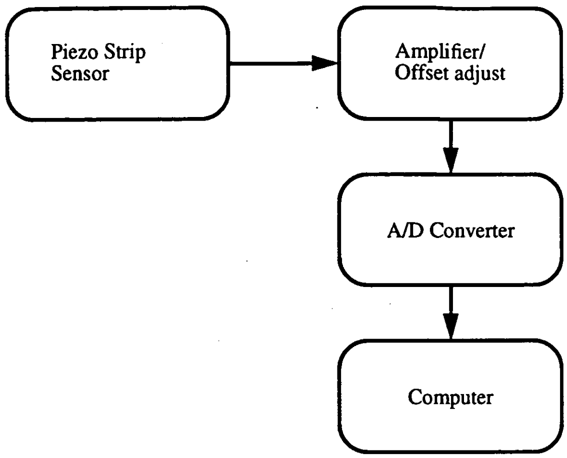

FIGURE 4 Schematic of piezoelectric strip sensor data acquisition system.

seven-channel instrumentation amplifier is generally used with high input impedance at voltage gains of 1 to 10 to match the piezoelectric outputs to the ADC input requirements.

Data from up to six loops and up to six piezoelectric strips are acquired cyclically. The total data rate is about 50 to 100 kilosamples/sec, providing ample time for resolution of individual sensors' outputs. Amplitude resolution is about 1 part in 4,096.

Phase I data were collected in one of two modes: first a "spooling" mode was used: the data stream was directly recorded on 90-MB high-speed, removable disks for later analysis. Later the capability of collecting event mode data was developed and employed: PC-based, on-line analysis reduced the incoming data stream to a list of sensor-activation events, thus obviating the need to record large amounts of quiescent data.

GROUND TRUTH DETERMINATION

A two-channel video system, illustrated in Figure 5, was used to acquire the data needed to determine ground truth. The two cameras viewed the test site from widely differing angles on opposite sides of the roadway. The primary camera view was perpendicular to the road at an angle of about 40 degrees above the horizontal. Data were recorded on videotapes, together with a signal light that indicated the timing of the PC sensor-data acquisition runs.

Analysis of the video data was largely done by playing the tape into a workstation-based image digitizer, using a software image comparator to select only frames taken during a run and with a vehicle present. Digitized frames were classified by a human analyst. Use of the workstation to preselect the relevant images increased the classification rate from about 1/10 real time to about 1/3 real time. Generally, one camera's digitized image was adequate for classification and lane determination. This process was expensive, but not prohibitively so. The cost of ground truth determination was mitigated by reusing the data for multiple sensor groupings and by repeatedly analyzing the sensor signals as adaptive algorithms were developed.

Formal quality control procedures were observed to evaluate and maintain the accuracy of ground truth determination. At least 10 percent (randomly selected) of the data runs were reclassified and the accuracy of the ground truth determination was found to be better than 99 percent in vehicle volume, major class determination, and lane determination (to the nearest lane). This accuracy is more than adequate for training and testing the sensor-based classification system. The ground truth data base from STS1 currently contains 2,216 vehicles, mostly of classes 2a to 2d and 3a to 3d.

SIGNAL PREPROCESSING

Given the complex character of the sensor signals, signal preprocessing plays a crucial role in preparing the data for input to the

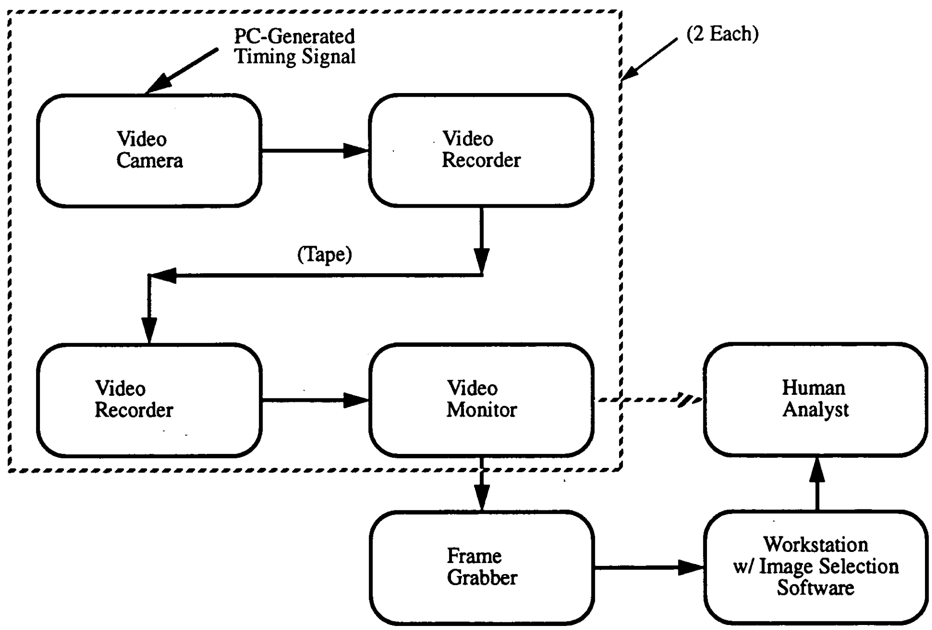

FIGURE 5 Schematic of video data acquisition system.

neural networks. Signal preprocessing steps are discussed in two subgroups here: adaptive signal conditioning steps and data representation steps.

Adaptive Signal Conditioning and Pulse Extraction

The importance of adaptive signal conditioning can be seen by considering the properties of loop and piezoelectric sensor signals. The most difficult aspects of loop signal processing are poor signal-to-noise ratio, significant systematic errors (e.g., asymmetric results of measurements on the up- and down-transition signals), and high ratio of drift to signal. The piezoelectric strips, on the other hand, give processing challenges from three different characteristics: large dynamic range (~1,000:1), large sensor-to-sensor variations (~10:1), and large variations in response due to particular interaction details (~10:1).

By using a sequence of signal conditioning steps, reliable detection and data reduction of the sensor signals are achieved: (a) even-odd correction removes sampling asymmetries of the loop signals; (b) low-pass filtering improves the signal-to-noise ratio, particularly for loops; finally, adaptive adjustments to signal (c) amplitude and (d) noise levels compensate for sensor-to-sensor and event-to-event signal variations. To remain within PC processing capabilities, adaptive (but non-neural-network) signal processing techniques are used in these initial signal-conditioning steps.

The extraction of active signal pulses is performed by an adaptive triggering algorithm. The algorithm distinguishes between baseline (quiescent) and active signal behavior by using a pulse height spectrum for each data channel. The trigger's sensitivity is varied adaptively, using moving averages that account for recent average noise and signal levels. The trigger also incorporates a slope-sensitive term and logic that helps to prevent multiple triggering during a single piezoelectric event.

Data Representation

One additional group of tasks must be accomplished before presenting the data to the neural net for solution: choosing a representation for the data. The representation determines what information the neural network must process. If too much extraneous information is presented to the network, the neural net can be overwhelmed. This is analogous to a signal-to-noise problem. On the other hand, if the representation chosen does not include the information to be processed, the neural net can be underinformed, that is, the network can be reduced to the status of fortune teller.

For the TVCM application representation requires signal reduction, screening, parsing, and subselecting the signal data. The signals are reduced by extracting simple signal statistics from the detailed signal profiles, for example, peak amplitude, full widths at half- and quarter-maximum, time of peak amplitude, and integral between the half-maximum points. The screening steps apply known physical constraints to remove extraneous pulses. Constraints currently used include minimum and maximum sensor pulse widths and amplitudes, implied vehicle speed greater than 0, and implied axle separation distances greater than 0.6 m (2 ft). One constraint, although not absolutely physically defensible, appears to be helpful, namely, restricting the dynamic range of signals corresponding to one vehicle to a factor of 8:1. Parsing associates subgroupings of the signals into vehicle events. The vehicle parser is built on a few observations that appear to be quite accurate, at least within the authors' current experience: that one vehicle usually generates a single magnetic loop pulse, that an implied gap of more than 24.4 m (80 ft) between axles always signifies a separate vehicle, and that piezoelectric signals usually belong to the vehicle with the nearest (in-time) magnetic loop signal. The signal parser is the most complex nonadaptive part of the classification system. Only time will tell whether it is fully adequate to all traffic and site conditions.

Data subselection is the final task, and that is discussed separately in the next paragraph since subselection issues are expected to be different for different vehicle classes. Also the data subselection issues are closely interwoven with the definitions of the classification scheme and the overall architecture chosen for the classification system (Figure 6). The basic idea is to divide the classification parameter space according to the number of axles detected for a vehicle and then to choose among the classes having constant numbers of axles by using neural networks trained to the task. There are not enough data on the universe of vehicle and installation types to determine whether the initial axle count determination can be performed accurately enough to support this classification system architecture or not. At present the architecture is serving well.

Returning to the data subselection issue, specifically for classes 2a to 2d and 3a to 3d, by a combination of observational, deductive, and statistical analyses, it was determined that the data containing most of the information for distinguishing the boundary between these two classes is the peak amplitude of the magnetic loop data. The reason for this is believed to be that most class 2 vehicles have lower ground clearances than most class 3 vehicles. Therefore, most class 2 vehicles yield larger changes in loop inductance and greater peak loop signal amplitude. This analysis indicates that the practical limit to the accuracy of the separation of these two classes is about 90 percent on a vehicle-by-vehicle basis. That is, given typical measurement errors, traffic behavior, and vehicle configurations, about 10 percent of class 2 vehicles will appear to be class 3 vehicles and about 10 percent of class 3 vehicles will appear to be class 2 vehicles. A large part of the crossover of class 2 vehicles into class 3 appears to be due to off-track events, which reduce the change in loop inductance because of the lateral offset of the vehicle over the loop. A large part of the crossover from class 2 into class 3 appears to be caused by the fact that some class 3 (utility) vehicles are actually built on car chassis and thus do not have larger ground clearances than most cars. To some extent these two

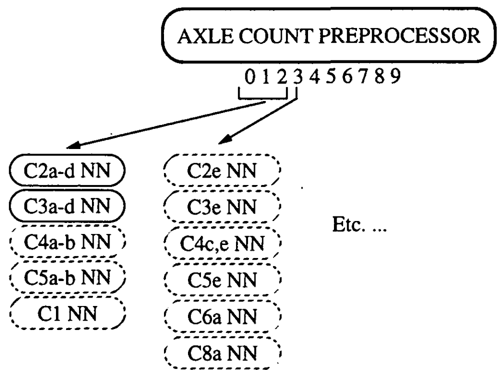

FIGURE 6 Overview of classification system architecture.

crossover effects largely cancel, and it is possible, in an average sense, to end up with greater than 90 percent overall accuracy for an ensemble of vehicles.

One other important issue of adaptation arose in connection with using the loop peak amplitude to distinguish the class 2–3-class boundary. It was found that for unknown reasons the absolute scaling of the peak loop amplitude shifts from one data acquisition run to another; this shift has not been traced to a reparable cause. However, the problem has apparently been solved by observing that there exists a relatively stable vehicle population that gives a fixed maximum signal, and this provides an on-line calibration factor.

Having resolved the crucial issues of data conditioning and representation, the data are ready to be delivered to a classification neural net to obtain the completed classification solution. Note that by "completed," it is meant fully functioning for classes 2a to 2d and 3a to 3d rather than complete in the sense of having solved the entire classification problem.

CONNECTIONIST HYPERPRISM CLASSIFICATION NEURAL NETWORK

The classification network used in this work, the connectionist hyperprism classification (CHC) network, is designed to recognize multidimensional patterns presented by the various vehicle signatures produced by the TVCM sensors and to produce corresponding classification outputs. The CHC network has architectural features (Figure 7) that are well matched to the needs of the intended TVCM applications.

The CHC network operates on roughly the same principle as clustering algorithms (*13*), whereas it draws most of its numerical approach from typical neural network methods. Two data sets are imagined, one for training and another for testing, that each contains a number of anonymous samples (labeled 0) plus some number of tagged samples (labeled 1) that are representative of a single class (e.g., several signal sets that correspond to the same vehicle class). Each sample vector (p) consists of an N-dimensional set of inputs x_{pi}, together with the desired output, o_p, equal in this case to 0. or 1. It is assumed that there are M class 1 members of the training set, and initially a network was chosen that contains M nodes or basis functions, each centered at one of the unique training datum points.

The CHC network uses N-dimensional hyperprism basis functions (Figure 8). Each basis function has a vector center, $\boldsymbol{x}_c$, in the input parameter space, and produces nonzero output in a connected region about its center, having width $\boldsymbol{b}_a$ above the center and $\boldsymbol{b}_b$ below it. At the center the basis function's output value is equal to the weight f_c. When, for dimension i, the datum point coordinates satisfy $x_{cji} - b_{bji} < x_{pi} < x_{cji} + b_{aji}$, then the ith component of the jth basis function is

$$f_{ji}(x) = f_{cji} \cdot \{1. - [(1. - m_e) \cdot |x_{pi} - x_{cji}|/b_{wji}]\} \tag{1}$$

where b_{wji} is the appropriate width parameter, either b_{aji} or b_{bji}. Within the active domain the basis function's value is the product of these N components. Outside its active domain the basis function is zero. The constant m_e is the same for all basis functions in the network, and in practice we often use m_e equal to 1., so the basis function components are simply N-dimensional top-hat functions. The network output is

$$g(\boldsymbol{x}) = \Sigma f_j(\boldsymbol{x}) \tag{2}$$

The network training algorithm contains two main parts: one part adjusts the basis function central amplitudes f_c based on only the class 1 data, whereas the other adjusts the widths $\boldsymbol{b}_a$ and $\boldsymbol{b}_b$ based on all of the training data. The f_c's are adjusted to minimize the root mean square error in the network's calculation of the class 1 datum points. The widths are adjusted according to a self-organizing algorithm (*14*), adjusting the domain of each basis function to regulate the number of class 0 datum points that fall within the active region and resetting the width when basis function overlap occurs. The training algorithms are iterative and on-line in the sense that the basis function amplitudes and widths need not be static in time but can grow or shrink to reflect the currently appropriate training conditions.

The training algorithm for the jth node's central amplitude f_{cj} weights each datum point by a manually adjustable parameter, w_1, according to its target output value o_p:

$$w_p = (w_1 \cdot o_p) + [(1. - w_1) \cdot (1. - o_p)] \tag{3}$$

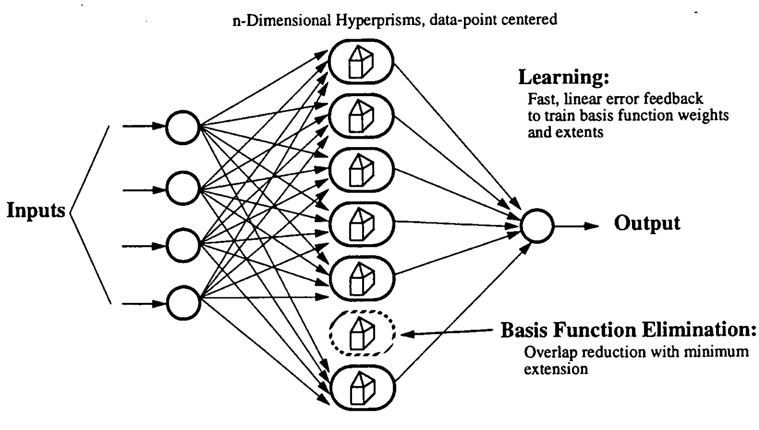

FIGURE 7 Architecture of CHC neural network.

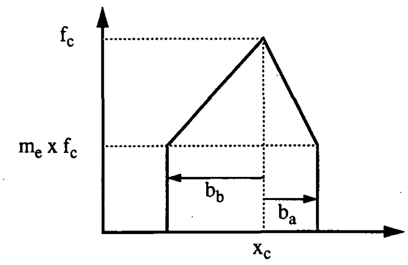

FIGURE 8 Basis function of CHC neural network.

The iterative adjustment to the central amplitudes is then given by

$$f_{cj}^{n+1} = f_{cj}^{n} \{1 + [\alpha\, w_p\, (g(x_p) - o_p)]\} \quad (4)$$

where α is a learning rate parameter and n is the iteration count. For most of this work α equal to 0.1 and w_1 equal to 0.7 were used.

The training algorithm that adjusts the basis function widths is slightly more elaborate. It operates in two successive stages—one that adjusts widths on the basis of datum point inclusion and another that revises the widths to remove basis function overlap.

The datum point-based width adjustment increases the appropriate widths as class 1 points are encountered within the basis function's active domain and decreases the widths as included class 0 points are found. The choice of what widths to adjust is made by calculating the distance (d_{pji}) of each point included within the active domain to each dimension's nearest basis function edge and choosing the smallest. The data-dependent width adjustment is

$$b_{wji}^{n+1} = (b_{wji}^{n}) \cdot \{1. + [\beta\, (b_{wji}^{n}/b_{avg})(b_1\, o_p + b_0\, (1. - o_p))]\} \quad (5)$$

where β is an overall width learning rate (0.01 − 1.0, for this work), and b_1 (~0.1) and b_0(~−0.2) are the width adjustment factors associated with class 1 and class 0 datum points, respectively. A maximum basis function half-width is enforced (b_{max} = 0.2 here).

The overlap-based width adjustment eliminates basis function overlap. This part of the training operates as a logical constraint that shifts basis function boundaries by the least amount that removes overlap. Basis functions are allowed to overlap only if removal of the overlap would reduce a basis function below a set minimum half-width (b_{min} = 0.005 here).

Finally, the training algorithm includes a basis function elimination scheme that removes basis functions whose widths in any dimension have become less than an elimination threshold value (b_{elim} = 0.01, typically) and whose elimination would not permanently orphan any class 1 datum points. This algorithm is not useful for all classification problems, but if it is used it decreases the size of the network required and increases training and testing speeds. In the present application the basis function elimination works very well. Generally, the network size can be reduced from 30 to 40 nodes to 5 to 10 nodes, whereas the performance of the classifier is either constant or actually improves slightly.

CLASSIFICATION RESULTS

A sample of the training data and the corresponding fit produced by a network trained to identify class 2a to 2d vehicles are shown in Figure 9. The CHC network solution shown uses very little basis function elimination, and thus has more nodes than the minimum required to obtain good performance. The results of applying this network to a test data set are illustrated in Figure 10.

Four networks have been similarly trained to handle class 2 and class 3 identifications for six sensor groupings. One advantage of using one network per class is that an estimate can be obtained of the classification error by comparing the sum of the networks' outputs with the actual, known total vehicle count. Since the errors here are dominated by overlap of the two classes, the estimated error is given by the difference between the sum of the network's outputs and the actual vehicle count. Table 2 shows the results of classifying a data set consisting of STS1 measurements for which ground truth is known. The results are summed over six independently processed sensor groupings. The CHC networks used here were

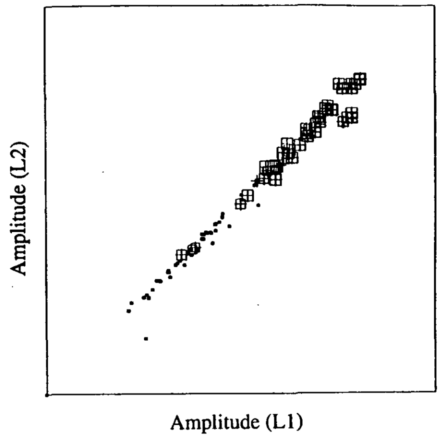

FIGURE 9 Training data (small + is class 0 datum point; large + is class 1 datum point) and network fit (shown by boxes, scaled the same way as the datum point pluses) for sample class 2a to 2d classification task.

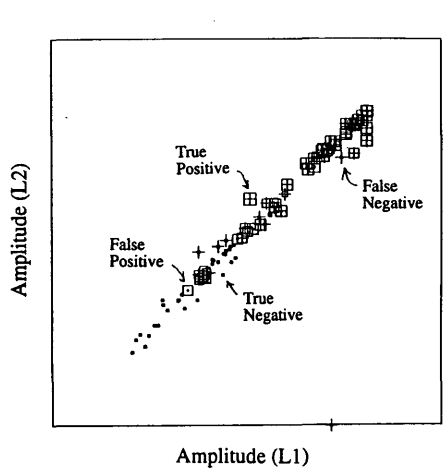

FIGURE 10 Sample test data and network prediction for same network shown in Figure 9. The four kinds of test prediction outcomes are labeled.

TABLE 2 Composite Results of Off-Line Classification Tests on All STS1 Data Processed to Ground Truth Status

Category	NN Pred.	Ground Truth	Act. Error
Volume	6407	6438	-31
Class 2	3955	3828	127
Class 3	2452	2562	-110

trained using about 10 percent of the STS1 data set. The overall volume accuracy obtained is better than 99 percent. The inferred memberships of classes 2 and 3 are accurate to better than 95 to 98 percent in net population count when the classification neural networks have been tuned to near-optimum performance.

CONCLUSIONS AND FUTURE DIRECTIONS

An end-to-end vehicle classification system, based on adaptive and neural network techniques, has been successfully developed and demonstrated that achieves quite good classification of vehicles in classes 2a to 2d and 3a to 3d. Current net volume accuracy is about 99 percent, and classification accuracy is better than 95 percent for the two classes handled by the system when the neural networks are specifically trained for the installation being used to collect the classification data. These accuracies significantly exceed those of an off-the-shelf commercial unit tested under the same circumstances.

In the near future the authors intend to extend the classification system to other vehicle classes (which requires acquisition and analysis of additional data) and to implement some of the neural network-based fault detection ideas.

ACKNOWLEDGMENTS

The authors thank David Albright of the Alliance for Transportation Research for valuable support and discussions throughout this work. The authors thank L. Blair, D. Wilson, K. Lee, and C. Barnes for helpful comments and support as well.

This research was supported by the U.S. Department of Transportation. The cooperation and various kinds of assistance by the U.S. Department of Energy and the New Mexico State Highway and Transportation Department were very important as well.

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Publication of this paper sponsored by Committee on Transportation Data and Information Systems.

Multimodal Trip Distribution: Structure and Application

DAVID M. LEVINSON AND AJAY KUMAR

A multimodal trip distribution function estimated and validated for the metropolitan Washington, D.C., region is presented. In addition a methodology for measuring accessibility, which is used as a measure of effectiveness for networks, using the impedance curves in the distribution model is described. This methodology is applied at the strategic planning level to alternative high-occupancy vehicle alignments to select alignments for further study and right-of-way preservation.

One of the components of travel demand models is the estimation of the rate of decay with distance (or time) from an origin: the greater the separation between an origin and destination the lower the propensity to make the trip. Because time is the key indicator of separation in the utility of a trip maker and travel time and trip quality vary by mode, the decay function is expected to be different for different modes. Not only do travel speeds vary by mode but the choice of mode also partly influences locational decisions and individual willingness to make trips of certain lengths. For instance households wanting to use transit (heavy rail in particular) are more likely to locate along major transit facilities. However, conventionally, trip distribution functions are estimated for automobile trips only and are applied to trips by all modes. The main justification for this procedure is that more than 80 percent of all trips are made by privately owned vehicles, and specific treatment of transit and other modes is not expected to improve model performance significantly. However, with the emerging concern with the environment in recent years and the response of managing travel demand, local and state planning jurisdictions are grappling with a need to evaluate the feasibility of introducing high-occupancy vehicle (HOV) and transit facilities. It therefore becomes important to explicitly account for different distribution characteristics of modes other than single-occupancy vehicles (SOVs). This research hopes to fill this gap by estimating a multimodal trip distribution function for the metropolitan Washington, D.C., region. In addition an application of the model to the evaluation of multimodal networks is described.

Use is made of afternoon peak period transportation planning models developed by the Montgomery County Planning Department (MCPD) over the past few years (*1–4*). Key elements of the model structure include segmentation of trip purposes by direction, which permits accounting for chained trips, peak hour factoring as a function of congestion between origin and destination, the multimodal gravity model for trip distribution described here, and the feedback of travel time outputs from assignment into distribution to ensure travel time consistency through the model chain. Travel time feedback, along with multimodal distribution, will help capture the impact of induced demand—the construction of significant transportation facilities will alter demand patterns over time, even with no change in land-use activity. The impact of transportation on land-use activities is not modeled but is considered exogenous to the model in planning application.

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TRIP DISTRIBUTION

Model Structures

Over the years modelers have used several different formulations of trip distribution. The first was the Fratar or growth model. This structure extrapolated a base year trip table to the future on the basis of growth, but it took no account of changing spatial accessibility because of increased supply or changes in travel patterns and congestion. The next models developed were the gravity model and the intervening opportunities model. Evaluation of several model forms in the 1960s concluded that "the gravity model and intervening opportunity model proved of about equal reliability and utility in simulating the 1948 and 1955 trip distribution for Washington, D.C." (*5*). The Fratar model was shown to have weakness in areas experiencing land-use changes. Because comparisons between the models showed that either could be calibrated equally well to match the observed conditions, because of computational ease, gravity models became more widely spread than intervening opportunities models. Some theoretical problems with the intervening opportunities model were discussed by Whitaker and West (*6*) concerning its inability to account for all trips generated in a zone, which makes it more difficult to calibrate, although techniques for dealing with the limitations have been developed by Ruiter (*7*).

With the development of logit and other discrete choice techniques, new, demographically disaggregate approaches to travel demand were attempted (*8*). By including variables other than travel time in determining the probability of making a trip, it is expected to make a better prediction of travel behavior. The logit model and gravity model have been shown by Wilson (*9*) to be of essentially the same form as the model used in statistical mechanics, as an entropy maximization model. The applications of these models differ in concept in that the gravity model uses impedance by travel time, perhaps stratified by socioeconomic variables, in determining the probability of trip making, whereas a discrete choice approach brings those variables inside the utility or impedance function. Discrete choice models require more information for estimations and more computational time.

Ben-Akiva and Lerman (*10*) have developed combination destination choice and mode choice models using a logit formulation for work and non-work trips. Because of computational intensity, these formulations tended to aggregate traffic zones into larger districts or rings in estimation. In current application some models, including, for instance, the transportation planning model used in Portland, Oreg., use a logit formulation for destination choice (*11*). Research by Allen (*12*) used utilities from a logit-based mode choice model in determining composite impedance for trip distribution. However, that approach, using mode choice log-sums, implies that destination choice depends on the same variables as mode choice. The approach taken in this paper uses mode choice probabilities as a weighting factor and develops a specific impedance function or *f*-curve for each mode for work and non-work trip purposes.

Feedback of Congested Travel Times

One of the key drawbacks to the application of many early models was the inability to take account of congested travel time on the road network in determining the probability of making a trip between two locations. Although Wohl (*13*) noted as early as 1963 research into the feedback mechanism or the "interdependencies among assigned or distributed volume, travel time (or travel 'resistance') and route or system capacity," this work has yet to be widely adopted with rigorous tests of convergence or with a so-called equilibrium or combined solution (*14*). Haney (*15*) suggests that internal assumptions about travel time used to develop demand should be consistent with the output travel times of the route assignment of that demand. Although small methodological inconsistencies are necessarily a problem for estimating base year conditions, forecasting becomes even more tenuous without an understanding of the feedback between supply and demand. Initially heuristic methods were developed by Irwin and Von Cube [as quoted in Florian et al. (*16*)] and others, and later formal mathematical programming techniques were established by Evans (*17*). In the model used in this paper, congested travel times from route assignment are fed back into demand estimation, and the new demand is reassigned to the congested network until convergence (*1*).

A key point in analyzing feedback is the finding in earlier research by the authors that commuting times have remained stable over the past 30 years in the Washington, D.C., metropolitan region, despite significant changes in household incomes, land-use patterns, family structures, and labor force participation (*18*). The commuting time of 28.8 min found in the 1988 Household Travel Survey is almost identical to the Bureau of the Census journey to work time of 29.5 min. Moreover, over the past 20 years even non-work travel times have remained fairly stable, generally between 19 and 20 min for home to non-work trips and 18 min for non-home-based non-work trips.

The stabilities of travel times and distribution curves over the past three decades give a good basis for the application of trip distribution models for relatively long-term forecasting. This is not to suggest that there exists a constant travel budget. According to travel budget hypothesis, commuters in different situations would exhibit very similar travel behaviors and make all budget allocation adjustments on non-travel times (*19*). Prendergast and Williams (*20*) contradict the constant travel budget hypothesis by stating that consumers will substitute among budget components in response to relative price and income changes. However, in spite of the importance given to road pricing in the transportation literature, out-of-pocket transportation costs have remained fairly low. The fact that other factors, including the typical 5-day-a-week commute to work, have not changed significantly suggests a comparatively strong basis on which to estimate a trip distribution model to develop synthetic trip tables for transportation forecasting. Even though commuting times have remained relatively stable, they vary significantly by mode; typically, automobile trips are shorter than transit trips.

Data

The data source for the estimation of the trip distribution model consists of detailed person travel surveys conducted by the Metropolitan Washington Council of Governments for 1968 and 1987–1988 (*21,22*). The 1968 survey consists of a sample of about 20,000 households making 135,000 trips, whereas the 1987–1988 sample involved 8,000 households and 55,000 trips. Each household was assigned a specific 24-hr travel day, and information was collected on all trips made by members of that household on that day. A trip was defined as one-way travel from one address to another. The locations of both ends of the trip were reported along with the time of departure and arrival. Trip duration was obtained by subtracting the time of departure from the time of arrival. These data also report trip purpose at both origin and destination ends, making it possible to identify work trips by accounting for trip chaining (which is defined as travel to a non-work location on the way between home and work).

Three primary travel modes are defined in the two surveys, transit, automobile, and walking. Travel by automobile is further divided by number of persons per vehicle, in which Auto-1 is a driver with no passengers, Auto-2 is a trip in a car with a driver and one passenger, and Auto-3 is a trip in a car with a driver and two or more passengers. Transit includes both rail (Metrorail and commuter rail) and bus. The 1988 survey also provides information on the mode of access to Metrorail, which includes walk to rail or walk to bus to rail (WCT), automobile driver or park and ride (ADT), and automobile passenger or kiss and ride (APT).

Seven trip purposes are defined in this application: home to work (H2W), work to home (W2H), home to other (H2O), other to home (O2H), other to work (O2W), work to other (W2O), and other to other (O2O). For estimation these were grouped into three categories, work, non-work, and chained work. Because chained work trips (W2O) were observed to have a very similar distribution to work to home (W2H), these purposes were consolidated for the estimation of trip impedance. The approach adopted here is different from that undertaken in earlier studies, which only differentiate between home-based and non-home-based trips. By segmenting trips by direction, a better understanding of asymmetric travel patterns, such as linked trips, is possible.

Estimation

Many conventional trip distribution models are stratified by income or automobile ownership, which serves as a surrogate for income. Although in concept stratification for income (or any number of other demographic variables) is desirable, this model was not stratified because income is not available from the 1988 survey and automobile ownership is approaching one car per licensed driver in the region. Thus, the number of transit-dependent (zero-automobile) households who make work trips was extremely small in the sample, and with the stratification by mode, it was too small on which to estimate separate models.

The 1988 Household Travel Survey was used to determine the number of trips by a 5-min time band for each mode and purpose. Using ordinary least squares regression, impedance functions were estimated for application in the gravity model, with the dependent variable being the number of trips per unit area in each 5-min time band. Travel time and mathematical transforms of travel time serve as independent variables. In model estimation the average density of opportunities available in each 5-min time band is assumed to be uniform. In model application the opportunities available (in trips) is multiplied against the impedance function. The number of opportunities is estimated by assuming 5-min radius circular time contours: the first circle (0–5 min) has an area of 25π min squared, the second circle (5–10 min) has an area of $100\pi - 25\pi = 75\pi$ min squared, and so on. A more rigorous methodology could use a geographical information system to estimate the number of opportunities in true travel time contours around each zone. However, for an aggregate analysis this is unlikely to provide a significantly different result for model parameters. The parameters (*a, b, c, d*) are shown in Table 1 for work trips and Table 2 for non-work trips. Table 3 solves the work trip equations for a variety of travel times. The impedance function uses the following equations:

$$f(C_{ijm}) = e^{(a \cdot t + b \cdot t^{0.5} + c \cdot t^{2} + d)} \quad (1)$$

where $f(C_{ijm})$ is the impedance function for travel time t and a, b, c, and d are the calibration coefficients shown in Tables 1 and 2.

The multimodal impedance function (f_{ij}) is thus expressed as follows:

$$f_{ij} = \sum_{m=1}^{M} P_{ijm} \cdot f(C_{ijm}) \quad (2)$$

subject to

$$\sum_{m=1}^{M} (P_{ijm}) = 1 \quad (3)$$

where

P_{ijm} = probability of using mode m on a trip from i to j (from mode choice model),
C_{ijm} = travel time from i to j using mode m, and
$f(C_{ijm})$ = friction (impedance) function (negative exponential) described in Tables 1 and 2.

In the application of Equation 2 the probabilities from the mode choice model are multiplied by the modal impedance on an origin-destination basis and are summed to obtain composite impedance. A doubly constrained gravity model is used. In that model the impedance matrix for work trips is balanced against each of the production and attraction (origin and destination) vectors to obtain the trip table for work trip purposes (this process is repeated for chained work trips and each non-work trip purpose). These all-mode trip tables are multiplied by the mode choice probabilities to obtain vehicle trips by class (SOV, HOV) and transit person trip tables (walk access, automobile access), which are then assigned. In the feedback procedures described in an earlier paper (*1*), vehicle trips are assigned for a single iteration, producing new origin-destination travel times. The new times are used to update modal probabilities and then impedance matrices. This process is continued, with the new demand assigned to the congested network until convergence.

Validation

The travel time (C_{ij}), multimodal impedance functions (f_{ij}), and then demand to be assigned (T_{ij}) are updated after each iteration of route assignment to ensure consistency between input and output travel times. Because of the travel time feedback method used, the model produces trips, aggregated to 5-min time bands, that appear similar to the observed data, as shown in Figure 1.

The Friedman nonparametric method was used to test the hypothesis that the three travel time distributions—model output, observed 1988, and observed 1968—have been drawn from the same population. A chi-square of 6.3 results (with a 0.042 significance). We fail to reject the hypothesis at the conventional 95 percent confidence level, which implies that there is not enough statistical evidence to suggest that the three distribution curves are different.

On a specific origin-to-destination basis, trip distribution faces a more rigorous test than the comparison with 5-min cohorts. Although travel times can be easily matched when feedback is used along with balancing procedures, area-to-area flows may depend on other factors. These other socioeconomic factors are not directly considered in the distribution model, but are partially captured in

TABLE 1 Multimodal Spatial Trip Distribution Impedance Function (Work Trips).

MODES:	Auto Drive to Transit	Auto Pass. to Transit	Walk to Transit	Auto-1	Auto-2	Auto-3+	Walk
VARIABLE:							
TIME	0.05	-0.11	-0.08	-0.08	-0.07	-0.06	-0.14
	(2.3)	(-3.8)	(-7.9)	(-17.2)	(-16.4)	(-10.6)	(-11.6)
TIME^0.5	-	0.642	0.265	-	-	-	-
	-	(2.1)	(2.3)	-	-	-	-
TIME^2.0	-0.0011	-	-	-	-	-	-
	(-4.6)	-	-	-	-	-	-
CONSTANT	-2.92	-2.90	-1.91	-0.97	-1.03	-1.31	-0.58
r-squared	0.87	0.88	0.98	0.94	0.94	0.87	0.94

(T-statistic in parentheses)

TABLE 2 Multimodal Spatial Trip Distribution Impedance Function (Non-Work Trips)

MODE:	Auto-1	Auto-2+	Transit	Walk
VARIABLE:				
TIME	-0.16	-0.16	-0.07	-0.19
	(-6.7)	(-8.4)	(-15.3)	(-11.1)
TIME^2.0	0.000663	0.000758	-	-
	(2.7)	(3.7)	-	-
CONSTANT	-0.39	-0.36	-1.32	-0.19
r-squared	0.95	0.96	0.93	0.95

(T-statistic in parentheses)

mode choice, which does affect the model. It is possible to replicate area-to-area flows by using adjustment factors; however, the stabilities of these adjustment (or *K*) factors over time have not been established. Nevertheless, adjusting the model to match the observed data would seem a better assumption than not making any adjustment. Therefore, in model application, factors are developed that adjust base year trip tables to observed base year origin-destination flows, as developed by gradient reduction methods (*23*).

A second source of error is inaccuracies in the estimates of impedance matrices for the various modes; thus, the balancing procedures will provide a best-fit match of the origin-destination travel times, but those times may not be accurate. Although observed peak-hour travel times are available for the road network for select links, these data do not provide uniform coverage. The link volume delay functions were estimated to match observed congested travel times. Transit routes were specified to match reported headways and schedules. Walk times were estimated assuming 3 mi/hr on a straight-line, euclidean distance. A third factor, travel cost, was also not accounted for in the distribution model, because cost is highly correlated with time.

It would appear that the largest source of error or uncertainty between the applied model and the Household Travel Survey is the apparent tendency of survey respondents to round travel times. Most respondents rounded to the nearest 5-min, but a large number rounded to the nearest 15 min. For instance, a trip maker may actually leave at 5:02 and arrive home at 5:23, a trip of 21 min, but may report leaving at 5:00 and arriving at 5:30, a trip of 30 min, almost a 50 percent rounding error. It is hoped, but not possible to verify, that those rounding up are canceled by those rounding down. This tendency to round was more pronounced in 1968 than in 1988, but it is less apparent in the cumulative distribution curve shown in Figure 1 than it would be in a probability distribution curve.

APPLICATION

The application described in this paper presents a methodology for evaluating long-term additions to the transportation network used by different modes using the trip distribution functions estimated in the previous section. The method for evaluation is based on measures of accessibility by the several modes. The use of accessibility to test the relative impacts of different networks is in contrast to evaluating traffic volumes or total travel times on each of the alternatives.

This work is undertaken as part of the development of the Transitway HOV Vehicle Network Plan for Montgomery County, Md. The model output will facilitate decisions related to reserving transportation rights-of-way within the county and make recommendations for prioritizing the construction of facilities in the proposed transportation alignments. This plan will amend and supplement the county's current Master Plan of Highways. Because

TABLE 3 Evaluation of Impedance Functions (Work Trips)

MODES: / TIME	Auto Drive to Transit	Auto Pass. to Transit	Walk to Transit	Auto-1	Auto-2	Auto-3+	Walk
0	0.054	0.055	0.148	0.380	0.357	0.270	0.560
5	0.067	0.135	0.182	0.257	0.247	0.202	0.277
10	0.080	0.144	0.159	0.174	0.170	0.151	0.137
15	0.089	0.133	0.130	0.118	0.118	0.113	0.068
20	0.095	0.114	0.104	0.080	0.081	0.085	0.033
25	0.096	0.094	0.081	0.054	0.056	0.063	0.016
30	0.092	0.075	0.063	0.037	0.039	0.047	0.008
35	0.083	0.058	0.048	0.025	0.027	0.035	0.004
40	0.072	0.044	0.036	0.017	0.018	0.027	0.002
45	0.058	0.033	0.027	0.011	0.013	0.020	0.001
50	0.045	0.024	0.021	0.008	0.009	0.015	0.000
55	0.033	0.018	0.015	0.005	0.006	0.011	0.000
60	0.023	0.013	0.011	0.004	0.004	0.008	0.000
65	0.015	0.009	0.008	0.002	0.003	0.006	0.000
70	0.010	0.007	0.006	0.002	0.002	0.005	0.000
75	0.006	0.005	0.005	0.001	0.001	0.003	0.000
80	0.003	0.003	0.003	0.001	0.001	0.003	0.000
85	0.002	0.002	0.002	0.001	0.001	0.002	0.000
90	0.001	0.002	0.002	0.000	0.000	0.001	0.000

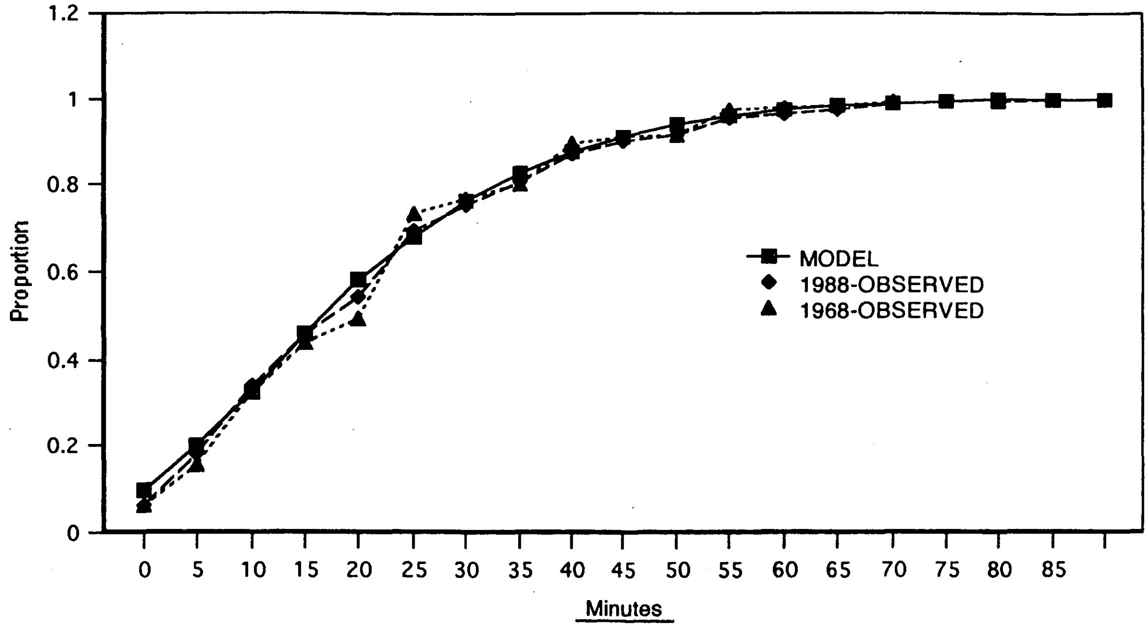

FIGURE 1 Work trip travel time distribution: afternoon peak period, automobile modes, metropolitan Washington, D.C.

combinations of more than 18 alignments are being evaluated simultaneously and up to three modes are possible on each alignment, this is the most ambitious undertaking of its kind that the county has attempted.

The objective of this study, as described in the *Transitway HOV Network Plan Issues Report* (*24*), is to increase the mobility of Montgomery County residents and workers. Mobility is used here to mean the access to jobs by households. As noted above experience over the past 30 years in metropolitan Washington, D.C., shows that individuals will maintain an average separation between home and work of about 30 min. In the long term it is doubtful whether a significant network improvement in a congested urban environment will actually reduce travel times. Downs' Iron Law of Congestion states that network improvements enable individuals to make longer trips, enable travelers who are not in the peak now to switch to the peak, and induce additional travelers to that facility (*25*). However, network additions can improve accessibility or the availability of destinations. If within the same travel time additional destinations or opportunities can be reached, then an improvement to mobility has been made. This study was thus directed to evaluating the accessibility of alternative network alignments.

Earlier research has reported that "the network design problem is an NP-hard problem that defies efficient solution techniques" (*26*). The problem gets especially acute when testing for 18 alignments and three modes in a model of the entire Baltimore-Washington, D.C. region, with a 16,000-link network. To the authors' knowledge no procedure that attempts to evaluate the impact of network alignments and prioritize networks on the basis of accessibility has been used. The solution methodology proposed in this paper does not guarantee the optimal solution, but it lays the groundwork for quantifying the impacts of each alignment on a consistent basis, particularly in an attempt to rank the benefit-cost ratio of the alignments.

The problem is broken into two components. The first is to develop a criterion for evaluating a network as a whole. The second is to determine what a particular facility contributes to that network.

Evaluating Networks

Extensive research has been undertaken in the field of the network design problem. An excellent summary is provided by Magnanti and Wong (*27*). The essence of the discrete network design models, they suggest, is "to choose those arcs (e.g., roadways or railbeds) to include, or add to, a transportation network accounting for the effects that the design decision will have on the operating characteristics of the transportation system." To evaluate the benefits of alternatives, a consistent measure of effectiveness is needed.

Conventionally, the objective function of the network design problem is to minimize user costs (e.g., travel time) and system costs (e.g., construction) subject to a variety of constraints, such as facility capacity. This conventional approach does not successfully account for elastic demand in which travel time may not be minimized by an additional facility. Adding a facility may result in an increase in travel along that facility such that link travel time declines only marginally, and system travel time (as measured in vehicle hours of travel, for instance) may increase.

Consumer surplus has been suggested as a measure of user benefits in the economic evaluation of transportation alternatives (*28*). Consumer surplus is defined in economic terms as the difference between the amounts people would willingly pay at the margin for various amounts of a specific good and the amount they do pay at market prices, or as the area above the demand curve and below the price line (*29*). However, in reviewing evaluation methods, Hutchinson (*30*) notes that "it seems clear that the real economic good of interest to an urban community at the level of strategic planning is the broad accessibility properties of a region." For that reason a similar approach that does not depend on trips but that depends only on the easier-to-predict and fixed estimated activity at the trip ends is accessibility. Hanson (*31*) states: "Personal accessibility is usually measured by counting the number of activity sites (also called 'opportunities') available at a given distance from the person's home and 'discounting' that number by the intervening distance." Here opportunities are defined as the number of jobs in a zone, whereas discounting is achieved by a function of the travel time (the trip distribution impedance curves estimated in the previous section) to those jobs obtained from a transportation model. Because the model is applied to the p.m. peak period, employment is in the origin traffic zone here.

The accessibility equation used is

$$A_{jm} = \sum_{i=1}^{I} [f(C_{ijm}) \cdot \mathrm{EMP}_i] \quad (4)$$

where

A_{jm} = accessibility index for residential zone j by mode m,
$f(C_{ijm})$ = friction factor between zones i and j by mode m, and
EMP_i = employment in zone i.

This process is performed as well for accessibility to homes from workplaces. To evaluate the entire network, the accessibility index for each zone is averaged, weighted by the number of households in the zone. This evaluation is important because the benefits to the system are paramount. The equation for this is

$$B^1_m = \sum_{j=1}^{J} (A_{jm} \cdot \mathrm{HH}_j) / \sum_{j=1}^{J} (\mathrm{HH}_j) \quad (5)$$

where

B^1_m = benefit of network 1 by mode m,
= countywide weighted average of accessibility indexes, and
HH_j = households in destination zone j.

Achieving a multimodal or composite benefit is important. Adding a facility should be expected in general to improve accessibility for each mode because congestion will decline, helping any mode that uses the road network (SOV, HOV, bus). There are situations in which this will not occur; Braess's paradox is one example in which adding a link can result in worse conditions overall (*32*). Accessibility in systems with elastic demand and traffic-sensitive intersection control will not necessarily improve with an added facility. Improving accessibility in one corridor may increase demand in that corridor, worsening conditions in both perpendicular corridors (east-west congestion will worsen if more traffic signal green time is given to north-south movements as an example) and in somewhat parallel corridors (increased demand from one origin owing to travel time savings on one set of links increases travel times for other origins sharing unimproved links with the first origin).

The composite work trip benefit is considered here as a simple summation of the mode-specific benefits (Equation 6):

$$B^1_w = \sum_{m=1}^{M} B^1_{wm} \quad (6)$$

where B^1_w is the composite (multimodal) benefit for work trips (average accessibility index) and B^1_{wm} is the benefit for mode m for work trips.

Parenthetically, an extension to this model would consider accessibility for all activities (trip purposes) pursued in the course of a day. Some research has investigated non-work accessibility (*33*). A general formulation of an accessibility index might weight work accessibility by work trip frequency or time spent at work and nonwork activities by their frequency or duration. Non-work could further be separated into more detailed activity patterns (shop, school, etc.). Such a generalized composite accessibility score may take the following form:

$$B^1_T = \sum_{p=1}^{P} F_p B^1_p \quad (7)$$

where F_p is the frequency or duration of purpose p (work, school, etc.) and B^1_p is the composite (multimodal) benefit for purpose p.

Evaluating Individual Facilities

A means for estimating the contribution of each alignment to the system needs to be developed, which avoids the large combination of possible alternatives. Here, the measure of effectiveness of the alignment is considered by evaluating two networks. The first network has all possible alignments; the second network has all alignments except that under consideration. By considering all possible alignments, the benefit of the doubt is given to the alignment under test. For instance, in an HOV scenario HOV time savings on other facilities may increase the utility on the facility under test. The following equation is used to obtain the benefit from the facility under test:

$$B = B^2 - B^1 \quad (8)$$

where B^2 is benefit (average accessibility) from the full network and B^1 is the benefit from the test network.

For the first round of analysis an alignment that was not viable (a benefit-cost ratio below a certain threshold) after considering the benefits of all other proposed complementary alignments to the network probably could be eliminated from further analysis. Later rounds of analysis may add alignments to a base network rather than subtract alignments from a complete network to determine the recommended sequencing of network additions.

It is difficult, however, to translate change in accessibility into monetary terms. At this point in the analysis we are not directly estimating dollar costs, but evaluation requires that we have some surrogate for cost. In this study we propose to use distance (mileage) as that surrogate. A benefit per mile will enable a direct comparison of the suitability of the alignments of the same mode. Each alignment will be ranked by its benefit-cost (accessibility-mileage) ratio, in which the benefit is the improvement in accessibility and the cost is mileage.

Results

This section presents some results of an application of the methods discussed above to evaluate a number of HOV alignment alternatives. This application uses the year 2010 as a forecast horizon, with land use forecasts and anticipated networks consistent for that time period (*34*). Of the 18 alignments considered in the full study, 8 were considered feasible for possible HOV treatment. They were tested as described earlier, some as adding lanes and some as converting lanes from a baseline assumption. They are described in brief as follows.

- Improvements to links that currently exist:
  1. I-495 (Capital Beltway) from I-270 East Spur to I-95, add one lane in each direction;
  2. I-495 from American Legion Bridge to I-270 West Spur, add one lane in each direction;
  3. I-95 from I-495 to I-695 (Baltimore Beltway), add one lane in each direction.
- Changes in operation for links that currently exist:
  4. US-29 from I-495 to MD-650, convert one lane in each direction, and from MD-650 to I-70, add one lane in each direction;
  5. Clara Barton Parkway from Canal Street to I-495, convert two lanes in peak direction.
- Changes in assumed operation for links that are planned:
  6. Inter-County Connector (ICC), from I-370 to I-95, convert one lane in each direction;
  7. M-83 from ICC to I-270, convert one lane in each direction; and
  8. MD-27 from I-270 to MD-80, add one lane in each direction.

As can be seen from Table 4, the improvements that had the highest benefit to Montgomery County residents and employers per mile in terms of added accessibility were adding two lanes to the Capital Beltway (I-495) within the county. This facility is heavily congested, running at levels of service E and F during the peak period. Adding to I-95, which is less congested and just outside of the county, had less accessibility impact for county residents and workers, as might be expected. From a regional perspective it has a higher accessibility, suggesting that benefits to a locality may differ somewhat from those to the region.

The conversion of lanes from general purpose to HOV use has run into some controversy, most recently on the Dulles Toll Road in Virginia. Two of the conversions described here are real, in that they would convert existing pavement to HOV use. The others are only conversions in the modeling sense because the facility has not yet been constructed. One lane of a facility, which was assumed as HOV-2 only in the full network, was converted to general purpose in the test network.

Of the real conversions, the highest benefit was associated with the Clara Barton Parkway, which is an existing limited-access facility between downtown Washington, D.C., and the Capital Beltway running parallel to the Potomac River. Accessibility increased by conversion from general purpose to HOV-2+ lanes. In addition, travel speeds increased, whereas the person throughput remained about the same (the number of vehicles on the facility was halved).

Projects 1, 2, and 3 were recommended to the state for further study, whereas Alignment 6 is currently under intensive study. Alignments 5 and 8 are being pursued as part of this study. Alignment 7 worked better as an SOV addition, although it closely paralleled an already planned HOV lane, and so it was dropped. Similarly, Alignment 4 parallels Alignment 3, and so it was not pursued for automobile HOV treatment.

TABLE 4 Multimodal Accessibility Benefit by HOV Alignment

	Access to Jobs	Access to Houses
Full-Network	119900	66000
1) I-495 East Leg	3510 362/mile	3040 313/mile
2) I-495 West Leg	5390 1172/mile	4140 900/mile
3) I-95	1530 67/mile	810 35/mile
4) U.S. 29	-60 -2.5/mile	620 25/mile
5) Clara Barton Pkwy.	2625 208/mile	-130 -18/mile
6) ICC	280 15/mile	910 48/mile
7) M-83	880 107/mile	1730 210/mile
8) MD 27	2808 208/mile	2492 184/mile

CONCLUSION

The trip distribution impedance functions were developed for each of seven modes and work and non-work purposes in a transportation planning model. A method for combining these mode-specific functions into a single composite impedance function by using mode shares as weights was implemented. The multimodal trip distribution impedance functions were tested in a transportation planning model with feedback between different components to produce consistent results. This method has the advantage that it accounts for changes in transportation supply better than does a conventional gravity model that uses only automobile impedance. Because transportation planning more and more must deal with additions of multiple modes, models need to account for all of these choices.

A method for evaluating networks using multiple modes was developed in this paper to support transportation planning and decision making. The benefits are defined as the accessibility between homes and jobs provided by the network given a fixed land-use pattern. Accessibility is measured as the sum of the area under the trip distribution impedance curve (or *f*-curve). Costs are approximated as distance in this preliminary planning model. The use of multimodal distribution with travel time feedback is necessary to estimate accessibility by automobile, a major component in total accessibility.

The relationships described in this paper have a number of implications for transportation planners. An increase in supply will generally result in an increase in transportation accessibility and therefore in realized demand. This relationship is a variation on Say's Law, developed in the late 1700s, which states that "supply creates its own demand" (*35*). Thus, the widespread usage of fixed demand or travel time between locations in various transportation planning applications will, of itself, miss a key factor in new facility utilization, induced demand. An example of this induced demand can be seen with the introduction of Metrorail in metropolitan Washington, D.C. A new service constructed between 1968 and the present resulted in a doubling of transit work trip mode shares from 5 to 10 percent. The individuals choosing transit did so because on the particular trips they make, rail transit is preferable to other modes. In addition, because of the transit service, these individuals and the firms or government agencies for which they work locate to take advantage of this new transportation supply. Because Washington, D.C., has a high proportion of federal employment, the locational decision on the part of work sites was not made on a strictly economic basis, which can be seen in Washington's higher than average home-to-work trip travel time, 29.5 min, second only to New York City's (D. Levinson and A. Kumar, Accessibility, Propensity, and Mobility, working paper, 1993). Nevertheless, use of only automobile-travel times in the demand estimation or measurement of accessibility would misstate the patterns of transit demand, because transit trips tend to be longer in duration than automobile trips. The spatial interaction decision happens all of the time on a smaller scale with various changes in supply and the demand of other trip makers as measured through congested travel time.

ACKNOWLEDGMENTS

The authors would like to acknowledge the staff of the Montgomery County Planning Department, in particular John Bailey, Shahriar Etemädi, Caroline Honig-Seiden, John Matthias, Yetta McDaniel, and Chris Winters.

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The views expressed here are those of the authors and do not represent those of the Montgomery County Planning Department.

Publication of this paper sponsored by Committee on Passenger Travel Demand Forecasting.